



**MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES
IN PURE AND APPLIED SCIENCES**



**IN CW625N BRASS ALLOYS,
REDUCING THE DEZINCIFICATION RESISTANCE
UNDER THE STANDARD (ISO 6509),
WITHOUT APPLYING HEAT TREATMENT**

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Ph.D. THESIS
Department of Mechanical Engineering

ADVISOR

Prof. Dr. Bülent EKİCİ

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TABLE OF CONTENTS

	PAGE
ACKNOWLEDGEMENT	i
TABLE OF CONTENTS	ii
ÖZET.....	vi
ABSTRACT	ix
CLAIM FOR ORIGINALITY	xii
SYMBOLS	xiii
ABBREVIATIONS	xiv
LIST OF FIGURES	xv
LIST OF TABLES.....	xviii
1. INTRODUCTION.....	1
1.1. General Information.....	1
1.1.1. European Standards (EN) Specifications	2
1.2. Objective of the Work.....	3
2. BRASS ALLOYS AND THEIR PROPERTIES.....	5
2.1. The Physical and Chemical Properties of Brass Alloys	5
2.1.1. Casting Ability	5
2.1.2. Forging Ability.....	5
2.1.3. Heat and Electrical Conductivity	6
2.1.4. Strength Property	6
2.1.5. Corosion Resistance	8
2.1.6. Machinability	8
2.1.7. Welding Properties.....	9
2.2. Classification of Brass Alloys	9

2.2.1.	Alfa (α) Brasses.....	10
2.2.1.1.	Yellow Alpha Brasses	10
2.2.1.2.	Red Brasses.....	11
2.2.2.	Alpha - Beta Brasses (Duplex Brass).....	11
2.2.2.1.	Admiralty Brasses	12
2.2.2.2.	Automat brasses (High Machinable Brasses)	12
2.2.2.3.	Forgable Brasses	12
2.2.3.	Gamma (γ) Brasses.....	12
2.2.4.	High Strength Brasses (Mixed Brasses)	12
2.3.	Effects of Elements Added to Brass Alloy in Composition.....	13
2.3.1.	The Effect of Zinc Element Addition on Alloy	14
2.3.2.	The Effect of Lead Element Addition on Alloy.....	15
2.3.3.	The Effect of Tin Element Addition on Alloy	15
2.3.4.	The Effect of Silisium Element Addition on Alloy	15
2.3.5.	The Effect of Arsenic Element Addition on Alloy	16
2.3.6.	The Effect of Nickel and Nickel Silver Elements Additions on Alloy	16
2.3.7.	The Effect of Aluminum Element Addition to Alloys	16
2.4.	Corrosion in Brass Alloys	16
2.4.1.	Corrosion Resistance	17
2.4.2.	Dezincification Occurrences Conditions	18
2.4.3.	Precautions To Be Taken Against Dezincification	18
2.5.	Manufacturing Methods for Brass Alloys.....	19
2.5.1.	Intermediate Product Manufacturing Methods of Brass Alloys	19
2.5.1.1.	Extrusion Method.....	19
2.5.1.2.	Hot Pressing Method.....	20
2.5.1.3.	Forging Method	21
2.5.1.4.	Casting Method.....	22
2.5.1.5.	Wire Drawing Method	22
2.5.1.6.	Strip and Plate Production Methods.....	22
2.5.1.7.	Pipe Production Method.....	23
2.5.1.8.	Pleyt (Platinalar)	23
2.5.2.	Methods Used in Chipless Shaping of Brass Alloys.....	24
2.5.2.1.	Bending Method.....	24
2.5.2.2.	Cold Forming Method.....	24
2.5.2.3.	Deep Drawing Method	25
2.5.2.4.	Hot Rolling	25
2.5.2.5.	Extrusion.....	25

2.5.2.6.	Hot Pressing.....	25
2.5.2.7.	Heat Treatment	25
2.5.3.	Methods for Joining Brass Alloys.....	27
2.5.3.1.	Soldering.....	27
2.5.3.2.	Oxy Acetylene Welding	28
2.5.3.3.	Arc Welding with Covered Electrodes.....	28
2.5.3.4.	Protective Gas Supply	29
2.5.4.	Machinability and Chip Removal Methods in Brass Alloys	29
2.5.4.1.	Orthogonal Cutting	32
2.5.4.2.	Relatif Relative Processing Capability.....	36
2.5.4.3.	Drilling Method	37
2.5.4.4.	Turning Method	38
2.5.4.5.	Milling Method	38
3.	MATERIAL AND METHODOLOGY OF THE STUDY	40
3.1.	General Metodology of Hot Forging Brass and Studied Material	40
3.2.	Experimental Studies.....	43
3.2.1.	Obtaining Samples and Applied Parameters	43
3.2.1.1.	Production of Samples with Different Forging Parameters	43
3.2.1.2.	Determination of Different Cooling Types After Forging	45
3.2.1.2.1.	Cooling in Calm Air	45
3.2.1.2.2.	Cooling with Fan	46
3.2.1.2.3.	Cooling in Water	46
3.2.2.	Chemical Composition Measurement	48
3.2.3.	Heat Treatment Application	48
3.2.4.	Mechanical Testing - Hardness Measurement.....	49
3.2.5.	Microstructure Investigation.....	49
3.2.6.	Dezincification Test	50
3.2.7.	Machinability Test	51
3.3.	Statistical Analysis	53
4.	RESULTS AND DISCUSSIONS.....	55
4.1.	Cooling Results of Cooling Method Groups	55
4.2.	Chemical Compositon Results.....	83
4.3.	Heat Treatment Results	86
4.4.	Hardness Measurement Results	86

4.5. Microstructure Results	88
4.6. Dezincification Resistance Results	100
4.6.1. Second Heat Treatment Requirement	117
4.6.1.1. Harness Measurement Results	117
4.6.1.2. Microstructure Results	119
4.6.1.3. Dezincification Resistance Results	121
4.7. Machinability Results	123
4.7.1. Chip Structures and Drilling Forces.....	123
4.7.2. Surface Roughness	129
4.8. Statistical Analysis (Analysis and Discussion of Experimental Result)	130
4.8.1. Taguchi Method	130
4.8.1.1. Un-Heat Treated Groups	131
4.8.1.2. Heat Treated Group.....	134
4.8.2. Anova Analysis	136
4.8.2.1. Un-Heat Treated Groups	136
4.8.2.2. Heat Treated Group.....	142
4.9. Financial Benefits to Companies Applying the Alternative Method	149
5. CONCLUSIONS AND FUTURE WORK.....	155
6. REFERENCES.....	157
CURRICULUM VITAE	164

ÖZET

CW625N PİRİNÇ ALAŞIMLARDA ISI İŞLEMİ UYGULANMADAN STANDART ALTINDA (ISO 6509) DEZİNFİKASYON DİRENCİNİN AZALTILMASI

Pirinç alaşımları, diğer malzemeler gibi, korozyonun kaçınılmaz etkisi altındadır. CW625N (CuZn35Pb1) alaşımına kurşunsuz alaşım denir, çünkü bileşiminde maksimum 1,6 Pb içerir. CW625N Sıcak dövme için uygun kurşunsuz pirinç alaşımı, dünya için yeni bir alaşım türüdür.

Şehir su hatları, doğalgaz kazan tesisatları, armatürler, termik ve nükleer enerji santrallerinin soğutma hatları gibi alanlarda korozyonun önlenmesi önemli olan pirinç malzemelerin kullanıldığı alanlardır. Sıcak şekillendirme için uygun CW625N (CuZn35Pb1) pirinç alaşımı dünya için yeni bir alaşım türüdür. Geleneksel imalat yönteminde alaşım istenilen kompozisyon değerlerinde elde edilmesinden sonra; sıcak dövme ile parçalara istenilen geometrik şekil verilir ve ardından parçalar vakumda soğutulur. Soğuyan ürünler için son ürün formunu verebilmek için talaşlı işlem uygulanır. Ara aşamada, dövme işleminden sonra alaşımın çinkosuzlaşma direncini arttırmak amacıyla ısıtma işlemi uygulanır. Ancak bu uygulama çok pahalıdır ve üretim sürecini de oldukça yavaşlatır.

Bu çalışmada; yeni bir alaşım tipi CW625N için geleneksel üretim yöntemi kullanmak yerine alternatif bir üretim süreci bulmak amaçlandı. Sıcak dövme ile şekillendirmeye uygun olan bu yeni alaşım için tez kapsamında; üç dövme basıncı (70-80 ve 90Bar) ve üç dövme sıcaklığı (750-765 ve 780°C) altında test parçalarına geometrik şekilleri için sıcak dövme uygulandı. Test numuneleri için dövme sonrası uygulanmak üzere üç tip soğutma yöntemi (vakumda soğutma, fan ile soğutma ve suda soğutma) belirlendi ve uygulandı. Test parçalarına farklı dövme ve farklı soğutma uygulamalar sonucunda; vakumda soğutulan ısıtma işlemi uygulanan grup, vakumda soğutulan ısıtma işlemi uygulanmayan grup, fan soğutulan ve ısıtma işlemi uygulanmayan grup, su ile soğutulan ve ısıtma işlemi uygulanmayan grup olarak toplamda 4 ana grup oluşturuldu. Her bir parametre uygulaması için üç test parçası yani toplamda 108 adet test numunesi üretildi.

Her bir parametre için; numunelerin zamana bağlı soğutma eğrileri, her bir numunenin kimyasal bileşim değerleri, yüzey sertlik değerleri, mikroyapı görüntüleri, mikroyapı içerisindeki tane büyüklük değerleri, çinkosuzlaşma (dezincification) dirençlerine, beta tane büyüklüklerine, beta faz oranlarına, talaşlı imalat aşamasında matkap ile delme işlemi uygulaması ile oluşan delme kuvvetleri, talaş yapıları ve işlenen yüzeye ait pürüzlülük değerleri elde edildi ve incelendi. Bu 4 gruba ek olarak, işlenebilirlik testinden sonra başka bir grup daha eklenmiştir. Isıl işlem grubu için dezinsifikasyon testi sonuçları incelendiğinde; standart kapsamı dışında 11 test numunesi tespit edildi. Bu sebeple çalışmada yeni bir grup oluşturuldu. Çinkosuzlaşma direncini sağlamak için 11 parçaya ikinci kez ısıl işlem uygulandı. Bu yeni gruba 2 kez ısıl işlem uygulanan grup adı verildi. Bu numuneler üzerinde yüzey sertlik ölçümü, mikroyapı incelemesi, çinkosuzlaşma testleri ve işlenebilirlik deneyleri tekrar yapılmıştır. Elde edilen tüm veriler tek tek incelendi.

Bu yeni alaşım üzerinde üç önemli konu vardır. Bunlar; optimum dövme parametresini belirlemek, dezinfikasyon direncinin yüksek olmasını (istenen standart kapsamında elde edilmesi) sağlamak ve alaşımın iyi işlenebilir olmasını sağlamaktır. Bu doğrultuda; yapılan tüm testlerin değerlendirilmesi neticesinde iki ana prosesin tüm sonuçları direk ve en çok etkilediği saptandı. Bunlar; sıcak dövme ile şekillendirilen alaşımın soğutulma yöntemi ve ısıl işlem prosesidir.

Isıl işlem pahalı ve nihai ürün için üretim sürecini uzatan bir prosestir. Geleneksel yöntem olan dövme sonrası şekillendirilen ürünlerin sakın havada soğutulması ve sonrasında ısıl işlem uygulaması ile istenen standartlar kapsamında dezinsifikasyon dirençleri elde edilmesi mümkün olmaktadır. Bu çalışmada; sakın havada soğutulan ürünler 2 grup altında incelenmiştir ve sadece bir gruba ısıl işlem uygulanmıştır. Böylelikle farklı sıcaklık ve farklı basınç parametreleri ile oluşturulan 4 grup (her bir grup içerisinde 27 adet test numunesi yer almaktadır) arasında kıyaslamalar ve somut bulgular elde edilmiştir.

Sakin havada soğuyan numunelere ısıl işlem uygulanmayan grup içerisinde hangi parametre de şekillendirilmesine (dövülmesine) bağlı olmadan dezinsifikasyon standartı kapsamı dışında kalmıştır. Isıl işlem prosesi ile alaşım içerisindeki dezinfikasyon

direnci azaltıcı beta fazını düşürme etkisiyle standart içerisinde kalınmış olup, bu prosesin alaşım üzerindeki direk etkisi saptanmıştır.

Alaşımın içerisinde kurşun miktarı ne kadar yüksek olursa, alaşım o kadar iyi işlenir. Çalışmada kullanılan alaşım adından da anlaşıldığı gibi kurşunsuz bir alaşımdır yani alaşım içerisindeki kurşun miktarı azaltılmış olup standart gereği %1,6 sınırlandırılmıştır. Bu durum; işlenebilirliği direk etkileyen unsurdur. İşlenebilirlik deneyi sonuçları incelendiğinde; ısıtma işlemi uygulanmayan 3 gruptan biri olan fan ile soğutulan numunelerde istenilen sonuçlar elde edilmiştir. Isıtma işlemi uygulanan grup numuneleri ile fan ile soğutulan grubun numunelerine ait sonuçlar kıyaslandığında ise talaş yapılarının benzer olduğu görülmüştür. Ancak dezinsifikasyon test sonucuna göre 5. grup oluşturulan ve ikinci kez ısıtma işlemi uygulanan grubun işlenebilirlik sonuçları (talaş yapısı) istenilen yapıda olmamıştır. Sakin havada soğutulan ve bir kez ısıtma işlemi uygulanan grup ile fanla soğutulan grup işlenebilirlik açısından uygunluğu tespit edilmiştir.

Tez çalışmasında; geleneksel bir deneysel çalışma yani farklı parametreler sebebiyle toplamda 108 adet test numunesi üzerinde tek tek çalışmalar yapıldı. Her bir deneyde elde edilen bulgular tek tek incelendi. Tüm bu çalışmalara ilaveten taguchi deney tasarımı ve annova varyans analizi uygulandı. Bu istatistiksel analizler sonucu elde edilen bulgular geleneksel çalışma ile elde edilen bulgularla kıyaslandı. Her iki deneysel metot ile yapılan çalışmalar neticesinde bulguların amaçlanan hedefe ulaşıldığı tespit edildi. En iyi dövme parametresi belirlenmiştir. Alaşımda istenilen çinkosuzlaşma direnç değerlerine ve iyi işlenebilirlik sonuçlarına ulaşılmıştır.

Yukarıdaki tüm sonuçlara ek olarak, bu çalışmanın en önemli sonucu; geleneksel üretim yöntemi yerine düşük maliyetli alternatif bir yöntem keşfedilmiştir. Gerek dezinsifikasyon test sonuçları gerekse işlenebilirlik test sonuçları incelendiğinde; dövme ile şekillendirilme işlemi sonrası; ürünlerin sakın havada soğutulup ısıtma işlemi uygulanması (geleneksel yöntem) prosesleri yerine, alaşım ürünlerinin fan ile soğutulması işlemi alternatif bir metot olarak bulunmuştur.

ABSTRACT

IN CW625N BRASS ALLOYS, REDUCING THE DEZINCIFICATION RESISTANCE UNDER THE STANDARD (ISO 6509), WITHOUT APPLYING HEAT TREATMENT

Brass alloys, like other materials, are under the inevitable effect of corrosion. The CW625N (CuZn35Pb1) alloy is called a lead-free alloy because it contains a maximum of 1.6 Pb in its composition. CW625N Lead-free brass alloy, suitable for hot forging, is a new alloy type for the world.

Brass materials are using of at the most important areas, which such as city water lines, natural gas boiler installations, armatures, cooling lines of thermal and nuclear power plants. For the all these areas prevention of corrosion is the most important. CW625N (CuZn35Pb1) brass alloy suitable for hot forming is a new type of alloy for the world. In the traditional manufacturing method, after the alloy is obtained at the desired composition values; With hot forging, the parts are given the desired geometric shape and then the parts are cooled in calm air. Machining process is applied to give the final product form for the cooled products. In the intermediate stage, after the forging process, heat treatment is applied to increase the dezincification resistance of the alloy. However, this application is very expensive and also slows down the production process.

In this study; it is aimed to find an alternative manufacturing process instead of using the traditional method for a new alloy type CW625N. Three types of cooling methods (cooling in calm air, cooling with fan and cooling in water) were applied for hot forged samples manufactured under the conditions of the three forging pressure (70-80 and 90 Bar) and the three forging temperature (750-765 and 780°C). Three types of cooling methods (calm air cooling, fan cooling and water cooling) were determined and applied for the test samples to be applied after the forging. As a result of different forging and different cooling applications to test pieces; A total of 4 main groups were formed as calm air cooled heat treated group, calm air cooled non heat treated group, fan cooled and non heat treated group, water cooled and non heat treated group. Three test pieces, ie 108 test samples in total, were produced for each parameter application. For each parameter; time-dependent cooling curves of the samples, chemical composition values of each sample, surface

hardness values, microstructure images, grain size values in the microstructure, dezincification resistances, beta grain sizes, beta phase ratios, drilling application in the machining stage drilling forces, chip structures and roughness values of the treated surface obtained and examined. In addition to these 4 groups, another group was added after the machinability test. When the dezincification test results are examined for the heat treatment group; out of the standard scope, 11 test samples were detected. For this reason, a new group was created in the study. To ensure dezincification resistance, 11 parts were heat treated for the second time. This new group was given the name of the group, which was heat treated twice. Surface hardness measurement, microstructure examination, dezincification tests and machinability tests were repeated on these samples. All data obtained were examined one by one.

There are three important issues on this new alloy. These; to determine the optimum forging parameter, to ensure high dezincification resistance (to be achieved under the desired standard) and to ensure that the alloy is well machinable. In this direction; as a result of the evaluation of all the tests performed, it was found that the two main processes directly and the most affected all the results. These; the method of cooling and heat treatment of the alloy formed by hot forging.

Heat treatment is expensive and extends the production process for the final product. it is possible to obtain dezincification resistances within the scope of the required standards by cooling the products formed after forging, which is the traditional method, in calm air and subsequent heat treatment. In this study; products cooled in calm air were examined under 2 groups and only one group was heat treated. thus, comparisons and concrete findings were obtained between 4 groups (27 test samples in each group) formed with different temperature and pressure parameters.

The samples which were cooled in calm air were not covered by the dezincification standard, regardless of which parameter was formed (forged) in the group without heat treatment. With the effect of reducing the dezincification resistance reducing beta phase in the alloy by the heat treatment process, the standard effect of this process on the alloy was determined.

The higher the amount of lead in the alloys, the better the alloy is processed. As the name of the alloy used in the study is a lead-free alloy, as the name calls, the amount of lead in the alloy is reduced and the standard requirement is limited to 1.6%. This

situation; directly affect the machinability. When the machinability test results are examined; The desired results were obtained in the samples cooled by fan which is one of the 3 groups without heat treatment. When the results of heat treated group samples and fan cooled group samples were compared, chip structures were similar. However, according to the results of the dezincification test, the machinability results (chip structure) of the group that formed the 5th group and the second times heat treated group are not in the desired structure. The suitability of the air cooled and one time heat treated group and the fan cooled group are found to be suitable for machinability.

In the thesis study; Because of a traditional experimental study, i.e. different parameters, individual studies were carried out on 108 test samples in total. The findings obtained in each experiment were examined one by one. In addition to all these studies, taguchi experiment design and annova variance analysis were applied. The findings obtained from these statistical analyzes were compared with the findings obtained from the traditional study. As a result of the studies carried out with both experimental methods, it was determined that the findings reached the intended target. The best forging parameter has been determined. The desired dezincification resistance values and good machinability results have been achieved in the alloy.

In addition to all the above results, the most important result of this study; A low-cost alternative method was discovered instead of the traditional production method. When both the dezincification test results and machinability test results were examined, it is found that; instead of cooling the products in calm air and applying heat treatment (conventional method), cooling of alloy products with fan has been found as an alternative method.

CLAIM FOR ORIGINALITY

IN CW625N BRASS ALLOYS, REDUCING THE DEZINCIFICATION RESISTANCE UNDER THE STANDARD (ISO 6509), WITHOUT APPLYING HEAT TREATMENT

The originality of this work can be summarised as follows:

1. To obtain products by determining multiple forging parameters and different cooling types after forming by forging a new alloy type CuZn35Pb1 (CW625N).
2. Different forging parameters, heat treatment applications and cooling methods; effect of the tests applied on cw625n alloy. Accordingly;
 - Determination of optimum forging parameters in hot forging of this lead-free brass alloy
 - Providing the dezincification resistance value within the scope of the standard in test samples studied in multiple parameters
 - Determination of good machinability
3. Within the scope of the thesis; Traditional experimental study (despite the excessive experimental load) is statistical (taguchi experiment design and annova variation analysis application) analysis. Comparison of all findings obtained with both methods.
4. It is found that; Instead of cooling the products in calm air and applying heat treatment (conventional method), cooling of alloy products with fan has been found as an alternative method.

June 2020,

Prof. Dr. Bülent EKİCİ

Serap ÖZHAN DOĞAN

SYMBOLS

α	Alpha
β	Beta
γ	Gamma
CO_2	Carbon dioxide
$CuZn35Pb1$	Zinc ratio 35% and lead-free brass alloy
$CW625N$	Zinc ratio 35% and lead-free brass alloy
Cu	Copper
Zn	Zinc
Pb	Lead
Al	Aluminum
Fe	Iron
Cr	Chromium
P	Potassium
Zr	Zirconium
Sn	Tin
Si	Silicon
Mn	Manganese
Be	Beryllium
Ni	Nickel
As	Arsenic
Te	Tellurium
S	Sulfur
Ag	Silver
Cd	Cadmium

ABBREVIATIONS

B.C. Before Christ

DF : Degree of freedom

Seq SS : Sum of squares

Contribution : Percentage of effect (contribution) to the parameter examined

Adj SS : Adjusted sum of squares

Adj MS : Adjusted mean squares

F-Value : Ratio of variance between groups to variance within group

P-Value : Significance value

LIST OF FIGURES

	PAGE
Figure 1. Brass (Example of usage of brass) [2]	1
Figure 2. Electrical resistance of brass and Zn effect on heat conduction [8].....	6
Figure 3. Cu-Zn phase diagram [23].....	10
Figure 4. Effects of added elements on brass if extra feature asked [24]	13
Figure 5. Mechanical properties of brass and interaction with the composition that they contain [1].....	14
Figure 6. Effect of elements on electrical conductivity [11,32]	14
Figure 7. Manufacturing methods of copper and their alloys.....	19
Figure 8. Cu-Pb relation in alloy [1].....	31
Figure 9. Chip formation	32
Figure 10. Orthogonal cutting and cutting angles	32
Figure 11. Consecutive sliding plates and modeling method	33
Figure 12. Deformation information in machining.....	34
Figure 13. Continuous chip.....	34
Figure 14. Discontinuous chip.....	35
Figure 15. Sawtooth chip formation	36
Figure 16. Chip types a) Continuous chip b) Discontinuous chip c) Sliced chip d) Agglomerate chip	36
Figure 17. Factors affecting machinability	37
Figure 18. Drilling process	37
Figure 19. Before and after graphite prosses	44
Figure 20. Hot forged shaped test sample	45
Figure 21. Cooled Methods	46
Figure 22. Spectral Analylsis System.....	48
Figure 23. Used AFC Holcroft CQI9 brand heat treatment furnace.....	49
Figure 24. Sample measurement points.....	49
Figure 25. Bakelite images of test samples	50
Figure 26. Images of dezincification test stages	51
Figure 27. Special apparatus prepared for experimental study.....	52
Figure 28. Surface roughness measurement	53
Figure 29. Cooling curves comparison graph for 5070 groups	57
Figure 30. Cooling curves comparison graph for 5080 groups	61
Figure 31. Cooling curves comparison graph for 5090 groups	64
Figure 32. Cooling curves comparison graph for 6570 groups	67
Figure 33. Cooling curves comparison graph for 6580 groups	70
Figure 34. Cooling curves comparison graph for 6590 groups	73
Figure 35. Cooling curves comparison graph for 8070 groups	76
Figure 36. Cooling curves comparison graph for 8080 groups	79
Figure 37. Cooling curves comparison graph for 8090 groups	82

Figure 38. Microstructure images of all test samples	99
Figure 39. The dezincification images of the cooled in calm air and heat-treated samples.	104
Figure 40. The dezincification images of the cooled in calm air and un-heat treated samples	108
Figure 41. The dezincification images of the cooled with fan samples.....	112
Figure 42. The dezincification images of the cooled in water samples.....	116
Figure 43. Microstructure images of samples cooled in calm air and heat treated twice	120
Figure 44. Microstructure images of samples cooled in calm air and heat treated twice	122
Figure 45. The criterias which are hardness, grain size (perpendicular and parallel) and beta grain size	132
Figure 46. The criterias which are drilling force, dezincification depth (perpendicular and parallel), beta phase ratio and surface roughness	133
Figure 47. The criterias which are beta phase ratio, drilling force, dezincification depth (perpendicular and parallel), and surface roughness	134
Figure 48. The criterias which are hardness, grain size (perpendicular and parallel), beta grain size	135
Figure 49. Analysis of variance for transformed response for hardness parameters...	136
Figure 50. Analysis of variance for transformed response for grain size perpendicular parameters.....	137
Figure 51. Analysis of variance for transformed response for grain size (parallel) parameters.....	138
Figure 52. Analysis of variance for transformed response for dezincification depth (perpendicular) parameters.....	138
Figure 53. Analysis of variance for transformed response for dezincification depth parallel parameters.....	139
Figure 54. Analysis of variance for transformed response for beta grain size parameters	140
Figure 55. Analysis of variance for transformed response for beta phase ratio parameters.....	141
Figure 56. Analysis of variance for transformed response for drilling force parameters	141
Figure 57. Analysis of variance for transformed response for surface roughness parameters.....	142
Figure 58. Analysis of variance for transformed response for hardness parameters...	143
Figure 59. Analysis of variance for transformed response for grain size (perpendicular) parameters.....	144
Figure 60. Analysis of variance for transformed response for grain size (parallel) parameters.....	144

Figure 61. Analysis of variance for transformed response for dezincification depth (perpendicular) parameters	145
Figure 62. Analysis of variance for transformed response for dezincification depth (parallel) parameters	146
Figure 63. Analysis of variance for transformed response for beta grain size parameters	147
Figure 64. Analysis of variance for transformed response for beta phase ratio parameters.....	147
Figure 65. Analysis of variance for transformed response for drilling force parameters	148
Figure 66. Analysis of variance for transformed response for surface roughness parameters.....	149



LIST OF TABLES

	PAGE
Table 1. Definitions of brass [1]	2
Table 2. Definitions by EN 12164 standards [1]	2
Table 3. The descriptions of brass in EN standards according to lead rates [1]	3
Table 4. EN 12165 European standards for hot forging processes	3
Table 5. Mechanical properties of pure brass according to DIN 17660	7
Table 6. Mechanical properties of automat brass according to DIN 17660	7
Table 7. Mechanical properties of special brass according to DIN 17660	8
Table 8. Common usage of rod and profile of brass.....	20
Table 9. The most common brass alloy with hot forging method applied	21
Table 10. Chemical composition of CW625N alloy according to CEN / TS 13388 standard [71]	42
Table 11. Mechanical properties of alloy [71].....	42
Table 12. Physical properties of alloy [71]	42
Table 13. Manufacturing capability of alloy [71]	43
Table 14. Distribution table of parameters for 108 samples	44
Table 15. Temperature and pressure plans of produced 108 samples	45
Table 16. Given groups codes.....	47
Table 17. Fixed Parameters in Machinability.....	52
Table 18. Taguchi Matrix (P=3, L=3) for Non-Heat Treated Groups	53
Table 19. Taguchi Matrix (P=2, L=3) for Heat Treated Groups	54
Table 20. The cooling values and the cooling curve of the 5070F	55
Table 21. The cooling values and the cooling curve of the 5070S	56
Table 22. The cooling values and the cooling curve of the 5070W	57
Table 23. The cooling values and the cooling curve of the 5080F	59
Table 24. The cooling values and the cooling curve of the 5080S	60
Table 25. The cooling values and the cooling curve of the 5080W	61
Table 26. The cooling values and the cooling curve of the 5090F	62
Table 27. The cooling values and the cooling curve of the 5090S	63
Table 28. The cooling values and the cooling curve of the 5090W	64
Table 29. The cooling values and the cooling curve of the 6570F	65
Table 30. The cooling values and the cooling curve of the 6570S	66
Table 31. The cooling values and the cooling curve of the 6570W	67
Table 32. The cooling values and the cooling curve of the 6580F	68
Table 33. The cooling values and the cooling curve of the 6580S	69
Table 34. The cooling values and the cooling curve of the 6580W	70
Table 35. The cooling values and the cooling curve of the 6590F	71
Table 36. The cooling values and the cooling curve of the 6590S	72
Table 37. The cooling values and the cooling curve of the 6590W	73
Table 38. The cooling values and the cooling curve of the 8070F	74

Table 39. The cooling values and the cooling curve of the 8070S	75
Table 40. The cooling values and the cooling curve of the 8070W	76
Table 41. The cooling values and the cooling curve of the 8080F	77
Table 42. The cooling values and the cooling curve of the 8080S	78
Table 43. The cooling values and the cooling curve of the 8080W	79
Table 44. The cooling values and the cooling curve of the 8090F	80
Table 45. The cooling values and the cooling curve of the 8080S	81
Table 46. The cooling values and the cooling curve of the 8090W	82
Table 47. The chemical composition element values of 108 test	83
Table 48. Hardness results of 108 test pieces	86
Table 49. Grain sizes of all test samples	89
Table 50. The dezincification depth value which in samples of cooled in calm air and heat-treated	101
Table 51. Beta grain sizes and beta phase ratios which in cooled in calm air and heat-treated	102
Table 52. The dezincification depth value which in samples of cooled in calm air and un-heat treated	105
Table 53. Beta grain sizes and beta phase ratios which in cooled in calm air and un-heat treated	106
Table 54. The dezincification depth value which in samples of cooled with fan	109
Table 55. Beta grain sizes and beta phase ratios which in cooled with fan	110
Table 56. The dezincification depth value which in samples of cooled in water	113
Table 57. Beta grain sizes and beta phase ratios which in cooled in water	114
Table 58. Hardness results of 11 pieces of samples, which heat treated twice	117
Table 59. The grain size values of samples heat treated twice	120
Table 60. The dezincification depth value which in samples of cooled in calm air and heat-treated twice	121
Table 61. The beta grain sizes and beta phase ratios in structure	122
Table 62. Chip structures and measured drilling force of first time heat treated samples	123
Table 63. Chip structures and measured drilling force of non-heat treated samples	124
Table 64. Chip structures and measured drilling force of samples cooled with fan	125
Table 65. Chip structures and measured drilling force of samples cooled in water	127
Table 66. Chip structures and measured drilling force of second time heat treated samples	128
Table 67. Surface roughness results ($R_a, \mu m$)	130
Table 68. Criterias of unheat treated groups	131
Table 69. Criterias of heat treated group	131
Table 70. The effect of three criteria on hardness parameter	136
Table 71. The effect of three criteria on the grain size (perpendicular) parameter in the microstructure	137

Table 72. The effect of three criteria on the grain size (parallel) parameter in the microstructure.....	137
Table 73. The effect of three criteria on dezincification depth (perpendicular) parameter	138
Table 74. The effect of three criteria on dezincification depth (parallel) parameter ..	139
Table 75. The effect of three criteria on beta grain size parameter	140
Table 76. The effect of three criteria on beta phase percentage parameter	140
Table 77. The effect of three criteria on drilling force parameter	141
Table 78. The effect of three criteria on the surface roughness parameter.....	142
Table 79. The effect of two criteria on the surface hardness parameter	143
Table 80. The effect of two criteria on microstructure grain size (perpendicular) parameter	143
Table 81. The effect of two criteria on microstructure grain size (parallel) parameter	144
Table 82. The effect of two criteria on dezincification depth (perpendicular) parameter	145
Table 83. The effect of two criteria on dezincification depth (parallel) parameter	146
Table 84. The effect of two criteria on beta grain size parameter	146
Table 85. The effect of two criteria on beta phase ratio parameter	147
Table 86. The effect of two criteria on drilling force parameter	148
Table 87. The effect of two criteria on the surface roughness parameter.....	148
Table 88. The amount of monthly production manufacturer of some of the companies who are in Turkey.....	149
Table 89. The most widely produced brass alloys shaped by hot forging.....	150
Table 90. Özhan Company's 100ton production schedule.....	150
Table 91. Daily heat treatment capacity	150
Table 92. Heat treatment time for 100 tons of product (days).....	151
Table 93. Un-Heat treatment time for 100 tons of product (days).....	152
Table 94. Machining process time required for 100ton.....	153
Table 95. As a result of alternative method application, the heat treatment gain of Özhan Company from only 1200 tons of annual production.	153
Table 96. Cost calculation in kilogram basis for 2020	153
Table 97. With the elimination of the heat treatment cost.....	154
Table 98. Profit rate calculation when it is calculated over 1200 tons per year	154

1. INTRODUCTION

1.1. General Information

Brass is a alloy that obtained by adding zinc to the copper element. Brass is the most commonly used alloy for industrial and aesthetic applications. At the same time, it is a non-ferrous material that widely used in engineering. Brass has the ability to melt and it is very tough and easily machinable material. Therefore, it is widely used for outdoor applications and sanitary systems which expose to corrosive environments [1]. Besides, the most important features of brasses are atmospheric corrosion resistancy, hot and cold forming tendency (deep drawing, hot forging, pressing) and easy brazing.

In Industrial brass contains copper and zinc elements as well as other elements which, are lead, nickel, manganese, iron, aluminum, arsenic, antimony, tin and phosphorus. The internal structure and mechanical properties of the brass with high strength and corrosion resistance are proportional to the zinc content of the alloy. By selecting the copper, zinc and additionaly elements into the chemical composition, material can obtain the desired strength, ductility, hardness, conductivity, formability, abrasion resistance, color and corrosion resistance [24,68].



Figure 1. Brass (Example of usage of brass) [2]

Brass was discovered in the 500s BC, but the exact date and place of this discovery is still unknown. Brass alloys were obtained by mixing metallic copper and zinc ore (calamine) until the 16th century. Due to the idiosyncrasy of calamine, there were difficulties in its liquidation. Therefore, metallic zinc could not be separated from its ore until the 16th century. Then, before the 16th century, metallic copper was forged into powder and zinc ore was added to the crucible to obtain brass. In the ladle, zinc vaporized by the effect of heat diffused into copper and formed brass alloy.

1.1.1. European Standards (EN) Specifications

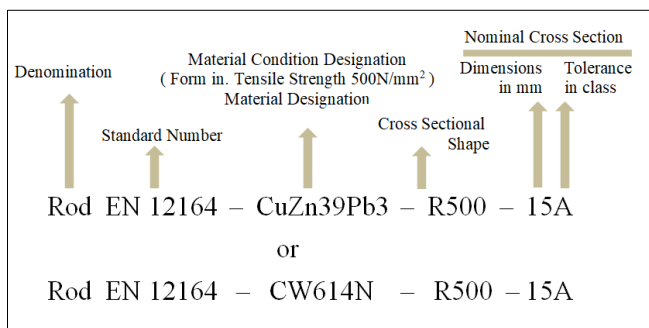
As part of the standardization process, uniform definitions are accepted for copper and their alloys in all product forms. The definitions of copper (Cu) and its alloys are available in two forms that symbol and number. In general, the coding system provides a viable method for identifying grinder and foundry products [3].

The product definition (EN-European Norm) is assumed in internationally accepted terms. The order of identification coding and the EN numbers for brass are given in Table 1 and Table 2.

Table 1. Definitions of brass [1]

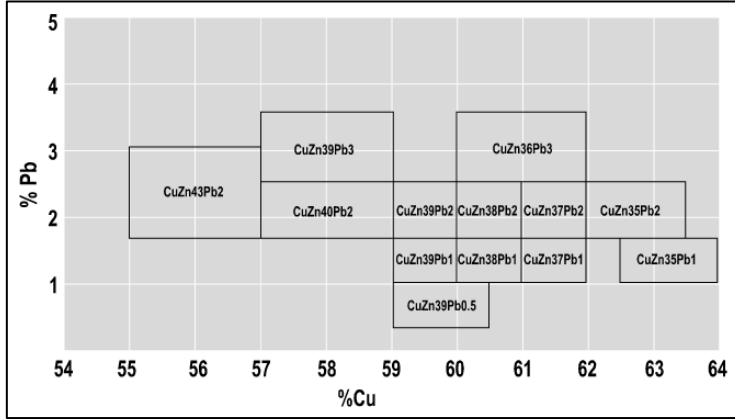
DENOMINATION	e.g., rod. wire. strip. etc.
STANDARD NUMBER	EN XXXX
MATERIAL DESIGNATION	Alloy symbol or number. e.g. CuZn30 or CW505L
MATERIAL CONDITION DESIGNATION	Mechanical property requirements. e.g. R380 for minimum tensile strength of 380N/mm ²
CROSS-SECTIONAL SHAPE	e.g. RND-round or sQR-square
NOMINAL CROSS-SECTIONAL SHAPE	e.g. 15 for 15mm
TOLERANCE CLASS	e.g. for wire: A.B. C. D or E
CORNER TYPE	Where appropriate. e.g. SH-sharp or RD-rounded

Table 2. Definitions by EN 12164 standards [1]



Brasses are also defined according to their lead element content. These definitions are shown Table 3.

Table 3. The descriptions of brass in EN standards according to lead rates [1]



In addition, the standard definitions of EN and ASTM for hot forged brasses are shared in Table 4.

Table 4. EN 12165 European standards for hot forging processes

BRASS ALLOYS		
EN	EN No	ASTM
CuZn21Si3P	CW724R	C69300
CuZn40	CW509L	C27450
CuZn42	CW510L	C28500
CuZn38As	DW511L	C27453
CuZn39Pb3	CW614N	C38500
CuZn40Pb2	CW617N	C38000
CuZn36Pb2As	CW602N	C35330
CuZn35Pb1	CW625N	-
CuZn33Pb1	CW626N	-
CuZn38Pb2	CW608	-
CuZn39Pb2	CW612N	C37700
CuZn32Pb2AsFeSi	CW709R	-
CuZn37Mn3Al2PbSi	CW713R	C67420

1.2. Objective of the Work

Brass materials are using of at the most important areas, which such as city water lines, natural gas boiler installations, armatures, cooling lines of thermal and nuclear power plants. After the hot forging, the alloy is cooled in calm air and introduced into machining for the final product. In the intermediate stage, heat treatment is applied to

increase the dezincification resistance of the alloy after forging. However, this application is very expensive and also slows down the production process.

CW625N (CuZn35Pb1) brass alloy suitable for hot forming is a new type of alloy for the world. In this study; it is aimed to find an alternative manufacturing process instead of using the traditional method for the CW625N. The purpose, zinc resistance (dezincification) and machinability of the alloy must be high. Within the thesis study; three types of cooling methods were applied to hot forged samples manufactured under the conditions of 70-80-90Bars forging pressure and 750-765-780 degrees forging temperature. Some of the samples were cooled in calm air, some in water and some with fan. Half of the samples cooled in calm air were used to the heat treatment process in the classical production process. For each cooled sample; chemical composition ratios, hardness values, particle size in microstructure, cooling curves, dezincification depths, beta phase ratios, beta grain sizes, and status of machinability, which with parameters of chip structures, drilling forces and surface roughnesses, were examined.

After obtaining all test results, the results will be evaluated by using the taguchi method and Anova statistical test method. The aim; determining the optimum forging parameter is high dezincification resistance (to be obtained within the desired standard) and the machinability of the alloy.

2. BRASS ALLOYS AND THEIR PROPERTIES

2.1. The Physical and Chemical Properties of Brass Alloys

Brass alloys are preferred in many engineering applications. In addition, many different manufacturing methods can be applied and it is possible to obtain the desired properties with each method. Desired properties (strength, ductility, hardness, conductivity, formability, abrasion resistance, color, hygienic, re-use and corrosion resistance) can be obtained by selection of copper and zinc ratio.

Generally, it has low melting point of about 900°C to 940°C depending on its composition. The density of brass is approximately 8.4grams/cm³ [4]. Its flow characteristics make it a relatively easy material to cast. By varying the proportions of copper and zinc, the mechanical properties of the brass can be changed, producing hard and soft brasses.

Material microstructures; It is highly influenced by the parameters applied in production processes, and generally any changes in the microstructure affect the properties of the material as it can significantly change strength, toughness, hardness, ductility, even thermal and electrical properties [5,9,13,25, 32,61,66]. The basic properties of brass alloys are given below as substances.

2.1.1. Casting Ability

Copper-zinc alloys are suitable for casting by all the casting methods [1,6,7,24,50]. Depending on the composition of the alloy, the tensile strength values are between 200-800N/mm² and the breaking elongation values are between 4% and 35%. The ability to remove chips from the parts produced by casting method is very good. In addition, the amount and purity of the alloying elements in zinc alloys are important. Deflection in these ratios affect the strength and corrosion properties adversely. Therefore, surface quality and castability of the alloy reduce.

2.1.2. Forging Ability

The forging ability of brass alloys varies depending on the copper content. Generally forgeable brass; Contains over 62% copper and cold-workable alpha brass or contains

62% less copper and beta brass that requires hot processing. They have hot and cold formability. That means; brasses can be formed chipless by rolling or forging by the cold or hot processes. Brasses are also suitable for deep drawing. It is possible to produce different sizes of rods, sheets, pipes, wires and profiles [1,15,32,35,38,50,53,55,62].

2.1.3. Heat and Electrical Conductivity

Brasses can show good heat and electrical conductivity properties. They also have a good spark resistance [16,35,38].

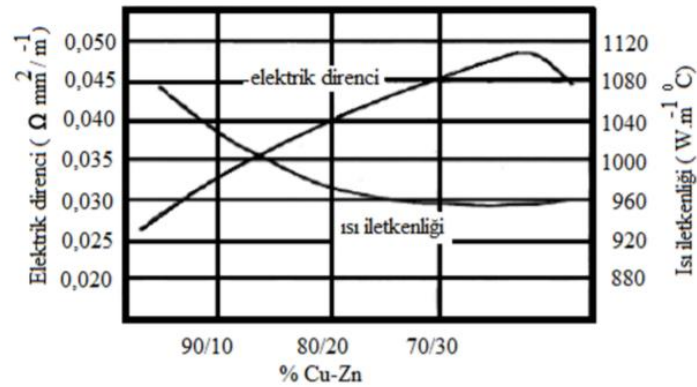


Figure 2. Electrical resistance of brass and Zn effect on heat conduction [8]

As shown in Figure 5, the electrical resistance of the material increases while the thermal conductivity decreases as the amount of Zn in the alloy increases [8].

2.1.4. Strength Property

Especially beta brasses are less ductile but more strength. Because of their excellent mechanical properties and workability, good products such as plumbing fixtures and fittings, low pressure valves, gears, bearings, decorative materials for ornamentation, hardware are obtained [1,9,15,39].

The strength of the brass does not significantly change below 200°C temperature. Around 300°C, the strength of the brass reduces by only 30%. The properties of the

brass depend on the amount of Zn in the alloy composition. If the amount of Zn increases, its strength increases as well.

Mechanical properties of pure brasses are less than brass alloys. The mechanical properties of some pure brass materials are shared in Table 5.

Table 5. Mechanical properties of pure brass according to DIN 17660

Brass Alloys	Tensile Strength Rm (N/mm ²)	Flow Limit Rp0.2 (N/mm ²)	Rupture Point %		Hardness HB10
			A5	A10	
Cuzn10	240 - ≤ 350	140-290	45-8	40-5	50-105
CuZn15	260 - ≤ 460	140-410	45-12	40-8	55-140
CuZn20	270 - ≤ 490	150-440	48-12	42-9	55-145
CuZn28	270 - ≤ 520	160-470	50-8	45-5	55-150
CuZn30	270 - ≤ 520	160-470	50-8	45-5	55-150
CuZn36	300 - ≤ 610	180-580	48-12	43-8	55-190
CuZn37	300 - ≤ 610	180-580	48-12	43-8	55-190
CuZn40	340 - ≤ 470	240-390	43-12	38-9	75-130

The mechanical properties of some automat brass materials are shared in Table 6.

Table 6. Mechanical properties of automat brass according to DIN 17660

Brass Alloys	Tensile Strength (N/mm ²)	Flow Limit (N/mm ²)	Rupture Point %		Sertlik HB10
			A5	A10	
CuZn36Pb1.5	290 - ≤ 540	200-490	50-12	44-8	60-160
CuZn37Pb0.5	290 - ≤ 540	200-490	50-12	44-8	60-160
CuZn36Pb3	340 - ≤ 460	250-350	35-12	-	85-140
CuZn38Pb1.5	360 - ≤ 540	240-490	43-12	38-9	75-150
CuZn39Pb0.5	340 - ≤ 540	240-490	43-12	38-9	75-150
CuZn39Pb2	360 - ≤ 590	270-540	40-9	35-6	85-160
CuZn39Pb3	360 - ≤ 5000	250-390	32-11	-	90-145
CuZn40Pb2	380 - ≤ 610	300-570	35-8	30.5	90-165

Mechanical properties of some developed special brass alloys are shared in Table 7.

Table 7. Mechanical properties of special brass according to DIN 17660

Brass Alloys	Tensile Strength (N/mm ²)	Flow Limit (N/mm ²)	Rupture Point %		Hardness HB10
			A5	A10	
CuZn20Al2	330 - ≤ 390	90-240	30-25	-	65-100
CuZn23Al16Mn4Fe3	≤ 780	≤ 540	≤ 8	-	190
CuZn28Sn1	≤ 320	≤ 100	≤ 40	-	65-100
CuZn31Si1	440 - ≤ 490	200-290	22-15	-	120-150
CuZn35Ni2	440 - ≤ 540	190-390	20.12	-	120-150
CuZn38SnAl	390 - ≤ 450	140-260	25-18	-	80-115
CuZn38Sn1	≤ 340	≤ 140	≤ 30	-	80-120
CuZn40Al2	540 - ≤ 640	240-310	18.11	-	150-170
CuZn40Mn2	440 - ≤ 490	170-270	20-18	-	120-135
CuZn40Mn1Pb	390 - ≤ 490	150-290	22-15	-	110-140

2.1.5. Corrosion Resistance

The corrosion resistance of brass materials is remarkable. Generally has good corrosion resistance and they are highly ductile. When the brass exposes to the atmosphere, a very thin layer forms on its surface to protect the material against corrosion [10,11].

When a suitable brass alloy is selected, it can be used in sea water without corrosion [10,27,28]. In particular, the use of a tin element in the alloy increases the resistance of the corrosive effect of sea water.

2.1.6. Machinability

Brass alloys used in a wide range of parts and final products in terms of durability, forging ability, corrosion resistance, machinability, conductivity and many other features. Brass with forging ability has excellent corrosion resistance and machinability. Chemical composition of the brass alloys effects the machinability ability [12,13]. While brasses containing less than 55% copper is not easy to process, leaded brass is easy to process. Brasses with very good machinability is top class in precision measurements in the manufacture of small parts compared to other metals. Especially, alpha brasses have superior cold processing properties and it is widely used in producing of bolt, pin and screw. Brasses are suitable for perfect forming by extrusion,

hot forging and casting [1,5,16,32,35,38,50]. In addition to these advantages, the fact that recycling value for burrs and sawdusts are very high compared to other metals increases the importance.

Good machinability is determined by evaluating good chip removal from the material and the structure of the resulting chip [14,15]. Due to the excellent mechanical properties and machinability; it finds good applications in plumbing fixtures and fittings, low pressure valves, heat exchangers, ship propellers, some components in equipping ships, electrical and electronic components, gears, bearings, hardware and other decorative architectural [16,17].

2.1.7. Welding Properties

The evaporation of zinc during welding is a very serious problem for the welding of brass alloy [18]. Therefore, it is considered that alloys with low zinc content can be welded while alloys with high zinc content are considered non-weldable [19]. While most of the brass alloys cannot be welded, TIG (Argon) or MIG (Gas Metal Arc Welding) welding methods are recommended in weldable alloys rather than electrode welding. TIG welding reduces the risk of zinc evaporation but still does not completely eliminate it because it has a narrower and controlled background. In brass alloys; electrode welding is often not preferred because it requires slag compression and the use of a large welding port.

Because of the brass contains 55% copper can not be machined easily, they can be used only in powdered brazing process.

2.2. Classification of Brass Alloys

Brasses are divided into four groups according to their chemical and physical structure: Alpha (α), Alpha-Beta ($\alpha+\beta$), Gama (γ) and Mixed (High strength) brasses [20,21,22]. While Alpha (α), Alpha-Beta ($\alpha + \beta$) and Mixed (High strength) brasses are used for commercial purposes, Gamma (γ) brass is not used commercially due to its brittleness.

The phase diagram of the Cu-Zn alloy is shared in Figure 3 below.

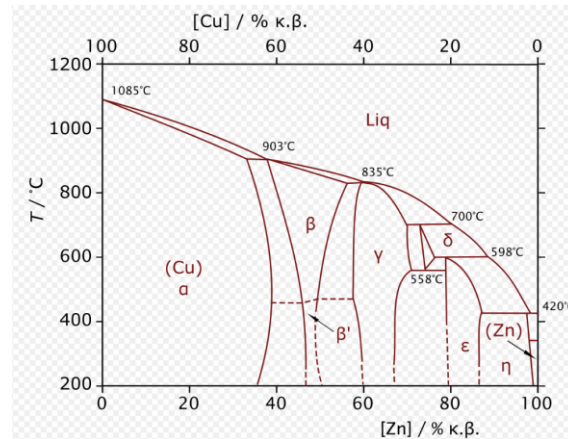


Figure 3. Cu-Zn phase diagram [23]

2.2.1. Alfa (α) Brasses

The alpha phase is a SCC (Surface Centered Cubic) solid solution. The composition of brass with a chemical composition of less than 39% zinc consists only the alpha phase. During solidification; Due to the solidification occurring, the structure of alpha brass includes not only the α but also the β phase. This situation depends on the cooling rate and how close the alloy composition is to the α or $\alpha + \beta$ boundary.

Alpha brasses have superior cold processing properties and they are widely used in bolt, pin and screw making. Copper alloys have properties that are hard, strong and somewhat difficult to process. Best formability; It contains 32% zinc in its composition [67].

Copper is a red metal. Alpha brasses varies from yellow to red depending on their color and composition (with increasing zinc content). Due to their color separation, α brass is divided into two main parts. They are yellow alpha brasses and red brasses.

2.2.1.1. Yellow Alpha Brasses

This type of brass alloys contain between 20% to 36% zinc in their composition. Ductility and strength properties are very good and suitable for cold processing applications. Yellow alpha brasses are usually annealed after cold Rolling and drawing process.

This type of brass alloy shows intergranular cracking after cold processing. Tension cracking or stress regeneration cracking caused by internal stresses that remain in the structure after cold working, particularly in ammonia environments. Annealing process with between 150°C to 300°C for 30 to 60 minutes is sufficient to prevent this danger in many cases. Therefore, cold processed yellow brass should be annealed in order to prevent the stress.

There is a dezincification problem for yellow brasses. This type of corrosion occurs in freshwater environments with high oxygen and CO₂ and seawater. Improvements can be made by adding As, Sb, or P in certain proportions to the brass composition to prevent the dezincification.

2.2.1.2. Red Brasses

These brasses contain between 5% to 20% zinc. Tension cracking and dezincification which occur for yellow brass are not seen for red brasses. The most commonly used red brasses used for electrical Works, boiler pipes, fuse covers, ornaments and emblems which are for gold-plated items. They have cold or hot machining properties. They are especially preferred for any application requiring deep drawing.

2.2.2. Alpha - Beta Brasses (Duplex Brass)

These brasses contain between 54-62% copper. it contains higher levels of zinc in its composition; it means that these brass is brighter than alpha brass. [67]. When the Cu-Zn equilibrium diagram is considered, it is seen that the structures of the alloys in this composition consist of Alpha (α) and Beta (β) phases [9,12,45].

The beta (β) phase is harder and brittle than the α phase at room temperature. Therefore, cold processing of $\alpha + \beta$ brass is more difficult than α brass. When high temperatures are reached; In the structure of brass, alpha phase and HMK (Volume Centered Cubic) structure and easily processable β phase is formed. [32,59]. If the alloy contains more than 39% Zn, the material is converted into the $\alpha + \beta$ phase. Therefore, plastic forming of $\alpha + \beta$ brass is applied at high temperature.

Alpha and beta brasses are formed by forged and hot extruded. From these kind of brasses; bolt, nut, gasket, faucet etc. products are obtained.

2.2.2.1. Admiralty Brasses

It contains 60% Cu, 39% Zn, 1% Sn in the alloy. These brasses are particularly resistant to seawater corrosion. They are generally preferred for applications such as ship shafts, piston rods, valve covers, welding rods, condenser plates. If 1.75% Pb is added to the composition of this brass, its workability is considerably increased.

2.2.2.2. Automat brasses (High Machinable Brasses)

It has the highest machinability and its composition consists of 61.5% Cu, 35.5% Zn, and 3% Pb.

2.2.2.3. Forgable Brasses

They are the highest hot working alloys among all brass. Therefore, they are selected for applications requiring hot forging. Its composition consists of 60% Cu, 39% Zn, 2% Pb.

2.2.3. Gamma (γ) Brasses

Another phase seen in brasses is the gamma (γ) phase. In the phase structure, the alloy contains more than 45% zinc. γ brasses contains hard Cu_2Zn_3 crystals and can be processed neither hot nor cold [of]. Therefore very crisp and undesirable in commercial brass [7]. There is no industrial use.

In Cu-Zn alloy diagram, melting points of Cu and Zn are different. But the liquefaction point for only 63% Cu is about 900°C [44].

2.2.4. High Strength Brasses (Mixed Brasses)

In order to increase the mechanical properties of brass; In addition to copper, nickel, manganese, iron, tin or silicon elements may be added besides zinc. The additions may confer good bearing properties and high wear resistance as well as providing high strength. The effect of heat treatment on the wear behavior of high- strength brasses is complex, and depends on the volume fraction, the distribution of phases and presence of intermetallic particles in the microstructure [49]. However, these additions do not exceed

5% of the total amount of other elements in the alloys. These added elements increase the tensile strength without affecting the elongation property. Their most important advantage is that their castings are non-porous and have mechanical properties equivalent to forged parts. These alloys can be used in any application where resistance is important.

2.3. Effects of Elements Added to Brass Alloy in Composition

Alloy elements are added to copper-zinc alloys for various reasons. By selecting copper and zinc alloy in appropriate chemical composition, materials having desired properties such as strength, ductility, hardness, conductivity, formability, abrasion resistance, color and corrosion resistance can be obtained [24,30,32,34]. Industrial brasses include copper and zinc additions as well as other alloying elements. These elements; tin, lead, nickel, manganese, iron, aluminum, arsenic, antimony and phosphorus. These additional alloying elements give the brass additional Properties.

Due to excellent corrosion resistance properties of brasses, they are the most economical materials for many applications. In industrial use of copper and its alloys have a variety of behavior in various corrosive environments such as atmospheric corrosion, soil corrosion, fresh water corrosion, sea water corrosion and corrosion in industrial chemicals, which are frequently encountered.

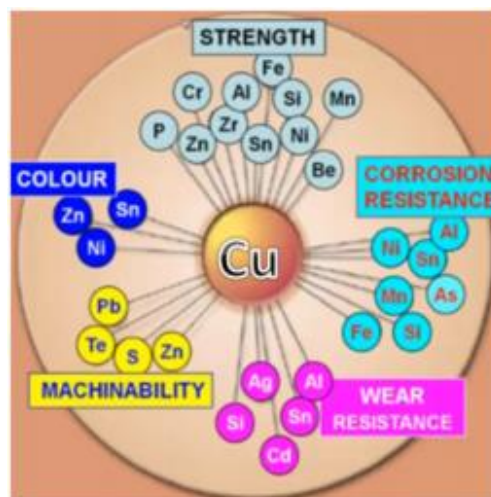


Figure 4. Effects of added elements on brass if extra feature asked [24]

2.3.1. The Effect of Zinc Element Addition on Alloy

Brass is the alloy that obtained by adding zinc to the copper element. The increase in zinc in the composition increases the tensile strength of the brass while decreasing the % elongation. It provides good strength and high ductility properties and is especially preferred for wire form manufacturing. Mechanical properties change depending on the composition of brass is given in Figure 5.

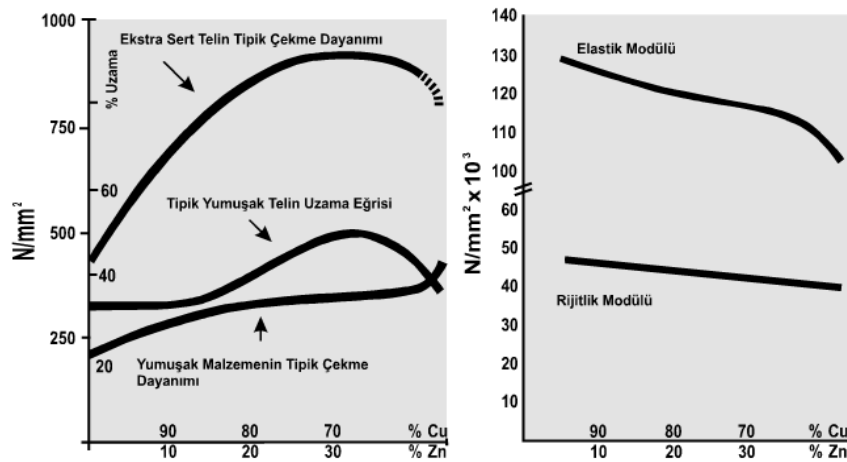


Figure 5. Mechanical properties of brass and interaction with the composition that they contain [1]

The graph showing the significant effect of zinc additions to copper on electrical resistance and thermal conductivity are shared in Figure 6. These values; help explain many successful applications of brasses in electrical applications and heat exchangers.

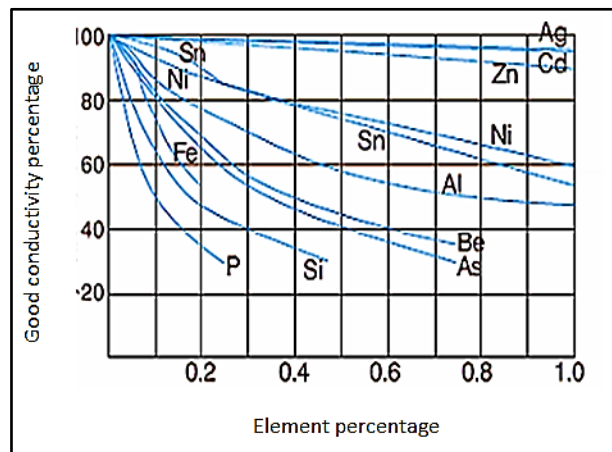


Figure 6. Effect of elements on electrical conductivity [11,32]

When the element percentage values shared in Figure 6 are examined; it can be determined how the percentage of electrical conductivity changes for each element.

2.3.2. The Effect of Lead Element Addition on Alloy

One of the most important elements affecting machinability [14,17,33]. Lead is added to the copper at a maximum rate of 40% and gives the structure a certain level of brittleness. Up to 3%Pb can be added to alpha-beta brasses to improve processability. Lead added at 5% or more increases the machinability of the alloy but reduces the tensile strength. Lead, copper and zinc do not form a solid solution together. However, it is dispersed throughout the alloy as a discontinuous phase. Looking at the microstructure, they appear as droplets scattered over the material.

Lead element has no effect on corrosion resistance. In addition, lead is not added to the formable alpha brass. Because, if the beta phase is insufficient, it causes cracking during hot processing.

2.3.3. The Effect of Tin Element Addition on Alloy

To ensure corrosion resistance of the alloy, 1% tin may be added to the composition. Tin alloyed brass materials increase the corrosion resistance and hardness of the material compared to conventional brass materials [27,29,41]. Thus, the alloy is made abrasion-resistant. Despite some degree of color improvement, it does not change its workability. It also increases dezincification resistance. Hardness and durability can be increased by adding 3-5% to leaded red brass and semi-red brass. Also tin addition; it improves the force, formability and electrical conductivity required by the various electrical connectors.

2.3.4. The Effect of Silisium Element Addition on Alloy

The addition of this element to the composition increases the strength and abrasion resistance of the brass alloy [15,16,47]. Also sometimes; It helps to reduce the oxidation of zinc and fluidity when welding gas. therefore, it is incorporated into casting brass and

filler alloys. The addition of silisium increases the beta phase ratio. Same time; Addition of silisium to alloy has some negative effect on cutting tool life in machining process.

2.3.5. The Effect of Arsenic Element Addition on Alloy

A small amount of arsenic is added to the alpha brass alloys, often to provide protection against dezincification Corrosion [1,16]. Arsenic and antimony can be added to all brass alloys containing less than 80% copper by a small amount of about 0.05% by weight to prevent dezincification types of corrosion in yellow brass alloys.

2.3.6. The Effect of Nickel and Nickel Silver Elements Additions on Alloy

Copper-nickel-zinc alloys known as nickel silver containing 10-20% nickel can be considered as special brass. They are used to obtain extra strength [32,60]. They have a silver appearance rather than a typical brass color. They show similar corrosion properties to alpha brass in almost every respect. However, higher versions of nickel have superior resistance to tarnishing and stress corrosion cracking. When nickel is added to copper, the color of the alloy turns white. In addition, when nickel-copper alloys contain 10-30% by weight of nickel, they have very high corrosion resistance. When added with iron-nickel up to a nominal value of 1.4% by weight, the resistance to impact corrosion increases significantly.

2.3.7. The Effect of Aluminum Element Addition to Alloys

Aluminum is known as supporting beta phase in Cu-Zn alloys. Aluminum is in the form of solid solution in copper up to 9.5%. It gives hardness to yellow brass. In addition, Al added to specific brass alloys (70-30 brass alloys) prevents dezincification [29,57,69].

2.4. Corrosion in Brass Alloys

There are many types of corrosion in brass. These types of corrosion can be avoided by appropriate material selection and appropriate process processes. Corrosion; they cause undesirable changes in metal or alloys, chemically, physically or mechanically.

Corrosion is the name given to both the decomposition reaction of metal and alloy and the damage caused by this reaction [27, 28, 29, 39].

2.4.1. Corrosion Resistance

Due to their excellent corrosion resistance, brass is the most economical material for many applications. Copper and its alloys; There is a variety of behavior in various corrosive environments such as atmospheric corrosion, soil corrosion, freshwater corrosion, sea water corrosion and industrial chemicals corrosion [28]. Atmospheric effects form a thin dark film on the brass. This effect then progresses to a protective green layer called Patina. It is thin and protective in this layer, but appears to be more rough and dusty in dry environment and not tarnished. No long-term adverse effects. In the marine environment, a similar green patina layer is formed. however, this film also contains basic chlorides. Like other copper alloys, brass has excellent resistance to corrosion under normal atmospheric conditions. This film eventually stabilizes, ie it does not progress and gains a protective property [41]. It is very thin and smooth looking and does not occur on moving parts. The rusting process in iron is not like this and cannot be compared with the rust formed.

If protective oxide film layers are examined; when exposed to open atmospheric conditions, the brass gradually becomes darker on the outside. This layer occurs in a very thin and slow developing process. Surface oxide films contain a certain amount of sulphate in the film if sulfur contamination is present. Fresh water; forms a protective oxide layer even in the presence of calcium salt, magnesium and iron.

When the correct brass is selected, it can be used in seawater applications without corrosion problem. High strength brasses; They contains manganese which provides excellent atmospheric corrosion resistance, and in continuous use the effect of the atmosphere only gives a dark bronze appearance.

In electrical applications; The oxides formed in brass have no negative effect as the insulating layer in the oxides formed in aluminum. In many applications such as electrical equipment and hydraulic installation products, brasses are preferred because of its high corrosion resistance to both air and various fluids. Such brasses are alloys

with high mechanical strength and increased dezincification resistance. General purpose brass is less processable than processability.

2.4.2. Dezincification Occurrences Conditions

Copper and its alloys; Although they are resistant to atmospheric and many chemical effects, they are susceptible to pitting corrosion and dezincification and aggressive media [10,40,51,70].

When the brass is exposed to polluted atmospheric conditions for a long time, dezincation spots may begin to form. However, the actual de-zincification occurs in acidic or very salty water environments. Generally, the pH value of drinking water is 7 and it is tried to be around 7. Some mineral waters are used to meet industrial needs, even if the pH remains below 7. under these conditions, the exposure of the brass to the negative effect is unavoidable situation.

There are two reasons that increase the rate and probability of dezincification. These are temperature rise and bonding with more than one noble metal. If brass material is used in collectors of copper hot water tanks, dezincification can occur because both water temperature and different material effects are combined. There is usually no danger at normal temperature. Therefore, standards have been established in developed countries according to the dewatering resistance of brass used in sanitary plumbing.

2.4.3. Precautions To Be Taken Against Dezincification

In order not to suffer from dezincification, it is necessary to use a brass alloy that is resistant to dezincification [22,26,72]. In order to prevent dezincification, some arsenic must be added to the alpha brass alloys used in heat exchangers, other plumbing pipes and fittings. If no precaution are taken, the density of the copper diffraction rings will gradually increase and the density of the α -brass will decrease with the progress of the dezincification [16,59].

Alpha brass, which is used in strips and sheets and which are not aluminum brass, do not contain arsenic since they generally contain purposes without risk of dezincification. In highly corrosive environments, aluminum brass or sometimes brass

alloys containing less than 15% zinc are used. These brasses are resistant to dezincification. Nickel silver (German silver) is also subjected to dezincification corrosion.

Bar, profiles and machining and hot forging operations will be done; alpha-beta brass is generally preferred. These brasses are exposed to de-zinc corrosion under undesirable conditions. Arsenic must be added to the alloy to provide a satisfactory heat value from the hot forging and extrusion temperatures. Alloy; additional heat treatments for the beta phase should ensure that the material is in the zinc-resistant alpha phase [22,59].

2.5. Manufacturing Methods for Brass Alloys

2.5.1. Intermediate Product Manufacturing Methods of Brass Alloys

Brass alloys are produced by a variety of techniques. In addition to the effects of the alloy, the processes of the manufacturing methods also have a significant impact on the physical properties of the alloy.

The basic manufacturing method for copper and copper alloys is shown in Figure 7 below.

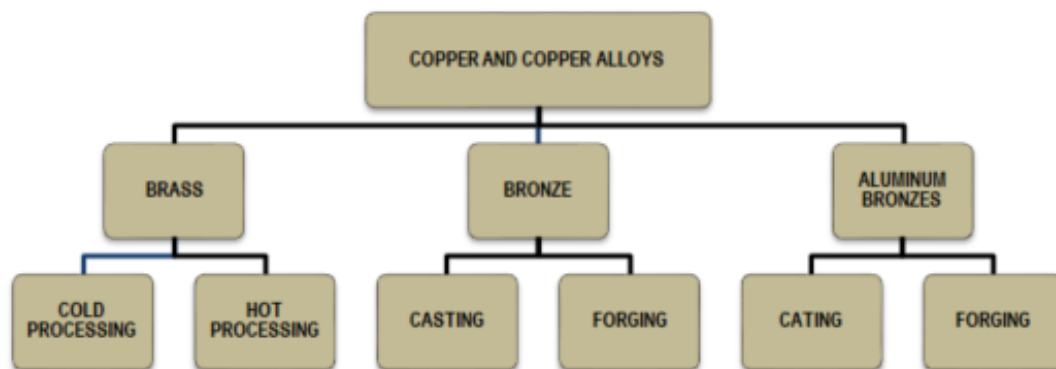


Figure 7. Manufacturing methods of copper and their alloys

2.5.1.1. Extrusion Method

Most of the alpha + beta ($\alpha + \beta$) brass is produced by extrusion and the obtained forms are round, hexagon and profiles. Alpha brass can be produced as a semi-finished product, and then the final size and strength values are obtained by the cold drawing method.

To beta brass; Cold forming process application is not suitable after hot processing. If the final size is to be obtained directly by extrusion, alpha + beta brass should be used [20]. The basic working principle of the extrusion is that it is extruded into a shaped mold by applying force to the hot metal. It is removed from the press with a suitable tensile conveying system and then cooled at room temperature. Extruded products can be cold-drawn to improve mechanical properties, tolerances and surface values. Material is smooth and homogeneous after cold drawing. Hollow section profiles can also be obtained by extrusion method. The use of hollow section profiles in the manufacture of many parts gives the manufacturer a more economic advantage. Alloy types and their properties of commonly used rod and profile brasses are shared in Table 8.

Table 8. Common usage of rod and profile of brass

Composition and EN Number	Properties
CuZn39Pb3 CW614N	High speed automat brass.
CuZn40Pb2 CW617N	Hot forged brass
CuZn36Pb2As CW602N	It is resistant to dezincification. Good corrosion resistance.
CuZn39Pb2 CW612N	Suitable for machinability and drilling.
CuZn37Pb2 CW606N	It has excellent machinability and is suitable for bending.
CuZn43Pb2 CW623N	Suitable for profiles.
CuZn43Pb2Al CW624N	Aluminum profile brass.
CuZn36Sn1Pb CW712R	Admiralty brass. Corrosion resistance is good.
CuZn40Mn1Pb1AlFeSn CW721R	It has high tensile strength.

2.5.1.2. Hot Pressing Method

Hot forging is done by compressing the hot solid billet between a two-part die. Molds should be designed with minimum tolerances, minimum burrs possible and reduced extra surface cleaning. Usually this method is used in alpha + beta brass alloys.

Table 9. The most common brass alloy with hot forging method applied

Composition and EN Number	Properties	Approximate Tensile Strength N/mm ²
CuZn40Pb2 CW617N	This is the he most common forging brass. Suitable for shaping complex parts. Good machinability	360
CuZn39Pb3 CW614N	Perfect machinability	360
CuZn39Pb2 CW612N	Its cold work ductility is better than CuZn40Pb2	350
CuZn39Pb2As CW602N	Dezincification resistance brass. It is usually used in faucet fittings.	280
CuZn40 CW509L	Lead-free alloy. Very good ductility. Perfect hot working ability. Low machinability.	340
CuZn40Mn3Al2PbSi CW713R	High strength brass. It has excellent wear resistance by the addition of silica in the alloy.	510
CuZn40Mn1Pb1AlFeSn CW721R	High strength brass. The addition of lead in the alloy has improved the machinability.	440
CuZn40Mn1Pb1FeSn CW722R	High strength brass with no aluminum. It is solderable.	390

2.5.1.3. Forging Method

It is generally used in the manufacture of small and large parts in the application of the forging method. The brass is hot forged as follows: when the press closes the dies with a single hit on the billet, it turns it into the part to be realized. The preheated billets are appropriately moved between the anvil and the movable head to give the desired round, square or special shape. With special forging hammers and punches, the product can be produced in desired dimensions.

More attention should be paid when annealing leaded brass. Single-phase alloys are more suitable for open forging than Alpha + Beta brass. This type of brass; bolts, nuts, gaskets, faucets, etc. products are obtained [20,26, 47,50]

2.5.1.4. Casting Method

It is one of the oldest manufacturing methods. It is the removal of the molten liquid metal from the mold by pouring it into a shaped mold and then cooling it. Products are obtained in the same size and shape as surface cleaning and finishing applications.

With the casting method, it is possible to obtain the product in exactly the desired dimensions according to the desired shape and technical characteristics of the part.

Choosing the casting process is an important element in the design cycle. However, in some cases, it is a decision that can be left to the mold. Most of the time, the size of the product to be used in the process solves in a logical manner with the shape and technical requirements [46].

2.5.1.5. Wire Drawing Method

The production of brass wires is a cold drawing process in which the brass material is gradually drawn with various sizes of molds. The hardness, tensile strength and spring property of the wire obtained as a result of these processes are considerably improved from the initial values of the material prior to drawing. In existing systems. Depending on the chemical composition, tensile strength of 300-850N/mm² and hardness of 200HB can be produced.

In the manufacture of wires, depending on the ductility properties of brass, it is possible to reduce the cross-sections up to 90% and above, but these values can be obtained by repeating the stress relief method.

Wires are usually produced in round form. Wire with diameters from 0.10mm to 8.0mm can be produced. Pins, clips, springs, zippers and many other applications are used for brass wires, especially for electrical applications.

2.5.1.6. Strip and Plate Production Methods

Strips are generally; They are produced from slabs produced in semi-continuous systems. They are then rolled into hot-rolled strip and rolled cold. Then 625°C softening

annealed to improve the coarse crystal structure. Thus, the softened strip is re-formed to the desired size by cold drawing again.

Plates are flat planar products wider than 300mm and thinner than 10mm. Alloys used in strips are generally used. In addition, they are manufactured from aluminum brass with extra corrosion resistance and low lead brass. Surface sensitivity is not sought for many plate applications. Manufacturing is facilitated when extraction oil is used, but it is sometimes preferred to polish at least one face, particularly for decorative purposes. In addition, the material hardness should be very well adjusted to the intended thickness when obtaining a quality surface. Otherwise, cracks, tears or other errors may occur in edge cutting, bending and drawing operations.

2.5.1.7. Pipe Production Method

It is obtained from welded pipes and strips. Since there is no cold drawing process, there are cheaper production costs. This method produces large volumes of pipes. The strips are shaped by crimping and then formed into tubes by welding.

Welded brass pipes are generally produced for decorative purposes where physical properties such as tensile strength are not very important. Dikişsiz borular, genellikle içi boş olarak ekstrüzyon preslerinde basılır ve soğuk çekme yöntemi uygulanarak istenilen ölçülerde elde edilebilirler. Amaca göre gerilim giderme tavlama yapılabilir.

Brass pipes are also produced in standard form in circle form. Thus, it is used without problems with standard fittings materials. In addition, brass pipes are manufactured according to customer requirements with other non-standard size and shape changes. Round, square and hexagon forms are available on the market. They can be manufactured in twisted, notched, decorative patterns and grooved forms.

2.5.1.8. Pleyt (Platinalar)

In general, plates are used in heat exchangers. The brass plates are used even if the heat exchanger pipes used are not brass. They are produced by giving the final shape in hot drawing line. They are optionally acidified or surface-treated. Cutting the ends with

scissors, sawing or other cutting methods is provided. Their thickness is usually greater than 10mm.

2.5.2. Methods Used in Chipless Shaping of Brass Alloys

The geometry of the final product is usually made by machining rolled standard bars. Thus, low cost processing methods can be used. Lead brass is widely used because of its good machinability [1,62,63,64]. The methods chipless shaping used for brass are share below.

2.5.2.1. Bending Method

Bending is made by calculating the minimum bending angle for the parts to be formed by cutting from sheet or strip, depending on the degree of hardness of the alloy and the rolling direction.

In bending method; stretching on the outer surface of the material and compression on the inner surface. In the middle region there is a neutral (unaffected) plane remaining with the first dimension. In this central region; Since the material exhibits elastic behavior, the elastic tension that exists in the neutral plane as long as the bending force is applied to the material disappears when the applied force is removed. Thus, the spring-back is seen on the bent part with the removal of the bending force.

2.5.2.2. Cold Forming Method

Cold forming is limited in duplex brass containing lead. For parts that require machining from the bar and then cold forming; high copper and low lead alloys are used.

Rivets, needles, screws and similar parts are produced from wire material by cold blowing. Single-phase alloys are easily riveted. Riveting; it is important to produce smooth-edged, correctly curved, and properly drawn.

2.5.2.3. Deep Drawing Method

The most important method used to obtain cylindrical products from sheet metal is deep drawing. When the depth of the part is larger than its diameter, the process is called deep drawing. Theoretically, the thickness of the material does not differ during drawing, but in practice thinning can occur on the cylinder walls [1,8].

2.5.2.4. Hot Rolling

The casted brass materials are subjected to hot rolling to give good strength and ductility.

2.5.2.5. Extrusion

Billet; it is pulled from the continuous horizontal drafting system, cut and annealed. then using appropriate molds; extrusion press; round, square, hexagon or special profiles are produced. For the extrusion of hollow rods, a mandrel extrusion system is used. The extrusion method is also applied to the duplex brass with good ductility [59].

2.5.2.6. Hot Pressing

In hot pressing method; It is a very economical method for mass production of all brass alloys in the weight range of 3-20kg using shaped molds. This method yields a near-finished product requiring a very small surface treatment. Press molds are designed according to the required shape and obtained by using cores for perforated parts in the part.

2.5.2.7. Heat Treatment

Heat treatment applications require very good knowledge and experience. Temperature and duration of the process; The amount of product varies with metal composition, degree of cold forming, furnace properties and heat measurement methods [3,8,35,36,56].

Annealing

Cold processed brass is applied for 30-60 minutes in order to relieve the internal tension by gradually annealing at approximately 250°C. This stress prevents cracks caused by corrosion and is important because it minimizes deformation during machining. Stress reduction annealing; it has a small measurable effect on the mechanical properties of the material.

Applied temperature; It causes structural changes at 400°C and above, and the material starts to temper or soften over time. The strengthening effect in cold processed alloys is approximately 500°C. In order to reach the cold processed characteristics lost after annealing, cold process should be applied again. Since the zinc in the brass is volatile during annealing, it is difficult to obtain a shiny surface.

Full Annealing

The brass is heated up to 30-60 minutes at 500-550°C for softening. it is then cooled in air or water. Excessive grain growth, especially for alpha alloys, is prevented by quenching or rapid quench cooling. Flash annealing can be performed at higher temperatures for extremely short periods of time. However, precautions are required to avoid excessive grain growth.

Stress Relief

Feature to eliminate internal resistance; Depending on the section size, low heat annealing is used at 250-300°C between 30-60 minutes.

Softening Annealing

It is possible to reduce many cold-hardened brass alloys to moderate hardness by controlled heat treatment. Results; hardness, grain size, homogeneity and other relevant properties.

2.5.3. Methods for Joining Brass Alloys

Since the main metal forming the brass is copper, its source is more copper-like. The fact that brass contains zinc makes the welding difficult. The problem in the welding of brass materials is due to the evaporation of zinc during welding [19,37,39]. Evaporation of zinc (905°C) disrupts the chemical composition of the alloy. A good ventilation is required during welding. Otherwise, the welder will be exposed to zinc-oxide fumes which are harmful to health. In addition, zinc-oxide fumes prevent visibility and the spread of molten metal, thus wetting the surface to be welded. Evaporation causes too much zinc loss. This changes the physical and mechanical properties of the base metal. In these alloys, the amount of zinc decreases with decreasing amount of zinc and increases the suitability for melting welding. This evaporation results in porous welding seams. At the same time, a red color is formed in the welding zone due to the evaporation of Zn.

additionally; High thermal conductivity of brass is high thermal expansion coefficient. As a result, the internal stresses in the post-weld internal structure arise and this is a situation that needs attention.

Although hydrogen can easily penetrate high-temperature copper, the presence of zinc prevents this phenomenon in brass. Therefore, this phenomenon which is a big problem in the welding of copper does not present a danger in the welding of brass.

However; Zinc evaporates if the necessary precautions are not taken due to the low boiling point (907°C) of the zinc contained in the brass as an alloying element. therefore, brass becomes brittle due to loss of alloy. In addition, the resulting vapors create a pore inside the seam, causing a decrease in the strength of the weld.

2.5.3.1. Soldering

All brasses are easily combined with brazing alloys according to EN 1044 standard. By forming a wide variety of brass copper zinc alloys; and lead, aluminum, tin, phosphorus, silicon and manganese. This diversity leads to very different behaviors during welding. A porous structure occurs in the welding application of lead-containing brasses, and

temperature fragile occurs in the alloy. Therefore; it is preferred to combine them by soldering, not by welding.

When flux material is used, if the component is allowed to remain on it, it is likely to cause corrosion on the brass. It should be cleaned as soon as possible. If the component is still hot after brazing, it is easy to clean, but the welded brass material must not be cooled immediately. In the case of sudden cooling, cracks may occur at the weld site.

Soldering; lead / tin is made using lead-free solders in EN 29453 or slag builders such as borax. There should be no temperature difference between the parts during soldering. The pressure applied to the materials during soldering should not be left before the material cools down. Otherwise; Due to the microstructure of the solder, cracks and breaks occur in the solder. In some cases, the parts to be applied before soldering must be de-stressed.

2.5.3.2. Oxy Acetylene Welding

Nowadays, oxy-acetylene welding is used frequently. Particularly used for joining pipes made of brass containing a high amount of copper. It is preferred because it is suitable for welding in any position. Since the heat conductivity of brass is weaker than that of copper, a smaller flame is needed in the weld. Strong oxidizing flame is used in the welding of brass.

An oxide layer forms on the surface of the bath due to the use of an oxidizing flame when welding. This oxide layer prevents the evaporation of the zinc and thus the loss of large amounts of zinc. Lead, even in small amounts in brass, adversely affects welding ability. In particular, when the Pb content is greater than 0.5%, the weld seam is porous.

2.5.3.3. Arc Welding with Covered Electrodes

The brass can be welded easily with covered electrodes. Here, phosphor bronze (tin bronze) and aluminum bronze electrodes are used. If the brass contains lead, welding becomes difficult and it becomes impossible to obtain seamless welding without pores.

A weld is usually required during welding and the process can only be performed in the horizontal groove position. They are welded by pre-annealing. Reverse polarity must be used at the direct current with the recommended maximum current strength. The smallest possible welding bath should be established. The arc must always burn between the weld metal and the electrode. Oscillation should be given up to three times its diameter and the process should proceed slowly. In this way, zinc loss is minimized.

2.5.3.4. Protective Gas Supply

Nowadays brass can be welded easily by both TIG and MIG welding method. Parts other than thin plates should be pre-annealed at 200-300°C. Due to brittleness, pre-annealing should not be done on brass containing silicon.

Due to the formation of a brittle aluminum layer at the welding, MIG or TIG welding methods are preferred. Electrode selection is made according to zinc ratio and alloy elements. A good level of welding quality can be achieved with an arc welding with a covered electrode. In addition, it is used where high tensile and high fatigue resistance is required.

Although the quality of welds made by the TIG method is of medium level, this method is most commonly used in the production and repair of brass. A mixture of argon, helium or inert gases is used as the protective gas according to the material to be welded.

Copper-zinc alloy electrodes may not be used for welding with shielding gas. Because of the evaporation of zinc, the weld seam is extremely porous.

In MIG welding, electrodes of the same composition are generally used. Pretreatment is recommended in order to reduce the current intensity and reduce zinc evaporation.

2.5.4. Machinability and Chip Removal Methods in Brass Alloys

Machining is one of the most important and common manufacturing methods. Machining is one of the biggest problems that are tried to be solved in the machining industry. Machinability is therefore an important concept for machining. Machining

should be considered as a system property that includes the process and the material together. Workability; it is the combination of the ability of the cutting tool to cut the workpiece and to cut the workpiece.

In the machining process, the work piece (semi-finished; casting, forged, rolled) to bring the desired geometry, over the appropriate machine tool (lathe, milling, drill) and using the cutting tool in the form of chips. This ensures the desired dimensions and surface quality.

The focus of the chip removal theory is the formation of chip. Chip removal process is based on elastic and plastic deformation; physical events such as friction on the workpiece and tool, heat generation, chip breakage and shrinkage, hardening of the surface of the workpiece, wear of the tool tip.

In order to take advantage of the excellent machinability of brass, it is necessary to apply the correct machining tool and techniques. To increase productivity; The geometry, speed, feed and cutting depth parameters of the machining tool must be well adjusted.

Machinability is an important concept for machining. Machinability; process and material together. It is not possible to put the materials in a general order in terms of machinability. Generally; machining and various other shaping processes are required.

A good workable material; In machining process, it should be processed with high chip volume in a short time. The newly formed surface should be of good quality (low surface roughness). Tool material should be less wearable and long-lasting during the process. Same time; While determining preferred machining methods, it is an important criterion to be economical.

Although essentially all brasses are easy to process, the lead added into the alloy further enhances these properties, making brass in front of all other metals. Because of these properties, brass has been accepted worldwide with the standard of machinability [10,16,17,30,60].

The purpose of the brass is based on their corrosion resistance and high machinability. The reason for increasing machinability by adding lead in brass is that lead acts as a lubricant.

The effects of copper, zinc and lead contents on machining of brass are summarized in the following graph.

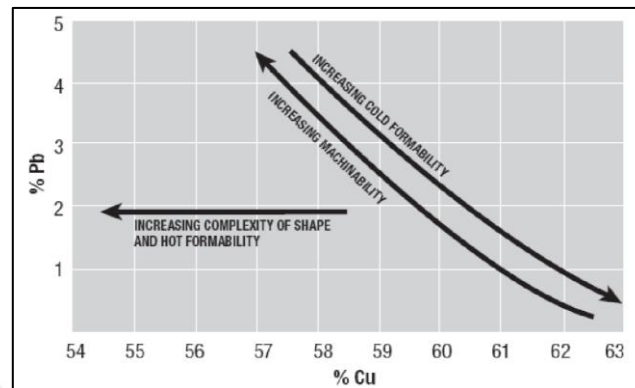


Figure 8. Cu-Pb relation in alloy [1]

There are also different processability correlations between the chemical composition and processability parameters in the alloy [1,16,33,42,43,58,60,63,64,69].

In machining of brass; abrasion of the base surface, tip wear, crater wear, rounding of the edges, edge grinding, edge cracking, sudden breakage.

In case of workpiece contact with cutting tool; With the applied cutting speed, the workpiece is subjected to different mechanical (high stresses) and thermal forces (temperatures). Continuation of the cutting process, the tension of the material is reached to the yield limit. Up to this point; Since the material is in the elastic deformation region, the material can return to its initial state if the cutting is stopped or retracted at this point.

By continuing the cutting process, when the yield limit of the material is exceeded, the plastic behavior zone where permanent deformations occur is entered.

When the stresses exceed the yield limit of the material; the surface layers, called sawdust, slip off the cutting surface of the tool along the workpiece. If the forces are stopped or withdrawn in this region, there is no such thing as returning the material to its original state. Chip (sawdust) removal principles:

- The cutting tool is a harder material than the workpiece,
- The cutting tool; rigid bonding and withstand extreme pressure during chip removal

- Relative movement between the workpiece and the tool tip, in order to achieve optimum cutting effect,
- Has a certain geometry that provides maximum cutting effect with sufficient tool life.

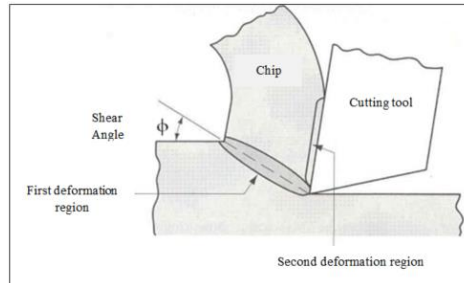


Figure 9. Chip formation

2.5.4.1. Orthogonal Cutting

An important relationship can be established between orthogonal cutting geometry and chip ratio, chip angle and shear plane angle.

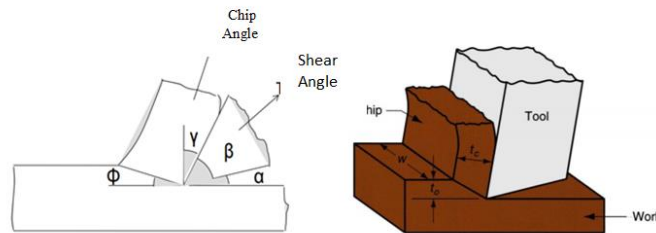


Figure 10. Orthogonal cutting and cutting angles

α : Free Angle

β : Shear Angle

ϕ : Slip Angle

γ : Chip Angle

t_0 : Shear Depth

t_c : Chip Thickness

r : Chip Ratio

$$r = \frac{t_0}{t_c}$$

The chip angle; while allowing the chip to move away from the workpiece, the wedge angle; allows the tool to penetrate the workpiece. The free angle ensures that the tool

does not rub the workpiece against the surface. Chip thickness; The cutting ratio is always greater than 1, since it is greater than the cutting depth in all conditions. In orthogonal cutting, the width represented by w has no effect. If the slip plane length I_s is accepted here;

$$t_0 = I_s \sin \phi$$

$$t_c = I_s \cos(\phi - \alpha) \text{ olur.}$$

According to this;

$$r = (I_s \sin \phi) / [I_s \cos(\phi - \alpha)] = (\sin \phi) / \cos(\phi - \alpha)$$

$$\tan \phi = (r \cos \alpha) / (1 - r \sin \alpha)$$

The slip unit deformation on the slip plane is found by examining the shape system below.

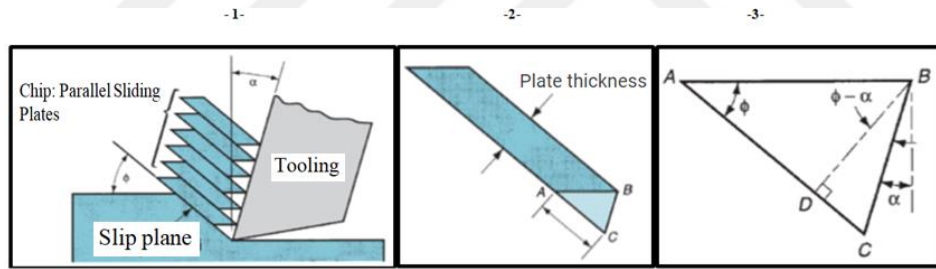


Figure 11. Consecutive sliding plates and modeling method

The sliding unit deformation occurs in each plate of the successive sliding chips shown in Figure 15.

$$\gamma = \frac{AC}{BD} = \frac{(AD+DC)}{BD}$$

$$\gamma = \tan(\phi - \alpha) + \cot \phi$$

Although machining operations such as turning, milling, drilling or screwing may vary; The chip formation mechanism on the workpiece is generally the same. In general, the

sawdust takes place in a very narrow zone (first deformation zone) by local sliding. When the cutting tool comes into contact with the workpiece, elastic deformation first occurs on the workpiece. With the ongoing cutting process, the yield strength of the workpiece is then exceeded and the workpiece material undergoes plastic deformation. With the relative movement of the cutting tool and the workpiece, high accumulation of dislocation occurs in the annealed workpiece material during the plastic deformation. This causes hardening of the deformation in the workpiece. The deformed area is cut from the cutting surface and discarded in the form of chips.

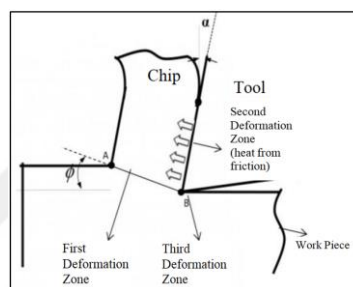


Figure 12. Deformation information in machining

Continuous Chip

It is seen in material types that are capable of deformation. In high-ductility materials, the chip flows smoothly (flowing chip), whereas in materials with low ductility, the surface of the chip begins to layer in parallel. Then chip type is formed periodically. Small progress, small depths and small passes occur. Low friction between chip and chip surface

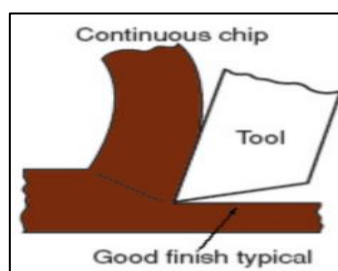


Figure 13. Continuous chip

During chip formation, the deformation of the material takes place in a narrow sliding zone (1st deformation zone). Due to the friction, a second deformation zone is formed on the surface of the tool chip with continuous chip. The second deformation zone becomes thicker as tool chip friction increases. In continuous chip formation, the thickness of the 1st deformation zone may increase. It is often the result of machining soft materials at low cutting speeds and low chip angles. This increases the surface roughness and causes permanent surface stresses. Due to the high stress in continuous chip formation, it hardens to cold and reaches high hardness values, causing tool wear.

Discontinuous Chip

Due to the discontinuous structure in chip formation, forces change continuously during machining. As a result; The stiffness of the tool holder, clamping elements and the machine tool is important in cutting operations with sliced and discontinuous chips. If these are not rigid enough, the machine tool is subject to vibration. This causes the workpiece surface and dimensions to exceed the desired tolerances. It also speed up tool wear. The high friction between the tool and sawdust, the feed and the excess of the pile contribute to the formation of the chip in this way.

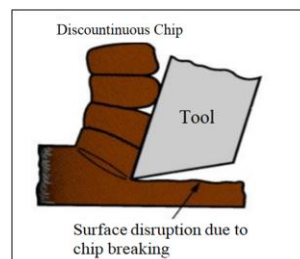


Figure 14. Discontinuous chip

In the processing of materials with low or no ductility; In the slip region, the crack in the load caused by the cutting conditions progresses and causes the small particles to break. This type of chip, which is formed in brittle materials, naturally causes a poor machining surface in the material. Ideal chips for machining; short spiral and helical shaped chips.

Sliced (Sawtooth) Chip

Sliced, non-homogeneous, low and high slip deformation with semi-continuous chips. In metals with low thermal conductivity and strength decreasing rapidly with temperature increase; (eg titanium) this behavior is seen. These chips have the shape of a saw tooth.

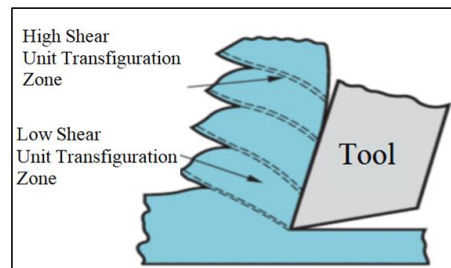


Figure 15. Sawtooth chip formation

Agglomerate chip

During the machining process; is the form of chip formed by the gradual deposition of workpiece material in layers on the cutting tool. During the cutting process, this chip can form at the tip of the cutting tool.

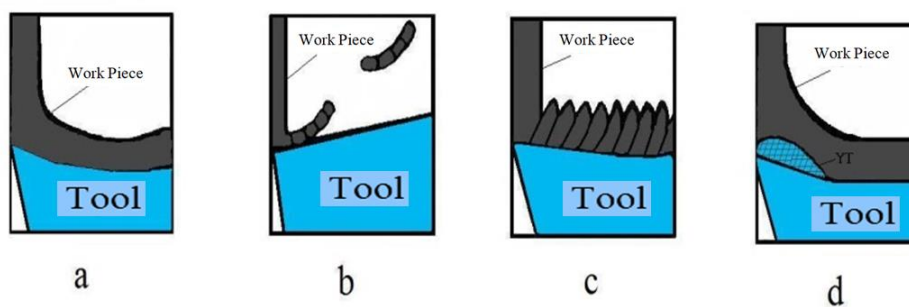


Figure 16. Chip types a) Continuous chip b) Discontinuous chip c) Sliced chip d) Agglomerate chip

2.5.4.2. Relatif Relative Processing Capability

Provided that other stock removal factors remain the same; For a certain tool life, it is measured by comparing the cutting speeds of materials in roughing.

It is possible to establish a relationship between Brinell hardness or tensile strength and relative processing ability of materials. Generally; the greater the Brinell hardness or the

tensile strength of a material, the lower the relative processing ability (ie, relative shear rate) of that material.

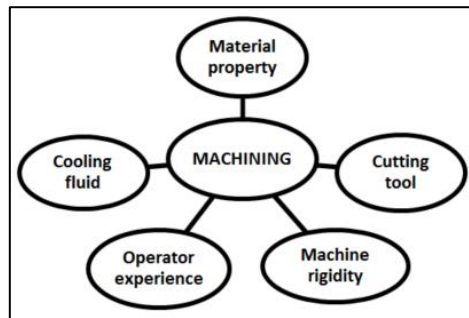


Figure 17. Factors affecting machinability

While defining the materials with good processability in production; cutting speed is high, tool life is long, cutting force is low, surface roughness is considered to be valid.

2.5.4.3. Drilling Method

Drilling is essentially a process of removing chips with a relative movement between the cutting tool and the workpiece. Figure 27. This process; It has an important place in the manufacturing industry such as turning and milling and is widely used and also among the machining processes. During drilling, the drill or workpiece or both rotate. The drilling process is fast and economical, but the cutting action is difficult and inefficient [65]. This is a difficult machining method because the chip output and coolant flow in drilling are limited.

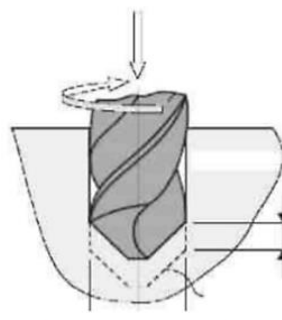


Figure 18. Drilling process

As is the case for all types of machining, the material properties of the drilled part are; material such as cutting tool, depth of cut, feed rate, speed are important.

During drilling process; extreme surface roughness, burr formation, ovality, axial misalignment, rapid tool wear, frictional temperature are encountered. During the drilling process; feed force, torque, tool wear and surface roughness can be controlled by determining the optimum cutting parameters. Optimum cutting parameters are determined to increase productivity and precision in production.

2.5.4.4. Turning Method

Turning is the stock removal process with the rotational movement of the part and the movement of the tool.

In lathes; The main turning operations are called either by the name of the cutting tool used or by turning. As an example; Taper turning, hole drilling, threading, grooving, cutting, reaming etc. mentioned.

n lathes; circular shaped parts, springs, screws and bolts can be produced, holes can be drilled. While turning lathes, which are widely and effectively used in the industry, demanded serious craftsmanship and work force in the past, production with CNC lathes has become very easy with the developing technology. There are 3 axes in universal lathes (progress, pass and mirror axis X-Z-C), while the number of axes in CNC lathes has increased up to 7. In addition to ease of operation, this has resulted in more precise manufacturing and cost advantages such as reduced production time.

2.5.4.5. Milling Method

Milling is the process of shaping by removing chips from the material with tools or special cutters with more than one insert around it.

With milling, tools with specific geometries are used to produce flat and curved surfaces, grooves, helical grooves, gears and screws.

Milling is the process of removing the workpiece from the workpiece that moves with a rotating tool. Milling takes place with the help of inserts around and / or around the tool. Therefore, milling is divided into circumferential and face milling.

Milling machines are named according to the spindle to which the tool is connected. Spindles with horizontal position; horizontal milling, vertical machines; called vertical milling. In addition, both horizontal and vertical milling machines are called universal milling.



3. MATERIAL AND METHODOLOGY OF THE STUDY

3.1. General Metodology of Hot Forging Brass and Studied Material

Today; national and international industrial brass alloys contain 0-45% zinc. Brass has two important phase regions. These are α -phase and β -phase compounds. In addition to brasses it can be processed easily with lead addition. The α -phase is ductile. So that can be cold processed and forged. The β -phase brasses; they can only be processed hot. It is suitable for casting because it is harder and stronger. However, the β -phase is weak against dezincification. Up to 4% lead is added to the brass materials. Lead-doped brass alloys have high dezincification resistance, but lead-containing alloys pose a major threat to human health. The World Health Organization (WHO) demands restrictions on the use of lead elements harmful to human health and the production of low leaded brass materials with high dezincification resistance in the World is negligible [52].

In this study; CW625N brass alloy, a new type of alloy, is used. This alloy suitable for hot forming has alpha and beta phases. Experimental samples will be produced from CW625N alloy. The traditional method applied for the production of brass alloys and different methods are aimed to be applied and examined.

The traditional method for brass alloys suitable for hot forging is as follows;

- To obtain the alloy in the composition range,
- Production of rods by extrusion method,
- Hot forging forming according to the desired geometry,
- Cooling in calm air, heat treatment process and
- Machining applications for the final product.

As mentioned above, brass suitable for hot forging; It is created by forging in hot presses by using molds that will obtain the geometry of the product. The forged products cool down in calm air. These cooled pieces are heat treated and the pieces are given the final form with the necessary processing method.

Companies producing brass in the sector; After hot forging of rod-shaped brass alloys, one or more heat treatments are applied to the forged parts to ensure dezincification

resistance and the desired standard. This heat treatment applied; Depending on the composition of the alloy, its duration and temperature range also varies from 500C to 600°C. Thus, it is aimed to provide single phase alpha structure by heat treatment. It is a mandatory but expensive and slower production process. The last stage; If the dezincification resistance of the products is at the desired level, machining methods suitable for the product design are applied for the final shape.

There are three important issues in this new alloy. These; determining the optimum forging parameter, ensuring high dezincification resistance (to be achieved in the desired standard) and the machinability of the alloy.

The studying alloy's chemical composition include maximum 1.6% Pb element. Therefore, the CuZn35Pb1 alloy is called the lead-free brass alloy. CW625N lead-free brass alloy is not common to use in production in the World. Therefore, each stage of this alloy is open to research and development.

In this study planned; CuZn35Pb1 alloy test samples formed by hot forging process with different parameters, which three different temperature and there different pressure parameters. Produced samples were cooled with three methods. These cooling methods were in calm air, with fan and in water. Two of them (cooling with fan and in water) are an application that has never been used.

The following studies performed on the test samples produced after the determined production conditions;

- Cooling times of test samples produced under different conditions and cooled under different conditions were examined.
- Some samples were heat treated and their effects were examined.
- Material surface hardness examined.
- Microstructures of each sample examined
- Dezincification resistance of each sample examined
- Machinability capabilities examined.
- All experimental results evaluated statistically.
- The benefit of the alternative method obtained as a result of this thesis study will bring to a company.

Properties of CuZn35Pb1 alloy determined according to the CEN/ TS 13388 standard is shared Table 10.

Table 10. Chemical composition of CW625N alloy according to CEN / TS 13388 standard [71]

<i>Elements</i>	<i>Cu</i>	<i>Pb</i>	<i>Sn</i>	<i>Fe</i>	<i>Ni</i>	<i>Al</i>	<i>Mn</i>	<i>As</i>	<i>Zn</i>	<i>Other</i>
<i>Min. %</i>	62.00	1.2	≤ 0.3	≤ 0.3	≤ 0.2	≤ 0.5	≤ 0.1	0.02	diff.	≤ 0.2
<i>Max. %</i>	64.00	1.6				≤ 0.7		0.15		

The properties mechanical and physical of CuZn35Pb1 alloy are shared in Table 11 and Table 12.

Table 11. Mechanical properties of alloy [71]

MECHANICAL PROPERTIES	
Tensile strength	>400 Mpa
Yield strength	~300 Mpa
Fracture elongation	>30 %
Brinell hardness	~110 HB

Table 12. Physical properties of alloy [71]

PHYSICAL PROPERTIES	
Density	8.4 kg/cm ²
Electrical Conductivity	19% ACS
Thermal Conductivity*	93 W/(mK)
Specific Heat	21.3x10 ⁻⁶ K
Eleasticity Module	100 kN/mm ²
Melting Point	875-900 °C

The Properties of manufacturing capability of the alloy are shown in Table 13.

Table 13. Manufacturing capability of alloy [71]

Machinability							
Weldability							
Hot Forming							
Cold Forming							
Corrosionresistance **	< 200 μ (* Use care to ascertain compatibility chemical substances)						

3.2. Experimental Studies

3.2.1. Obtaining Samples and Applied Parameters

In the production of test samples of CuZn35Pb1 lead-free alloy; the alloy was obtained in the appropriate composition range. After the alloy obtained in the melting pot, it is produced under the scope of TS EN 12164 by extrusion to commercial quality bars of 37mm diameter and 5.5m length [54]. The production of alloys and the production of rods was achieved at Company of PİREKS BAKIR ALAŞIMLARI SAN. and TİC. A.Ş. Produced rods; were brought to Company of KALE MUSLUK SAN. and TİC. A.Ş to obtain test samples by applying hot forging.

3.2.1.1. Production of Samples with Different Forging Parameters

For the forging temperature of 750°C, 780°C and 790°C, forging pressure 70Bar, 80Bar and 90 Bar values were determined and 108 test samples were produced under the scope of TS EN 12420 [53].

Each test parameter plans are given in Table 14.

Table 14. Distribution table of parameters for 108 samples

		Applied Forging Pressures		
		70 Bar	80 Bar	90 Bar
Applied Forging Temperatures	750°C	12 samples	12 samples	12 samples
	765°C	12 samples	12 samples	12 samples
	780°C	12 samples	12 samples	12 samples

The bars were cut into pieces of 400mm length. Each piece (which will enter the forging die) is called billet and each billet is 37mm in diameter and 1100gr in weight. The billets obtained from the bars cut before hot forging were subjected to graphite treatment. Examples of billets that have undergone a graphite process are shown in the Figure 19.

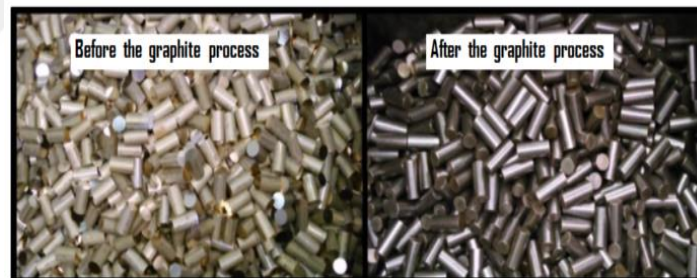


Figure 19. Before and after graphite prosses

Farmbrass brand hydraulic press which capable of applying 400tons pressing force used to produce samples in accordance with TS EN 12165 and TS EN 12420 standards [55]. The forged test samples is shown in Figure 20.



Figure 20. Hot forged shaped test sample

Additionally; different cooling methods were applied to the samples obtained from the forging. These methods; Immediately applied samples from the press.

3.2.1.2. Determination of Different Cooling Types After Forging

In brass production; in the classical production method applied throughout the world, cooling takes place in calm air. In this thesis, different types of cooling were determined and the test samples were produced according to the plan. This plan is shared in Table 15.

Table 15. Temperature and pressure plans of produced 108 samples

Temperature	Pressure	Cooling with Fan	Cooling in Calm Air	Cooling in Water
750 °C	70 Bar	3 pieces	6 pieces	3 pieces
	80 Bar	3 pieces	6 pieces	3 pieces
	90 Bar	3 pieces	6 pieces	3 pieces
765 °C	70 Bar	3 pieces	6 pieces	3 pieces
	80 Bar	3 pieces	6 pieces	3 pieces
	90 Bar	3 pieces	6 pieces	3 pieces
780 °C	70 Bar	3 pieces	6 pieces	3 pieces
	80 Bar	3 pieces	6 pieces	3 pieces
	90 Bar	3 pieces	6 pieces	3 pieces

3.2.1.2.1. Cooling in Calm Air

Samples carried into the basket by conveyor during forging process; without interfering with the purpose of cooling, it was expected to reach the ambient temperature in its

case. In this process, the cooling time takes a very long time due to the small spaces between the samples in the basket and the heat exchange between the samples in contact with each other. Continuous hot samples sent into the basket increase the time it takes for the heat to escape from the basket. Therefore, the baskets are taken from the press chamber after a certain amount has been filled and removed for cooling.

3.2.1.2.2. Cooling with Fan

Samples with permanent plastic shapes as a result of forging process; From the press conveyor to the baskets in which it was stored, it was left to be cooled by the fan. Fans; on the upper part of the baskets was placed on a portable metal frame. It was provided to carry out the cooling process directly on the samples in the basket and by conveying the ambient air. In this system, cooling was carried out by momentarily removing the temperature on the sample surface.

3.2.1.2.3. Cooling in Water

The forging process was carried out by cooling the samples which were permanently formed into plastic by sudden immersion in water. The temperature value of the samples immersed in water immediately before immersion; It is above 600°C.

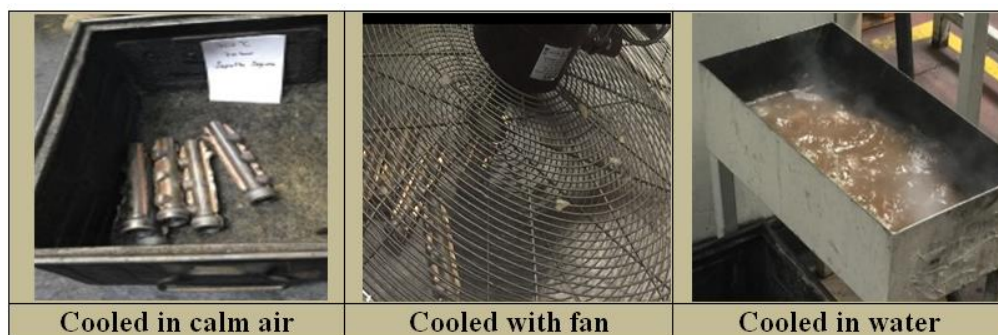


Figure 21. Cooled Methods

Codes were given to each of the 108 samples produced for ease of follow-up in experimental studies. These codes were given according to their cooling methods and forging parameters. These Codes are given in Table 16.

Table 16. Given groups codes

Cooling in Calm Air		Cooling with Fan	Cooling in Water
5070s0	5070s3	5070f1	5070w1
5070s1	5070s4	5070f2	5070w2
5070s2	5070s5	5070f3	5070w3
5080s0	5080s3	5080f1	5080w1
5080s1	5080s4	5080f2	5080w2
5080s2	5080s5	5080f3	5080w3
5090s0	5090s3	5090f1	5090w1
5090s1	5090s4	5090f2	5090w2
5090s2	5090s5	5090f3	5090w3
6570s0	6570s3	6570f1	6570w1
6570s1	6570s4	6570f2	6570w2
6570s2	6570s5	6570f3	6570w3
6580s0	6580s3	6580f1	6580w1
6580s1	6580s4	6580f2	6580w2
6580s2	6580s5	6580f3	6580w3
6590s0	6590s3	6590f1	6590w1
6590s1	6590s4	6590f2	6590w2
6590s2	6590s5	6590f3	6590w3
8070s0	8070s3	8070f1	8070w1
8070s1	8070s4	8070f2	8070w2
8070s2	8070s5	8070f3	8070w3
8080s0	8080s3	8080f1	8080w1
8080s1	8080s4	8080f2	8080w2
8080s2	8080s5	8080f3	8080w3
8090s0	8090s3	8090f1	8090w1
8090s1	8090s4	8090f2	8090w2
8090s2	8090s5	8090f3	8090w3

Each forged sample was measured every 20 seconds for nine minutes and temperature changes were recorded. Temperatures; It is measured with TROTEC TP7 brand infrared thermometer which can work in the range of -50°C and +1000°C. In the measurement of samples cooled only in water; PCE brand P-700 thermocouple with measuring range -200°C and +1760°C, tolerance $\pm 0.5^{\circ}\text{C}$ was used.

The values were noted when the coil temperature reached the desired value and the temperature of the sample sent to the mold surface was measured again after printing. then, temperature changes over 9 minutes were measured at regular intervals.

3.2.2. Chemical Composition Measurement

The chemical composition values were obtained by spectral analysis of each cooled test sample. The composition measurements of the samples were examined in Marmara University Metallurgical Materials Engineering Laboratory. Spectral analysis performed with Thermo Scientific Niton XL2 980 Goldo model apparatus. This used aparat is shown in Figure 22.



Figure 22. Spectral Analisis System

3.2.3. Heat Treatment Application

As mentioned in other parts of the thesis; the traditional method applied in brass alloys, is hot forging, cooling in calm air, heat treatment and finally machining process.

As shown in Table 61, the number of samples cooled in calm air is twice that of other cooling groups. This is because it is planned to heat-treat 27 test samples that cooled in calm air and have the same production conditions. The heat treatment process was applied in BODYCOTE ISTAS ISIL İŞLEM SAN. TİC. A.Ş.

The heat treated parts were kept at 550°C for 180 minutes and then cooled in calm air [48]. The 27 samples (sample cods s0, s1 and s2) which were heat treated using AFC Holdcroft CQI9 furnace is showed in Figure 23.



Figure 23. Used AFC Holcroft CQI9 brand heat treatment furnace

3.2.4. Mechanical Testing - Hardness Measurement

The hardness measurements of the samples were examined in Marmara University Mechanical Engineering Faculty Laboratory. TESKON TIME TH-500 analogue manual measuring device was used for hardness measurement. Rockwell hardness method (tested by immersion) was used in hardness tests. The device can measure hardness up to 150kgf. In HRB measurement; 1/16inch ball is used. Measurements were made at three different points of each sample. The picture of the measured device is shared in Figure 24.

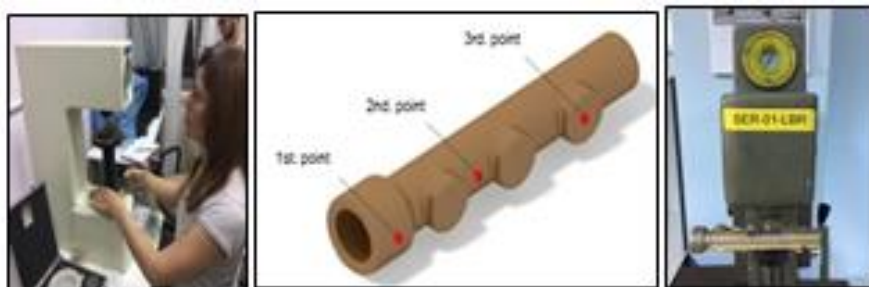


Figure 24. Sample measurement points

3.2.5. Microstructure Investigation

Metallographic samples were prepared for examining microstructure. It was taken sections which perpendicular and parallel to the direction of extrusion from each sample with Struers Labotom Discotom-5 brand cutting device. These sections were taken in bakelite. These bakalite samples were polished with sandpaper. Sanding sheets 80-150-

240-320-600-800 were used with Struers LaboPol-21 model aparat. Afterwards, microstructures of all samples were examined. In Marmara University Materials Engineers Laboratory; microstructure images with Nikon LJ80 optical microscope and grain sizes were obtained with Nikon Epiphot 300 model microscope and examined. Perpendicular and parallel to the direction of extrusion of test samples is shown Figure 25.

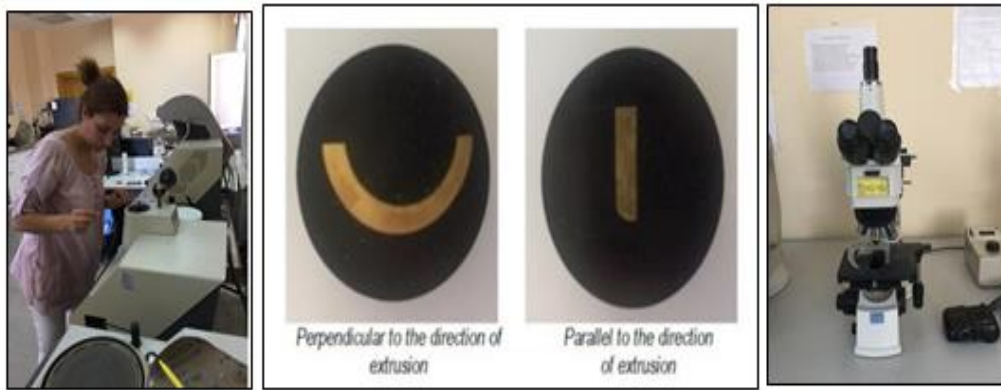


Figure 25. Bakelite images of test samples

The samples were examined at magnification 200 times. It was examined on microstructures and grain sizes.

3.2.6. Dezincification Test

Dezincification depths should be examined in perpendicular and parallel to the direction of extrusion. Experiments were performed scope of the dezincification test standard which According to TS EN ISO 6509-1 standard [31]. Used Nuve NB20 Water Bath device is shown in Figure 26.

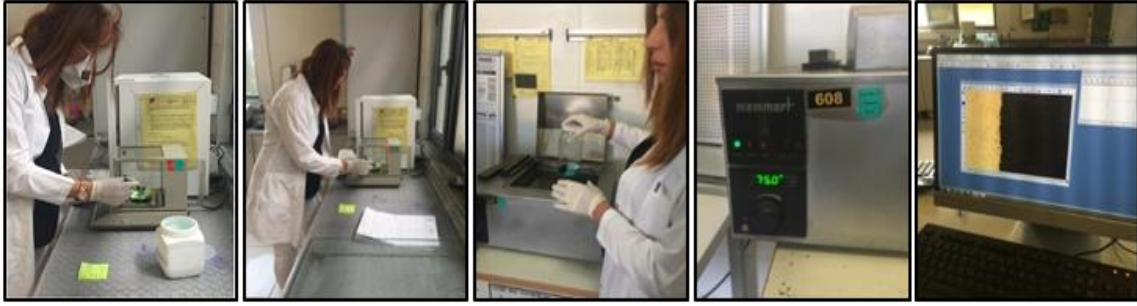


Figure 26. Images of dezincification test stages

It was kept at 75°C in Copper (II) Chloride Dehydrate at 1% solution for 24 hours in Nuve NB Water Bath device. The samples were pulled out from device and tested. The depths of the dezincification which the microstructure images, were taken from samples magnified 200 times by Nikon Eclipse Microscope using directly Clemex Vision Lite software.

For the determination of beta and alpha phase ratios; all samples were kept in a solution of 25°C [60g (NH₄)₂S₂O₈ + 50ml H₂O₂ + 700ml H₂O] for 45 seconds. Beta and alpha phase ratios were measured by Nikon Eclipse microscope using directly Clemex Vision Lite software. All the these group tests were applied in SARBAK METAL TİC. SAN. A.Ş.

3.2.7. Machinability Test

As mentioned earlier, the addition of lead to alloy is an element that improves the machinability of alpha and beta brass alloys. However, there is a minimized amount of lead in the alloy being studied. In the alloy samples obtained by taking into consideration the different parameters, Ø10mm drill diameter, 1000rpm rotation speed and 300mm/sec feed amount were determined drilling was applied to all parts. FELLER C-30 CNC Lathe device is used and this process TERSAN TERSANECİLİK SAN. TIC. A.Ş. realized in the machining workshop.



Figure 27. Special apparatus prepared for experimental study

A total of 119 carbide drill bits were used for each sample. Since it is not possible to read the cutting force applied on the device, a special mechanism has been prepared. Smart-ESIT brand Load-Cell was used in the prepared mechanism and mechanical and electrical connections were made to the machine.

After the determined parameters, the structure of cutting chips, cutting force and surface roughness values were examined [54].

In the workability study, the fixed parameters were shared in Table 17.

Table 17. Fixed Parameters in Machinability

Type of drill used	Used drill diameter	Tooling tip angle	Number of drill bits used	Revolution speed	Total Feed amount	Feedrate
Carbide, 45HRC, 3 cuttur mouth	Ø 10	118°	108 pieces for each sample separately (additionally 11 drill bits - for 2nd heat treated samples)	1000 rpm	30 mm	6 mm/sec

Mitutoya SJ-400 brand surface roughness with measuring device used for tests. These measurement were carried out in the Laboratory of ÜNİMETAL HASSAS DÖKÜM MAK. VE YED. PARÇA SAN. VE TİC. A.Ş Company. Measurements made with the help of electronic devices; during the movement and the resulting vibrations were determined by interpretation. 90° and 5μ sharp following type were used.

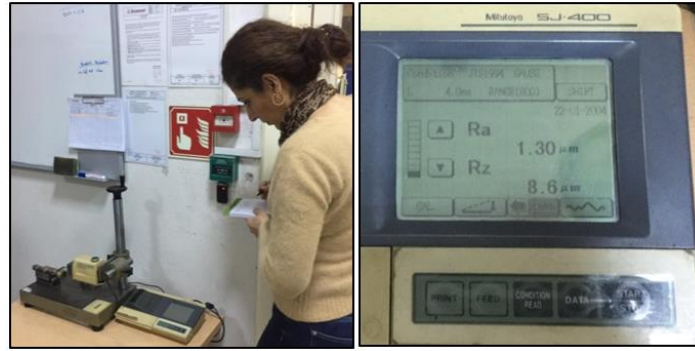


Figure 28. Surface roughness measurement

3.3. Statistical Analysis

All test studies to be examined for the manufacturability of a new alloy type are described above (3.1, 3.2 and all sub-substances thereof). These tests; It was done using traditional methodology, that is, for each sample (108 pieces) individually. In the 4th article of the thesis, the results are explained one by one.

By applying the statistical analysis method in item 3.3; The traditional methodology is intended to verify the effects of the tests applied to each individual sample. The results of the groups that were not heat treated (cooled in water, fan cooled and cooled in calm air) and heat treated (cooled in calm air and heat treated) were evaluated.

Firstly, Taguchi Method was applied in order to test many factors in very numbers. L9 orthogonal array is used for the groups that do not apply heat treatment. The orthogonal matrixes created are shared in Table 18.

Table 18. Taguchi Matrix (P=3, L=3) for Non-Heat Treated Groups

TAGUCHI L9 ORTHOGONAL ARRAY PARAMETERS			TEMPERATURE (°C)	PRESSURE (BAR)	COOLING METOD
Temperature (°C)	Pressure (Bar)	Cooling Method	750	70	Calm in air
1	1	1	765	80	In Water
1	2	2	780	90	With Fan
1	3	3			
2	1	2			
2	2	3			
2	3	1			
3	1	3			
3	2	1			
3	3	2			

Secondly; L3 orthogonal array is used for the heat treated group. The orthogonal matrixes created are shared in Table 19.

Table 19. Taguchi Matrix (P=2, L=3) for Heat Treated Groups

TAGUCHI L3 ORTHOGONAL ARRAY PARAMETERS			TEMPERATURE (°C)	PRESSURE (BAR)
Temperature (°C)	Pressure (Bar)	Cooling Method	750	70
1	1	1	765	80
1	2	2	780	90
1	3	3		
2	1	2		
2	2	3		
2	3	1		
3	1	3		
3	2	1		
3	3	2		

Parameter design of the thesis subject alloy was made by Taguchi method. Finally in this thesis study; Anova Analysis (variation analysis), one of the multi-factorial experiment analysis methods, was used. The purpose of the application of this analysis method; is to calculate the effect of a parameter on the experiment.

Minitab-17 program was used for Taguchi and Anova analyzes.

4. RESULTS and DISCUSSIONS

4.1. Cooling Results of Cooling Method Groups

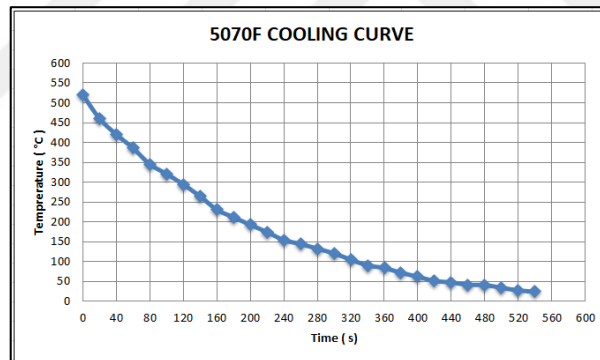
Forging was carried out when the coil temperature reached 600 degrees and the moment it went down to 500 degrees on the conveyor was expected. Subsequently, temperature measurements were made for each sample every 20 seconds for 540 seconds. The average recorded change values of the samples in each cooling group were taken and the cooling curves were extracted.

For the following Table 20, Table 21 and Table 23 groups, the forging temperature 750°C and pressure 70bar are constant. Only cooling methods, which are named with fan cooling, cooling in water and cooling in calm air, are different.

It taken the average of the cooling values of 5070f1, 5070f2 and 5070f3 samples. Thus, with the values formed cooling curve of the 5070F group and shared in Table 20.

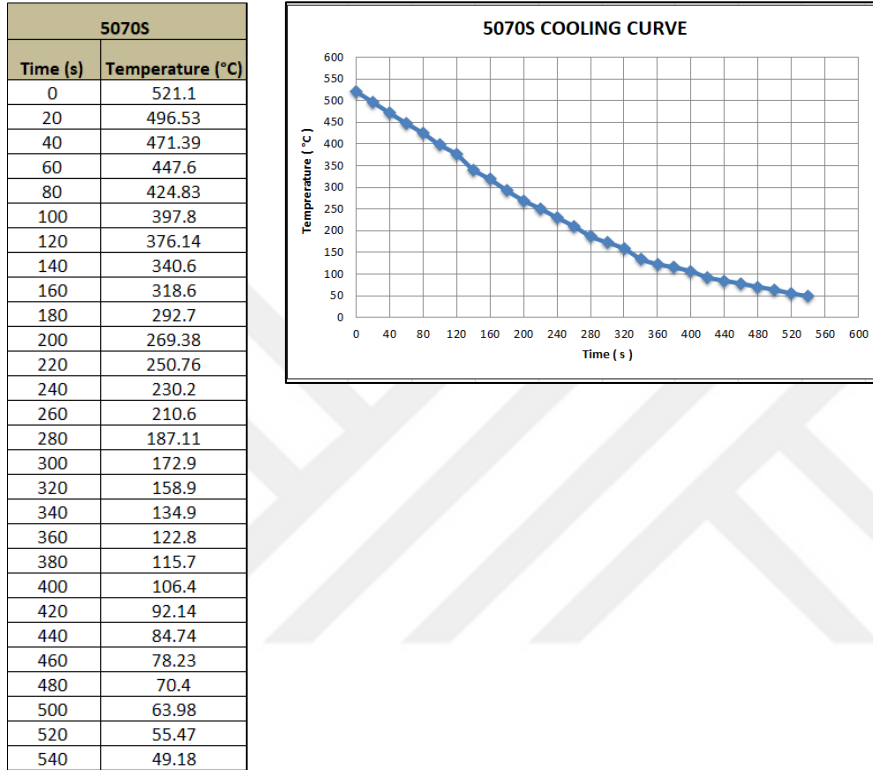
Table 20. The cooling values and the cooling curve of the 5070F

5070F	
Time (s)	Temperature (°C)
0	520.2
20	460.3
40	420.23
60	385.8
80	345.4
100	320.9
120	294.4
140	264.6
160	230.8
180	211.8
200	192.7
220	174.5
240	154.3
260	144.5
280	132.6
300	120.75
320	104.9
340	90.6
360	84
380	71.9
400	62
420	51.4
440	47.8
460	41.6
480	41
500	34.1
520	27.52
540	24.32



It taken the average of the cooling values of 5070s0, 5070s1, 5070s2, 5070s3, 5070s4 and 5070s5 samples. Thus, with the values formed cooling curve of the 5070S group and shared in Table 21.

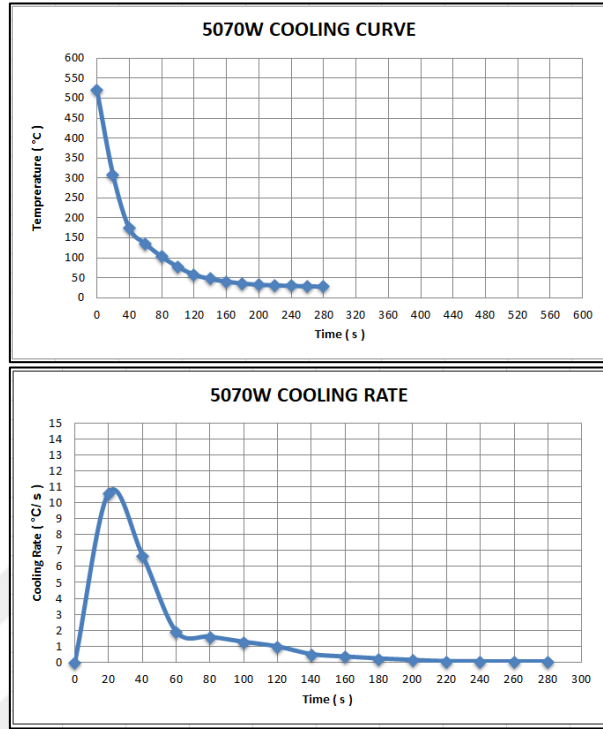
Table 21. The cooling values and the cooling curve of the 5070S



It taken the average of the cooling down values of 5070w1, 5070w2 and 5070w3 samples. For cooling group in water; besides the cooling down curves cooling down rates were also calculated. Thus; belongs to 5070W group is formed two graphicwith the values, which the cooling down curve and the cooling down rates are shared in Table 22.

Table 22. The cooling values and the cooling curve of the 5070W

5070W		
Time (s)	Temperature (°C)	Cooling Rate (°C/s)
0	520.53	0
20	307.8	10.64
40	173.8	6.7
60	135.4	1.92
80	103.1	1.61
100	77.6	1.28
120	57.8	0.99
140	47.6	0.51
160	40.5	0.36
180	35.7	0.24
200	32.65	0.15
220	31.17	0.07
240	29.89	0.06
260	28.97	0.05
280	28	0.05
300		
320		
340		
360		
380		
400		
420		
440		
460		
480		
500		
520		
540		



For the 3 test samples it is obtained in each forging pressure and temperature parameters, calculations were applied as in the examples above.

Time-dependent cooling down curves were analyzed according to cooling methods. The graph showing the cooling down curve of 5070 group is shared in Figure 29.

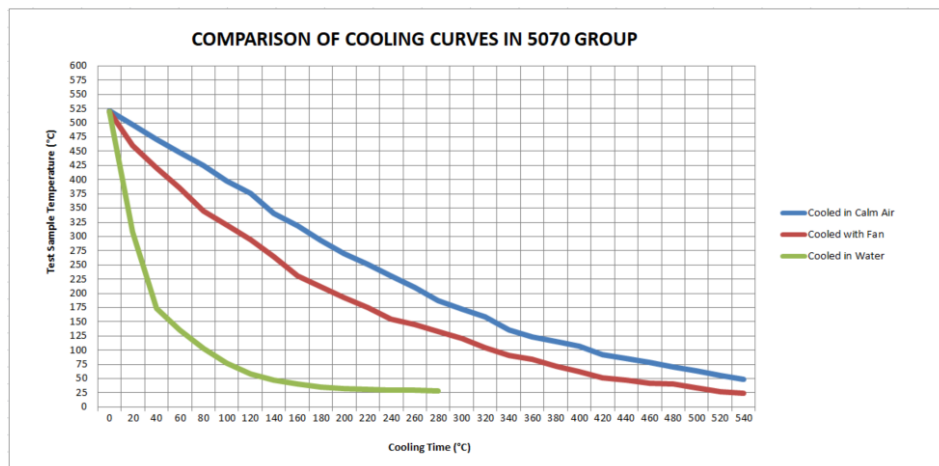


Figure 29. Cooling curves comparison graph for 5070 groups

When Figure 29 is examined; the samples cooled in the calm air are the slowest cooling group and the cooled samples in the water are the fastest cooling group. Additionally; when examined below 30°C; the fan group reached 520 seconds and the water group reached 240 seconds. However, it was not determined that the group cooled in calm air reached this value even at the record of 540 seconds.

Considering the values of the same forging conditions (pressure and temperature) and 3 different cooling methods, a total of 9 main groups are formed as above. The group created above is one of them. in fact, the arithmetic average of three test samples in each group was taken and then the cooling curves due to the cooling method differences were compared under their own conditions.

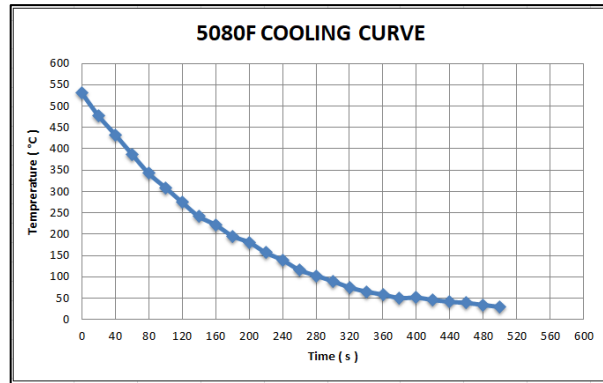
For the 8 groups formed in the same way, the results were calculated in the same way and shared individually below. For the 8 groups formed in the same way, the results were calculated in the same way and shared individually below. In addition, each group was created in charts where the results were compared and shared at the end.

For the following Table 23, Table 24 and Table 25 groups, the forging temperature 750°C and pressure 80bar are constant. Only cooling methods, which are named with fan cooling, cooling in water and cooling in calm air, are different.

It taken the average of the cooling values of 5080f1, 5080f2 and 5080f3 samples. Thus, with the values formed cooling curve of the 5080F group and shared in Table 24.

Table 23. The cooling values and the cooling curve of the 5080F

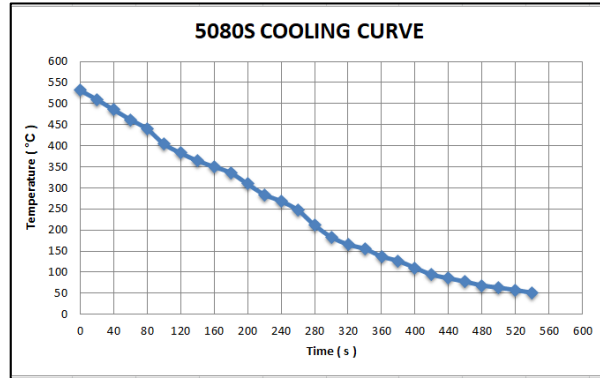
5080F	
Time (s)	Temperature (°C)
0	531.05
20	477.12
40	433
60	387.13
80	342.41
100	308.9
120	274.4
140	241.3
160	221.8
180	195.7
200	180.8
220	156.8
240	139.2
260	116.2
280	102.8
300	89.9
320	75.32
340	65.43
360	58.44
380	50.43
400	51.4
420	45.82
440	41.6
460	39.11
480	34.22
500	29.57
520	26.51
540	25.04



It taken the average of the cooling values of 5080s0, 5080s1, 5080s2, 5080s3, 5080s4 and 5080s5 samples. Thus, with the values formed cooling curve of the 5080S group and shared in Table 24.

Table 24. The cooling values and the cooling curve of the 5080S

5080S	
Time (s)	Temperature (°C)
0	531.26
20	509.67
40	485.4
60	461.96
80	439.85
100	404.34
120	382.75
140	364.45
160	350.2
180	335.64
200	309.4
220	284.17
240	268.5
260	247.3
280	211.4
300	183.4
320	165.7
340	155.5
360	137.5
380	126.7
400	110.35
420	94.4
440	85.74
460	77.64
480	68.68
500	63.54
520	57.83
540	51.27



It taken the average of the cooling down values of 5080w1, 5080w2 and 5080w3 samples. For cooling group in water; besides the cooling down curves cooling down rates were also calculated. Thus; belongs to 5080W group is formed two graphicwith the values, which the cooling down curve and the cooling down rates are shared in Table 25.

Table 25. The cooling values and the cooling curve of the 5080W

5080W		
Time (s)	Temperature (°C)	Cooling Rate (°C/s)
0	531.52	0
20	310.2	11.1
40	205.31	5.25
60	165.02	2.02
80	135.76	1.81
100	106.4	1.46
120	78.41	1.4
140	62.63	0.79
160	48.92	0.69
180	38.4	0.53
200	34.1	0.22
220	30.76	0.18
240	28.89	0.09
260	27.71	0.06
280	27.02	0.04
300		
320		
340		
360		
380		
400		
420		
440		
460		
480		
500		
520		
540		

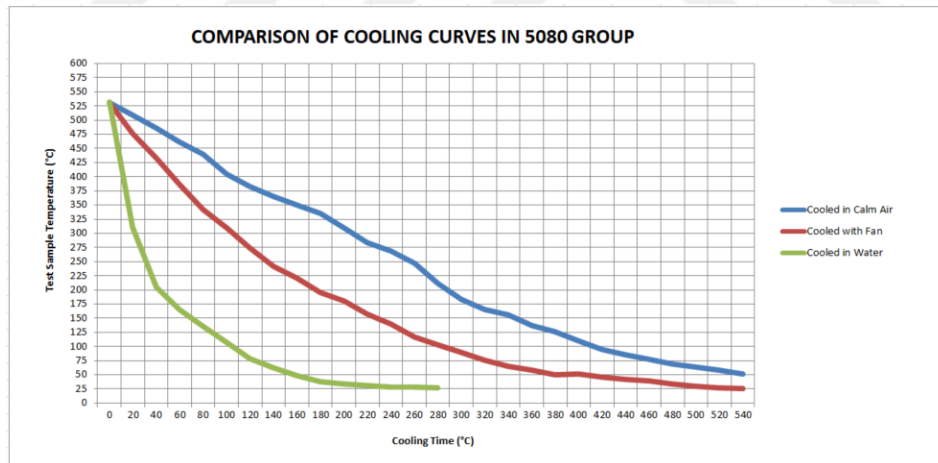
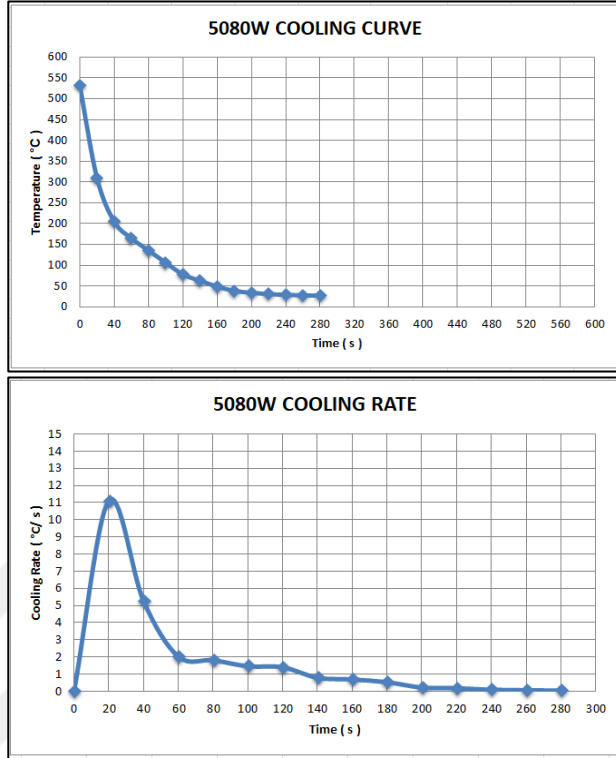


Figure 30. Cooling curves comparison graph for 5080 groups

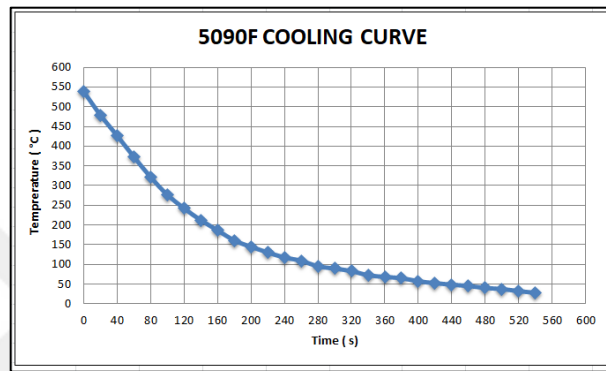
When Figure 30 is examined; the samples cooled in the calm air are the slowest cooling group and the cooled samples in the water are the fastest cooling group. Additionally; when examined below 30°C; the fan group reached 500 seconds and the water group reached 240 seconds. However, it was not determined that the group cooled in calm air reached this value even at the record of 540 seconds.

For the following Table 26, Table 27 and Table 28 groups, the forging temperature 750°C and pressure 90bar are constant. Only cooling methods, which are named with fan cooling, cooling in water and cooling in calm air, are different.

It taken the average of the cooling values of 5090f1, 5090f2 and 5090f3 samples. Thus, with the values formed cooling curve of the 5090F group and shared in Figure 26.

Table 26. The cooling values and the cooling curve of the 5090F

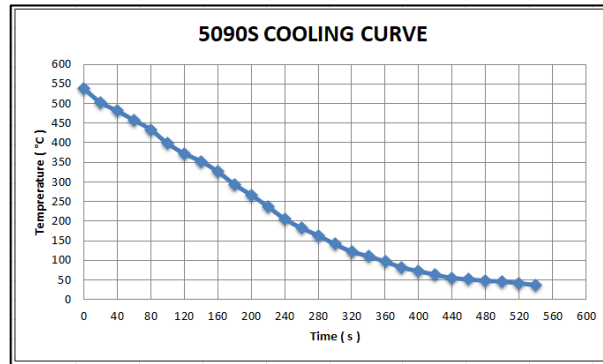
5090F	
Time (s)	Temperature (°C)
0	539.13
20	479
40	426.87
60	372.9
80	321.7
100	276.7
120	242.3
140	212.19
160	186.4
180	160.9
200	144.5
220	130.3
240	117.5
260	109.25
280	95.2
300	89.4
320	83.1
340	72.5
360	68.2
380	65
400	57.11
420	52.4
440	48.5
460	45.21
480	40.23
500	37.36
520	32.1
540	27.91



It taken the average of the cooling values of 5090s0, 5090s1, 5090s2, 5090s3, 5090s4 and 5090s5 samples. Thus, with the values formed cooling curve of the 5090S group and shared in Table 27.

Table 27. The cooling values and the cooling curve of the 5090S

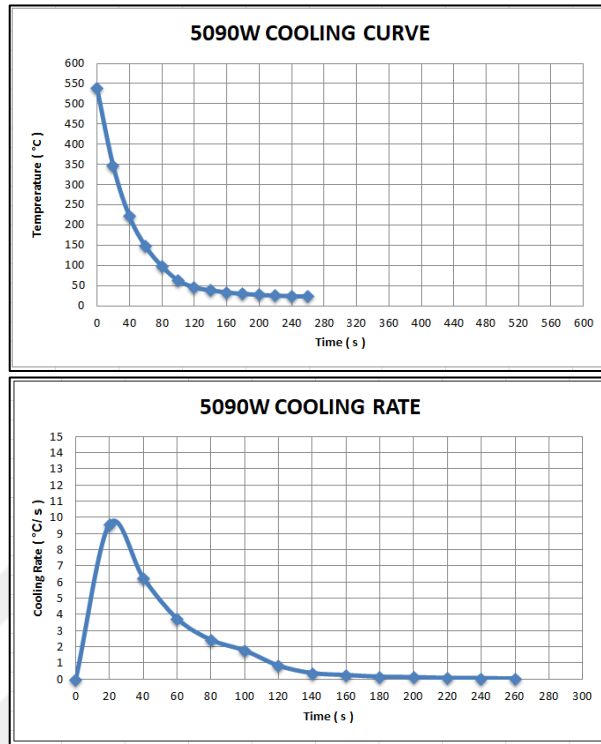
5090S	
Time (s)	Temperature (°C)
0	538.64
20	503.1
40	481.5
60	457.8
80	433.69
100	398.5
120	372.6
140	352.8
160	326.9
180	293.4
200	267.1
220	237.5
240	205.6
260	182.4
280	163.4
300	141.4
320	122.3
340	110.7
360	97.02
380	81.7
400	72.73
420	63.14
440	55.2
460	51.4
480	48.2
500	45.9
520	41.83
540	36.92



It taken the average of the cooling down values of 5090w1, 5090w2 and 5090w3 samples. For cooling group in water; besides the cooling down curves cooling down rates were also calculated. Thus; belongs to 5090W group is formed two graphicwith the values, which the cooling down curve and the cooling down rates are shared in Table 28.

Table 28. The cooling values and the cooling curve of the 5090W

5090W		
Time (s)	Temperature (°C)	Cooling Rate (°C/s)
0	538.23	0
20	346.4	9.6
40	221.7	6.24
60	146.94	3.74
80	98.4	2.43
100	63	1.77
120	46.25	0.84
140	38.58	0.38
160	33.41	0.26
180	30.12	0.16
200	27.45	0.13
220	25.76	0.08
240	24.31	0.07
260	23.56	0.04
280		
300		
320		
340		
360		
380		
400		
420		
440		
460		
480		
500		
520		
540		



For the 3 test samples it is obtained in each forging pressure and temperature parameters, calculations were applied as in the examples above.

Time-dependent cooling down curves were analyzed according to cooling methods. The graph showing the cooling down curve of 5070 group is shared in Figure 31.

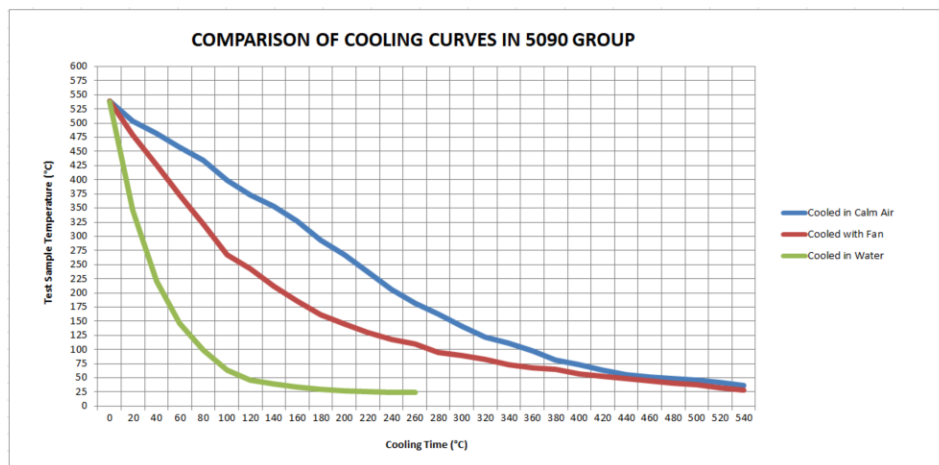


Figure 31. Cooling curves comparison graph for 5090 groups

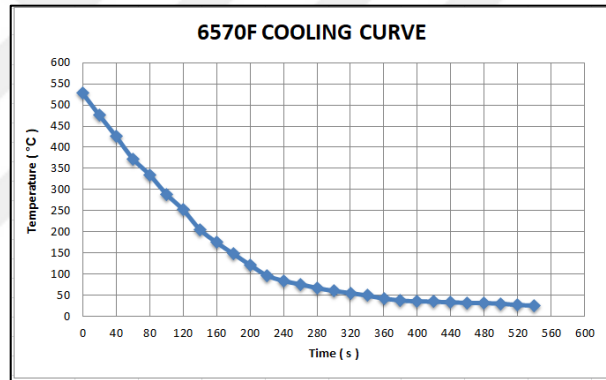
When figure 31 is examined; the samples cooled in the calm air are the slowest cooling group and the cooled samples in the water are the fastest cooling group. Additionally; when examined below 30°C; the fan group reached 540 seconds and the water group reached 200 seconds. However, it was not determined that the group cooled in calm air reached this value even at the record of 540 seconds.

For the following Table 29, Table 30 and Table 31 groups, the forging temperature 765°C and pressure 70bar are constant. Only cooling methods, which are named with fan cooling, cooling in water and cooling in calm air, are different.

It taken the average of the cooling values of 6570f1, 6570f2 and 6570f3 samples. Thus, with the values formed cooling curve of the 6570F group and shared in Table 20.

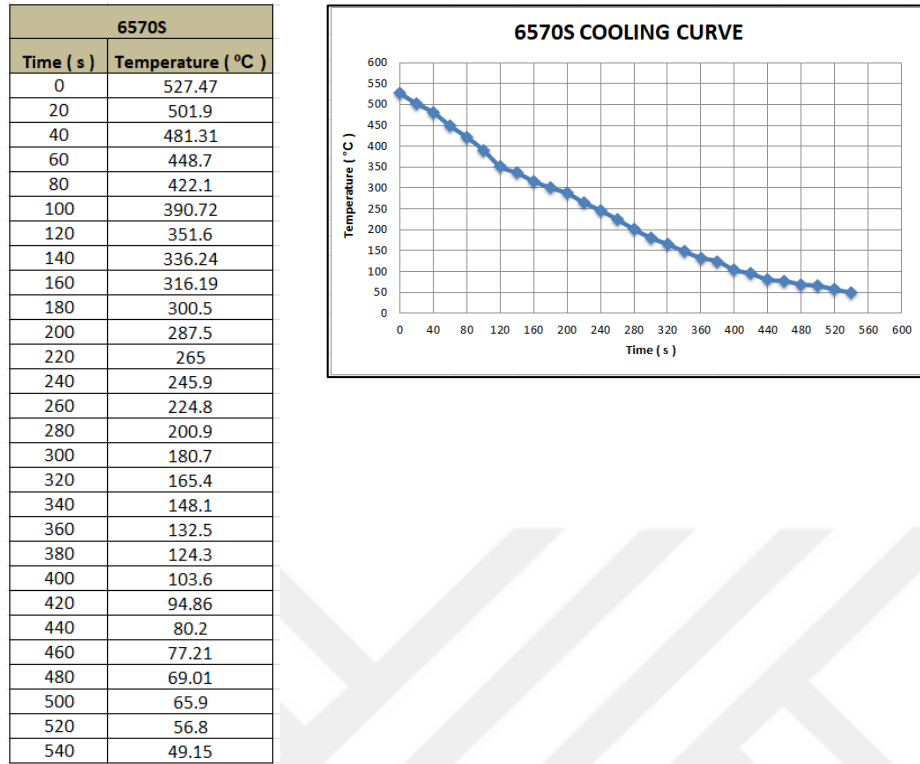
Table 29. The cooling values and the cooling curve of the 6570F

6570F	
Time (s)	Temperature (°C)
0	527.62
20	475.47
40	425.4
60	372.7
80	335.13
100	289.4
120	252.4
140	205.8
160	175.21
180	148.3
200	121.9
220	97.3
240	84.3
260	76.3
280	67.4
300	60.8
320	55.5
340	49.8
360	42.5
380	37.9
400	36.1
420	35.2
440	33.6
460	32.4
480	31.9
500	30.6
520	27.3
540	25.97



It taken the average of the cooling values of 6570s0, 6570s1, 6570s2, 6570s3, 6570s4 and 6570s5 samples. Thus, with the values formed cooling curve of the 6570S group and shared in Table 30.

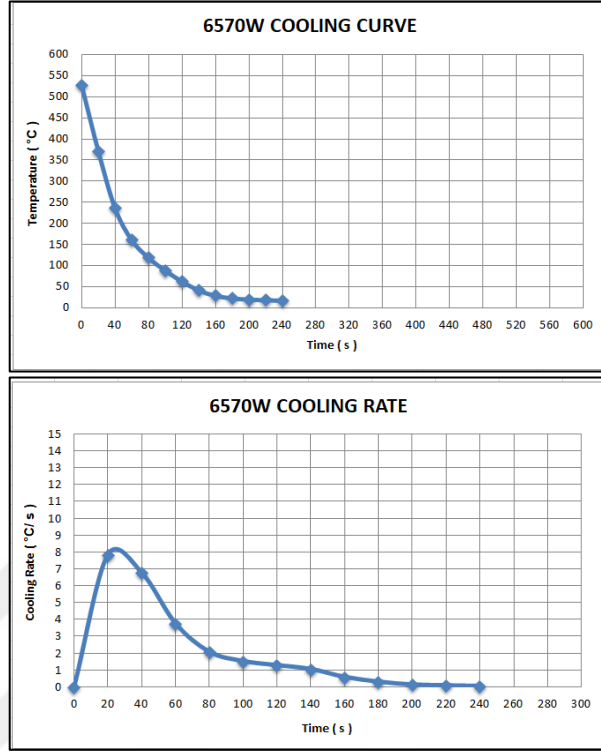
Table 30. The cooling values and the cooling curve of the 6570S



It taken the average of the cooling down values of 6570w1, 6570w2 and 6570w3 samples. For cooling group in water; besides the cooling down curves cooling down rates were also calculated. Thus; belongs to 6570W group is formed two graphicwith the values, which the cooling down curve and the cooling down rates are shared in Table 31.

Table 31. The cooling values and the cooling curve of the 6570W

6570W		
Time (s)	Temperature (°C)	Cooling Rate (°C/s)
0	527.35	0
20	370.5	7.85
40	235.21	6.77
60	160	3.76
80	118.42	2.08
100	88	1.53
120	61.23	1.29
140	40.21	1.06
160	28.42	0.59
180	22.37	0.31
200	19.72	0.14
220	18.04	0.09
240	17.1	0.05
260		
280		
300		
320		
340		
360		
380		
400		
420		
440		
460		
480		
500		
520		
540		



For the 3 test samples it is obtained in each forging pressure and temperature parameters, calculations were applied as in the examples above.

Time-dependent cooling down curves were analyzed according to cooling methods. The graph showing the cooling down curve of 6570 group is shared in Figure 32.

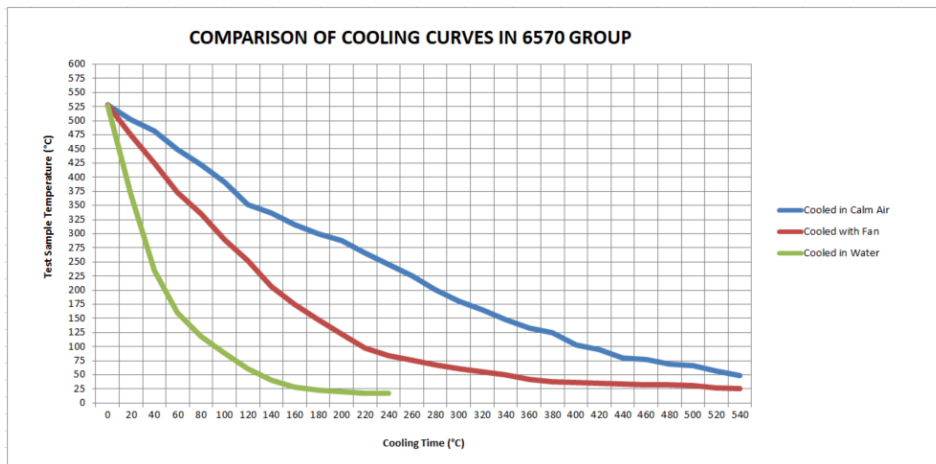


Figure 32. Cooling curves comparison graph for 6570 groups

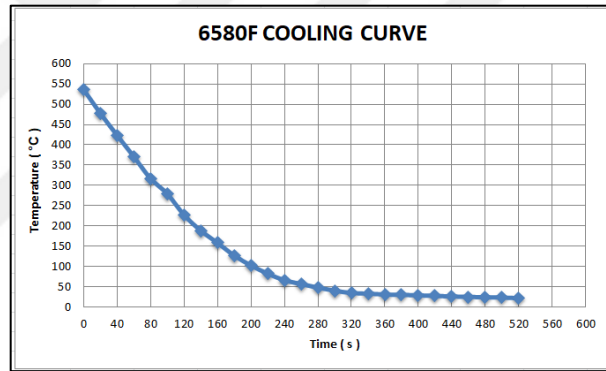
When Figure 32 is examined; the samples cooled in the calm air are the slowest cooling group and the cooled samples in the water are the fastest cooling group. Additionally; when examined below 30°C; the fan group reached 520 seconds and the water group reached 160 seconds. However, it was not determined that the group cooled in calm air reached this value even at the record of 540 seconds.

For the following Table 32, Table 33 and Table 34 groups, the forging temperature 765°C and pressure 80bar are constant. Only cooling methods, which are named with fan cooling, cooling in water and cooling in calm air, are different.

It taken the average of the cooling values of 6580f1, 6580f2 and 6580f3 samples. Thus, with the values formed cooling curve of the 6580F group and shared in Table 32.

Table 32. The cooling values and the cooling curve of the 6580F

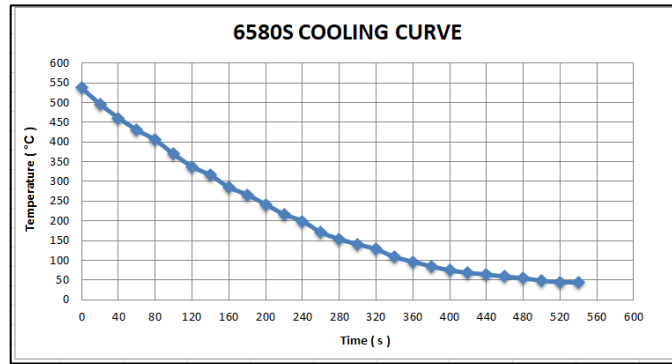
6580F	
Time (s)	Temperature (°C)
0	536.13
20	477.6
40	423.52
60	370.7
80	317.2
100	279.4
120	227.4
140	188.46
160	158.7
180	127.3
200	102.9
220	82.93
240	66.5
260	57.3
280	48.25
300	40.9
320	35.2
340	33.6
360	31.4
380	30.6
400	29.4
420	28
440	26.7
460	25.4
480	24.8
500	23.9
520	22.37
540	21



It taken the average of the cooling values of 6580s0, 6580s1, 6580s2, 6580s3, 6580s4 and 6580s5 samples. Thus, with the values formed cooling curve of the 5070S group and shared in Table 33.

Table 33. The cooling values and the cooling curve of the 6580S

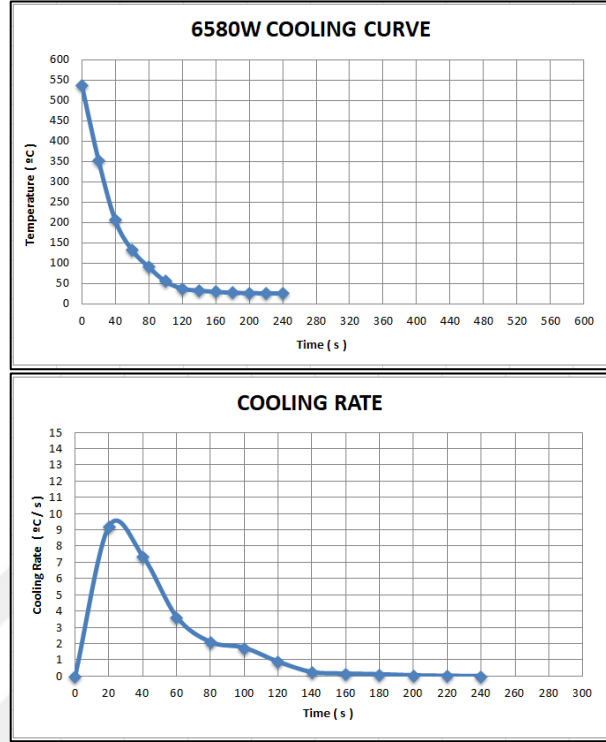
6580S	
Time (s)	Temperature (°C)
0	536.8
20	495.9
40	460.6
60	430.54
80	405.12
100	369.4
120	337.48
140	315.8
160	285.3
180	266.5
200	241.78
220	216.9
240	199.4
260	171.4
280	153.87
300	140.6
320	128.58
340	108.52
360	96.78
380	84.8
400	74.95
420	68.56
440	64.5
460	58.9
480	55.1
500	48.43
520	45.14
540	43.76



It taken the average of the cooling down values of 6580w1, 6580w2 and 6580w3 samples. For cooling group in water; besides the cooling down curves cooling down rates were also calculated. Thus; belongs to 6580W group is formed two graphicwith the values, which the cooling down curve and the cooling down rates are shared in Table 34.

Table 34. The cooling values and the cooling curve of the 6580W

6580W		
Time (s)	Temperature (°C)	Cooling Rate (°C/s)
0	536.81	0
20	352.51	9.22
40	205	7.38
60	132.04	3.65
80	90.17	2.1
100	55.23	1.75
120	37.59	0.89
140	32.63	0.25
160	29.54	0.16
180	27.28	0.12
200	26.33	0.05
220	26.02	0.02
240	25.85	0.01
260		
280		
300		
320		
340		
360		
380		
400		
420		
440		
460		
480		
500		
520		
540		



For the 3 test samples it is obtained in each forging pressure and temperature parameters, calculations were applied as in the examples above.

Time-dependent cooling down curves were analyzed according to cooling methods. The graph showing the cooling down curve of 6580 group is shared in Figure 33.

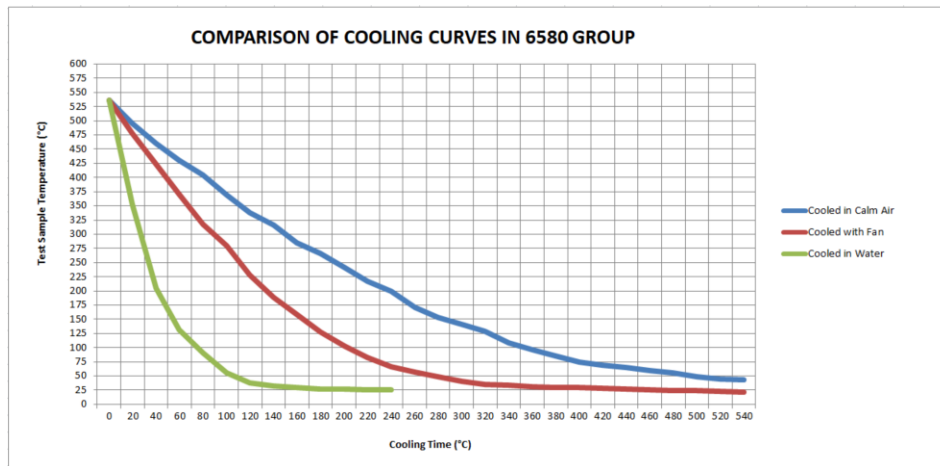


Figure 33. Cooling curves comparison graph for 6580 groups

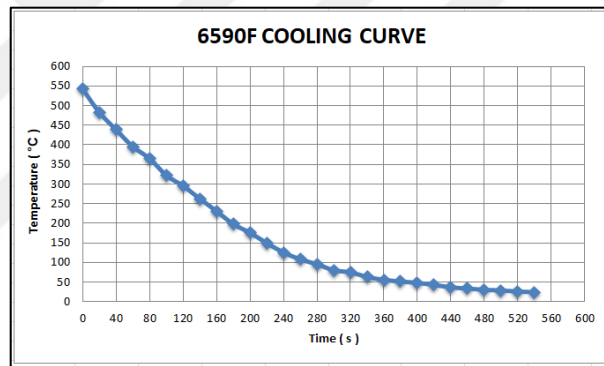
When Figure 33 is examined; the samples cooled in the calm air are the slowest cooling group and the cooled samples in the water are the fastest cooling group. Additionally; when examined below 30°C; the fan group reached 400 seconds and the water group reached 160 seconds. However, it was not determined that the group cooled in calm air reached this value even at the record of 540 seconds.

For the following Table 35, Table 36 and Table 37 groups, the forging temperature 765°C and pressure 90bar are constant. Only cooling methods, which are named with fan cooling, cooling in water and cooling in calm air, are different.

It taken the average of the cooling values of 6590f1, 6590f2 and 6590f3 samples. Thus, with the values formed cooling curve of the 6590F group and shared in Table 35.

Table 35. The cooling values and the cooling curve of the 6590F

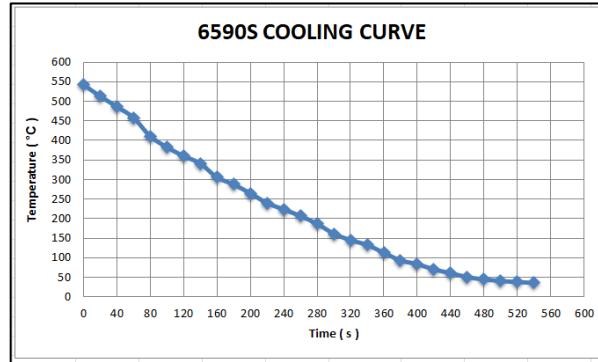
6590F	
Time (s)	Temperature (°C)
0	542.36
20	482.5
40	438.43
60	395.19
80	365
100	322.1
120	295.4
140	262.3
160	230.8
180	197.88
200	175.8
220	149.5
240	125.6
260	108.1
280	95.6
300	80.5
320	74.9
340	63.1
360	55.7
380	51.7
400	48.05
420	43.1
440	36.7
460	33.6
480	30.4
500	28.6
520	26.2
540	24.32



It taken the average of the cooling values of 6590s0, 6590s1, 6590s2, 6590s3, 6590s4 and 6590s5 samples. Thus, with the values formed cooling curve of the 6590S group and shared in Table 36.

Table 36. The cooling values and the cooling curve of the 6590S

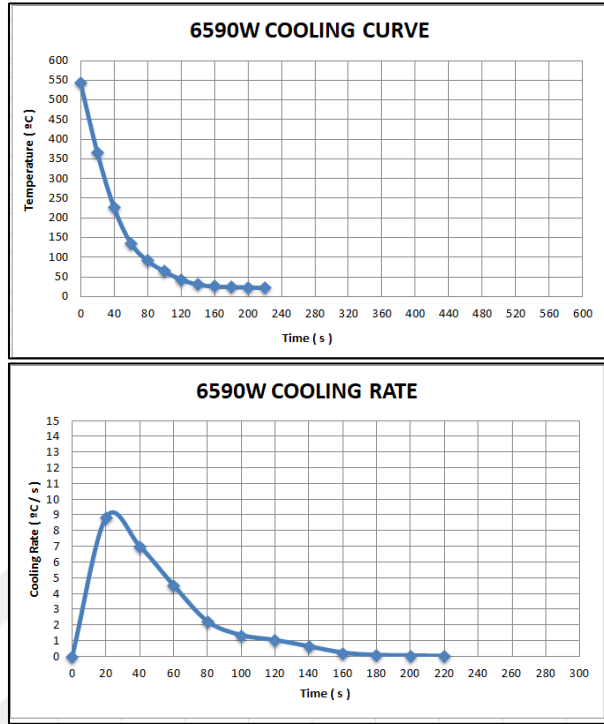
6590S	
Time (s)	Temperature (°C)
0	542.64
20	513.1
40	486.4
60	458.1
80	410.9
100	382.8
120	360.1
140	341
160	305.71
180	287.6
200	264.87
220	240.1
240	223.73
260	206.8
280	186.9
300	161.6
320	145.2
340	132.8
360	112.7
380	93.2
400	83.9
420	70.1
440	60.9
460	50.56
480	44.7
500	40.65
520	38.12
540	35.78



It taken the average of the cooling down values of 6590w1, 6590w2 and 6590w3 samples. For cooling group in water; besides the cooling down curves cooling down rates were also calculated. Thus; belongs to 6590W group is formed two graphicwith the values, which the cooling down curve and the cooling down rates are shared in Table 37.

Table 37. The cooling values and the cooling curve of the 6590W

6590W		
Time (s)	Temperature (°C)	Cooling Rate (°C/s)
0	542.17	0
20	365.4	8.84
40	225.5	7
60	135.33	4.51
80	90.8	2.23
100	63.8	1.35
120	43	1.04
140	30.23	0.64
160	25.56	0.24
180	23.92	0.09
200	22.85	0.06
220	22.24	0.03
240		
260		
280		
300		
320		
340		
360		
380		
400		
420		
440		
460		
480		
500		
520		
540		



For the 3 test samples it is obtained in each forging pressure and temperature parameters, calculations were applied as in the examples above.

Time-dependent cooling down curves were analyzed according to cooling methods. The graph showing the cooling down curve of 6590 group is shared in Figure 34.

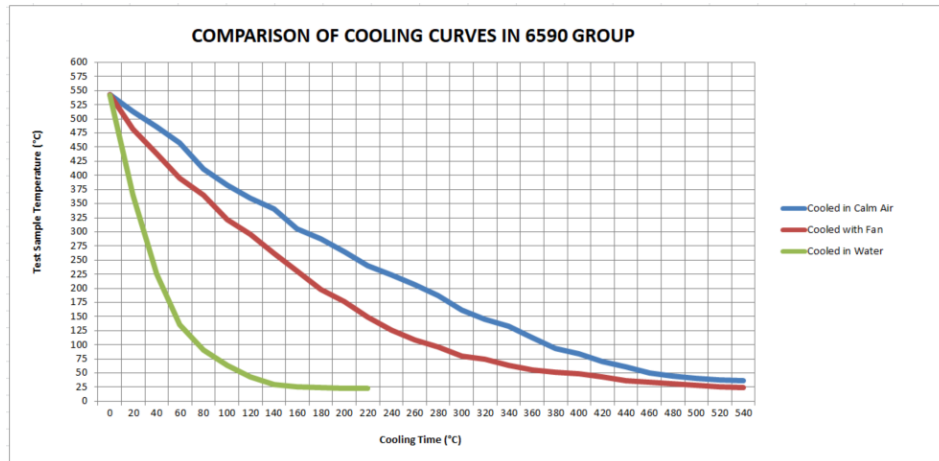


Figure 34. Cooling curves comparison graph for 6590 groups

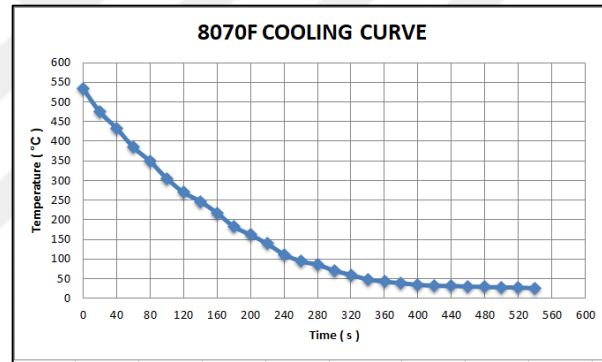
When Figure 34 is examined; the samples cooled in the calm air are the slowest cooling group and the cooled samples in the water are the fastest cooling group. Additionally; when examined below 30°C; the fan group reached 500 seconds and the water group reached 160 seconds. However, it was not determined that the group cooled in calm air reached this value even at the record of 540 seconds.

For the following Table 38, Table 39 and Table 40 groups, the forging temperature 780°C and pressure 70bar are constant. Only cooling methods, which are named with fan cooling, cooling in water and cooling in calm air, are different.

It taken the average of the cooling values of 8070f1, 8070f2 and 8070f3 samples. Thus, with the values formed cooling curve of the 8070F group and shared in Table 38.

Table 38. The cooling values and the cooling curve of the 8070F

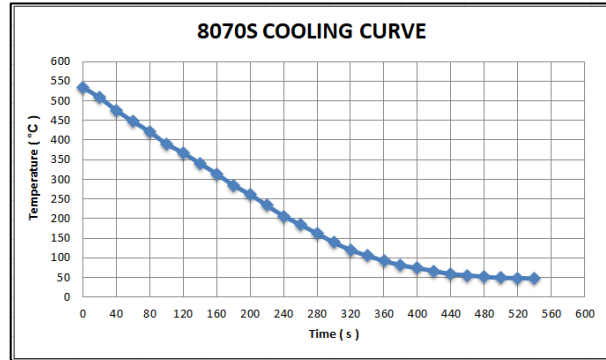
8070F	
Time (s)	Temperature (°C)
0	534.33
20	475
40	433.4
60	385
80	349.27
100	305.31
120	270.11
140	247
160	217.45
180	183
200	161.72
220	139.2
240	112
260	94.6
280	85.77
300	70.8
320	59.6
340	48.53
360	42.6
380	38.9
400	34.4
420	32.5
440	31.6
460	30.4
480	29
500	28.45
520	27.3
540	26



It taken the average of the cooling values of 8070s0, 8070s1, 8070s2, 8070s3, 8070s4 and 8070s5 samples. Thus, with the values formed cooling curve of the 8070S group and shared in Table 39.

Table 39. The cooling values and the cooling curve of the 8070S

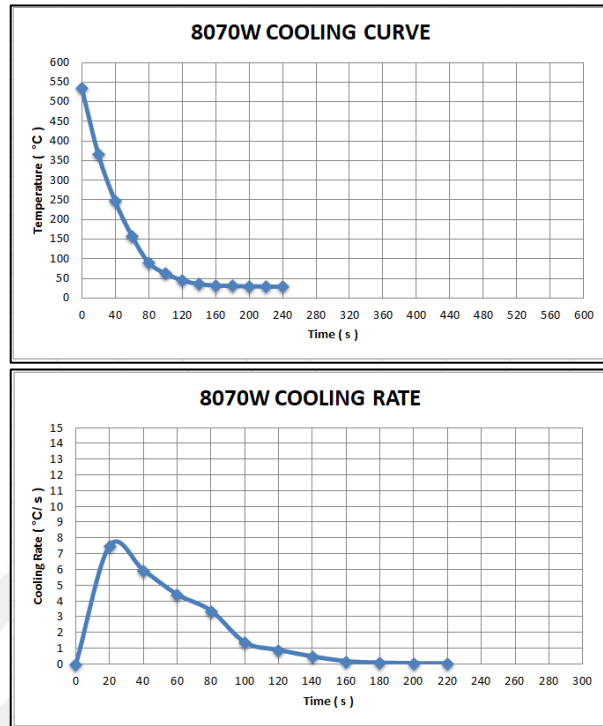
8070S	
Time (s)	Temperature (°C)
0	534.54
20	508.5
40	475.9
60	447.6
80	421.4
100	390.3
120	367.4
140	340.25
160	314.37
180	284.8
200	261.4
220	233.8
240	206.5
260	184.98
280	162.3
300	139.2
320	120.2
340	105.5
360	92.4
380	81.56
400	73.9
420	66.5
440	58.81
460	55.8
480	51.7
500	49.22
520	48.36
540	47.53



It taken the average of the cooling down values of 8070w1, 8070w2 and 8070w3 samples. For cooling group in water; besides the cooling down curves cooling down rates were also calculated. Thus; belongs to 8070W group is formed two graphicwith the values, which the cooling down curve and the cooling down rates are shared in Table 40

Table 40. The cooling values and the cooling curve of the 8070W

8070W		
Time (s)	Temperature (°C)	Cooling Rate (°C/s)
0	534.76	0
20	364.61	7.51
40	245.71	5.95
60	157.5	4.41
80	90	3.38
100	62.68	1.37
120	45	0.89
140	35.43	0.48
160	32	0.18
180	30.44	0.08
200	29.65	0.04
220	29.12	0.03
240	29.02	0.01
260		
280		
300		
320		
340		
360		
380		
400		
420		
440		
460		
480		
500		
520		
540		



For the 3 test samples it is obtained in each forging pressure and temperature parameters, calculations were applied as in the examples above.

Time-dependent cooling down curves were analyzed according to cooling methods. The graph showing the cooling down curve of 8070 group is shared in Figure 35.

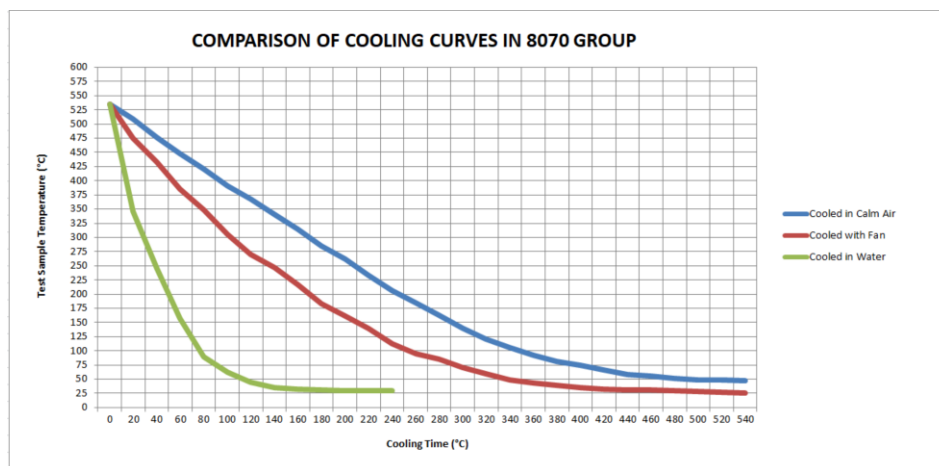


Figure 35. Cooling curves comparison graph for 8070 groups

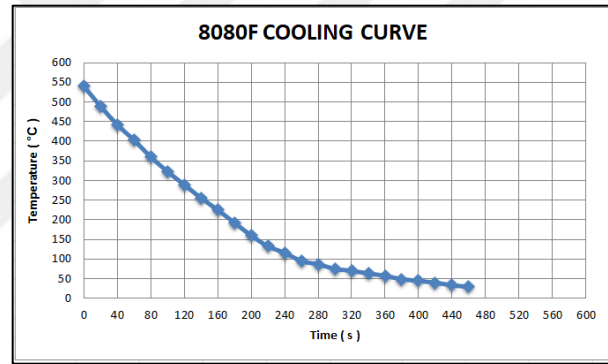
When Figure 35 is examined; the samples cooled in the calm air are the slowest cooling group and the cooled samples in the water are the fastest cooling group. Additionally; when examined below 30°C; the fan group reached 480 seconds and the water group reached 200 seconds. However, it was not determined that the group cooled in calm air reached this value even at the record of 540 seconds.

For the following Table 41, Table 42 and Table 43 groups, the forging temperature 780°C and pressure 80bar are constant. Only cooling methods, which are named with fan cooling, cooling in water and cooling in calm air, are different.

It taken the average of the cooling values of 8080f1, 80800f2 and 80800f3 samples. Thus, with the values formed cooling curve of the 8080F group and shared in Table 41.

Table 41. The cooling values and the cooling curve of the 8080F

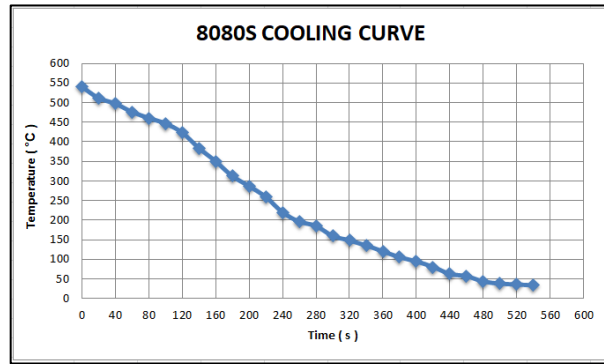
8080F	
Time (s)	Temperature (°C)
0	540.18
20	489
40	442
60	402.88
80	360
100	322.81
120	289.39
140	255.43
160	225.11
180	192.44
200	160
220	132.8
240	115.8
260	95.29
280	86.77
300	75.3
320	70.2
340	63.5
360	57.5
380	48.8
400	44.9
420	39.82
440	33.7
460	29.28
480	26
500	24.11
520	23
540	22.18



It taken the average of the cooling values of 80800s0, 8080s1, 8080s2, 8080s3, 8080s4 and 8080s5 samples. Thus, with the values formed cooling curve of the 8080S group and shared in Table 42.

Table 42. The cooling values and the cooling curve of the 8080S

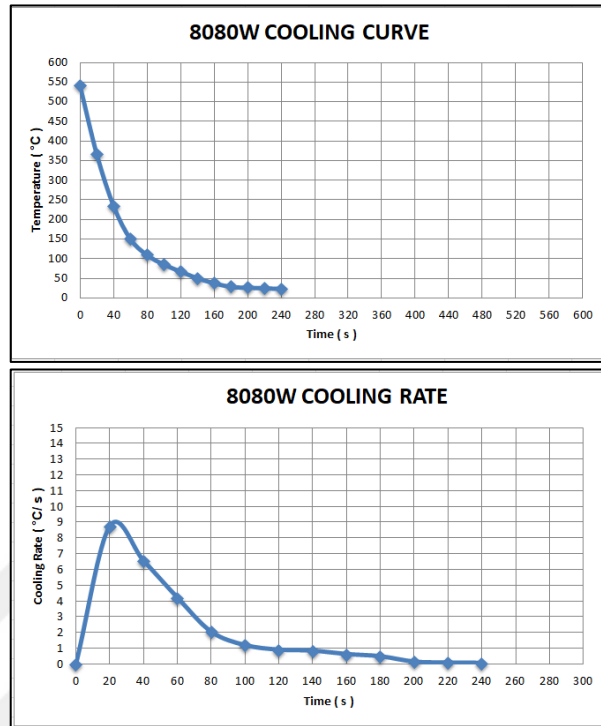
8080S	
Time (s)	Temperature (°C)
0	540.65
20	511.8
40	497.6
60	476.4
80	460.7
100	446.8
120	423.47
140	383.8
160	350.4
180	312.4
200	286.95
220	259.23
240	220
260	196.4
280	185.1
300	159.6
320	148.5
340	135.4
360	120.4
380	105.4
400	94.8
420	80.6
440	62.9
460	57.1
480	43.6
500	38.1
520	36
540	33.76



It taken the average of the cooling down values of 8080w1, 8080w2 and 8080w3 samples. For cooling group in water; besides the cooling down curves cooling down rates were also calculated. Thus; belongs to 8080W group is formed two graphicwith the values, which the cooling down curve and the cooling down rates are shared in Table 43.

Table 43. The cooling values and the cooling curve of the 8080W

8080W		
Time (s)	Temperature (°C)	Cooling Rate (°C/s)
0	540.14	0
20	365	8.76
40	234.04	6.55
60	150	4.21
80	109	2.05
100	85.11	1.2
120	67	0.91
140	50.12	0.85
160	37.65	0.63
180	28	0.49
200	26	0.15
220	24.35	0.09
240	23	0.07
260		
280		
300		
320		
340		
360		
380		
400		
420		
440		
460		
480		
500		
520		
540		



For the 3 test samples it is obtained in each forging pressure and temperature parameters, calculations were applied as in the examples above.

Time-dependent cooling down curves were analyzed according to cooling methods. The graph showing the cooling down curve of 8080 group is shared in Figure 36.

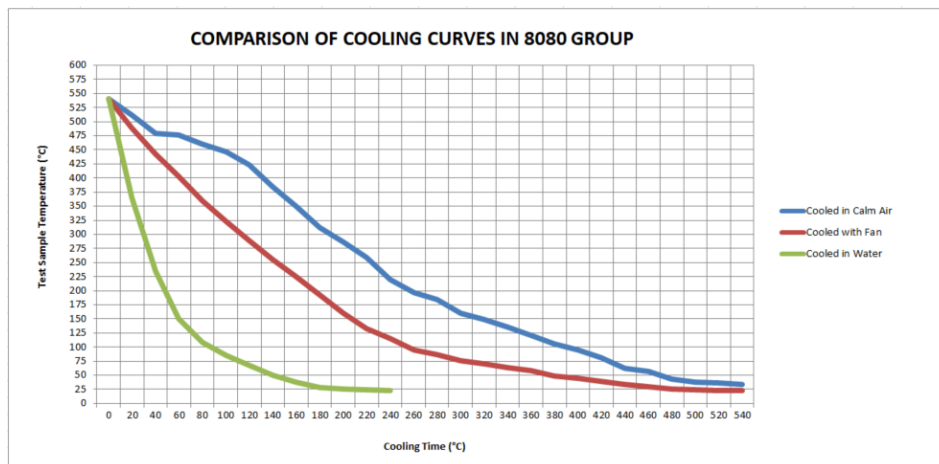


Figure 36. Cooling curves comparison graph for 8080 groups

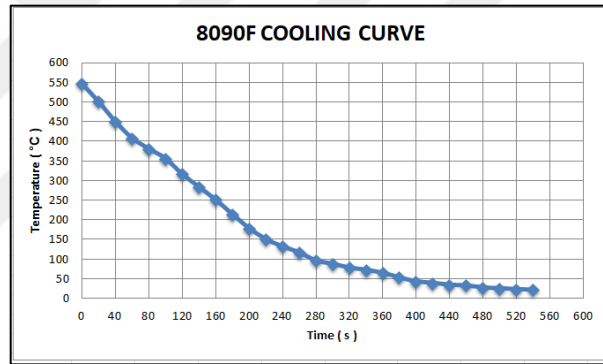
When Figure 36 is examined; the samples cooled in the calm air are the slowest cooling group and the cooled samples in the water are the fastest cooling group. Additionally; when examined below 30°C; the fan group reached 460 seconds and the water group reached 180 seconds. However, it was not determined that the group cooled in calm air reached this value even at the record of 540 seconds.

For the following Table 44, Table 45 and Table 46 groups, the forging temperature 780°C and pressure 90bar are constant. Only cooling methods, which are named with fan cooling, cooling in water and cooling in calm air, are different.

It taken the average of the cooling values of 8090f1, 8090f2 and 8090f3 samples. Thus, with the values formed cooling curve of the 8090F group and shared in Table 44.

Table 44. The cooling values and the cooling curve of the 8090F

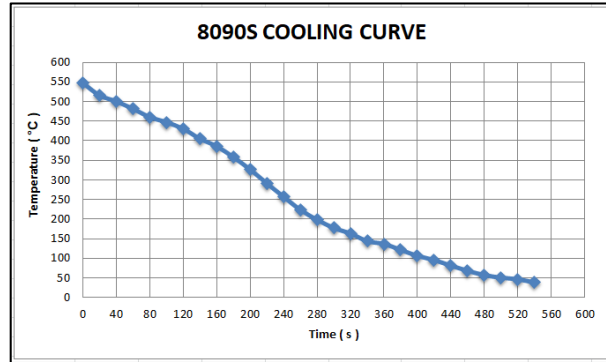
8080F	
Time (s)	Temperature (°C)
0	547.21
20	501.4
40	451
60	408.6
80	381.2
100	356.41
120	316.7
140	283.8
160	251.6
180	214.6
200	179
220	151.2
240	132.5
260	117.3
280	96.7
300	88.5
320	78.4
340	73.11
360	65
380	53.57
400	43.4
420	39.8
440	35
460	33.1
480	28.12
500	26
520	23.67
540	22.11



It taken the average of the cooling values of 8090s0, 8090s1, 8090s2, 8090s3, 8090s4 and 8090s5 samples. Thus, with the values formed cooling curve of the 8090S group and shared in Table 45.

Table 45. The cooling values and the cooling curve of the 8080S

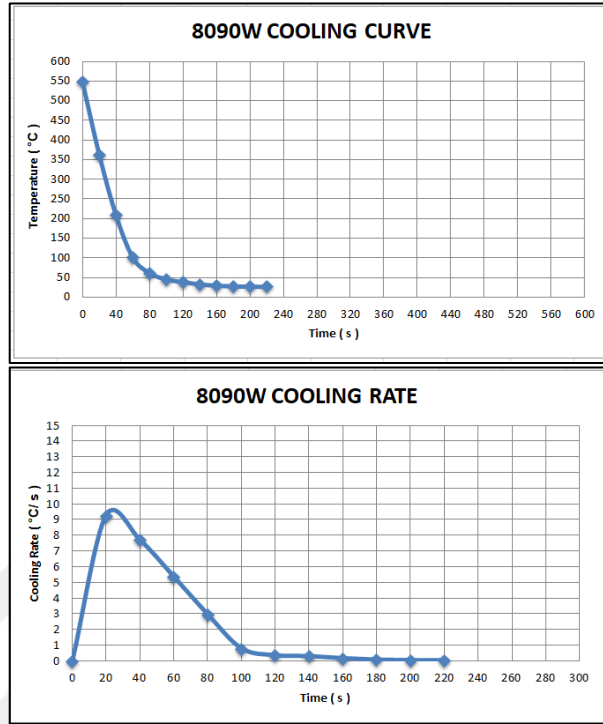
8090S	
Time (s)	Temperature (°C)
0	547.68
20	516
40	500.4
60	481.6
80	460.5
100	447.3
120	430.57
140	405.2
160	385.9
180	358.1
200	326.7
220	291.2
240	257.1
260	223.9
280	198.4
300	177.5
320	163.2
340	143.9
360	136.7
380	121.5
400	106.3
420	95.65
440	81.2
460	68.23
480	57.3
500	50.7
520	46.6
540	38.21



It taken the average of the cooling down values of 8090w1, 8090w2 and 8090w3 samples. For cooling group in water; besides the cooling down curves cooling down rates were also calculated. Thus; belongs to 8090W group is formed two graphicwith the values, which the cooling down curve and the cooling down rates are shared in Table 46.

Table 46. The cooling values and the cooling curve of the 8090W

8090W		
Time (s)	Temperature (°C)	Cooling Rate (°C/s)
0	547.72	0
20	362.11	9.28
40	208	7.71
60	100.6	5.37
80	61	2.98
100	45.13	0.8
120	38	0.36
140	32.14	0.3
160	28.83	0.17
180	27.26	0.08
200	26.58	0.04
220	26	0.03
240		
260		
280		
300		
320		
340		
360		
380		
400		
420		
440		
460		
480		
500		
520		
540		



For the 3 test samples it is obtained in each forging pressure and temperature parameters, calculations were applied as in the examples above.

Time-dependent cooling down curves were analyzed according to cooling methods. The graph showing the cooling down curve of 8090 group is shared in Figure 37.

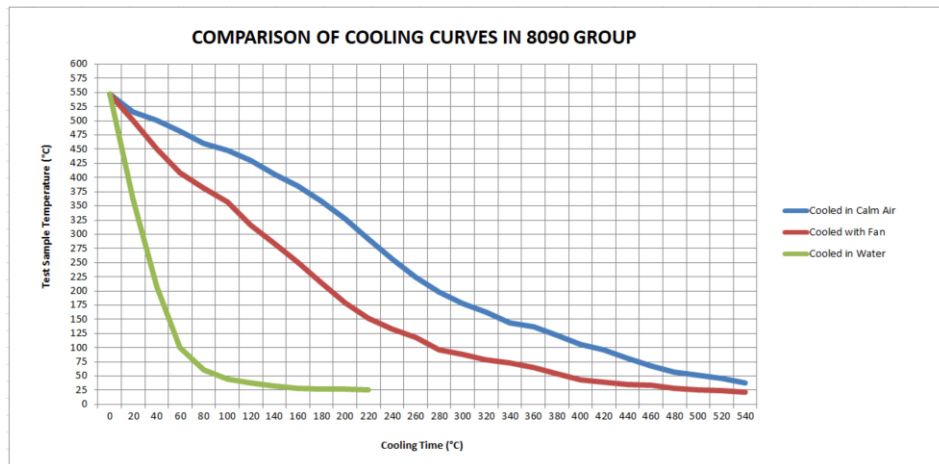


Figure 37. Cooling curves comparison graph for 8090 groups

When Figure 37 is examined; the samples cooled in the calm air are the slowest cooling group and the cooled samples in the water are the fastest cooling group. Additionally; when examined below 30°C; the fan group reached 480 seconds and the water group reached 160 seconds. However, it was not determined that the group cooled in calm air reached this value even at the record of 540 seconds.

When the examined the cooling down curves of the all groups; curves of samples of cooled with fan and cooled in calm air are observed slowly cooling and close to each other. When fan cooling values are examined; it was observed that cooling was faster than cooling in calm air but more controlled than cooling with water. But the curve of samples of cooled in water are observed sudden and rapid cooling.

4.2. Chemical Composition Results

The chemical composition values of the 108 test samples are shared under the cooling down group names for the traceability.

Alloy element values according to the spectral analysis results of 108 test samples are presented in Table 47.

Table 47. The chemical composition element values of 108 test

Sample Codes	ELEMENT %							
	Fe	Si	Cu	Zn	Al	Sn	Pb	Other
5070F1	0.168	0.361	62.030	35.039	0.623	0.170	1.229	0.380
5070F2	0.173	0.357	62.031	35.035	0.626	0.172	1.224	0.382
5070F3	0.172	0.362	62.038	35.034	0.618	0.167	1.225	0.384
5080F1	0.169	0.359	62.040	35.035	0.623	0.170	1.223	0.381
5080F2	0.172	0.361	62.034	35.032	0.617	0.169	1.231	0.384
5080F3	0.168	0.362	62.039	35.036	0.622	0.169	1.224	0.380
5090F1	0.172	0.361	62.038	35.035	0.621	0.171	1.219	0.383
5090F2	0.173	0.358	62.037	35.027	0.628	0.168	1.224	0.385
5090F3	0.173	0.355	62.033	35.026	0.629	0.172	1.230	0.382
6570F1	0.172	0.359	62.038	35.043	0.618	0.170	1.218	0.382
6570F2	0.167	0.365	62.036	35.028	0.627	0.173	1.221	0.383
6570F3	0.169	0.361	62.036	35.037	0.622	0.170	1.226	0.383
6580F1	0.172	0.364	62.029	35.026	0.627	0.173	1.225	0.384
6580F2	0.169	0.365	62.029	35.039	0.621	0.171	1.223	0.383
6580F3	0.173	0.360	62.031	35.027	0.634	0.167	1.228	0.380

6590F1	0.170	0.357	62.041	35.031	0.623	0.169	1.226	0.383
6590F2	0.173	0.361	62.041	35.033	0.621	0.168	1.221	0.382
6590F3	0.169	0.359	62.041	35.034	0.629	0.168	1.219	0.381
8070F1	0.156	0.320	62.081	35.064	0.534	0.130	1.324	0.391
8070F2	0.153	0.315	62.086	35.061	0.535	0.131	1.326	0.393
8070F3	0.172	0.359	62.035	35.029	0.623	0.175	1.227	0.380
8080F1	0.167	0.360	62.037	35.033	0.628	0.169	1.225	0.381
8080F2	0.155	0.314	62.083	35.062	0.532	0.137	1.324	0.393
8080F3	0.173	0.362	62.031	35.029	0.630	0.176	1.219	0.380
8090F1	0.177	0.357	62.033	35.029	0.626	0.171	1.223	0.384
8090F2	0.169	0.359	62.039	35.031	0.621	0.173	1.227	0.381
8090F3	0.153	0.312	62.086	35.063	0.531	0.138	1.325	0.392
5070S0	0.169	0.361	62.021	35.047	0.629	0.170	1.224	0.379
5070S1	0.179	0.360	62.018	35.029	0.632	0.169	1.231	0.382
5070S2	0.155	0.309	62.083	35.066	0.532	0.135	1.326	0.394
5080S0	0.152	0.312	62.084	35.063	0.533	0.134	1.329	0.393
5080S1	0.174	0.374	62.016	35.024	0.621	0.173	1.236	0.382
5080S2	0.179	0.368	62.026	35.031	0.625	0.161	1.225	0.385
5090S0	0.172	0.362	62.013	35.032	0.619	0.177	1.241	0.384
5090S1	0.170	0.363	62.024	35.041	0.621	0.166	1.230	0.385
5090S2	0.163	0.369	62.048	35.038	0.625	0.155	1.218	0.384
6570S0	0.151	0.316	62.087	35.063	0.531	0.133	1.327	0.392
6570S1	0.165	0.365	62.015	35.045	0.619	0.166	1.238	0.387
6570S2	0.156	0.314	62.086	35.064	0.535	0.130	1.324	0.391
6580S0	0.154	0.318	62.085	35.066	0.530	0.134	1.321	0.392
6580S1	0.168	0.361	62.022	35.040	0.629	0.169	1.227	0.384
6580S2	0.172	0.363	62.026	35.043	0.612	0.170	1.231	0.383
6590S0	0.175	0.366	62.043	35.028	0.614	0.167	1.226	0.381
6590S1	0.153	0.313	62.087	35.064	0.527	0.136	1.327	0.393
6590S2	0.168	0.359	62.030	35.035	0.620	0.173	1.232	0.383
8070S0	0.152	0.315	62.086	35.063	0.529	0.134	1.329	0.392
8070S1	0.165	0.361	62.041	35.037	0.625	0.168	1.221	0.382
8070S2	0.167	0.364	62.032	35.039	0.622	0.167	1.229	0.380
8080S0	0.157	0.318	62.085	35.061	0.531	0.132	1.323	0.393
8080S1	0.167	0.352	62.034	35.041	0.629	0.164	1.229	0.384
8080S2	0.154	0.315	62.087	35.064	0.526	0.138	1.325	0.391
8090S0	0.154	0.318	62.088	35.063	0.527	0.135	1.324	0.391
8090S1	0.153	0.317	62.086	35.066	0.523	0.136	1.326	0.393
8090S2	0.165	0.363	62.043	35.039	0.619	0.167	1.221	0.383
5070S3	0.172	0.366	62.041	35.043	0.613	0.172	1.210	0.383
5070S4	0.163	0.357	62.038	35.036	0.624	0.170	1.232	0.380
5070S5	0.169	0.360	62.037	35.028	0.625	0.167	1.233	0.381
5080S3	0.173	0.358	62.035	35.041	0.616	0.168	1.225	0.384
5080S4	0.162	0.361	62.029	35.035	0.627	0.169	1.237	0.380
5080S5	0.173	0.365	62.029	35.031	0.617	0.162	1.239	0.384
5090S3	0.163	0.355	62.032	35.034	0.626	0.179	1.231	0.380

5090S4	0.179	0.359	62.034	35.031	0.622	0.166	1.229	0.380
5090S5	0.174	0.354	62.034	35.037	0.621	0.164	1.233	0.383
6570S3	0.161	0.361	62.035	35.036	0.631	0.168	1.226	0.382
6570S4	0.172	0.361	62.027	35.033	0.627	0.169	1.228	0.383
6570S5	0.175	0.357	62.033	35.031	0.620	0.172	1.231	0.381
6580S3	0.173	0.359	62.031	35.033	0.623	0.169	1.228	0.384
6580S4	0.172	0.358	62.039	35.037	0.620	0.165	1.227	0.382
6580S5	0.171	0.356	62.036	35.038	0.629	0.167	1.219	0.384
6590S3	0.174	0.354	62.035	35.034	0.621	0.173	1.226	0.383
6590S4	0.173	0.365	62.029	35.030	0.631	0.167	1.225	0.380
6590S5	0.172	0.359	62.037	35.035	0.621	0.166	1.228	0.382
8070S3	0.167	0.359	62.036	35.032	0.623	0.178	1.222	0.383
8070S4	0.176	0.366	62.029	35.030	0.621	0.173	1.225	0.380
8070S5	0.179	0.359	62.032	35.027	0.619	0.175	1.229	0.380
8080S3	0.179	0.355	62.026	35.027	0.627	0.177	1.228	0.381
8080S4	0.176	0.365	62.030	35.032	0.611	0.174	1.232	0.380
8080S5	0.179	0.357	62.028	35.037	0.619	0.174	1.226	0.380
8090S3	0.153	0.322	62.087	35.063	0.527	0.133	1.323	0.390
8090S4	0.151	0.319	62.086	35.065	0.529	0.132	1.326	0.392
8090S5	0.172	0.361	62.033	35.029	0.629	0.169	1.227	0.380
5070W1	0.173	0.357	62.037	35.031	0.622	0.173	1.226	0.381
5070W2	0.177	0.358	62.029	35.035	0.629	0.170	1.218	0.384
5070W3	0.176	0.365	62.036	35.027	0.627	0.165	1.221	0.383
5080W1	0.171	0.354	62.028	35.033	0.632	0.174	1.228	0.380
5080W2	0.173	0.359	62.034	35.032	0.616	0.174	1.232	0.380
5080W3	0.176	0.363	62.027	35.024	0.628	0.175	1.225	0.382
5090W1	0.169	0.358	62.037	35.039	0.621	0.168	1.224	0.384
5090W2	0.174	0.354	62.034	35.034	0.630	0.163	1.231	0.380
5090W3	0.175	0.357	62.029	35.034	0.622	0.173	1.227	0.383
6570W1	0.172	0.363	62.031	35.033	0.624	0.167	1.228	0.382
6570W2	0.179	0.365	62.024	35.029	0.618	0.176	1.229	0.380
6570W3	0.171	0.361	62.034	35.031	0.624	0.169	1.230	0.380
6580W1	0.179	0.364	62.028	35.030	0.617	0.170	1.230	0.382
6580W2	0.172	0.358	62.029	35.032	0.625	0.173	1.227	0.384
6580W3	0.167	0.362	62.032	35.028	0.624	0.172	1.232	0.383
6590W1	0.177	0.361	62.031	35.027	0.626	0.175	1.223	0.380
6590W2	0.176	0.357	62.026	35.030	0.633	0.168	1.229	0.381
6590W3	0.179	0.361	62.023	35.028	0.623	0.179	1.227	0.380
8070W1	0.153	0.318	62.088	35.064	0.527	0.134	1.324	0.392
8070W2	0.155	0.317	62.087	35.062	0.530	0.136	1.323	0.390
8070W3	0.172	0.358	62.029	35.034	0.627	0.170	1.227	0.383
8080W1	0.156	0.319	62.086	35.062	0.528	0.132	1.325	0.392
8080W2	0.155	0.321	62.085	35.061	0.530	0.134	1.323	0.391
8080W3	0.153	0.320	62.087	35.060	0.532	0.132	1.324	0.392
8090W1	0.169	0.362	62.033	35.027	0.627	0.168	1.230	0.384
8090W2	0.174	0.364	62.026	35.029	0.630	0.167	1.228	0.382

8090W3 0.156 0.319 62.086 35.065 0.531 0.132 1.321 0.390

The element values of CW625N standard in Table 10 and the spectral analysis results of Table 44 are compared and all test samples are detected within scope of standard.

4.3. Heat Treatment Results

According to the sample plan produced for the thesis study, 27 of 54 test samples cooled in calm air (selected according to the same conditions) heat treatment process was applied. Heat treatment was applied at 550 degrees for 180 minutes.

4.4. Hardness Measurement Results

The measured hardness results of 108 pieces of samples are shared in Table 48.

Table 48. Hardness results of 108 test pieces

Number of Samples	Group Codes	Measurement - 1 (HRB)	Measurement - 2 (HRB)	Measurement - 3 (HRB)	Average-1	Average-2
HEAT TREATED PARTS COOLED IN CALM AIR						
1	5070s0	42.4	42.9	43.6	42.97	43.17
2	5070s1	42.6	43.3	43.8	43.23	
3	5070s2	42.8	43.3	43.8	43.30	
4	5080s0	42.7	43.2	44	43.30	43.23
5	5080s1	42.7	43.2	43.8	43.23	
6	5080s2	42.5	43.1	43.9	43.17	
7	5090s0	43.2	43.8	44.5	43.83	43.69
8	5090s1	43	43.7	44.4	43.70	
9	5090s2	42.8	43.5	44.3	43.53	
10	6570s0	42	42.6	43.4	42.67	42.84
11	6570S1	42.4	43	43.7	43.03	
12	6570s2	42.2	42.8	43.5	42.83	
13	6580s0	42	42.7	43.5	42.73	42.94
14	6580s1	42.3	43	43.8	43.03	
15	6580s2	42.4	43	43.8	43.07	
16	6590s0	42.7	43.5	44.3	43.50	43.50
17	6590s1	42.7	43.3	44	43.33	
18	6590s2	43	43.6	44.4	43.67	
19	8070s0	41.8	42.3	43	42.37	42.49
20	8070s1	42	42.5	43.2	42.57	
21	8070s2	42	42.5	43.1	42.53	
22	8080s0	41.8	42.6	43.4	42.60	42.76
23	8080s1	42.2	42.8	43.5	42.83	
24	8080s2	42.1	42.8	43.6	42.83	
25	8090s0	42.6	42.2	44	42.93	43.13

26	8090s1	42.5	43.3	44	43.27	
27	8090s2	42.5	43.2	43.9	43.20	
UN-HEAT TREATED PARTS COOLED IN CALM AIR						
28	5070S3	32.5	33.1	33.8	33.13	
29	5070S4	32.2	32.7	33.5	32.80	32.92
30	5070S5	32.1	32.8	33.6	32.83	
31	5080S3	32.8	33.4	34.2	33.47	
32	5080S4	32.7	33.3	34	33.33	33.33
33	5080S5	32.5	33.2	33.9	33.20	
34	5090S3	33	33.6	34.3	33.63	
35	5090S4	33.1	33.8	34.6	33.83	33.66
36	5090S5	32.8	33.5	34.2	33.50	
37	6570S3	32.1	32.7	33.5	32.77	
38	6570S4	32.8	32.5	33.2	32.83	32.78
39	6570S5	32	32.7	33.5	32.73	
40	6580S3	32.3	32.9	33.7	32.97	
41	6580S4	32.6	33.3	33.9	33.27	33.12
42	6580S5	32.5	33.1	33.8	33.13	
43	6590S3	32.7	33.5	34.3	33.50	
44	6590S4	32.7	33.3	34	33.33	33.52
45	6590S5	33	33.8	34.4	33.73	
46	8070S3	32	32.7	33.5	32.73	
47	8070S4	31.6	32.3	33.1	32.33	32.50
48	8070S5	31.7	32.4	33.2	32.43	
49	8080S3	31.2	32.8	33.6	32.53	
50	8080S4	32.4	32.9	33.2	32.83	32.74
51	8080S5	32.8	32.5	33.3	32.87	
52	8090S3	32.3	33	33.8	33.03	
53	8090S4	32.2	32.8	33.5	32.83	33.03
54	8090S5	32.5	33.2	34	33.23	
UN-HEAT TREATED PARTS COOLED WITH FAN						
55	5070F1	42.7	43.3	44	43.33	
56	5070F2	42.9	43.5	44.2	43.53	43.48
57	5070F3	43	43.5	44.2	43.57	
58	5080F1	43	43.5	44.2	43.57	
59	5080F2	43	43.6	44.3	43.63	43.51
60	5080F3	42.8	43.2	44	43.33	
61	5090F1	43	43.6	44.4	43.67	
62	5090F2	43.3	43.8	44.5	43.87	43.80
63	5090F3	43.2	43.8	44.6	43.87	
64	6570F1	42.1	42.8	43.5	42.80	
65	6570F2	42.2	42.8	43.6	42.87	42.90
66	6570F3	42.5	43	43.6	43.03	
67	6580F1	42.3	42.9	43.7	42.97	
68	6580F2	42.3	43.2	44	43.17	43.08
69	6580F3	42.4	43.1	43.8	43.10	
70	6590F1	42.8	43.4	44.3	43.50	
71	6590F2	43.2	43.7	44.5	43.80	43.68
72	6590F3	43	43.7	44.5	43.73	
73	8070F1	42.1	42.8	43.6	42.83	
74	8070F2	42	42.6	43.3	42.63	42.67
75	8070F3	41.7	42.5	43.4	42.53	
76	8080F1	41.8	42.3	43.1	42.40	
77	8080F2	42	42.5	43.3	42.60	42.61
78	8080F3	42.2	42.8	43.5	42.83	
79	8090F1	42	42.7	43.5	42.73	
80	8090F2	42.1	42.8	43.7	42.87	42.76
81	8090F3	41.9	42.6	43.5	42.67	

UN-HEAT TREATMENT COOLED IN WATER						
82	5070w1	44.9	45.5	46.2	45.53	
83	5070w2	45.1	45.8	46.6	45.83	45.69
84	5070w3	45	45.7	46.4	45.70	
85	5080w1	45	45.6	46.5	45.70	
86	5080w2	45.2	45.9	46.7	45.93	45.79
87	5080w3	45	45.7	46.5	45.73	
88	5090w1	45.3	45.8	46.5	45.87	
89	5090w2	45.2	45.9	46.7	45.93	45.90
90	5090w3	45.3	45.9	46.5	45.90	
91	6570w1	44.5	45.1	45.8	45.13	
92	6570w2	44.4	45.2	45.7	45.10	45.19
93	6570w3	44.7	45.3	46	45.33	
94	6580w1	44.5	45.2	46	45.23	
95	6580w2	44.3	45	45.8	45.03	45.10
96	6580w3	44.4	45	45.7	45.03	
97	6590w1	45	45.6	46.4	45.67	
98	6590w2	45	45.7	46.4	45.70	45.63
99	6590w3	44.8	45.5	46.3	45.53	
100	8070w1	44.2	44.7	45.4	44.77	
101	8070w2	44	44.7	45.5	44.73	44.73
102	8070w3	44	44.7	45.4	44.70	
103	8080w1	44	44.7	45.6	44.77	
104	8080w2	44	44.7	45.5	44.73	44.80
105	8080w3	44.2	44.9	45.6	44.90	
106	8090w1	44.6	45.3	46	45.30	
107	8090w2	44.5	45.1	45.8	45.13	45.32
108	8090w3	44.8	45.5	46.3	45.53	

When each group was examined; at the same forging temperature and increasing forging pressure effect, hardness values of parts are increased. When the forging pressure is kept constant and the effect of increasing forging temperature is examined, it is obtained that the hardness values of the parts decrease.

In addition, the cooling down methods of the test samples are found to directly affect the surface hardness. The highest surface hardness values are measured in water-cooled samples.

4.5. Microstructure Results

It was studied on microstructures and grain size. The grain size values of each group are shared in Table 49 below.

Table 49. Grain sizes of all test samples

Number of Samples	Group Codes	GRAIN SIZE (10x0.30)			
		Perpendicular to the direction of extrusion	Parallel to the direction of extrusion	Average	
				Perpendicular to the direction of extrusion	Parallel to the direction of extrusion
HEAT TREATED PARTS COOLED IN CALM AIR					
1	5070S0	9 μm	9 μm		
2	5070S1	9.5 μm	9.5 μm	9.34 μm	9.50 μm
3	5070S2	9.5 μm	10 μm		
4	5080S0	9.5 μm	9 μm		
5	5080S1	9.5 μm	10 μm	9.50 μm	9.67 μm
6	5080S2	9.5 μm	10 μm		
7	5090S0	9.5 μm	9.5 μm		
8	5090S1	9.5 μm	10 μm	9.67 μm	9.84 μm
9	5090S2	10 μm	10 μm		
10	6570S0	8.5 μm	9 μm		
11	6570S1	8 μm	8.5 μm	8.34 μm	8.84 μm
12	6570S2	8.5 μm	9 μm		
13	6580S0	8.5 μm	9 μm		
14	6580S1	8.5 μm	8.5 μm	8.84 μm	9.00 μm
15	6580S2	9.5 μm	9.5 μm		
16	6590S0	8.5 μm	9 μm		
17	6590S1	9.5 μm	10 μm	9.00 μm	9.34 μm
18	6590S2	9 μm	9 μm		
19	8070S0	7 μm	7.5 μm		
20	8070S1	7 μm	7 μm	7.00 μm	7.34 μm
21	8070S2	7 μm	7.5 μm		
22	8080S0	7.5 μm	8 μm		
23	8080S1	7.5 μm	7.5 μm	7.67 μm	7.84 μm
24	8080S2	8 μm	8 μm		
25	8090S0	8 μm	8.5 μm		
26	8090S1	7.5 μm	8 μm	8.00 μm	8.34 μm
27	8090S2	8.5 μm	8.5 μm		
UN-HEAT TREATED PARTS COOLED IN CALM AIR					
28	5070S3	13.5 μm	14 μm		
29	5070S4	13 μm	13.5 μm	13.34 μm	13.84 μm
30	5070S5	13.5 μm	14 μm		
31	5080S3	14 μm	14.5 μm		
32	5080S4	13.5 μm	14 μm	13.84 μm	14.34 μm
33	5080S5	14 μm	14.5 μm		
34	5090S3	14 μm	14.5 μm		
35	5090S4	14.5 μm	14.5 μm	14.17 μm	14.50 μm
36	5090S5	14 μm	14.5 μm		
37	6570S3	12.5 μm	13 μm		
38	6570S4	12.5 μm	12.5 μm	12.50 μm	12.84 μm
39	6570S5	12.5 μm	13 μm		
40	6580S3	12.5 μm	13 μm		
41	6580S4	13 μm	13.5 μm	12.67 μm	13.17 μm
42	6580S5	12.5 μm	13 μm		
43	6590S3	13 μm	13,5 μm		
44	6590S4	13 μm	13,5 μm	13.17 μm	13.50 μm
45	6590S5	13,5 μm	13.5 μm		
46	8070S3	12 μm	12,5 μm		
47	8070S4	11.5 μm	12 μm	11.67 μm	12.17 μm
48	8070S5	11.5 μm	12 μm		
49	8080S3	12 μm	12.5 μm	11.84 μm	12.34 μm

50	8080S4	11.5 µm	12 µm		
51	8080S5	12 µm	12.5 µm		
52	8090S3	12 µm	12.5 µm		
53	8090S4	12 µm	12.5 µm	12.17 µm	12.50 µm
54	8090S5	12.5 µm	12.5 µm		
UN-HEAT TREATED PARTS COOLED WITH FAN					
55	5070F1	9.5 µm	10 µm		
56	5070F2	9.5 µm	10 µm	9.34 µm	9.84 µm
57	5070F3	9 µm	9.5 µm		
58	5080F1	10 µm	10 µm		
59	5080F2	9.5 µm	10 µm	9.67 µm	10.00 µm
60	5080F3	9.5 µm	10 µm		
61	5090F1	10 µm	10.5 µm		
62	5090F2	10.5 µm	10.5 µm	10.34 µm	10.67 µm
63	5090F3	10.5 µm	11 µm		
64	6570F1	8.5 µm	8.5 µm		
65	6570F2	8.5 µm	9 µm	8.34 µm	8.67 µm
66	6570F3	8 µm	8.5 µm		
67	6580F1	8.5 µm	8.5 µm		
68	6580F2	8.5 µm	9 µm	8.50 µm	8.84 µm
69	6580F3	8.5 µm	9 µm		
70	6590F1	9 µm	9 µm		
71	6590F2	9.5 µm	9.5 µm	9.17 µm	9.34 µm
72	6590F3	9 µm	9.5 µm		
73	8070F1	7.5 µm	7.5 µm		
74	8070F2	7.5 µm	8 µm	7.50 µm	7.84 µm
75	8070F3	7.5 µm	8 µm		
76	8080F1	8 µm	8 µm		
77	8080F2	8 µm	8.5 µm	7.84 µm	8.17 µm
78	8080F3	7.5 µm	8 µm		
79	8090F1	8 µm	8 µm		
80	8090F2	8 µm	8.5 µm	8.34 µm	8.34 µm
81	8090F3	8.5 µm	8.5 µm		
UN-HEAT TREATED PARTS COOLED IN WATER					
82	5070W1	6.5 µm	7 µm		
83	5070W2	7 µm	7 µm	6.67 µm	7.17 µm
84	5070W3	6.5 µm	7.5 µm		
85	5080W1	7 µm	7.5 µm		
86	5080W2	7.5 µm	7.5 µm	7.17 µm	7.50 µm
87	5080W3	7 µm	7.5 µm		
88	5090W1	7 µm	8 µm		
89	5090W2	7.5 µm	7.5 µm	7.50 µm	7.84 µm
90	5090W3	8 µm	8 µm		
91	6570W1	5 µm	5.5 µm		
92	6570W2	5.5 µm	6 µm	5.17 µm	5.84 µm
93	6570W3	5 µm	6 µm		
94	6580W1	6 µm	6 µm		
95	6580W2	6.5 µm	6.5 µm	6.17 µm	6.34 µm
96	6580W3	6 µm	6.5 µm		
97	6590W1	6 µm	7 µm		
98	6590W2	6 µm	7 µm	6.00 µm	6.84 µm
99	6590W3	6 µm	6.5 µm		
100	8070W1	4.5 µm	5 µm		
101	8070W2	4 µm	4.5 µm	4.17 µm	4.67 µm
102	8070W3	4 µm	4.5 µm		
103	8080W1	4.5 µm	5 µm		
104	8080W2	4.5 µm	5 µm	4.34 µm	4.84 µm
105	8080W3	4 µm	4.5 µm		

106	8090W1	4.5 μm	5 μm		
107	8090W2	4.5 μm	5.5 μm	4.67 μm	5.17 μm
108	8090W3	5 μm	5 μm		

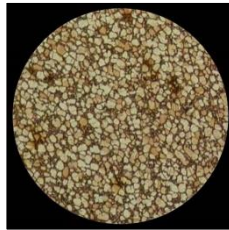
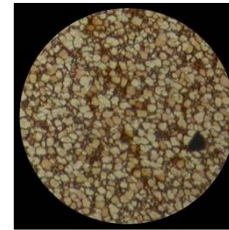
When the particle sizes are examined for parts cooled in calm air and subsequently heat treated; grain size is between 7 - 9.84 μm .

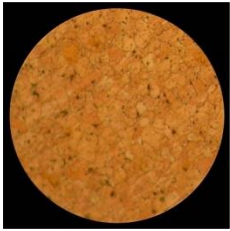
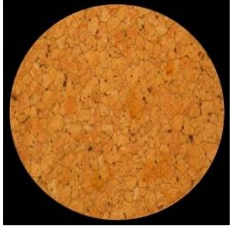
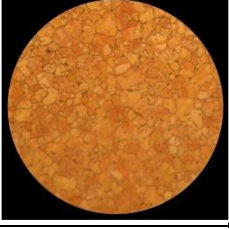
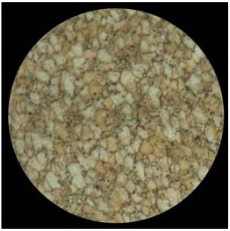
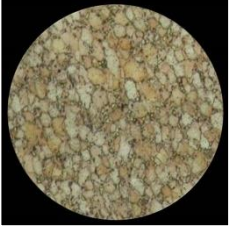
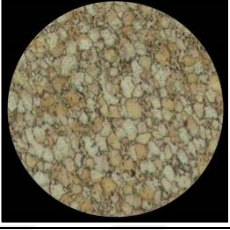
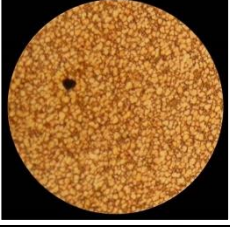
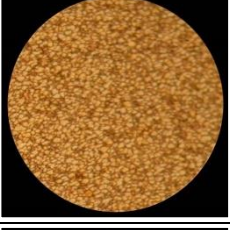
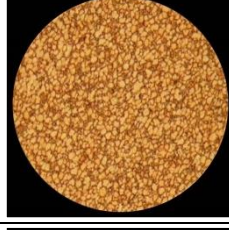
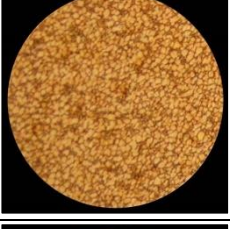
When the particle sizes are examined for parts cooled in calm air and unheat treated; grain size is between 11.67 - 14.50 μm . The effect of not having heat treatment on these samples is seen.

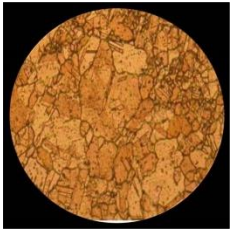
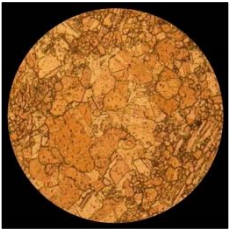
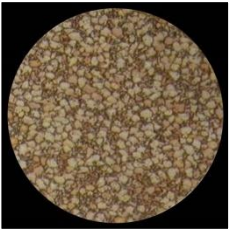
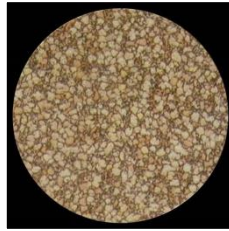
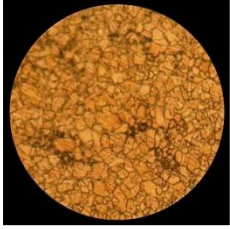
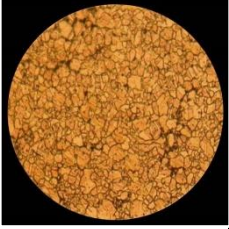
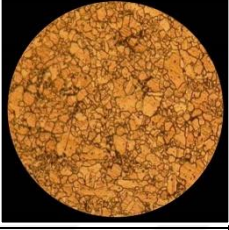
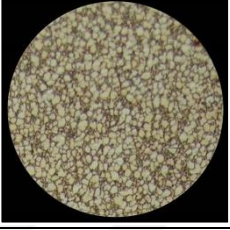
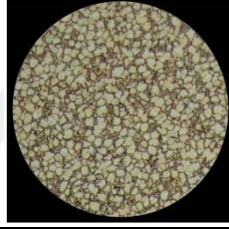
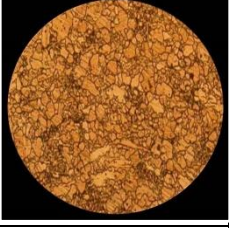
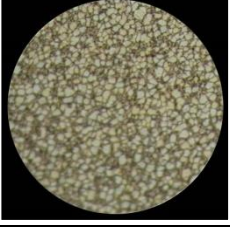
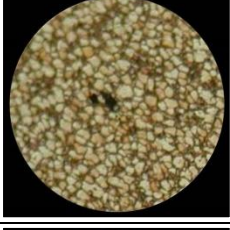
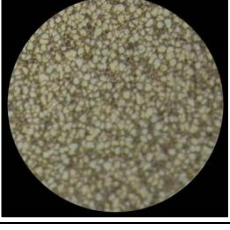
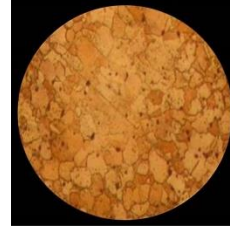
When the particle sizes are examined for parts cooled with fan; grain size is between 7.50 - 10.67 μm . When the parts cooled by fan are examined; It is found that there were approximate results with the parts that cooled in calm air and applied heat treatment. The results are obtained in this group show the effect of controlled cooling.

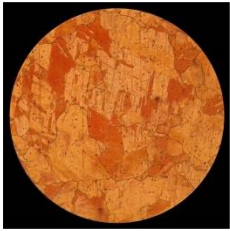
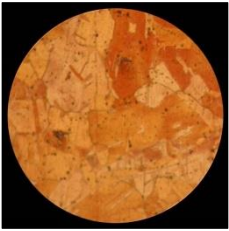
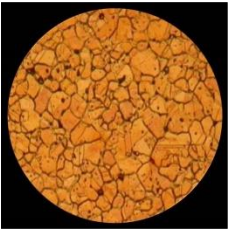
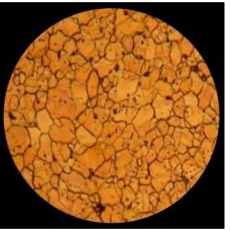
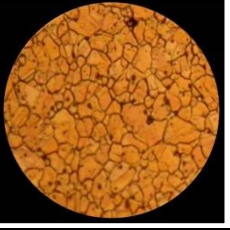
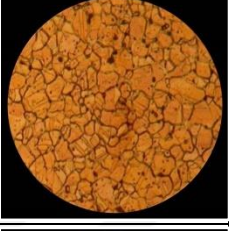
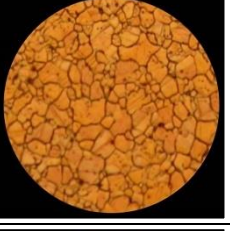
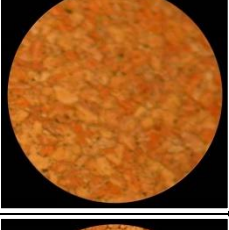
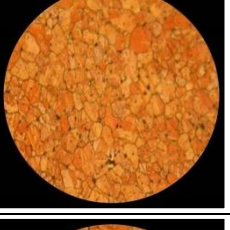
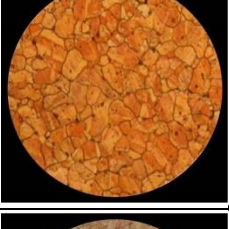
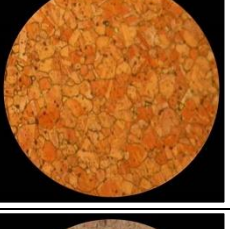
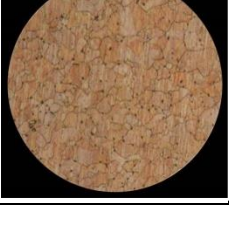
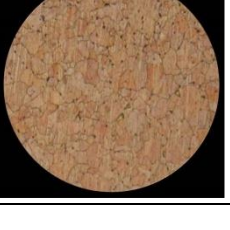
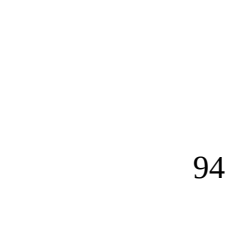
When the particle sizes are examined for parts cooled in water; grain size is between 4.17 – 7.84 μm . Looking at the results are obtained in this group; It is found that grain sizes are small values due to the effect of sudden cooling.

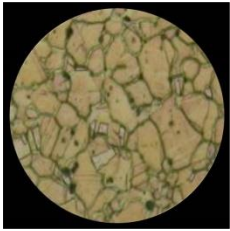
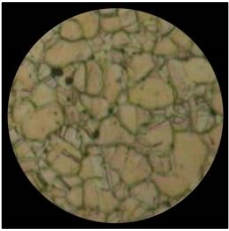
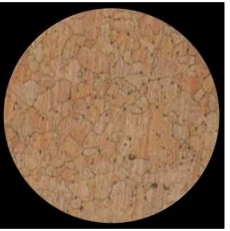
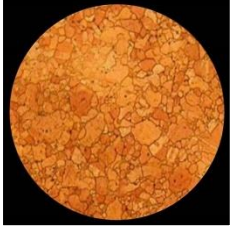
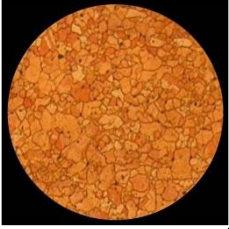
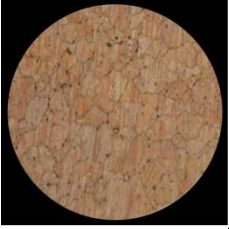
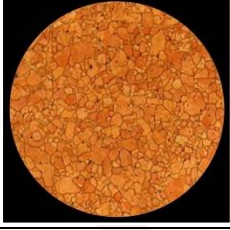
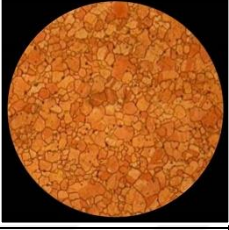
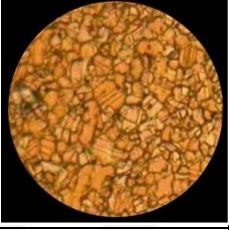
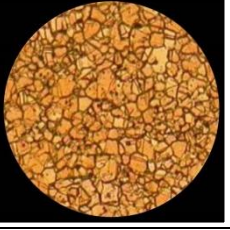
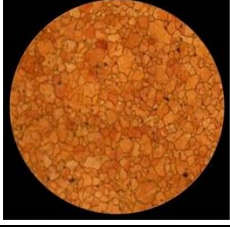
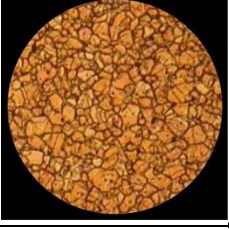
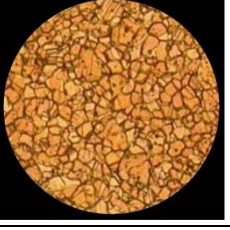
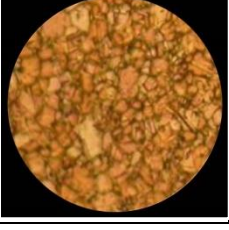
The samples were examined at magnification two hundred times. Microstructure images of magnified 200 times taken from samples are shown in Figure 38.

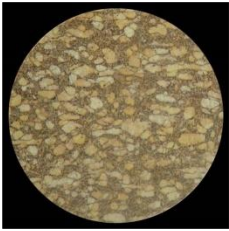
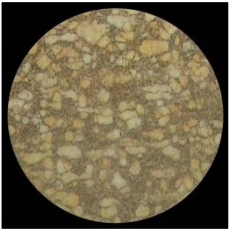
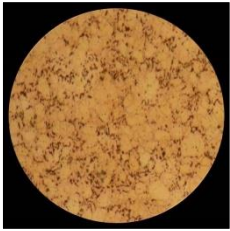
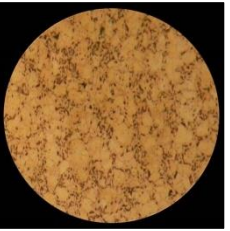
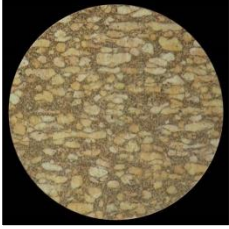
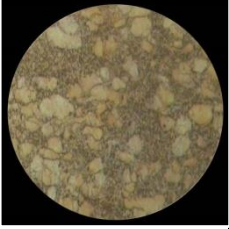
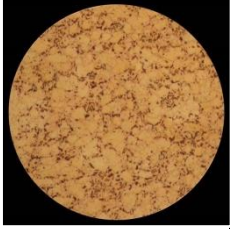
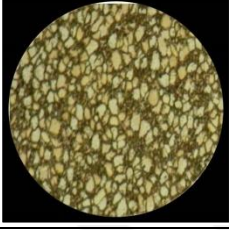
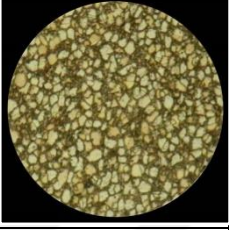
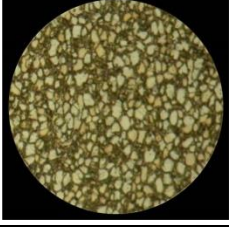
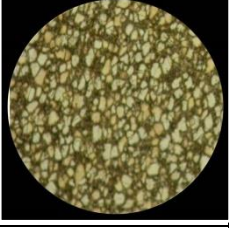
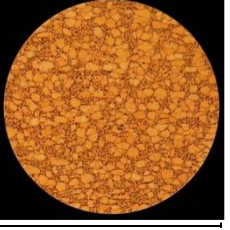
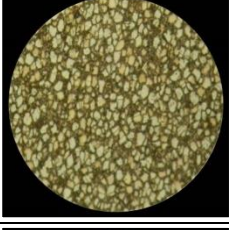
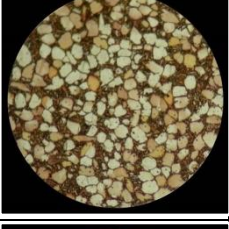
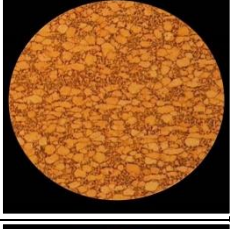
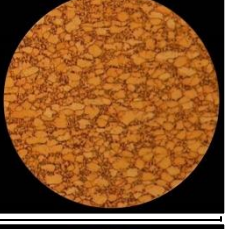
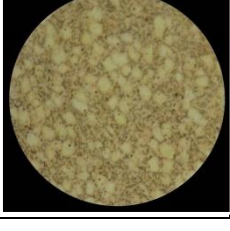
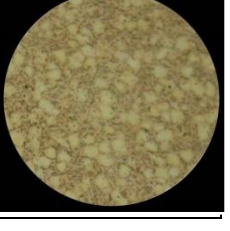
MICROSTRUCTURE IMAGES OF SAMPLES					
Group Codes	Perpendicular to the direction of extrusion (x200)	Parallel to the direction of extrusion (x200)	Group Codes	Perpendicular to the direction of extrusion (x200)	Parallel to the direction of extrusion (x200)
SAMPLES COOLED IN CALM AIR (HEAT TREATED)					
5070s0			6580s2		

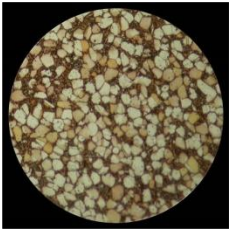
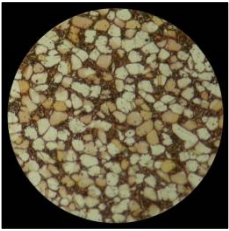
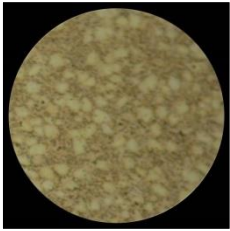
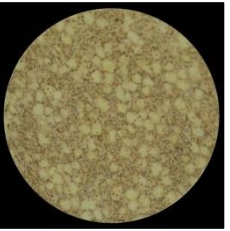
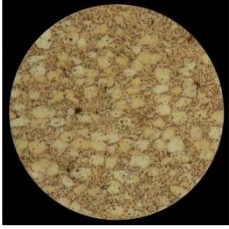
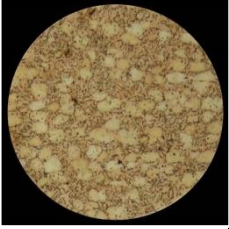
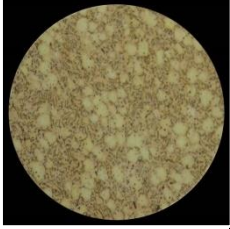
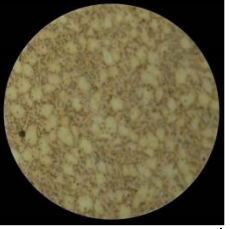
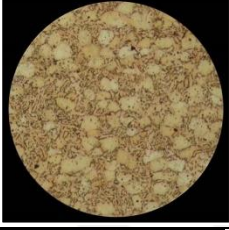
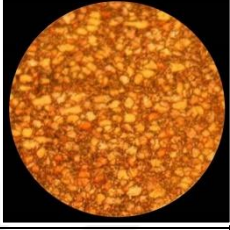
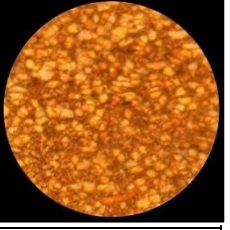
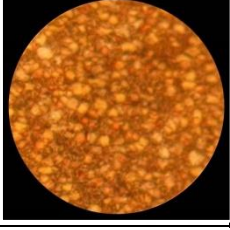
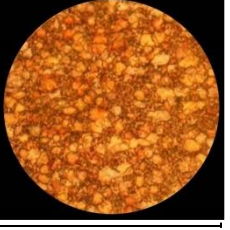
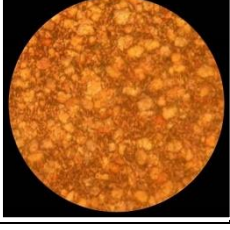
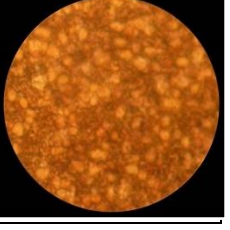
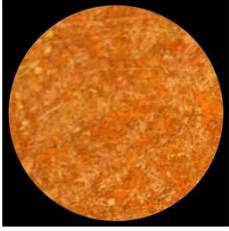
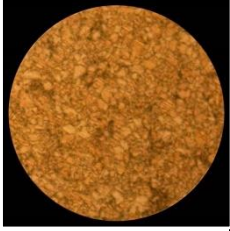
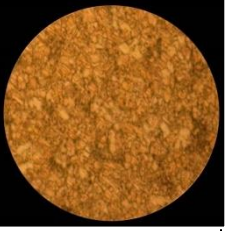
5070s1			5070s2			5080s0			5080s1			5080s2			5090s0			5090s1			6590s0			6590s1			6590s2			8070s0			8070s1			8070s2			8080s0		
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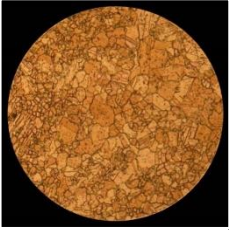
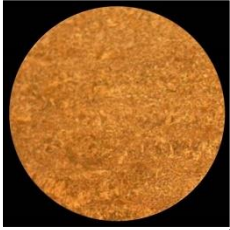
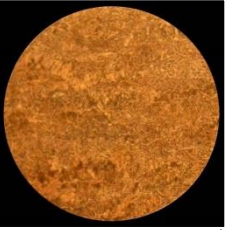
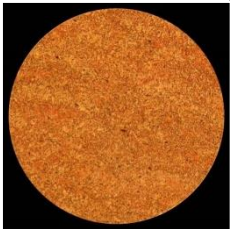
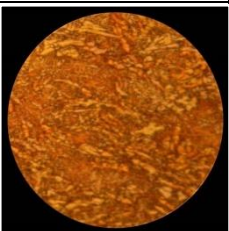
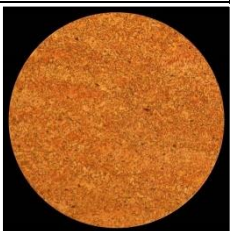
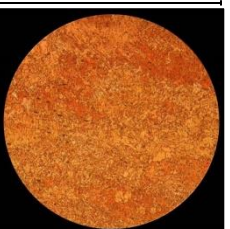
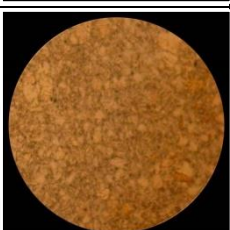
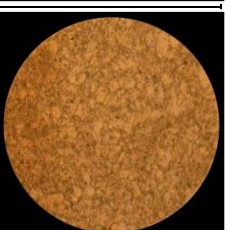
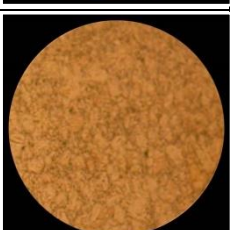
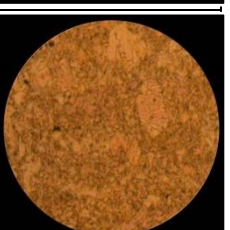
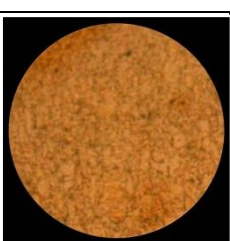
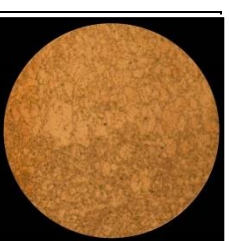
5090s2			8080s1		
6570s0			8080s2		
6570s1			8090s0		
6570s2			8090s1		
6580s0			8090s2		
6980s1					
SAMPLES COOLED IN CALM AIR and UN-HEAT TREATED)					
5070s3			6580s5		

5070s4			5070s5			5080s4			5090s3			5090s5			6590s4			8070s3			8070s5			8080s4			8090s3			8090s5			8100s4			8110s3
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5090s5			8080s4		
6570s3			8080s5		
6570s4			8090s3		
6570s5			8090s4		
6580s3			8090s5		
6580s4					
SAMPLES COOLED WITH FAN					
5070f1			6580f3		

5070f2			6590f1		
5070f3			6590f2		
5080f1			6590f3		
5080f2			8070f1		
5080f3			8070f2		
5090f1			8070f3		
5090f2			8080f1		

5090f3			8080f2		
6570f1			8080f3		
6570f2			8090f1		
6570f3			8090f2		
6580f1			8090f3		
6580f2					
SAMPLES COOLED IN WATER					
5070w1			6580w3		

5090w2			8080w1		
5090w1			8070w3		
5080w3			8070w2		
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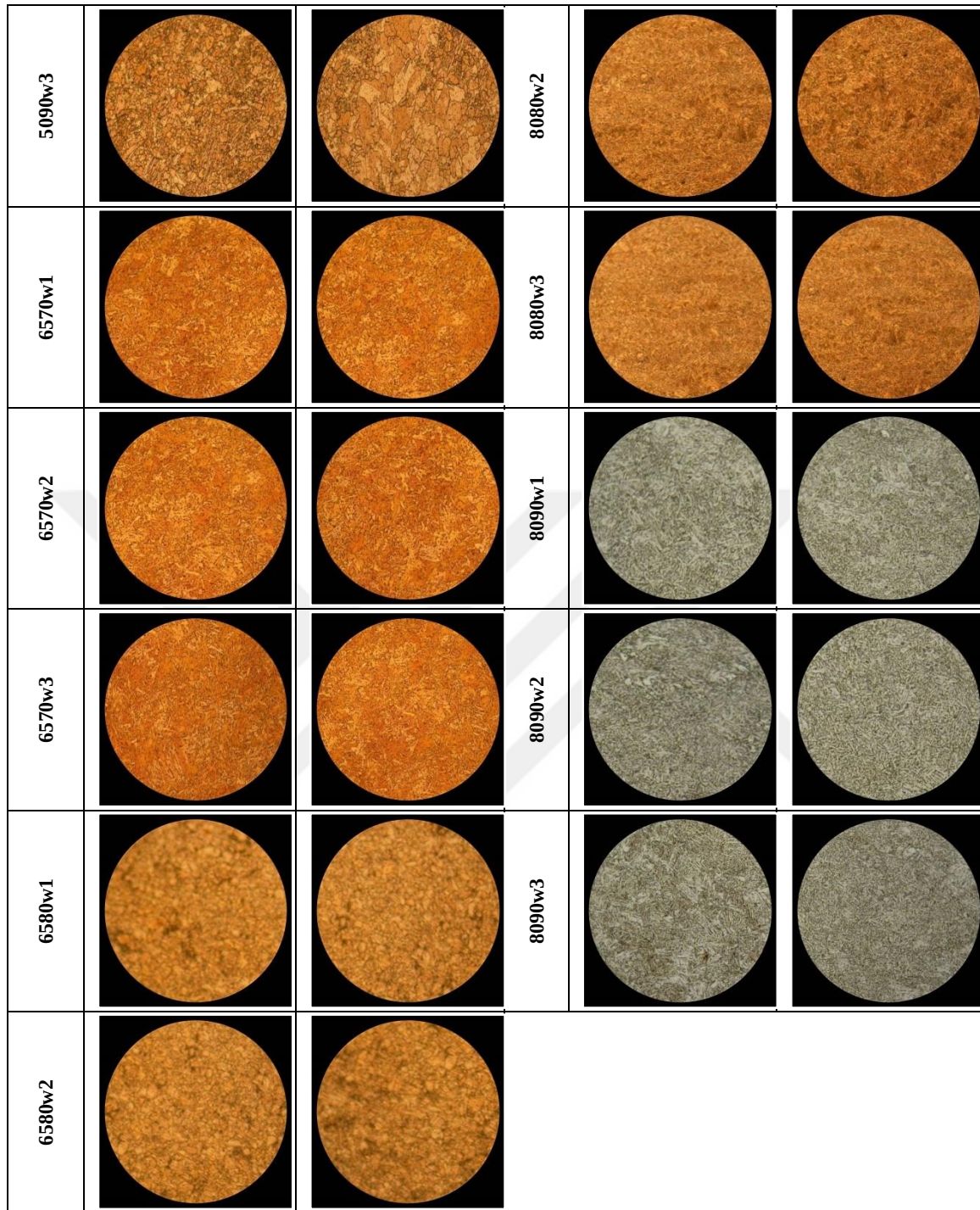


Figure 38. Microstructure images of all test samples

For each group; When we match the microstructure images and grain size values, it was found that forging temperature and forging pressures had no direct effects.

While the forging temperature is constant, the increase in forging pressure increases the grain size within the microstructure. While the forging pressure is constant, the forging

temperature increase reduces the grain size in the microstructure. The applied temperature does not meet the expectation of the increase in grain size effect. Therefore, it has been found that forging does not directly affect the increase in pressure and temperature. Whereas, direct effects of different cooling methods and heat treatment applications are obtained.

The main factor; after heating the billets, instead of the effect of shaping with the selected forging temperature and forging pressure values, the direct effect of slow, sudden and controlled cooling down are determined. If it is explained in detail this effect; is occurred in the time from the shaped temperatures to until cools down. In heat treatment process; the microstructure is more stable due to the application of a constant temperature depending on the time. If we evaluate the samples cooled in calm air after the hot forging, heat treatment application are reduced the grain size. Likewise, this situation has been detected in the cooling method with fan which is controlled cooling down. When samples cooled in water were examined; As seen in the microstructure images due to the sudden cooling effect, needle-like structures were formed. This is why the hardness value of this group is harder than other groups.

When their microstructures are examined; In the heat treatment group cooled in calm air with the fan group with similar grain size, it has martensite (needle-like) structures, although not intense. And also; Needle-free structures were not found in the group that was cooled in calm air and did not apply heat treatment. It was determined that all samples in the group cooled in water due to sudden cooling consisted of very dense, even completely needle-like structures.

4.6. Dezincification Resistance Results

In this section, all results are analyzed as divided into groups. the groups are as follows;

- The first group is the group that is cooled in calm air and heat treated,
- The second group; Group cooled in calm air and not heat treated,
- Third group; fan cooled and non-heat treated group,
- The fourth group; It is a group that is cooled in water and not heat treated.

Dezincification depth, beta phase percentage and dezincification depth images are given for each group. After giving the test values obtained in each group, the evaluations of each group are shared at the end.

Within the scope were prepared and measured all samples for testing. The results of all test samples are shown in Table 50, Table 55, Table 57, and Table 59. The results of beta-grain size and beta-phase ratios are shared in Table 54, Table 56, Table 58, and Table 60. Two hundred times magnified images obtained from the dezincification resistance analyzes of each sample are shared in Figure 39, Figure 40, Figure 41 and Figure 42.

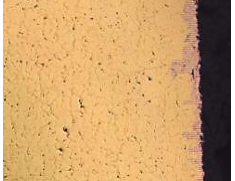
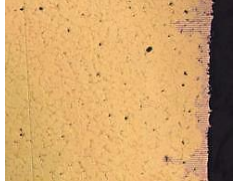
The test results of firstly, cooled in calm air then heat treated samples are shown Table 50, Table 51 and Figure 39.

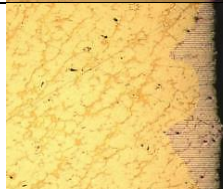
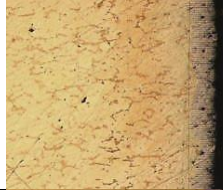
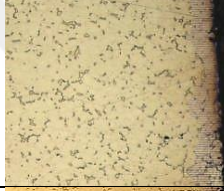
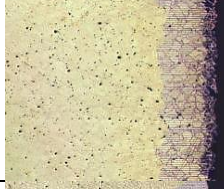
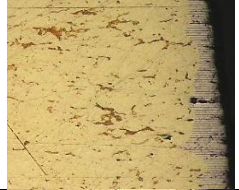
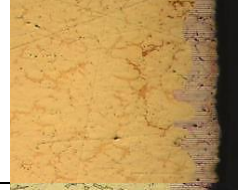
Table 50. The dezincification depth value which in samples of cooled in calm air and heat-treated

Group Codes	DEZINCIFICATION DEPTH			
	(Cooled in calm air and heat treated)			
	Perpendicular to the direction of extrusion (Max. Tolerance 100 μ m)		Parallel to the direction of extrusion (Max. Tolerance 200 μ m)	
	Min. Value	Max. Value	Min. Value	Max. Value
5070s0	16.20	51.28	21.24	120.47
5070s1	14.35	64.37	18.63	132.65
5070s2	123.46	158.22	135.63	210.17
5080s0	51.73	125.48	96.13	218.54
5080s1	23.44	71.08	38.16	145.13
5080s2	43.70	94.68	62.17	120.45
5090s0	45.14	72.58	40.61	117.23
5090s1	28.17	80.46	35.72	96.28
5090s2	26.49	57.25	23.65	91.14
6570s0	60.27	153.14	47.51	223.66
6570s1	63.70	90.21	57.86	133.45
6570s2	28.73	99.62	85.47	228.16
6580s0	57.34	101.20	90.53	225.87
6580s1	41.62	94.76	60.83	157.14
6580s2	16.43	47.26	30.61	63.88
6590s0	34.27	76.18	40.56	138.22
6590s1	82.30	153.14	78.43	224.28
6590s2	26.17	88.73	69.82	130.54
8070s0	40.65	104.57	86.42	238.13
8070s1	26.37	90.83	68.24	190.11
8070s2	30.51	99.78	72.40	183.56
8080s0	71.23	118.26	170.08	234.51
8080s1	40.16	75.42	27.16	94.68
8080s2	27.15	116.43	122.31	230.77
8090s0	67.33	123.14	78.36	231.04
8090s1	31.28	104.72	45.68	240.73
8090s2	35.42	98.52	67.88	193.26

Table 51. Beta grain sizes and beta phase ratios which in cooled in calm air and heat-treated

Group Codes	BETA GRAIN SIZE		BETA AND ALPHA PHASE RATIO		
	Min. Value (μm)	Max. Value (μm)	Beta Phase Ratio (%)	Alpha Phase Ratio (%)	Total Fields (μm^2)
5070s0	0.03	7.12	6.34	93.66	190131.55
5070s1	0.04	7.54	6.12	93.88	190131.55
5070s2	0.07	7.32	9.72	90.28	190131.55
5080s0	0.05	7.68	9.34	90.66	190131.55
5080s1	0.03	7.70	6.23	93.77	190131.55
5080s2	0.07	7.56	6.07	93.93	190131.55
5090s0	0.04	7.73	6.28	93.72	190131.55
5090s1	0.04	7.84	6.47	93.53	190131.55
5090s2	0.06	7.26	6.11	93.89	190131.55
6570s0	0.07	8.45	10.76	89.24	190131.55
6570s1	0.04	8.12	6.63	93.37	190131.55
6570s2	0.03	8.65	10.48	89.52	190131.55
6580s0	0.06	9.28	10.50	89.50	190131.55
6580s1	0.05	8.27	6.94	93.06	190131.55
6580s2	0.05	8.14	6.76	93.24	190131.55
6590s0	0.07	8.75	6.58	93.42	190131.55
6590s1	0.06	8.61	10.51	89.49	190131.55
6590s2	0.07	7.84	6.84	93.16	190131.55
8070s0	0.03	9.69	11.46	88.54	190131.55
8070s1	0.03	9.32	7.45	92.55	190131.55
8070s2	0.06	10.11	7.36	92.64	190131.55
8080s0	0.05	9.73	11.39	88.61	190131.55
8080s1	0.05	9.48	7.10	92.90	190131.55
8080s2	0.05	9.16	11.82	88.18	190131.55
8090s0	0.04	9.12	11.63	88.37	190131.55
8090s1	0.06	9.51	11.74	88.26	190131.55
8090s2	0.05	9.38	7.30	92.70	190131.55

DEZINIFICATION IMAGES OF TEST SAMPLES (COOLED IN CALM AIR AND HEAT TREATED)					
Group Codes	Perpendicular to the direction of extrusion (x200)	Parallel to the direction of extrusion (x200)	Group Codes	Perpendicular to the direction of extrusion (x200)	Parallel to the direction of extrusion (x200)
5070s0			6580s2		
5070s1			6590s0		

6570s1			6570s0			5090s2			5090s1			5090s0			5080s2			5080s1			5080s0			5070s2		
8090s0			8080s2			8080s1			8080s0			8070s2			8070s1			8070s0			6590s2			6590s1		

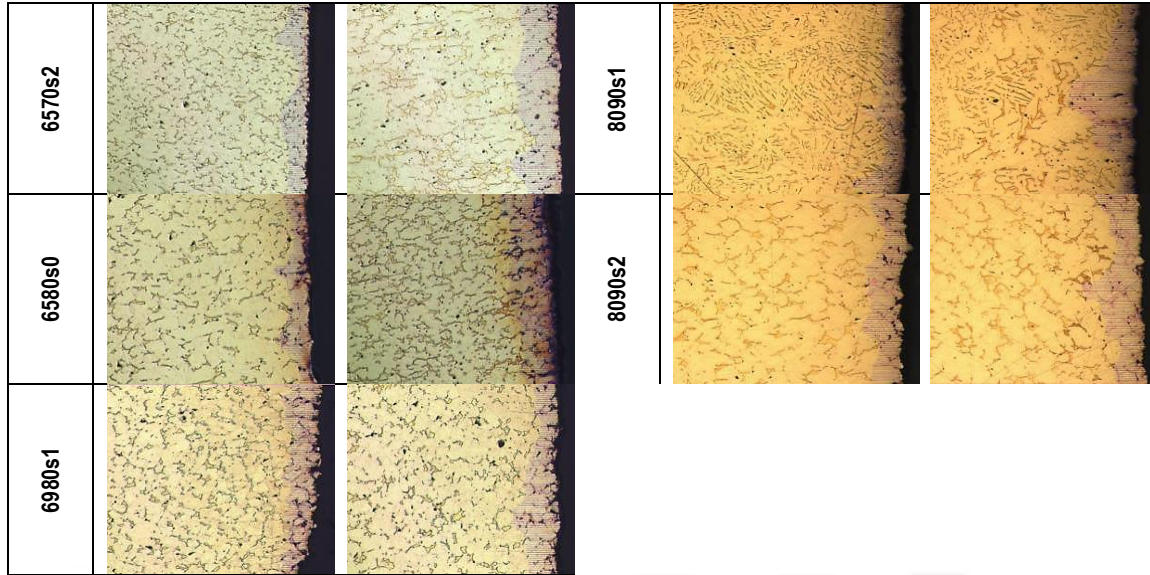


Figure 39. The dezincification images of the cooled in calm air and heat-treated samples.

According to the TS EN ISO 6509-1 standard dezincification depths should be examined in perpendicular and parallel to the direction of extrusion. Respectively, it should be 100 μ m and 200 μ m [31]. When the results in Table 50 are examined; dezincification depth values of 16 parts (samples 5070s0, 5070s1, 5080s1, 5080s2, 5090s0, 5090s1, 5090s2, 6570s1, 6580s1, 6580s2, 6590s0, 6590s2, 8070s1, 8070s2, 8080s1 and 8090s2), which are heat treated and cooled in calm air, are found to be in the scope of standard. But, the dezincification depth of 11 parts (samples 5070s2, 5080s0, 6570s0, 6570s2, 6580s0, 6590s1, 8070s0, 8080s0, 8080s2, 8090s0 and 8090s1) exceed the standard value.

When Table 51 is examined; the beta phase ratios of 11 samples are different if evaluated in the forging temperature-pressure parameter groups. The beta phase ratios in the 5070s0 and 5070s1 samples are 7.12% and 7.54%, whereas in the 5070s2 sample it is 9.72%. The beta phase ratios in the 5080s1 and 5080s2 samples are 6.23% and 6.07%, whereas in the 5080s0 sample it is 9.34%. The beta phase ratio in the 5090s0, 5090s1 and 5070s2 samples are 6.28%, 6.47% and 6.11%. The beta phase ratio in the 6570s1 sample is 6.63%, whereas in the 6570s0 and 6570s2 samples they are 10.76% and 10.48%. The beta phase ratios in the 6580s1 and 6580s2 samples are 6.94% and 6.76%, whereas in the 6580s0 sample it is 10.50%. The beta phase ratios in the 6590s0 and 6590s2 samples are 6.58% and 6.84%, whereas in the 6590s0 sample it is 10.51%. The beta phase ratios in the 8070s1 and 8070s2 samples are 7.45% and 7.36%, whereas

in the 8070s0 sample it is 11.46%. The beta phase ratio is 7.10% in the 8080s1 sample, whereas in the 8080s0 and 8080s2 samples they are 11.39% and 11.82%. The beta phase ratio is 7.10% in the 8080s1 sample, whereas in the 8080s0 and 8080s2 samples they are 11.39% and 11.82%. The beta phase ratio is 7.30% in the 8090s2 sample, whereas in the 8090s0 and 8090s1 samples they are 11.63% and 11.74%.

As determined in Table 50 and Figure 39 evaluations; the dezincification depth values of 11 of the 27 samples are not in the scope of the standard. The dezincification resistance analysis images in Figure 46 support the obtained findings.

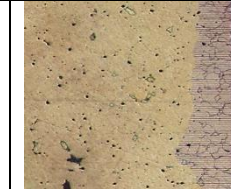
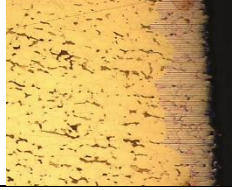
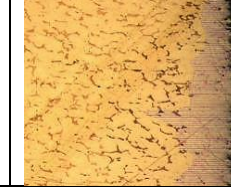
The test results of secondly, cooled in calm air then un-heat treated samples are shown Table 52, Table 53 and Figure 40.

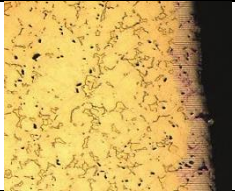
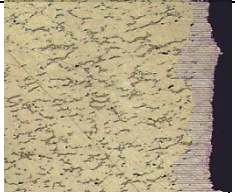
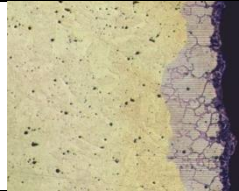
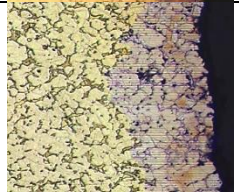
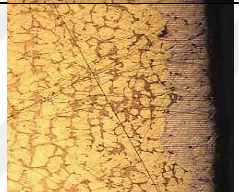
Table 52. The dezincification depth value which in samples of cooled in calm air and un-heat treated

Group Codes	DEZINCIFICATION DEPTH			
	(Cooled in calm air and un-heat treated)			
	Perpendicular to the direction of extrusion (Max. Tolerance 100 μ m)		Parallel to the direction of extrusion (Max. Tolerance 200 μ m)	
	Min. Value	Max. Value	Min. Value	Max. Value
5070s3	84.56	144.37	92.50	251.28
5070s4	88.33	140.26	135.41	234.67
5070s5	91.26	121.56	62.49	231.17
5080s3	54.26	115.31	122.18	251.54
5080s4	140.10	255.23	131.81	242.37
5080s5	95.84	251.76	140.11	239.82
5090s3	72.29	131.71	97.56	242.48
5090s4	105.35	220.47	131.13	253.45
5090s5	64.51	99.83	128.34	247.48
6570s3	72.33	242.65	90.51	268.13
6570s4	154.58	172.31	53.40	262.26
6570s5	83.25	174.40	92.60	251.87
6580s3	79.12	164.27	215.42	260.27
6580s4	62.18	191.44	96.80	262.53
6580s5	90.14	187.56	134.75	267.63
6590s3	51.26	148.35	82.41	273.77
6590s4	56.38	127.61	93.15	268.55
6590s5	55.79	118.14	106.58	267.43
8070s3	81.46	128.93	94.31	237.54
8070s4	108.56	163.42	87.28	239.31
8070s5	113.82	130.98	114.79	262.37
8080s3	75.30	137.28	130.12	243.68
8080s4	74.39	162.60	209.42	288.27
8080s5	238.67	266.43	263.52	261.76
8090s3	167.16	276.28	301.44	346.21
8090s4	150.47	245.83	138.24	327.49
8090s5	156.32	239.18	150.72	268.65

Table 53. Beta grain sizes and beta phase ratios which in cooled in calm air and un-heat treated

Group Codes	BETA GRAIN SIZE		BETA AND ALPHA PHASE RATIO		
	Min. Value (μm)	Max. Value (μm)	Beta Phase Ratio (%)	Alpha Phase Ratio (%)	Total Fields (μm^2)
5070s3	0.03	12.73	9.67	90.33	190131.55
5070s4	0.03	12.48	9.18	90.82	190131.55
5070s5	0.06	13.11	9.54	90.46	190131.55
5080s3	0.05	12.59	9.49	90.51	190131.55
5080s4	0.05	12.23	9.51	90.49	190131.55
5080s5	0.05	12.61	9.34	90.66	190131.55
5090s3	0.04	13.45	9.28	90.72	190131.55
5090s4	0.06	13.26	9.73	90.27	190131.55
5090s5	0.05	12.75	9.65	90.35	190131.55
6570s3	0.06	13.64	10.38	89.62	190131.55
6570s4	0.05	13.24	10.89	89.11	190131.55
6570s5	0.05	13.32	10.54	89.46	190131.55
6580s3	0.07	14.48	10.76	89.24	190131.55
6580s4	0.06	14.64	10.17	89.83	190131.55
6580s5	0.06	12.73	10.82	89.18	190131.55
6590s3	0.05	14.56	10.46	89.54	190131.55
6590s4	0.05	12.46	10.33	89.67	190131.55
6590s5	0.07	13.21	10.25	89.75	190131.55
8070s3	0.05	13.28	11.87	88.13	190131.55
8070s4	0.04	14.72	11.45	88.55	190131.55
8070s5	0.04	13.14	11.68	88.32	190131.55
8080s3	0.04	14.13	11.47	88.53	190131.55
8080s4	0.06	12.78	11.23	88.77	190131.55
8080s5	0.06	15.82	11.54	88.46	190131.55
8090s3	0.05	13.57	12.65	87.35	190131.55
8090s4	0.05	15.64	12.41	87.59	190131.55
8090s5	0.05	15.34	11.34	88.66	190131.55

DEZINIFICATION IMAGES OF TEST SAMPLES (COOLED IN CALM AIR AND UN-HEAT TREATED)					
Group Codes	Perpendicular to the direction of extrusion (x200)	Parallel to the direction of extrusion (x200)	Group Codes	Perpendicular to the direction of extrusion (x200)	Parallel to the direction of extrusion (x200)
5070s3			6580s5		
5070s4			6590s3		

6570s4			5090s5		5090s4		5090s3		5080s5		5080s4		5080s3		5070s5	
8090s3			8080s4		8080s3		8070s5		8070s4		8070s3		6590s5		6590s4	

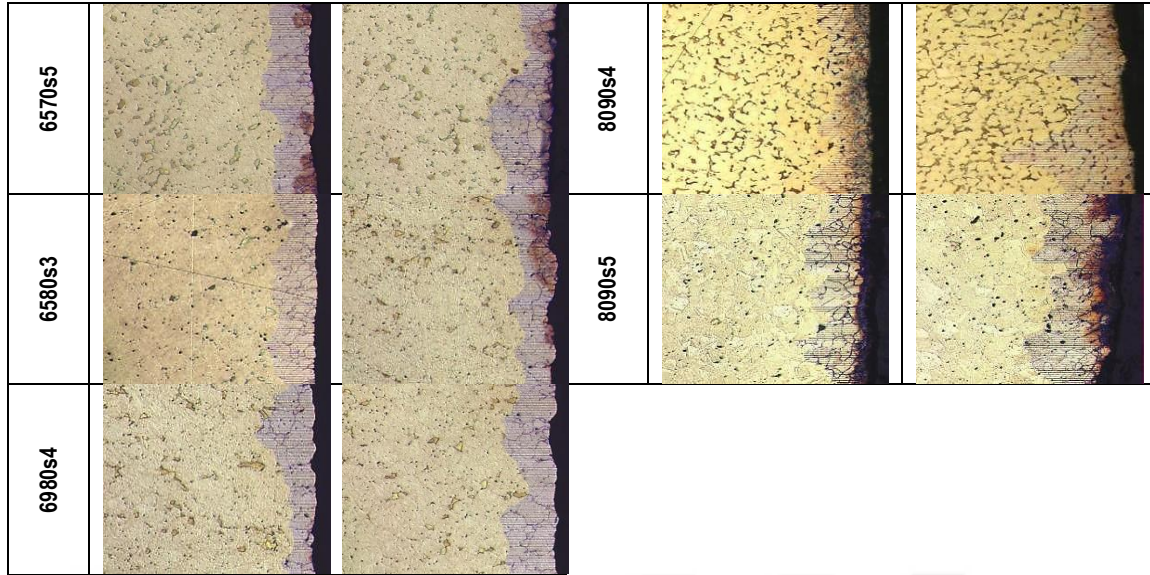


Figure 40. The dezincification images of the cooled in calm air and un-heat treated samples

When the results in Table 52 are examined; dezincification depth values of 27 parts, which are un-heat treated and cooled in calm air, are not found to be in the scope of standard. The dezincification depths of all parts are exceed the standard value.

When Table 53 is examined; the beta phase ratios in the 5070s3, 5070s4 and 5070s5 samples are 9.67%, 9.18% and 9.54%. The beta phase ratios in the 5080s3, 5080s4 and 5080s5 samples are 9.49%, 9.51% and 9.34%. The beta phase ratio in the 5090s3, 5090s4 and 5090s5 samples are 9.28%, 9.73% and 9.65%. The beta phase ratio in the 6570s3, 6570s4 and 6570s5 samples are 10.38%, 10.89% and 10.54%. The beta phase ratio in the 6580s3, 6580s4 and 6580s5 samples are 10.76%, 10.17% and 10.82%. The beta phase ratio in the 6590s3, 6590s4 and 6590s5 samples are 10.46%, 10.33% and 10.25%. The beta phase ratio in the 8070s3, 8070s4 and 8070s5 samples are 11.87%, 11.45% and 11.68%. The beta phase ratio in the 8080s3, 8080s4 and 8080s5 samples are 11.47%, 11.23% and 11.54%. While the beta phase ratio in the 8080s5 test sample is 11.34%, the beta phase rate in the 8090s3 and 8090s4 samples is higher. Percentage values are 12.65% and 12.4%, respectively. The increase of beta phase ratio in the structure decreases the dezincification resistance. The increase of beta phase ratio in the structure decreases the dezincification resistance. When all these are evaluated; are not obtained direct effect of forging pressure on beta phase ratio. However, forging temperature increase was found to be a factor increasing beta phase ratio.

As determined in Table 52 and Table 53 evaluations; the dezincification resistance analysis images in Figure 40 support the obtained findings. Considering the beta phase percentage evaluations among 3 samples belonging to their own conditions; only the 8090s3, 8090s4 and 8090s5 samples differ. This difference appears to be reflected in the dezincification depth values in the same way. Considering the chemical composition element values; the reason why three samples are different in element values compared to others; It has been determined that the element values that directly affect the dezincification resistance are low.

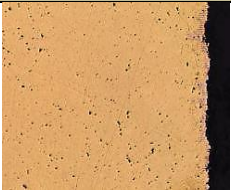
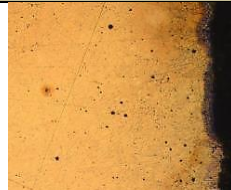
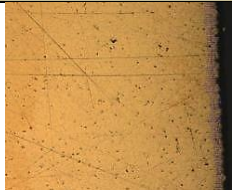
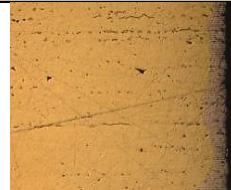
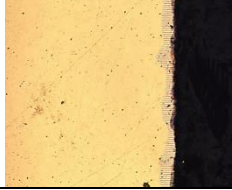
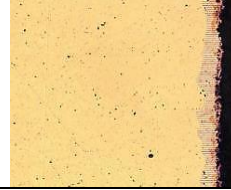
The test results of thirdly, cooled with fan samples are shown Table 54, Table 55 and Figure 41.

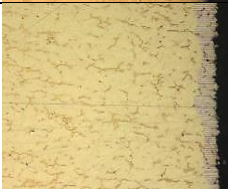
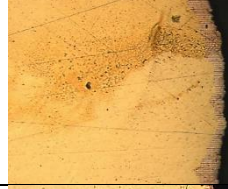
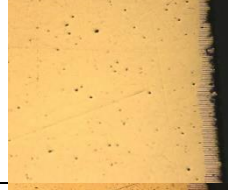
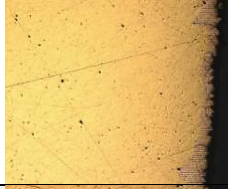
Table 54. The dezincification depth value which in samples of cooled with fan

Group Codes	DEZINCIFICATION DEPTH (Cooled with fan)			
	<i>Perpendicular to the direction of extrusion (Max. Tolerance 100 μm)</i>		<i>Parallel to the direction of extrusion (Max. Tolerance 200 μm)</i>	
	<i>Min. Value</i>	<i>Max. Value</i>	<i>Min. Value</i>	<i>Max. Value</i>
5070f1	10.12	32.45	13.24	73.84
5070f2	13.52	37.71	12.89	75.03
5070f3	11.34	34.19	14.28	69.47
5080f1	11.51	36.25	16.38	71.24
5080f2	15.19	37.77	10.62	70.15
5080f3	11.24	36.61	12.83	73.12
5090f1	14.41	38.43	12.35	69.40
5090f2	13.18	37.51	11.44	71.38
5090f3	15.27	39.30	13.20	72.65
6570f1	20.43	49.17	28.26	84.43
6570f2	18.13	55.20	26.42	82.74
6570f3	17.74	54.35	25.81	80.16
6580f1	17.53	49.67	27.12	86.84
6580f2	19.24	57.30	36.17	84.17
6580f3	18.69	44.15	26.70	79.83
6590f1	17.73	55.70	25.68	84.12
6590f2	19.40	56.18	27.41	83.40
6590f3	18.97	54.32	27.34	81.16
8070f1	29.75	73.11	65.41	137.15
8070f2	26.52	75.14	48.53	147.21
8070f3	22.15	87.52	37.34	132.53
8080f1	18.67	44.37	32.50	127.76
8080f2	24.36	74.58	29.76	131.34
8080f3	43.18	78.94	53.72	128.12
8090f1	46.34	75.71	61.63	126.14
8090f2	25.40	77.17	25.76	122.52
8090f3	45.76	75.52	32.48	135.63

Table 55. Beta grain sizes and beta phase ratios which in cooled with fan

Group Codes	BETA GRAIN SIZE		BETA AND ALPHA PHASE RATIO		
	Min. Value (μm)	Max. Value (μm)	Beta Phase Ratio (%)	Alpha Phase Ratio (%)	Total Fields (μm^2)
5070f1	0.05	8.55	6.58	93.42	190131.55
5070f2	0.04	9.27	6.13	93.87	190131.55
5070f3	0.04	8.22	6.72	93.28	190131.55
5080f1	0.04	8.14	6.84	93.16	190131.55
5080f2	0.06	8.65	6.46	93.54	190131.55
5080f3	0.06	8.34	6.17	93.83	190131.55
5090f1	0.05	8.53	6.34	93.66	190131.55
5090f2	0.05	7.70	6.58	93.42	190131.55
5090f3	0.05	8.45	6.74	93.26	190131.55
6570f1	0.04	9.12	7.12	92.88	190131.55
6570f2	0.04	9.65	7.34	92.66	190131.55
6570f3	0.04	10.11	7.45	92.55	190131.55
6580f1	0.06	9.87	7.96	92.04	190131.55
6580f2	0.06	9.10	7.17	92.83	190131.55
6580f3	0.05	9.23	7.28	92.72	190131.55
6590f1	0.05	8.87	7.69	92.31	190131.55
6590f2	0.05	9.61	7.78	92.22	190131.55
6590f3	0.04	8.78	7.32	92.68	190131.55
8070f1	0.04	9.97	9.07	90.93	190131.55
8070f2	0.06	9.62	9.13	90.87	190131.55
8070f3	0.06	10.14	8.84	91.16	190131.55
8080f1	0.05	9.53	8.73	91.27	190131.55
8080f2	0.05	9.28	8.86	91.14	190131.55
8080f3	0.05	9.45	8.17	91.83	190131.55
8090f1	0.04	9.18	8.48	91.52	190131.55
8090f2	0.06	9.27	8.65	91.35	190131.55
8090f3	0.06	9.28	8.70	91.30	190131.55

DEZINIFICATION IMAGES OF TEST SAMPLES (COOLED WITH FAN)					
Group Codes	Perpendicular to the direction of extrusion (x200)	Parallel to the direction of extrusion (x200)	Group Codes	Perpendicular to the direction of extrusion (x200)	Parallel to the direction of extrusion (x200)
5070Sf1			6580f3		
5070f2			6590f1		

6570f2			6570f1			5090f3			5090f2			5090f1			5080f3			5080f2			5080f1			5070f3		
8090f1			8080f3			8080f2			8080f1			8070f3			8070f2			8070f1			6590f3			6590f2		

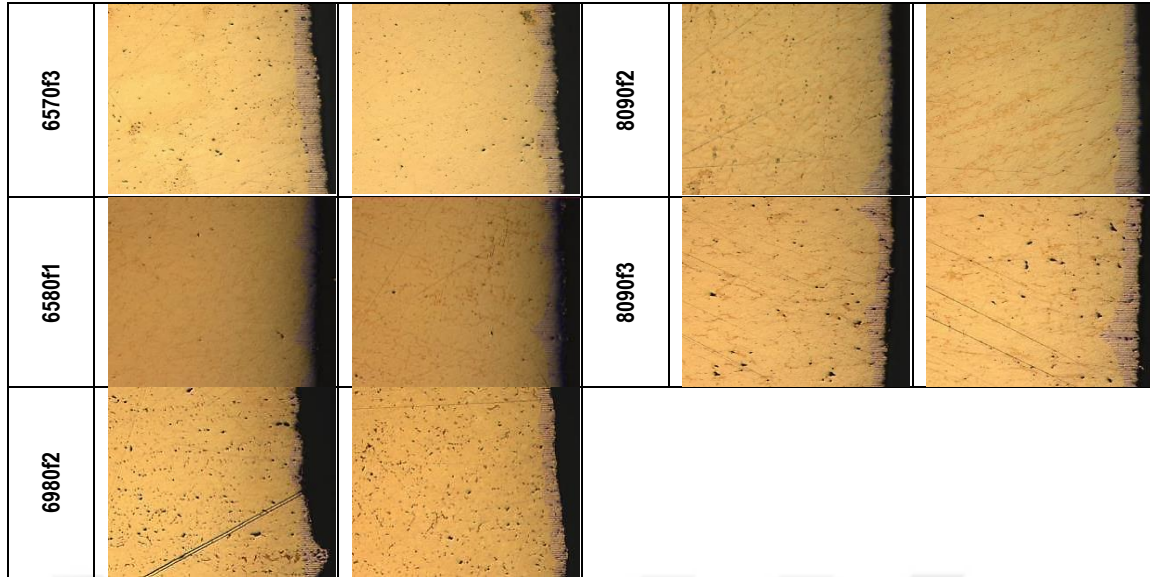


Figure 41. The dezincification images of the cooled with fan samples

When the results in Table 54 are examined; dezincification depth values of 27 parts, which cooled with fan, are found to be in the scope of standard. When the dezincification depth values were examined, it is found that it was close to the samples that were heat treated and cooled in calm air (compared to the samples not exceeding the standard).

When Table 55 is examined; the beta phase ratios in the 5070f1, 5070f2 and 5070f3 samples are 6.58%, 6.13% and 6.72%. The beta phase ratios in the 5080f1, 5080f2 and 5080f3 samples are 6.84%, 6.46% and 6.17%. The beta phase ratio in the 5090f1, 5090f2 and 5090f3 samples are 6.34%, 6.58% and 6.74%. The beta phase ratio in the 6570f1, 6570f2 and 6570f3 samples are 7.12%, 7.34% and 7.45%. The beta phase ratio in the 6580f1, 6580f2 and 6580f3 samples are 7.96%, 7.17% and 7.28%. The beta phase ratio in the 6590f1, 6590f2 and 6590f3 samples are 7.69%, 7.78% and 7.32%. The beta phase ratio in the 8070f1, 8070f2 and 8070f3 samples are 9.13%, 9.07% and 8.84%. The beta phase ratio in the 8080f1, 8080f2 and 8080f3 samples are 8.73%, 8.96% and 8.17%. The beta phase ratio in the 8090f1, 8090f2 and 9070f3 samples are 8.48%, 8.65% and 8.70%. The increase of beta phase ratio in the structure decreases the dezincification resistance. Table 58 examined the effects of forging parameters (pressure-temperature); the relations which are detected in the group which is cooled in calm air and un-heat treated are in the direction of support. When all these are

evaluated; are not obtained direct effect of forging pressure on beta phase ratio. However, forging temperature increase was found to be a factor increasing beta phase ratio. As determined in Table 54 and Table 55 evaluations; the dezincification resistance analysis images in Figure 41 support the obtained findings. But, when the beta phase percentages of the four groups in the same condition were examined, it was seen that there were differences only in the samples of 8070f1, 8070f2, 8080f2 and 8090f3. When looking at the chemical composition, it was determined that the amount of elements in the dezincification resistance values is less than the others.

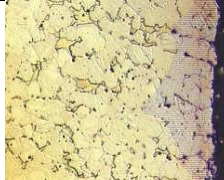
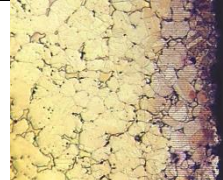
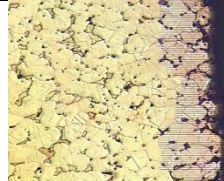
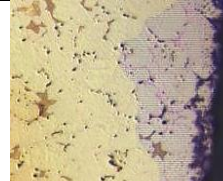
The test results of fourth, cooled in water samples are shown Table 56, Table 67 and Figure 42.

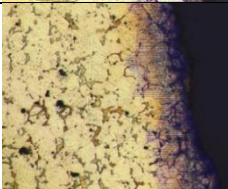
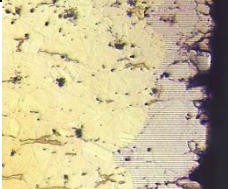
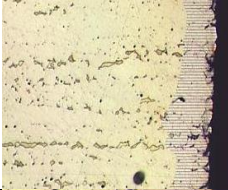
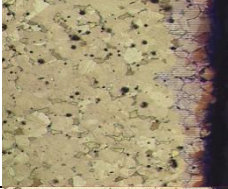
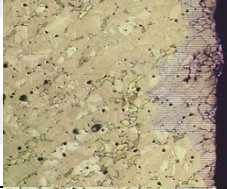
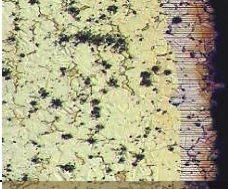
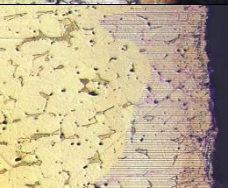
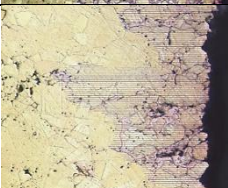
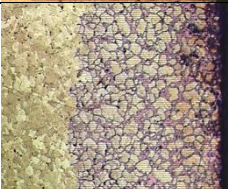
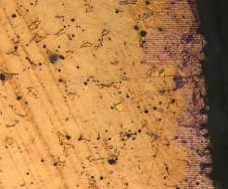
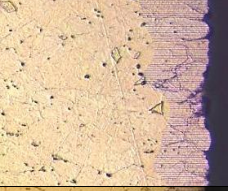
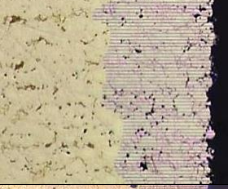
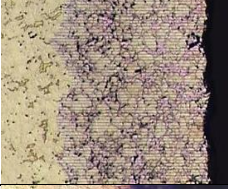
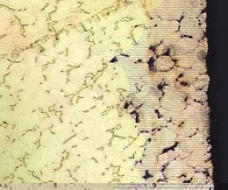
Table 56. The dezincification depth value which in samples of cooled in water

Group Codes	DEZINCIFICATION DEPTH (Cooled in calm air and un-heat treated)			
	Perpendicular to the direction of extrusion (Max. Tolerance 100 µm)		Parallel to the direction of extrusion (Max. Tolerance 200 µm)	
	Min. Value	Max. Value	Min. Value	Max. Value
5070w1	108.61	255.43	159.27	265.27
5070w2	95.33	249.35	128.64	280.36
5070w3	181.24	223.17	81.27	272.38
5080w1	114.27	266.81	260.43	278.56
5080w2	87.65	168.84	135.76	293.26
5080w3	127.43	156.27	116.44	301.67
5090w1	77.53	210.41	139.67	284.70
5090w2	118.16	176.84	227.83	291.56
5090w3	146.41	317.62	213.62	338.74
6570w1	140.63	282.24	211.54	334.43
6570w2	118.73	249.43	278.55	340.84
6570w3	106.22	315.18	122.56	349.22
6580w1	91.53	238.67	211.86	351.87
6580w2	236.43	350.26	185.72	376.12
6580w3	120.42	268.53	231.17	307.63
6590w1	117.53	337.54	259.58	362.51
6590w2	102.57	308.27	321.18	356.49
6590w3	136.68	324.37	244.27	335.48
8070w1	334.74	351.36	366.22	375.23
8070w2	132.45	320.71	342.74	380.76
8070w3	243.13	289.35	256.34	397.35
8080w1	345.52	387.32	377.42	413.12
8080w2	94.76	239.82	373.41	397.51
8080w3	97.52	218.43	368.16	389.67
8090w1	259.73	374.51	291.73	368.46
8090w2	282.15	360.86	268.48	375.74
8090w3	281.95	342.60	398.53	414.12

Table 57. Beta grain sizes and beta phase ratios which in cooled in water

Group Codes	BETA GRAIN SIZE		BETA AND ALPHA PHASE RATIO		
	Min. Value (μm)	Max. Value (μm)	Beta Phase Ratio (%)	Alpha Phase Ratio (%)	Total Fields (μm^2)
5070w1	0.05	17.12	12.57	87.43	190131.55
5070w2	0.04	17.64	11.86	88.14	190131.55
5070w3	0.05	17.35	11.23	88.77	190131.55
5080w1	0.04	17.42	12.81	87.19	190131.55
5080w2	0.04	18.11	11.55	88.45	190131.55
5080w3	0.03	17.76	12.62	87.38	190131.55
5090w1	0.04	17.65	11.48	88.52	190131.55
5090w2	0.05	17.45	11.80	88.2	190131.55
5090w3	0.04	18.34	12.37	87.63	190131.55
6570w1	0.04	19.41	14.34	85.66	190131.55
6570w2	0.03	20.13	13.80	86.20	190131.55
6570w3	0.05	20.15	13.76	86.24	190131.55
6580w1	0.04	19.89	14.43	85.57	190131.55
6580w2	0.04	19.77	14.40	85.60	190131.55
6580w3	0.05	20.36	14.13	85.87	190131.55
6590w1	0.04	21.46	13.52	86.48	190131.55
6590w2	0.05	20.72	14.48	85.52	190131.55
6590w3	0.04	20.54	13.87	86.13	190131.55
8070w1	0.04	21.34	16.45	83.55	190131.55
8070w2	0.03	20.76	15.11	84.89	190131.55
8070w3	0.05	21.18	15.65	84.35	190131.55
8080w1	0.04	19.67	16.72	83.28	190131.55
8080w2	0.05	21.73	15.35	84.65	190131.55
8080w3	0.04	22.24	16.51	83.49	190131.55
8090w1	0.04	21.83	16.48	83.52	190131.55
8090w2	0.04	21.42	15.81	84.19	190131.55
8090w3	0.04	22.36	16.63	83.37	190131.55

DEZINFICATION IMAGES OF TEST SAMPLES (COOLED IN WATER)					
Group Codes	Perpendicular to the direction of extrusion (x200)	Parallel to the direction of extrusion (x200)	Group Codes	Perpendicular to the direction of extrusion (x200)	Parallel to the direction of extrusion (x200)
5070w1			6580w3		
5070w2			6590w1		

6570w2			6570w1			5090w3			5090w2			5090w1			5080w3			5080w2			5080w1			5070w3		
8090w1			8080w3			8080w2			8080w1			8070w3			8070w2			8070w1			6590w3			6590w2		

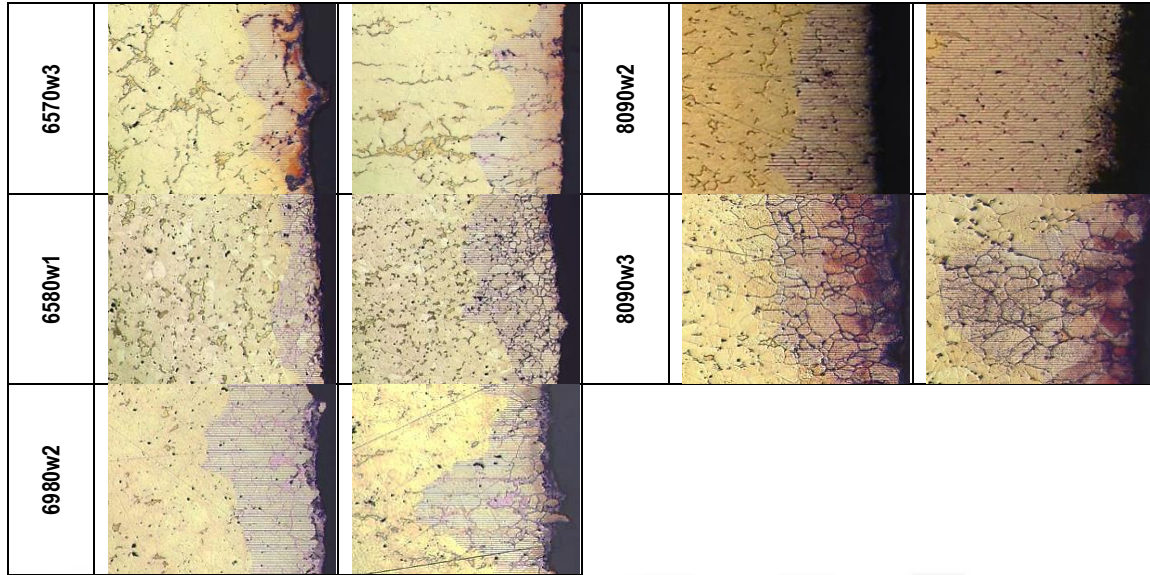


Figure 42. The dezincification images of the cooled in water samples

When the results in Table-56 are examined; dezincification depth values of 27 parts, which cooled with fan, are not found to be in the scope of standard. When when were examined all group; this group is with the lowest dezincification resistance. In other words, the group has the highest depth of dezincification.

When Table 57 is examined; the beta phase ratios in the 5070w1, 5070w2 and 5070w3 samples are 12.57%, 11.86% and 11.23%. The beta phase ratios in the 5080w1, 5080w2 and 5080w3 samples are 12.81%, 11.55% and 12.62%. The beta phase ratio in the 5090w1, 5090w2 and 5090w3 samples are 11.48%, 11.80% and 12.37%. The beta phase ratio in the 6570w1, 6570w2 and 6570w3 samples are 14.34%, 13.80% and 13.76%. The beta phase ratio in the 6580w1, 6580w2 and 6580w3 samples are 14.40%, 14.13% and 13.52%. The beta phase ratio in the 6590w1, 6590w2 and 6590w3 samples are 14.48%, 13.87% and 16.45%. The beta phase ratio in the 8070w1, 8070w2 and 8070w3 samples are 16.45%, 15.11% and 15.65%. The beta phase ratio in the 8080w1, 8080w2 and 8080w3 samples are 16.72%, 15.35% and 16.51%. The beta phase ratio in the 8090w1, 8090w2 and 8090w3 samples are 16.48%, 15.81% and 16.63%. The increase of beta phase ratio in the structure decreases the dezincification resistance.

As determined in Table 56 and Table 57 evaluations; the dezincification resistance analysis images in Figure 42 support the obtained findings.

4.6.1. Second Heat Treatment Requirement

11 of the 27 samples in the heat treatment group called the first group are not in the scope of standard. The heat treatment process is a conventional method for brass alloys and is intended to increase the dezincification resistance. 11 samples were re-heat treated and some tests were repeated. In addition, in industrial applications, the heat treatment process is repeated more than once in the same samples where necessary.

The parts were kept at 550°C for 180 minutes. For heat treating of 11 samples (samples 5070s2, 5080s0, 6570s0, 6570s2, 6580s0, 6590s1, 8070s0, 8080s0, 8080s2, 8090s0 and 8090s1) were used the same furnace (AFC Holdcroft CQI9). This process was done in same company. Repeated tests are as follows;

- I. Hardness measurement
- II. Microstructure investigation and grain size determination
- III. Dezincification resistance test, beta phase ratio and beta grain size determination

4.6.1.1. Hardness Measurement Results

The hardness measurements of the samples were examined in Marmara University Mechanical Engineering Faculty Laboratory. The same manual measuring device was used for hardness measurement. Rockwell hardness method (tested by immersion) was used in hardness tests.

Table 58. Hardness results of 11 pieces of samples, which heat treated twice

Group Codes	Measurement - 1 (HRB)	Measurement - 2 (HRB)	Measurement - 3 (HRB)	Average
5070s2-1	43.2	43.65	44.5	43.78
5080s0-1	43.37	43.81	44.35	43.84
6570s0-1	42.76	43.59	44.2	43.52
6570s2-1	42.8	43.56	44.65	43.67
6580s0-1	42.74	43.71	44.63	43.69
6590s1-1	42.7	43.85	44.78	43.78
8070s0-1	41.77	43.54	44.46	43.26
8080s0-1	41.85	43.38	44.92	43.38
8080s2-1	41.83	43.27	44.87	43.32
8090s0-1	43.32	44.2	45.24	44.25
8090s1-1	43.4	44.13	45	44.18

The following results were obtained when comparing Table-x with the values measured after the first heat treatment and Table-x1 with the values measured after the second heat treatment.

For part 5070s2; the measurement value after the first heat treatment was 43.30HRB and after the second heat treatment it increased to 43.78HRB.

For part 5080s0; the measurement value after the first heat treatment was 43.30HRB and after the second heat treatment it increased to 43.84HRB.

For part 6570s0; the measurement value after the first heat treatment was 42.67HRB and after the second heat treatment it increased to 43.52HRB.

For part 6570s2; the measurement value after the first heat treatment was 42.83HRB and after the second heat treatment it increased to 43.67HRB.

For part 6580s0; the measurement value after the first heat treatment was 42.73HRB and after the second heat treatment it increased to 43.69HRB.

For part 6590s1; the measurement value after the first heat treatment was 43.33HRB and after the second heat treatment it increased to 43.78HRB.

For part 8070s0; the measurement value after the first heat treatment was 42.37HRB and after the second heat treatment it increased to 43.26HRB.

For part 8080s0; the measurement value after the first heat treatment was 42.60HRB and after the second heat treatment it increased to 43.38HRB.

For part 8080s2; the measurement value after the first heat treatment was 42.83HRB and after the second heat treatment it increased to 43.32HRB.

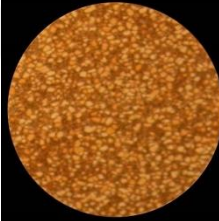
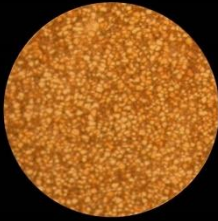
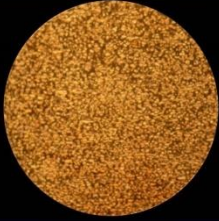
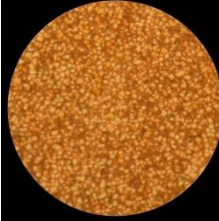
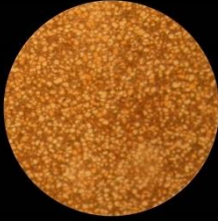
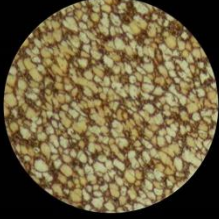
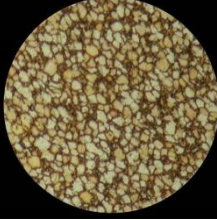
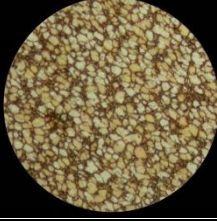
For part 8090s0; the measurement value after the first heat treatment was 42.93HRB and after the second heat treatment it increased to 44.25HRB.

For part 8090s0; the measurement value after the first heat treatment was 43.27HRB and after the second heat treatment it increased to 44.18HRB.

4.6.1.2. Microstructure Results

After the first heat treatment, samples were prepared for examining microstructure. It was taken sections which were perpendicular and parallel to the direction of extrusion from each sample. In Marmara University Materials Engineers Laboratory; microstructure images with Nikon LJ80 optical microscope and grain sizes were obtained with Nikon Epiphot 300 model microscope and examined. The samples were examined at magnification 200 times. It was examined on microstructures and grain sizes.

The microstructure images is shown in Figure 43.

SAMPLES COOLED IN CALM AIR (HEAT TREATED TWICE)					
MICROSTRUCTURE IMAGES OF SAMPLES					
Group Codes	Perpendicular to the direction of extrusion (x200)	Parallel to the direction of extrusion (x200)	Group Codes	Perpendicular to the direction of extrusion (x200)	Parallel to the direction of extrusion (x200)
5070s2-1			8080s0-1		
5080s0-1			8080s2-1		
6570s0-1			8090s0-1		
6570s2-1			8090s1-1		

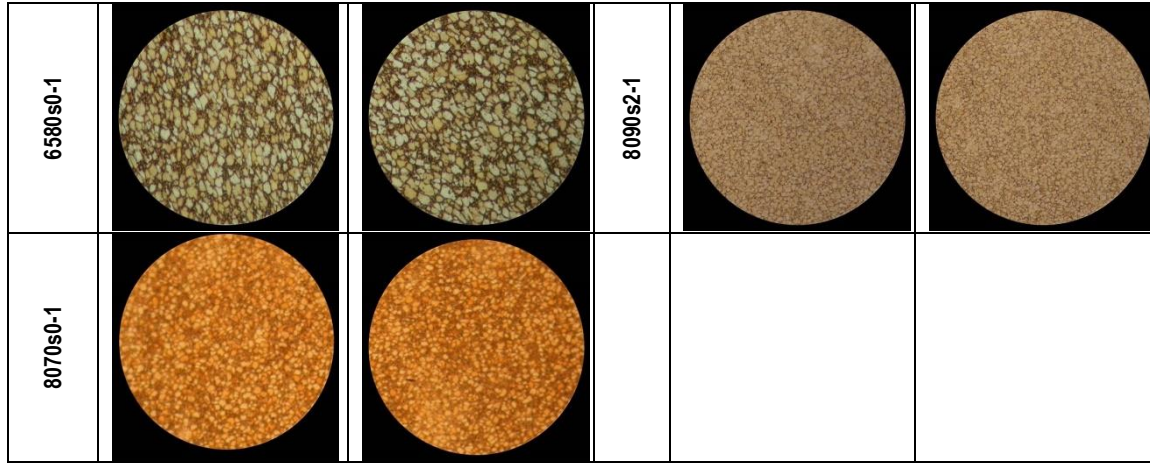


Figure 43. Microstructure images of samples cooled in calm air and heat treated twice

The grain size of these 11 samples, which were heat treated for the second time, was measured again and the results are presented in Table 59.

Table 59. The grain size values of samples heat treated twice

Number of Samples	Group Codes	GRAIN SIZE (10x0.30)	
		Perpendicular to the direction of extrusion	Parallel to the direction of extrusion
1	5070s2-1	5.5 μm	6 μm
2	5080s0-1	6 μm	6.5 μm
3	6570s0-1	6 μm	6.5 μm
4	6570s2-1	6.5 μm	6.5 μm
5	6580s0-1	7 μm	7 μm
6	6590s1-1	7 μm	7.5 μm
7	8070s0-1	6.5 μm	7 μm
8	8080s0-1	7.5 μm	7 μm
9	8080s2-1	7 μm	7.5 μm
10	8090s0-1	7.5 μm	7.5 μm
11	8090s1-1	7 μm	7 μm

11 samples after 1st and 2nd heat treatment; when microstructure images and grain sizes were compared, it was found that grain sizes decreased after the second process. When the microstructure images of grain sizes are reduced, this is supported. Effect of heat treatment on grain size reduction; it is also detected in the comparison of non-heat treated and cooled air cooled samples with calm air cooled and heat treated samples.

4.6.1.3. Dezincification Resistance Results

Dezincification depths should be examined in perpendicular and parallel to the direction of extrusion. The same equipments (nuve bath device, microscope, software) were used for this test. It was kept at 75°C in Copper (II) Chloride Dehydrate at 1% solution for 24 hours in Nuve NB Water Bath device. The depths of the dezincification which the microstructure images, were taken from samples magnified 200 times by the microscope using directly the software.

The dezincification depth results are shown in Table 60 and their images are shown in Figure 44..

Table 60. The dezincification depth value which in samples of cooled in calm air and heat-treated twice

Group Codes	DEZINCIFICATION DEPTH (Cooled in calm air and heat treated twice)			
	Perpendicular to the direction of extrusion (Max. Tolerance 100 μ m)		Parallel to the direction of extrusion (Max. Tolerance 200 μ m)	
	Min. Value	Max. Value	Min. Value	Max. Value
5070s2-1	9.23	33.48	20.16	65.37
5080s0-1	11.60	37.25	17.41	62.53
6570s0-1	15.38	40.74	18.50	77.48
6570s2-1	24.27	46.17	15.42	80.31
6580s0-1	23.51	50.55	22.37	84.26
6590s1-1	20.87	47.16	18.42	89.53
8070s0-1	34.60	60.13	29.36	98.17
8080s0-1	28.70	58.12	32.29	92.78
8080s2-1	30.28	62.34	41.35	118.40
8090s0-1	32.46	69.63	10.22	127.43
8090s1-1	25.78	59.24	27.61	93.56

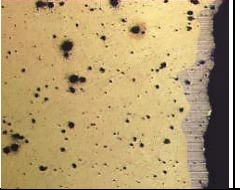
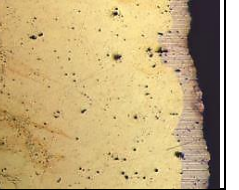
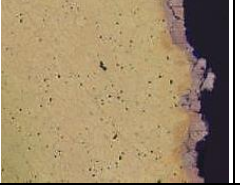
DEZINCIFICATION IMAGES OF TEST SAMPLES (COOLED IN CALM AIR AND HEAT TREATED)					
Group Codes	Perpendicular to the direction of extrusion (x200)	Parallel to the direction of extrusion (x200)	Group Codes	Perpendicular to the direction of extrusion (x200)	Parallel to the direction of extrusion (x200)
5070s2-1			8080s0-1		
5080s0-1			8080s2-1		



Figure 44. Microstructure images of samples cooled in calm air and heat treated twice

For the determination of beta and alpha phase ratios; all samples were kept in a solution of 25°C [60g (NH₄)₂S₂O₈ + 50ml H₂O₂ + 700ml H₂O] for 45 seconds. Beta and alpha phase ratios were measured by the microscope using directly the software.

All the these group tests were applied in SARBAK METAL TİC. SAN. A.Ş. The beta grain sizes and beta phase ratios are shared in table 61.

Table 61. The beta grain sizes and beta phase rations in structure

Group Codes	BETA GRAIN SIZE		BETA AND ALPHA PHASE RATIO		
	Min. Value (μm)	Max. Value (μm)	Beta Phase Ratio (%)	Alpha Phase Ratio (%)	Total Fields (μm ²)
5070s2-1	0.03	5.78	4.01	95.99	190131.55
5080s0-1	0.06	6.60	4.39	95.61	190131.55
6570s0-1	0.05	6.49	4.78	95.22	190131.55
6570s2-1	0.04	6.64	4.56	95.44	190131.55
6580s0-1	0.06	6.34	4.83	95.17	190131.55
6590s1-1	0.04	6.71	4.75	95.25	190131.55
8070s0-1	0.03	7.23	5.46	94.54	190131.55
8080s0-1	0.06	7.11	5.38	94.62	190131.55
8080s2-1	0.05	6.88	5.23	94.77	190131.55
8090s0-1	0.05	7.16	5.28	94.72	190131.55
8090s1-1	0.4	7.43	5.31	94.69	190131.55

When the results in table 63 are examined; dezincification depth values of 11 parts, which heat treated twice, are found to be in the scope of standard.

When beta phase ratios were examined, these ratios are decreased after the second heat treatment. Since the goal is to reduce the beta phase ratio in the structure, the desired target has been achieved.

The dezincification resistance analysis images in Table 52 support the obtained findings.

4.7. Machinability Results

4.7.1. Chip Structures and Drilling Forces

Chip structure and shear force values of each group during drilling process are shared in Table 62, Table 63, Table 64 and Table 65.

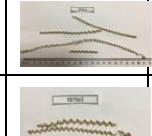
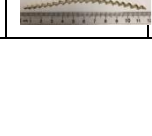
Table 62. Chip structures and measured drilling force of first time heat treated samples

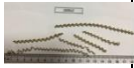
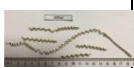
Sample Codes	Chip Structure	Measured Drilling Force (kgf)	Sample Codes	Chip Structure	Measured Drilling Force (kgf)	Sample Codes	Chip Structure	Measured Drilling Force (kgf)
5070s0		2.88	6570s0		2.81	8070s0		2.76
5070s1		2.94	6570s1		2.88	8070s1		2.79
5070s2		2.96	6570s2		2.85	8070s2		2.76
5080s0		2.96	6580s0		2.83	8080s0		2.78

5080s1		2.94	6580s1		2.88	8080s1		2.83
5080s2		2.92	6580s2		2.90	8080s2		2.83
5090s0		3.08	6590s0		3.01	8090s0		2.85
5090s1		3.05	6590s1		2.94	8090s1		2.92
5090s2		3.02	6590s2		3.03	8090s2		2.89

When the chip structures were examined; it is seen short and helical chip structures. These results (chip structures) are desirable when evaluated in terms of machinability of the alloy.

Table 63. Chip structures and measured drilling force of non-heat treated samples

Sample Codes	Chip Structure	Measured Drilling Force (kgf)	Sample Codes	Chip Structure	Measured Drilling Force (kgf)	Sample Codes	Chip Structure	Measured Drilling Force (kgf)
5070s3		1.49	6570s3		1.42	8070s3		1.43
5070s4		1.43	6570s4		1.44	8070s4		1.35
5070s5		1.44	6570s5		1.41	8070s5		1.37

5080s3		1.55	6580s3		1.48	8080s3		1.38
5080s4		1.53	6580s4		1.55	8080s4		1.44
5080s5		1.50	6580s5		1.52	8080s5		1.46
5090s3		1.59	6590s3		1.56	8090s3		1.50
5090s4		1.60	6590s4		1.53	8090s4		1.44
5090s5		1.56	6590s5		1.58	8090s5		1.54

When the chips structures were examined; it is seen continuous and long cylindrical chip structures. These results (chip structures) are undesirable when evaluated in terms of machinability of the alloy.

Table 64. Chip structures and measured drilling force of samples cooled with fan

Sample Codes	Chip Structure	Measured Drilling Force (kgf)	Sample Codes	Chip Structure	Measured Drilling Force (kgf)	Sample Codes	Chip Structure	Measured Drilling Force (kgf)
5070f1		2.96	6570f1		2.85	8070f1		2.85
5070f2		3.00	6570f2		2.86	8070f2		2.81
5070f3		3.01	6570f3		2.89	8070f3		2.79

5080f1		3.01	6580f1		2.88	8080f1		2.76
5080f2		3.03	6580f2		2.92	8080f2		2.80
5080f3		2.94	6580f3		2.91	8080f3		2.84
5090f1		3.03	6590f1		2.99	8090f1		2.82
5090f2		3.09	6590f2		3.07	8090f2		2.85
5090f3		3.09	6590f3		3.04	8090f3		2.81

When the chip structures were examined; it is seen short and helical chip structures. These results (chip structures) are desirable when evaluated in terms of machinability of the alloy. From the samples of the one time heat-treated group and the fan-cooled group have inevaluated the results obtained; in both of groups chip structures and drilling force values are found to be very close.

Table 65. Chip structures and measured drilling force of samples cooled in water

Sample Codes	Chip Structure	Measured Drilling Force (kgf)	Sample Codes	Chip Structure	Measured Drilling Force (kgf)	Sample Codes	Chip Structure	Measured Drilling Force (kgf)
5070w1		3.44	6570w1		3.34	8070w1		3.27
5070w2		3.47	6570w2		3.34	8070w2		3.26
5070w3		3.46	6570w3		3.37	8070w3		3.27
5080w1		3.46	6580w1		3.35	8080w1		3.27
5080w2		3.48	6580w2		3.29	8080w2		3.26
5080w3		3.46	6580w3		3.29	8080w3		3.29
5090w1		3.47	6590w1		3.47	8090w1		3.37
5090w2		3.48	6590w2		3.48	8090w2		3.36

5090w3		3.48	6590w3		3.45	8090w3		3.45
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When the chip structures were examined; it is seen very short and discontinuous chip structures. Chip angles are very small. After drilling, most of the chips of this group were obtained by adhering to each other. Additionally, this group has the highest drilling force.

The drilling forces (kgf) measured in each sample are given in Table 62, Table 63, Table 64 and Table 65. When these values are examined together with the hardness values in Table 48, it is determined that the drilling force is in parallel with the hardness values.

In addition, 11 samples were again tested for machinability after the second heat treatment the results are shared in table 66.

Table 66. Chip structures and measured drilling force of second time heat treated samples

Sample Codes	Chip Structure	Measured Drilling Force (kgf)	Sample Codes	Chip Structure	Measured Drilling Force (kgf)	Sample Codes	Chip Structure	Measured Drilling Force (kgf)
5070s2-1		3.02	6580s0-1		3.00	8080s2-1		2.92
5080s0-1		3.50	6590s1-1		3.02	8090s0-1		3.17
6570s0-1		2.96	8070s0-1		2.90	8090s1-1		3.15
6570s2-1		2.99	8080s0-1		2.93			

When the results of second times heat-treated samples were evaluated; short helical chips and little of the chips of this group were obtained by conjoined to each other.

The drilling forces (kgf) measured in each sample are given in Table 66. When these values are examined together with the hardness values (second time heat treated samples) in Table 58, it is determined that the drilling force is in parallel with the hardness values.

4.7.2. Surface Roughness

The surface roughness of all samples was measured after drilling. For the second heat-treated 11 samples, measurements were made on the surface and added to the results.

When the measured surface roughness values were examined; the one time heat-treated group and the fan cooled group results are close to one another and acceptable values are obtained. The chip structures of both groups are similar and when the applied forces are considered, these results are suitable for machinability.

When the group of the cooled in calm air and un-heat treatment is examined; surface roughness values are very high. Also; during machining, continuous chip structure occurs due to friction between tool and chips. This situation increases the surface roughness and the permanent surface stress causes.

When the group of the cooled in water is examined; surface roughness values are highest. For the good machinability this group results are not acceptable values. The chip structures examined also supports this result.

All the results of the measurement are shared in Table 67.

Table 67. Surface roughness results (Ra,µm)

SAMPLE CODES	SURFACE ROUGHNESS (RA, µm)	SAMPLE CODES	SURFACE ROUGHNESS (RA, µm)	SAMPLE CODES	SURFACE ROUGHNESS (RA, µm)	SAMPLE CODES	SURFACE ROUGHNESS (RA, µm)	SAMPLE CODES	SURFACE ROUGHNESS (RA, µm)
5070s0	1,58	5070F1	1,79	5070S3	3,61	5070w1	4,61	5070s2-1	2,37
5070s1	1,73	5070F2	1,86	5070S4	3,43	5070w2	4,78	5080s0-1	2,41
5070s2	1,76	5070F3	1,88	5070S5	3,45	5070w3	4,72	6570s0-1	2,25
5080s0	1,76	5080F1	1,88	5080S3	3,79	5080w1	4,72	6570s2-1	2,30
5080s1	1,73	5080F2	1,93	5080S4	3,73	5080w2	4,79	6580s0-1	2,31
5080s2	1,70	5080F3	1,79	5080S5	3,65	5080w3	4,74	6590s1-1	2,37
5090s0	2,02	5090F1	1,95	5090S3	3,88	5090w1	4,76	8070s0-1	2,12
5090s1	1,97	5090F2	2,04	5090S4	3,97	5090w2	4,79	8080s0-1	2,20
5090s2	1,86	5090F3	2,04	5090S5	3,81	5090w3	4,77	8080s2-1	2,14
6570s0	1,45	6570F1	1,50	6570S3	3,43	6570w1	4,41	8090s0-1	2,57
6570s1	1,64	6570F2	1,54	6570S4	3,45	6570w2	4,38	8090s1-1	2,40
6570s2	1,52	6570F3	1,64	6570S5	3,81	6570w3	4,50		
6580s0	1,47	6580F1	1,58	6580S3	3,51	6580w1	4,46		
6580s1	1,64	6580F2	1,70	6580S4	3,67	6580w2	4,36		
6580s2	1,65	6580F3	1,73	6580S5	3,61	6580w3	4,36		
6590s0	1,87	6590F1	1,87	6590S3	3,81	6590w1	4,71		
6590s1	1,79	6590F2	2,01	6590S4	3,73	6590w2	4,72		
6590s2	1,96	6590F3	1,98	6590S5	3,92	6590w3	4,61		
8070s0	1,30	8070F1	1,52	8070S3	3,92	8070w1	4,22		
8070s1	1,39	8070F2	1,41	8070S4	3,30	8070w2	4,19		
8070s2	1,36	8070F3	1,36	8070S5	3,33	8070w3	4,20		
8080s0	1,40	8080F1	1,29	8080S3	3,36	8080w1	4,22		
8080s1	1,51	8080F2	1,39	8080S4	3,45	8080w2	4,19		
8080s2	1,51	8080F3	1,52	8080S5	3,47	8080w3	4,23		
8090s0	1,54	8090F1	1,47	8090S3	3,54	8090w1	4,48		
8090s1	1,75	8090F2	1,54	8090S4	3,45	8090w2	4,36		
8090s2	1,72	8090F3	1,45	8090S5	3,66	8090w3	4,61		

The results of the second time heat-treated eleven samples examined; the surface roughness value is reasonable, but the chip structures are slightly troubled, there are cojoined chip structures.

At the same time; the drilling force applied to the samples in this group was examined, it is found that there are same rate changes the hardness (HRB) value and force (kgf) of each part. That is, more force is applied to the harder part.

4.8. Statistical Analysis (Analysis and Discussion of Experimental Result)

4.8.1. Taguchi Method

Taguchi analysis expresses with which values of the factors stated as a result, the desired response value has been reached. In this direction; the analysis criteria of the heat treated and non-heat treated groups are presented in Table 68 and 69 below.

Table 68. Criterias of unheat treated groups

Hardness (HRB)	GRAIN SIZE IN MICROSTRUCTURE (μm)- Perpendicular to the direction of extrusion	GRAIN SIZE IN MICROSTRUCTURE (μm)- Parallel to the direction of extrusion	DEZINCIFICATION DEPTH (μm)- Perpendicular to the direction of extrusion	DEZINCIFICATION DEPTH (μm)- Parallel to the direction of extrusion	BETA GRAIN SIZE (μm)	BETA PHASE RATIO (%)	MEASURED DRILLING FORCE (kgf)	SURFACE ROUGHNESS (RA, μm)
32.92	13.34	13.84	135.40	239.04	12.77	9.50	1.45	3.50
45.79	7.17	7.50	197.31	291.16	17.76	12.33	3.47	4.75
43.80	10.34	10.67	38.41	71.14	8.23	6.55	3.07	2.01
45.19	5.17	5.84	282.28	341.50	19.90	13.97	3.35	4.43
43.08	8.50	8.84	50.37	83.61	9.40	7.47	2.90	1.67
33.52	13.17	13.50	131.37	269.92	13.41	10.35	1.56	3.82
42.67	7.50	7.84	78.59	138.96	9.91	9.01	2.82	1.43
32.74	11.84	12.34	188.77	264.57	14.24	11.41	1.43	3.43
45.32	4.67	5.17	359.32	386.11	21.87	16.31	3.39	4.48

Table 69. Criterias of heat treated group

Hardness (HRB)	GRAIN SIZE IN MICROSTRUCTURE (μm)- Perpendicular to the direction of extrusion	GRAIN SIZE IN MICROSTRUCTURE (μm)- Parallel to the direction of extrusion	DEZINCIFICATION DEPTH (μm)- Perpendicular to the direction of extrusion	DEZINCIFICATION DEPTH (μm)- Parallel to the direction of extrusion	BETA GRAIN SIZE (μm)	BETA PHASE RATIO (%)	MEASURED DRILLING FORCE (kgf)	SURFACE ROUGHNESS (RA, μm)
43.17	9.34	9.50	91.29	154.43	7.33	7.39	2.93	1.69
43.23	9.50	9.67	97.08	161.37	7.65	7.21	2.94	1.73
43.69	9.67	9.84	70.10	101.55	7.61	6.29	3.05	1.95
42.84	8.34	8.84	114.32	195.09	8.41	9.29	2.85	1.54
42.94	8.84	9.00	81.07	148.96	8.56	8.07	2.87	1.59
43.50	9.00	9.34	106.02	164.35	8.40	7.98	2.99	1.87
42.49	7.00	7.34	98.39	203.93	9.71	8.76	2.77	1.35
42.76	7.67	7.84	103.37	186.65	9.46	10.10	2.81	1.47
43.13	8.00	8.34	108.79	221.68	9.34	10.22	2.87	1.67

4.8.1.1.Un-Heat Treated Groups

According to Table 68, the results of the taguchi analysis of the individual criteria are shared below. It was run in two stages according to the determined criteria.

For the first study; hardness, grain size in the microstructure and beta grain size were evaluated together. Here the normal value is conditioned to be the best. In order for the material to be processed, it is undesirable that the surface hardness is neither a soft nor a hard material. Microstructure size; being small means that the material is harder or too large means that the material is softer. Beta grain size; It is desirable to have a beta phase in the alloy for good machinability. Therefore, beta grain structure is important, and evaluation should be made by looking at the situation in the entire microstructure. That is, it is a criterion that directly affects the surface hardness structure. The criterias which are hardness, grain size (perpendicular and parallel) and beta grain size for the group without heat treatment taguchi analysis results are shared in Figure 45.

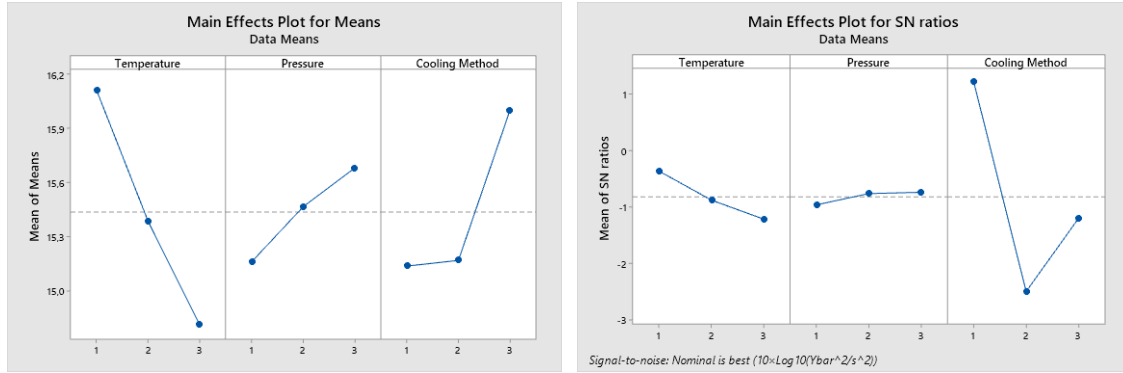


Figure 45. The criterias which are hardness, grain size (perpendicular and parallel) and beta grain size

In this case, looking at the signal to noise ratio (nominal is better) best significant value is as follows;

Temp: 765
Pressure: 80
Cooling Method: With fan

<u>SNRA1</u>	<u>MEAN1</u>
1.45398	15.3875
-1.92835	15.9825
-0.62082	16.9700
-2.66307	14.8875
-1.29242	15.8300
1.31265	15.4375
-1.67927	15.2075
0.93079	14.5875
-2.91248	14.6375

Small punching force is always desired. This statement indicates that less force is used when processing the material. The smaller the value obtained on the surface roughness, the smoother finish material means. Again, this is a desired situation.

The dezincification value must be low. Brass material has standards to meet and the biggest problem in alloys is dezincification. therefore, the smaller the value (if it can be much lower than the values set by the standards), the better the alloy is the product. Beta phase percentage rate is still in the same logic. High beta phase ratio causes dezincification. For this reason, this ratio is desired to be low. The criterias which are, drilling force, dezincification depth (perpendicular and parallel), beta phase ratio and

surface roughness for the group without heat treatment taguchi analysis results are shared in Figure 46.

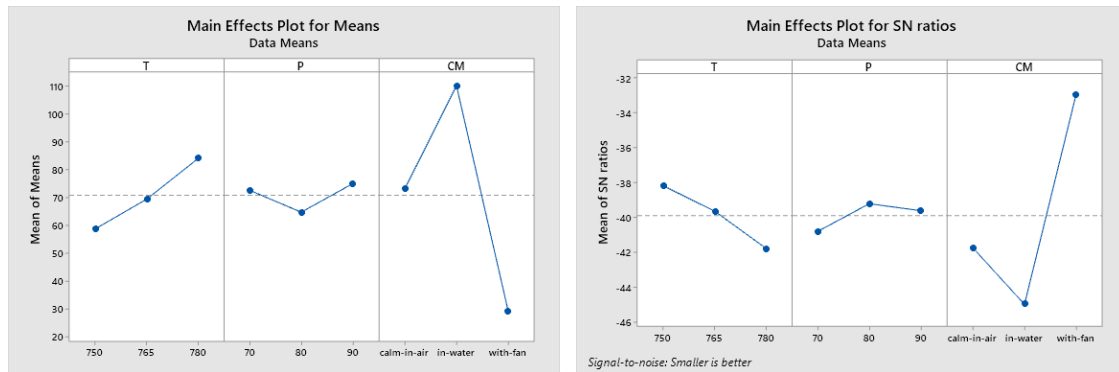


Figure 46. The criterias which are drilling force, dezincification depth (perpendicular and parallel), beta phase ratio and surface roughness

In this case, by looking at the signal to noise ratio (smaller is better) the best significant value comes out with the following values;

Temp: 750,
Pressure: 80,
Cooling Method: With fan

<u>SNRA2</u>	<u>MEAN2</u>
-41,8035	80,042
-43,9514	104,662
-31,2391	25,268
-45,9531	132,416
-32,8667	30,504
-42,5728	85,774
-37,1042	47,580
-43,2624	96,484
-47,4657	157,618

When these criteria are evaluated; As a result of Taguchi analysis, the forging temperature is 750°C, the forging pressure is 80bar and the cooling method is the best parameter.

4.8.1.2. Heat Treated Group

According to Table 69, the results of the taguchi analysis of the individual criteria are shared below. It was run in two stages according to the determined criteria.

The situations described in the section above without heat treatment still apply here. It is sought to be the beta phase ratio and disinfection depth that causes dezincification among the alloy products. When we say an easily machinable material, the applied force is low and therefore the less the drilling force, the better. The same is true for the surface roughness case. For the final product, the smaller the measured prestige value, the smoother the part is said to be smooth and of good quality.

The criterias which are, drilling force, dezincification depth (perpendicular and parallel), beta phase ratio and surface roughness for the group with heat treatment taguchi analysis results are shared in Figure 47.

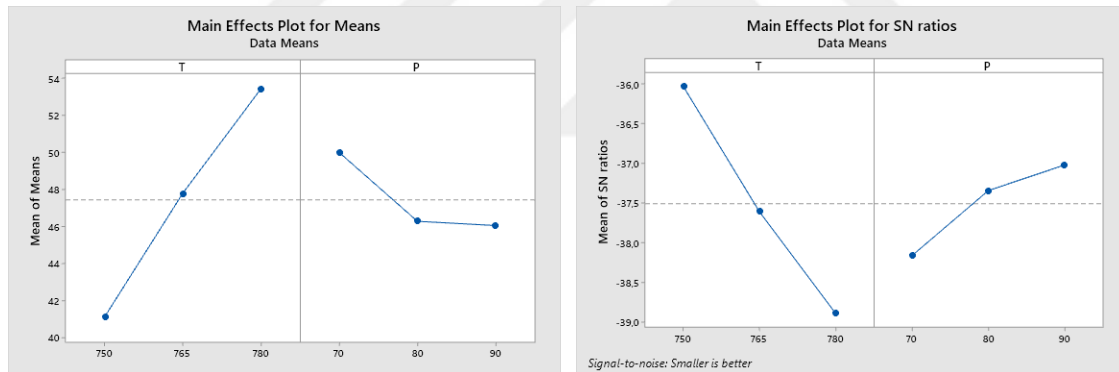


Figure 47. The criterias which are beta phase ratio, drilling force, dezincification depth (perpendicular and parallel), and surface roughness

In this case, by looking at the signal to noise ratio (smaller is better) the best significant value comes out with the following values;

Temp: 750
Pressure: 90

<u>SNRA1</u>	<u>MEAN1</u>
-36,8850	44,0329
-37,2842	45,8871
-33,9159	33,4629
-38,8026	53,4771

-36,4281	42,0086
-37,6010	47,8729
-38,8125	52,4857
-38,3208	50,9457
-39,5452	56,8143

The criteria; hardness is the greatest in the condition determined for grain sizes. It differs from the condition determined in the group that is not heat treated. The reason for this is that this group is heat treated and this process reduces the grain size.

The criterias which are, drilling force, dezincification depth (perpendicular and parallel), beta phase ratio and surface roughness for the group without heat treatment taguchi analysis results are shared in Figure 48.

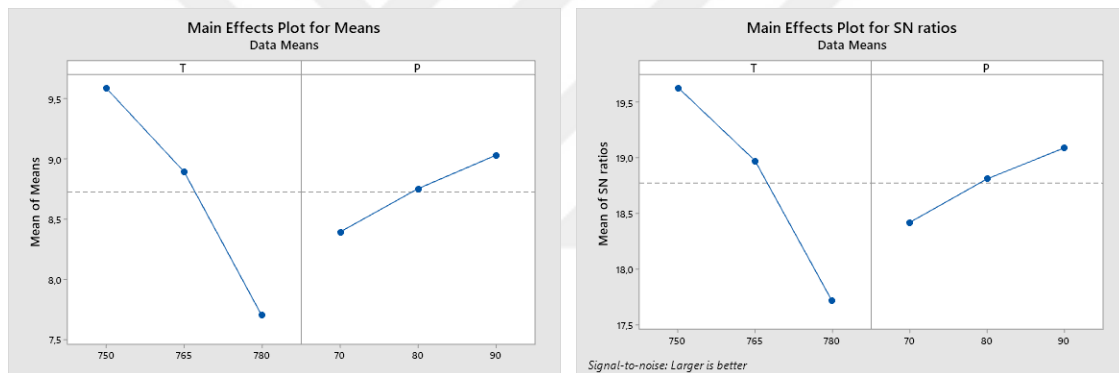


Figure 48. The criterias which are hardness, grain size (perpendicular and parallel), beta grain size

In this case, by looking at the signal to noise ratio (larger is better) the best significant value comes out with the following values;

Temp: 750
Pressure: 90

SNRA2	MEAN2
-36,8850	44,0329
-37,2842	45,8871
-33,9159	33,4629
-38,8026	53,4771
-36,4281	42,0086
-37,6010	47,8729

-38,8125 52,4857
-38,3208 50,9457
-39,5452 56,8143

When these criteria are evaluated; As a result of Taguchi analysis, the forging temperature is 750°C and the forging pressure is 90bar is the best parameter.

4.8.2. Anova Analysis

4.8.2.1. Un-Heat Treated Groups

The effect of cooling method, forging temperature and forging pressure factors on surface hardness examined below.

Table 70. The effect of three criteria on hardness parameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Temperature	2	3869	0.24%	3869	1934	9.04	0.100
Forging Pressure	2	3719	0.23%	3719	1860	8.69	0.103
Cooling Method	2	1578781	99.49%	1578781	789391	3689.95	0.000
Error	2	428	0.03%	428	214		

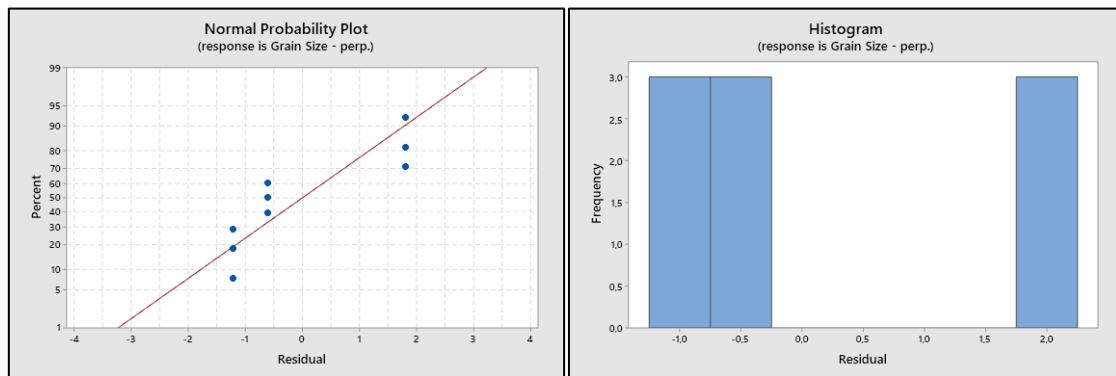


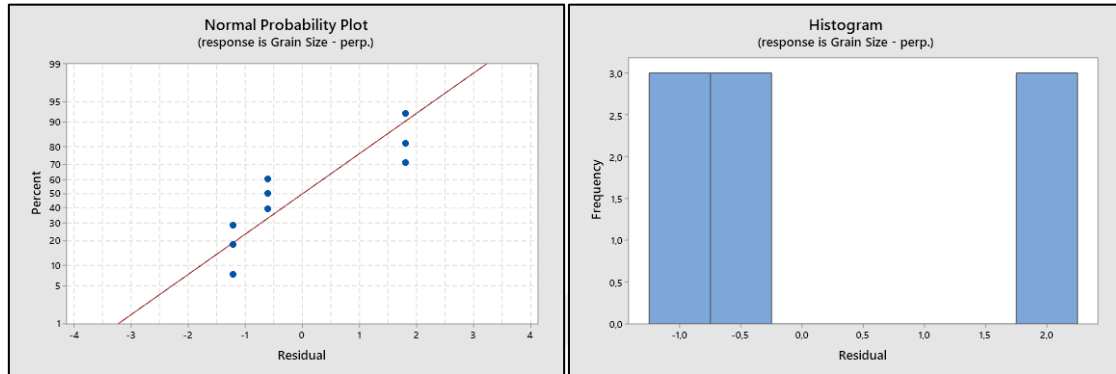
Figure 49. Analysis of variance for transformed response for hardness parameters

When Table 70 and Figure 49 are examined; It was determined that the effect of cooling method on surface hardness is 99.49%.

The effect of cooling method, forging temperature and forging pressure factors on the grain size (perpendicular) parameter in the microstructure examined below.

Table 71. The effect of three criteria on the grain size (perpendicular) parameter in the microstructure

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Temperature	2	2327.3	8.01%	2327.3	1163.6	150.74	0.007
Forging Pressure	2	353.1	1.21%	353.1	176.6	22.87	0.042
Cooling Method	2	26373.5	90.73%	26373.5	13186.8	1708.26	0.001
Error	2	15.4	0.05%	15.4	7.7		
Total	8	29069.4	100.00%				

**Figure 50.** Analysis of variance for transformed response for grain size perpendicular parameters

When Table 71 and Figure 50 are examined; It was determined that the effect of cooling method on the grain size-parallel parameter in the microstructure is 90.73%. In addition, the temperature of the forging is found to have an effect of 8.01%.

The effect of cooling method, forging temperature and forging pressure factors on the grain size (parallel) parameter in the microstructure examined below.

Table 72. The effect of three criteria on the grain size (parallel) parameter in the microstructure

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Temperature	2	7.818	7.53%	7.8177	3.9088	45429.46	0.000
Forging Pressure	2	1.068	1.03%	1.0679	0.5339	6205.68	0.000
Cooling Method	2	94.869	91.44%	94.8694	47.4347	551297.74	0.000
Error	2	0.000	0.00%	0.0002	0.0001		
Total	8	103.755	100.00%				

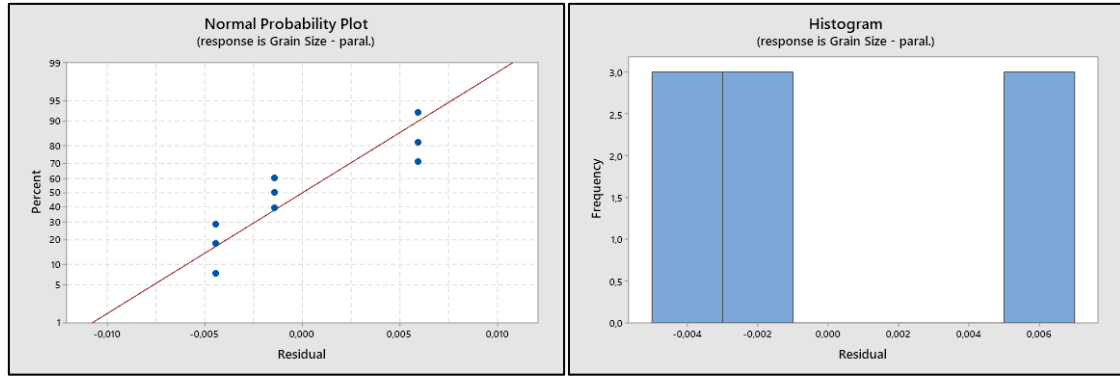


Figure 51. Analysis of variance for transformed response for grain size (parallel) parameters

When Table 72 and Figure 51 are examined; It was determined that the effect of cooling method on the grain size-parallel parameter in the microstructure is 91.44%. In addition, the temperature of the forging is found to have an effect of 7.53%.

The effect of cooling method, forging temperature and forging pressure factors on the dezincification depth (perpendicular) parameter in the microstructure examined below.

Table 73. The effect of three criteria on dezincification depth (perpendicular) parameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Temperature	2	0.46370	10.11%	0.46370	0.23185	62.65	0.016
Forging Pressure	2	0.05306	1.16%	0.05306	0.02653	7.17	0.122
Cooling Method	2	4.06425	88.58%	4.06425	2.03213	549.15	0.002
Error	2	0.00740	0.16%	0.00740	0.00370		
Total	8	4.58841	100.00%				

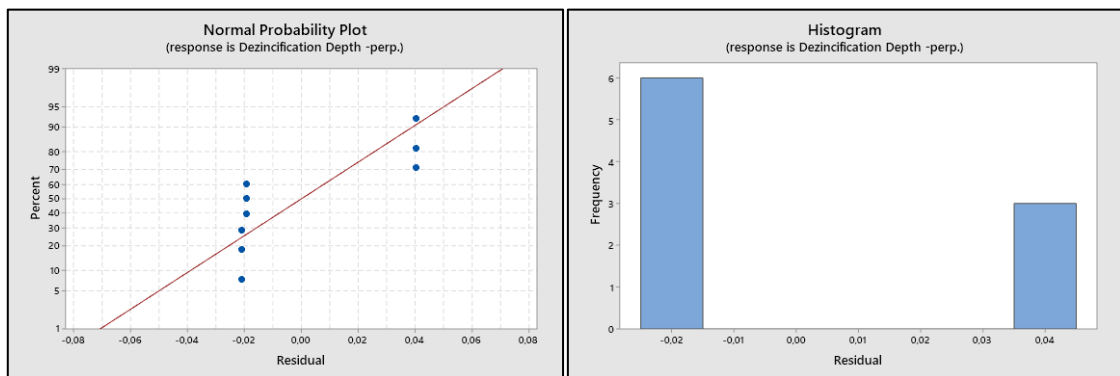


Figure 52. Analysis of variance for transformed response for dezincification depth (perpendicular) parameters

When Table 73 and Figure 52 are examined; It was determined that the effect of cooling method on the dezincification depth-perpendicular is 88.58%. In addition, the temperature of the forging is found to have an effect of 10.11%.

The effect of cooling method, forging temperature and forging pressure factors on the dezincification depth (parallel) parameter in the microstructure examined below.

Table 74. The effect of three criteria on dezincification depth (parallel) parameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Temperature	2	5909.5	6.01%	5909.5	2954.8	33.39	0.029
Forging Pressure	2	1577.6	1.60%	1577.6	788.8	8.92	0.101
Cooling Method	2	90675.8	92.21%	90675.8	45337.9	512.41	0.002
Error	2	177.0	0.18%	177.0	88.5		
Total	8	98339.9	100.00%				

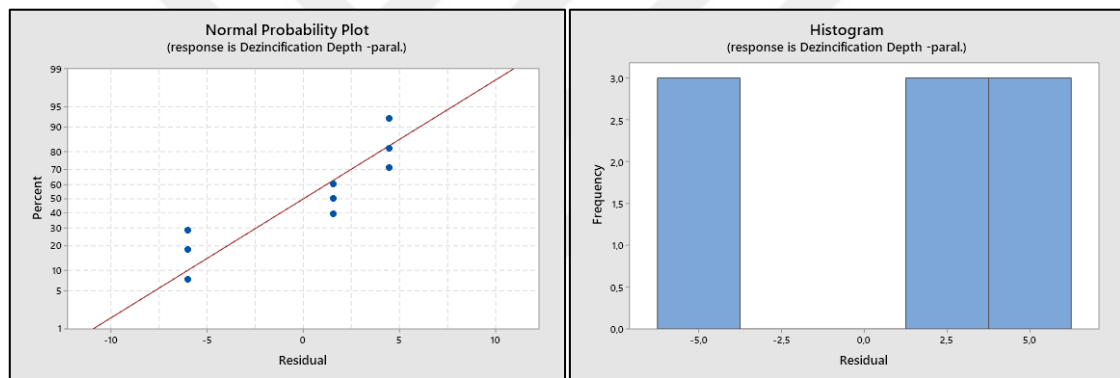


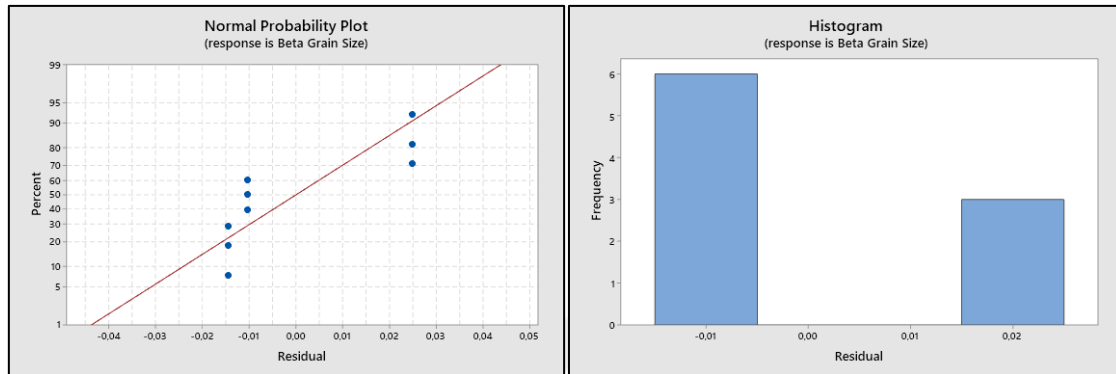
Figure 53. Analysis of variance for transformed response for dezincification depth parallel parameters

When Table 74 and Figure 53 are examined; It was determined that the effect of cooling method on dezincification depth-parallel is 92.21%. In addition, the temperature of the forging is found to have an effect of 6.01%.

The effect of cooling method, forging temperature and forging pressure factors on the beta grain size parameter in the microstructure examined below.

Table 75. The effect of three criteria on beta grain size parameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Temperature	2	0.042582	4.55%	0.042582	0.021291	15.04	0.062
Forging Pressure	2	0.000595	0.06%	0.000595	0.000298	0.21	0.826
Cooling Method	2	0.889924	95.08%	0.889924	0.444962	314.34	0.003
Error	2	0.002831	0.30%	0.002831	0.001416		
Total	8	0.935932	100.00%				

**Figure 54.** Analysis of variance for transformed response for beta grain size parameters

When Table 75 and Figure 54 are examined; It was determined that the effect of cooling method on the beta grain size is 95.08%. In addition, the temperature of the forging is found to have an effect of 4.55%.

The effect of cooling method, forging temperature and forging pressure factors on the beta phase percentage parameter parameter in the microstructure examined below.

Table 76. The effect of three criteria on beta phase percentage parameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Temperature	2	0.26890	15.11%	0.26890	0.134449	47.98	0.020
Forging Pressure	2	0.00853	0.48%	0.00853	0.004266	1.52	0.396
Cooling Method	2	1.49640	84.09%	1.49640	0.748202	267.00	0.004
Error	2	0.00560	0.31%	0.00560	0.002802		
Total	8	1.77944	100.00%				

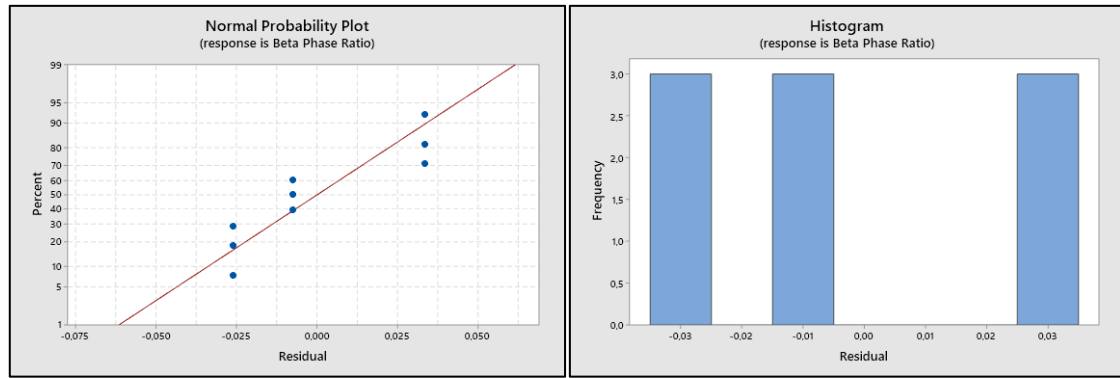


Figure 55. Analysis of variance for transformed response for beta phase ratio parameters

When Table 76 and Figure 55 are examined; It was determined that the effect of cooling method on the beta grain size is 84.09%. In addition, the temperature of the forging is found to have an effect of 15.11%.

The effect of cooling method, forging temperature and forging pressure factors on the drilling force parameter parameter in the microstructure examined below.

Table 77. The effect of three criteria on drilling force parameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Temperature	2	0.02042	0.34%	0.02042	0.01021	7.60	0.116
Forging Pressure	2	0.02676	0.44%	0.02676	0.01338	9.95	0.091
Cooling Method	2	6.02576	99.18%	6.02576	3.01288	2240.98	0.000
Error	2	0.00269	0.04%	0.00269	0.00134		
Total	8	6.07562	100.00%				

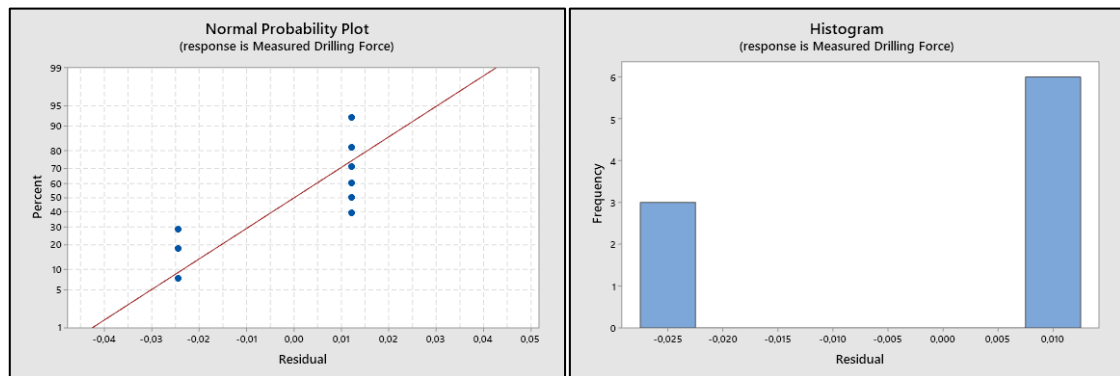


Figure 56. Analysis of variance for transformed response for drilling force parameters

When Table 77 and Figure 56 are examined; It was determined that the effect of cooling method on the drilling force parameter is 99.18%.

The effect of cooling method, forging temperature and forging pressure factors on the surface roughness parameter in the microstructure examined below.

Table 78. The effect of three criteria on the surface roughness parameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Temperature	2	0.01564	1.38%	0.01564	0.007818	10.43	0.088
Forging Pressure	2	0.01680	1.48%	0.01680	0.008401	11.20	0.082
Cooling Method	2	1.09848	97.00%	1.09848	0.549241	732.43	0.001
Error	2	0.00150	0.13%	0.00150	0.000750		
Total	8	1.13242	100.00%				

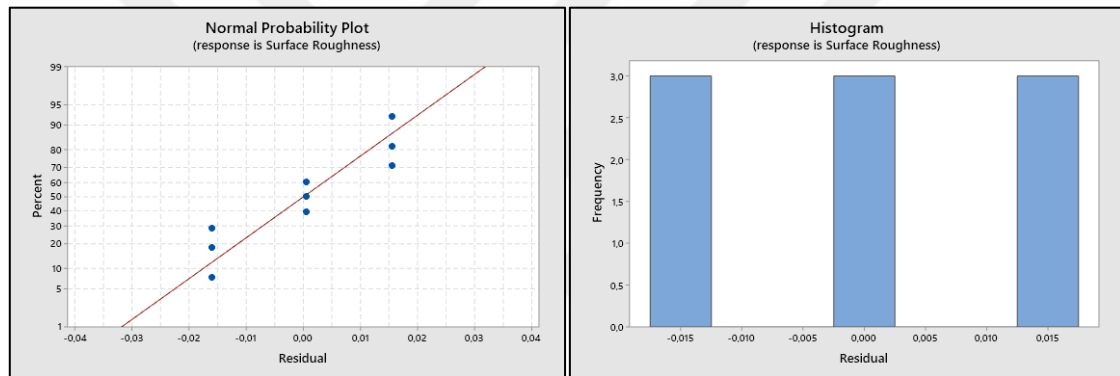


Figure 57. Analysis of variance for transformed response for surface roughness parameters

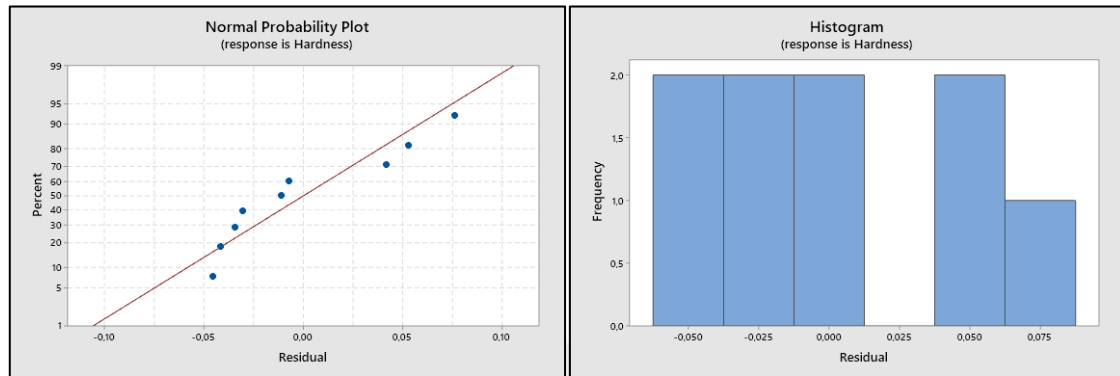
When Table 78 and Figure 57 are examined; It was determined that the effect of cooling method on the drilling force parameter is 97.00%.

4.8.2.2.Heat Treated Group

The effect of forging temperature and forging pressure factors on the surface roughness parameter in the microstructure examined below.

Table 79. The effect of two criteria on the surface hardness parameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Temperature	2	0.48586	43.23%	0.48586	0.242932	58.61	0.001
Forging Pressure	2	0.62149	55.30%	0.62149	0.310744	74.97	0.001
Error	4	0.01658	1.48%	0.01658	0.004145		
Total	8	1.12393	100.00%				

**Figure 58.** Analysis of variance for transformed response for hardness parameters

When Table 79 and Figure 58 are examined; It was determined that the effect of forging temperature on the surface hardness parameter is 43.23%. In addition, the pressure of the forging is found to have an effect of 55.30%.

The effect of forging temperature and forging pressure factors on the grain size (perpendicular) parameter in the microstructure examined below.

Table 80. The effect of two criteria on microstructure grain size (perpendicular) parameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
ForgingTemperature	2	5.73890	90.97%	5.73890	2.86945	574.82	0.000
Forging Pressure	2	0.54997	8.72%	0.54997	0.27499	55.09	0.001
Error	4	0.01997	0.32%	0.01997	0.00499		
Total	8	6.30884	100.00%				

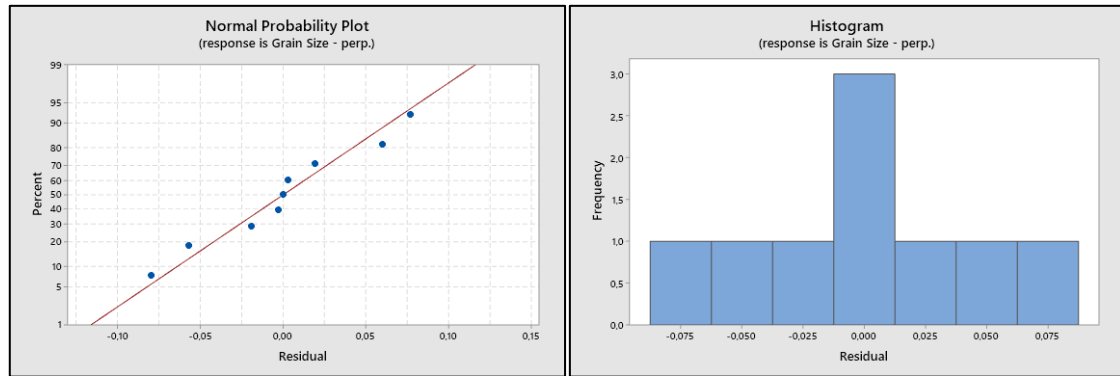


Figure 59. Analysis of variance for transformed response for grain size (perpendicular) parameters

When Table 80 and Figure 59 are examined; It was determined that the effect of forging temperature on the surface hardness parameter is 90.97%. In addition, the pressure of the forging is found to have an effect of 8.72%.

The effect of forging temperature and forging pressure factors on the microstructure grain size (parallel) parameter examined below.

Table 81. The effect of two criteria on microstructure grain size (parallel) parameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Tempreature	2	4.91832	91.01%	4.91832	2.45916	2064.12	0.000
Forging Pressure	2	0.48101	8.90%	0.48101	0.24050	201.87	0.000
Error	4	0.00477	0.09%	0.00477	0.00119		
Total	8	5.40410	100.00%				

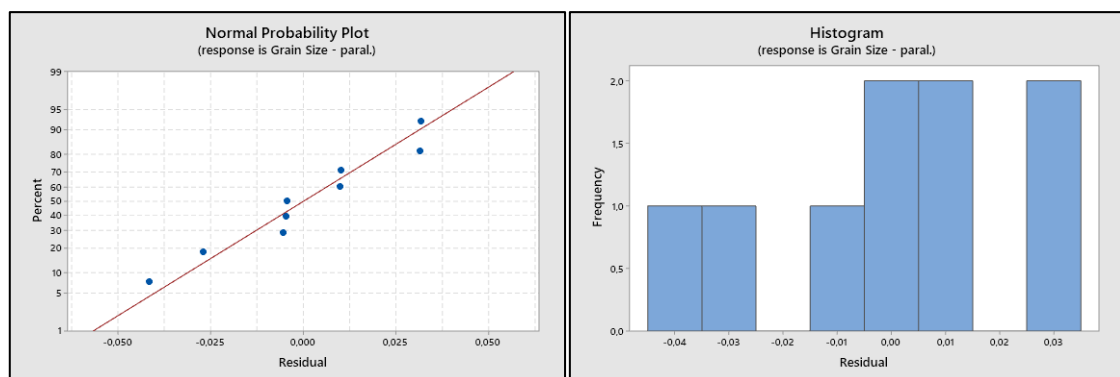


Figure 60. Analysis of variance for transformed response for grain size (parallel) parameters

Table 81 and Figure 60 are examined. While the effect of the forging temperature on the grain size-parallel in the microstructure is 91.01%, the effect of the forging pressure is determined to be 8.90%.

The effect of forging temperature and forging pressure factors on the dezincification depth (perpendicular) parameter examined below.

Table 82. The effect of two criteria on dezincification depth (perpendicular) parameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Tempreature	2	472.7	33.28%	472.7	236.35	1.12	0.411
Forging Pressure	2	104.3	7.34%	104.3	52.13	0.25	0.792
Error	4	843.5	59.38%	843.5	210.89		
Total	8	1420.5	100.00%				

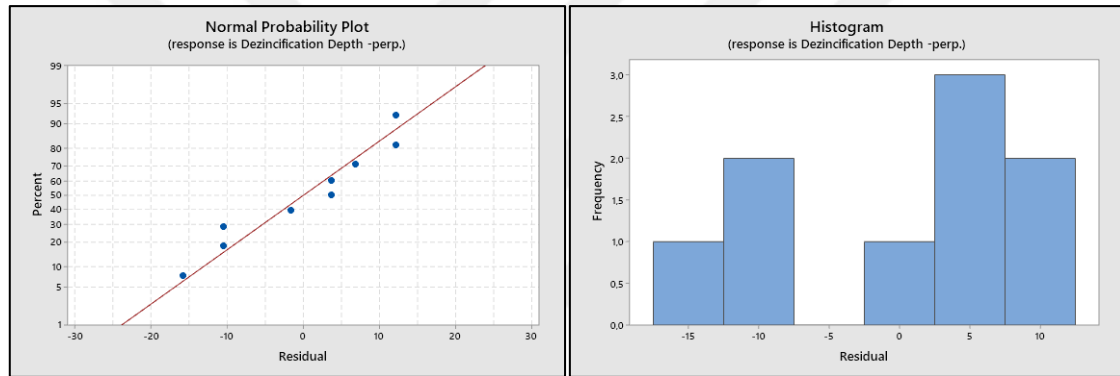


Figure 61. Analysis of variance for transformed response for dezincification depth (perpendicular) parameters

Table 82 and Figure 61 are examined. While the effect of the forging temperature on the dezincification depth (perpendicular) parameter is 33.28%, the effect of the forging pressure is determined to be 7.34%. But the effect is error is 59.38%. Additionally, in the above analysis, since the p-value is above the number of 0.1 for both factors, it does not make any statistical meaning.

The effect of forging temperature and forging pressure factors on the dezincification depth (parallel) parameter examined below.

Table 83. The effect of two criteria on dezincification depth (parallel) parameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Tempreature	2	719157104	65.43%	719157104	359578552	4.79	0.087
Forging Pressure	2	79880175	7.27%	79880175	39940088	0.53	0.624
Error	4	300068211	27.30%	300068211	75017053		
Total	8	1099105491	100.00%				

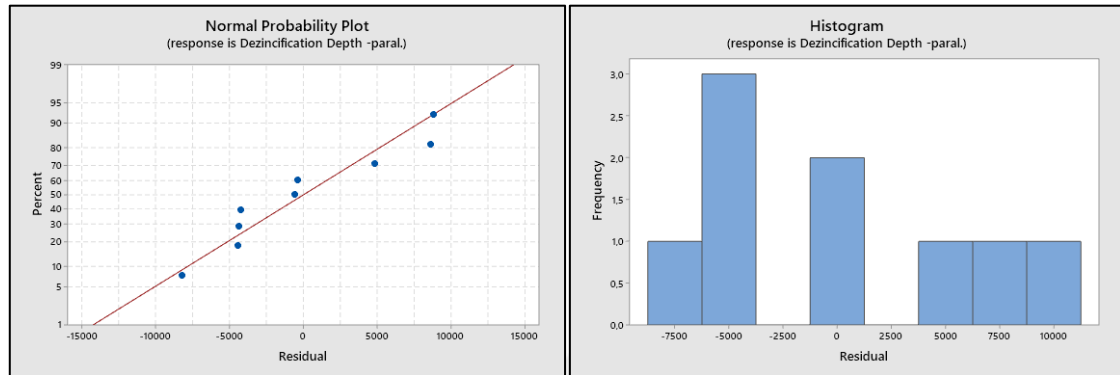
**Figure 62.** Analysis of variance for transformed response for dezincification depth (parallel) parameters

Table 83 and Figure 62 are examined. While the effect of the forging temperature on the dezincification depth (parallel) parameter is 65.43%, the effect of the forging pressure is determined to be 7.27%. Additionally, the effect is error is 27.30%.

The effect of forging temperature and forging pressure factors on the beta grain size parameter examined below.

Table 84. The effect of two criteria on beta grain size parameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Tempreature	2	0.172118	97.52%	0.172118	0.086059	90.09	0.000
Forging Pressure	2	0.000553	0.31%	0.000553	0.000277	0.29	0.763
Error	4	0.003821	2.16%	0.003821	0.000955		
Total	8	0.176492	100.00%				

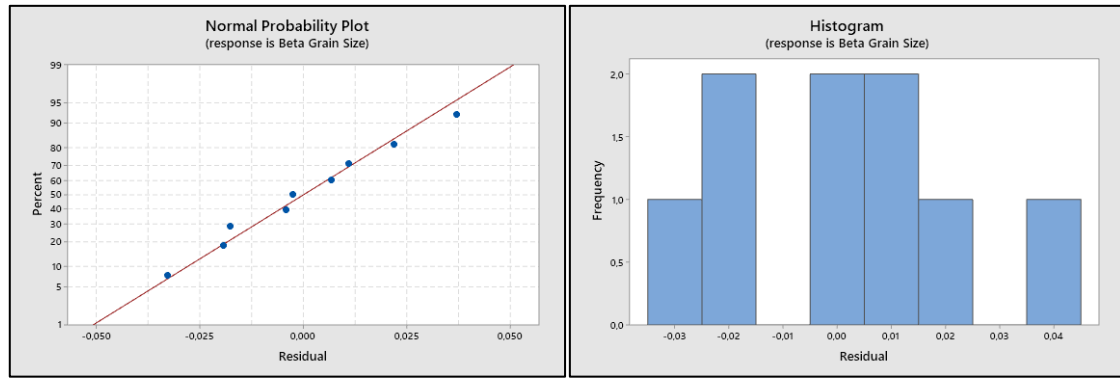


Figure 63. Analysis of variance for transformed response for beta grain size parameters

Table 84 and Figure 63 are examined. While the effect of the forging temperature on the dezincification depth (perpendicular) parameter is 97.52%, the effect of forging pressure is not determined.

The effect of forging temperature and forging pressure factors on the beta phase ratio parameter examined below.

Table 85. The effect of two criteria on beta phase ratio parameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Tempreature	2	0.005099	78.93%	0.005099	0.002550	8.73	0.035
Forging Pressure	2	0.000192	2.98%	0.000192	0.000096	0.33	0.737
Error	4	0.001169	18.09%	0.001169	0.000292		
Total	8	0.006461	100.00%				

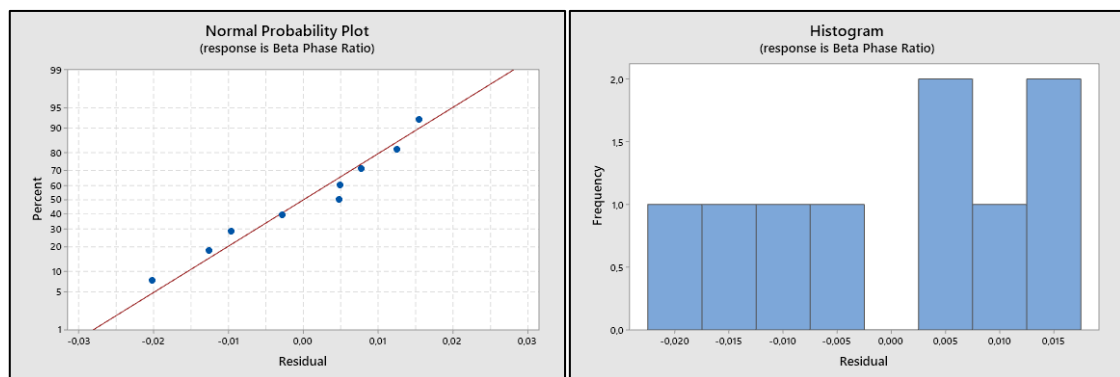


Figure 64. Analysis of variance for transformed response for beta phase ratio parameters

Table 85 and Figure 64 are examined. While the effect of the forging temperature on the dezincification depth (perpendicular) parameter 78.93%, the effect of forging pressure is not determined. The error contribution is 18.09%.

The effect of forging temperature and forging pressure factors on the drilling force parameter examined below.

Table 86. The effect of two criteria on drilling force parameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Tempreature	2	0.037401	61.35%	0.037401	0.018701	91.52	0.000
Forging Pressure	2	0.022741	37.31%	0.022741	0.011371	55.65	0.001
Error	4	0.000817	1.34%	0.000817	0.000204		
Total	8	0.060960	100.00%				

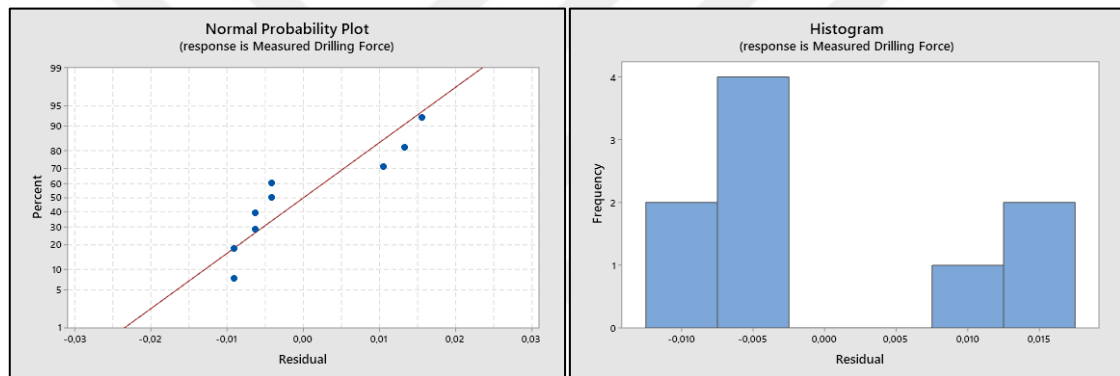


Figure 65. Analysis of variance for transformed response for drilling force parameters

When Table 86 and Figure 65 are examined; It was determined that the effect of forging temperature on the drilling force parameter is 61.35%. In addition, the pressure of the forging is found to have an effect of 37.31%.

The effect of forging temperature and forging pressure factors on the surface roughness parameter examined below.

Table 87. The effect of two criteria on the surface roughness parameter

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Forging Tempreature	2	1.38921	44.29%	1.38921	0.694607	81.65	0.001
Forging Pressure	2	1.71332	54.62%	1.71332	0.856659	100.70	0.000
Error	4	0.03403	1.08%	0.03403	0.008507		
Total	8	3.13656	100.00%				

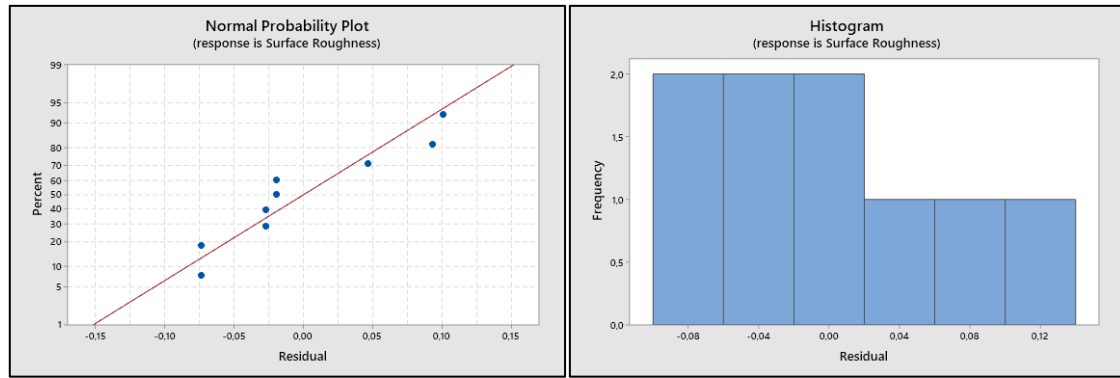


Figure 66. Analysis of variance for transformed response for surface roughness parameters

When Table 86 and Figure 65 are examined; It was determined that the effect of forging temperature on the surface roughness parameter is 44.29%. In addition, the pressure of the forging is found to have an effect of 54.62%.

4.9. Financial Benefits to Companies Applying the Alternative Method

In brass alloys suitable for forging; they pass 3 basic processes from rod to product.

- Hot forging
- Heat Treatment
- Machining

Monthly production capacities of brass alloys producing and machining are shared in Table 88.

Table 88. The amount of monthly production manufacturer of some of the companies who are in Turkey

Company Name	Monthly Brass Alloys Production
SARBAK	5500tons/month
PİREKS	3500 tons/month
TORUN METAL	4200tons/month
KALE MUSLUK	1800tons/month

Brass alloys differ in their suitability for hot and cold working. Table 89 lists some brass alloys suitable for hot forging.

Table 89. The most widely produced brass alloys shaped by hot forging

CW614N (CuZn39Pb3)	CW608N (CuZn38Pb2)
CW617N (CuZn40Pb2)	CW606N (CuZn37Pb2)
CW603N (CuZn36Pb3)	CW611N (CuZn39Pb1)
CW616N (CuZn40Pb1Al)	CW607N (CuZn38Pb1)
CW613N (CuZn39Pb2Sn)	CW602N (CuZn36Pb2As)
CW612N (CuZn39Pb2)	CW626N (CuZn33Pb1,5AlAs)

It has been assumed that Özhan Company has the capacity of forming 3000tons of brass alloy per month. It is assumed that the production of CW625N is 100tons / month of 3000tons. In line with these assumptions; below is the calculation of the heat treatment application process as the days spent (Thesis; it aimed to eliminate the heat treatment process, which is one of these applied processes. In this direction; the information about the application processes of a company shaping 100tons of brass alloys monthly is shared below).

Considering the test sample, calculations regarding how long Özhan company can obtain 100tons product are shared in Table 90.

Table 90. Özhan Company's 100tons production schedule

Produce Amount (Ton/Mounth)	Production Process Steps	How many days was it produced?	
100tons = 100.000kg	Hot Forging	5 products from 1 press in 1 minute 1 test sample 1.1 kilograms 1-day working time is 8 hours. 2640kg parts are produced in 1 day (8 hours) 5280kg (2 presses)	100.000 tons of products are forged in 19 days.

*Calculations are made by taking the weight of the part of the thesis sample.

In the thesis study; The heat treatment time is 180 minutes and based on this information, the daily heat treatment amount is calculated and shared in Table 91 below.

Table 91. Daily heat treatment capacity

Produce Amount	Production Process Steps	How many days was it produced?	
100tons = 100.000kg	Heat Treatment	1-day working time is 9 hours (including lunch time) Heat treatment is applied to 1 ton of product in 3 hours. Heat treatment is applied to 3 tons of product in 1 day.	?

While the product is hot forged, heat treatment applications continue at the same time. It was not sent to heat treatment only on the first day. The reason of this; not enough products can be forged.

Even if the products are shaped with 100tons of hot forging, the product has accumulated in stock due to its heat treatment application capacity.

In Table 92, the forging of 100tons product of Özhan Company and planning of heat treatment process are shared. In addition, if the production amount is sufficient in this table, it is calculated by assuming that the products are sent to heat treatment daily.

Table 92. Heat treatment time for 100 tons of product (days)

Heat treatment time of 100 tons of product	Amount of heat treatment in 1 day (kg/day)	Amount of product forged (kg/day)	The amount of product waiting for heat treatment order (kg/day)
1st day	0	5280	5280
2nd day	3000	5280	7560
3rd day	3000	5280	9840
4th day	3000	5280	12120
5th day	3000	5280	14400
6th day	3000	5280	16680
7th day	3000	5280	18960
8th day	3000	5280	21240
9th day	3000	5280	23520
10th day	3000	5280	25800
11th day	3000	5280	28080
12th day	3000	5280	30360
13th day	3000	5280	32640
14th day	3000	5280	34920
15th day	3000	5280	37200
16th day	3000	5280	39480
17th day	3000	5280	41760
18th day	3000	5280	44040
19th day	3000	4960	46000
20th day	3000	0	43000
21st day	3000	0	40000
22nd day	3000	0	37000
23rd day	3000	0	34000
24th day	3000	0	31000
25th day	3000	0	28000
26th day	3000	0	25000
26th day	3000	0	22000
27th day	3000	0	19000
28th day	3000	0	16000
29th day	3000	0	13000
30th day	3000	0	10000
31st day	3000	0	7000
32nd day	3000	0	4000

33rd day	3000	0	1000
34th day	1000	0	0
TOTAL	100.000kg	100.000kg	

Acceptances:

* The heat treatment company has been planned to this manufacturer every day upon separation of one furnace.

* At least 2 workers will work for handling, loading and unloading materials. Their cost has been ignored.

Özhan company; It removes the heat treatment process by applying the alternative method obtained as a result of the thesis study that cools the products shaped by hot forging with a fan.

Table 93, organized according to the outputs obtained in Table 92, is shared below.

Table 93. Un-Heat treatment time for 100 tons of product (days)

100 tons of product	Amount of heat treatment in 1 day (kg/day)	Amount of product forged (kg/day)
1st day	0	5280
2nd day	0	5280
3rd day	0	5280
4th day	0	5280
5th day	0	5280
6th day	0	5280
7th day	0	5280
8th day	0	5280
9th day	0	5280
10th day	0	5280
11th day	0	5280
12th day	0	5280
13th day	0	5280
14th day	0	5280
15th day	0	5280
16th day	0	5280
17th day	0	5280
18th day	0	5280
19th day	0	4960
TOTAL		100.000kg

By eliminating the need for heat treatment application, Özhan Company (The manufacturer) is gain 16 days.

Table 94 shares the time calculation required for the final machining process of the 100tons product.

Table 94. Machining process time required for 100tons

Produce Amount	Production Process Steps	How many days was it produced?	
100tons = 100.000kg	Machining Process (Drilling)	1-day working time is 8 hours	100.000 kg of products are machined in 19 days.
		1 hole is drilled in 120 products in 4hours (132kg)	
		1 hole is drilled to 264 kg product in 1 day.	
		20 machines process 5280 kg of product in 1 day	

Additionally; the advantage of a company that produces 100tons per month and therefore 1200tons per year is from the heat treatment price as follows.

Table 95. As a result of alternative method application, the heat treatment gain of Özhan Company from only 1200 tons of annual production.

Heat Treatment Kilogram Price (€)	Monthly heat treatment cost for 100tons production (€)	Annual heat treatment cost for 1200tons of production (€)	Annual heat treatment cost for 1200tons of production (₺)
25 cent	25.000,00 €	300.000,00 €	2.280.600,00 ₺

If it produces only 1200tons annually and does not use the heat treatment process by preferring the fan cooling method; company will benefit 300.000€ (2.280.600,00₺) and 16 days time.

The company produces 1200tons of CW625N alloy annually; The profit it provides in its normal processes and the snow percentages it will provide by removing heat treatment are shared below.

Table 96. Cost calculation in kilogram basis for 2020

Cost of rods to be forged (€/kg)	Final product cost to the company (production cost) (€/kg)	The profit that the company will add to the product (€/kg)	Sales price of the final product (Buying + Cost + Profit = Sales) (€/kg)
11,00 €	1,50 €	1,50 €	14,00 €



Heat treatment cost (€/kg)	0,25 €
The other cost (€/kg)	1,25 €

Having a profit of 1.5€ from the product with a cost of 12.5€ per kilogram means that the company makes a profit of 12%.

The profit increase obtained by the company, which does not apply heat treatment using the alternative method, without changing the sales price, is presented in Table 97 below.

Table 97. With the elimination of the heat treatment cost

Price of rods to be forged (€/kg)	Final product cost to the company (€/kg)	The profit that the company will add to the product (€/kg)	Sales price of the final product (Buying + Cost + Profit = Sales) (€/kg)
11,00 €	1,25 €	1,75 €	14,00 €

Having a profit of 1.75€ from the product with a cost of 12.25€ per kilogram means that the company makes a profit of 14.28%.

When calculated for 1200tons annual production; The percentage profit increase calculation between the company's heat treatment applied costs and the costs when it does not apply heat treatment is presented in Table 98 below.

Table 98. Profit rate calculation when it is calculated over 1200tons per year

1 kg cost of CW625N	12,50 €	1 kg cost of CW625N	12,25 €
1200tons price of CW625N	15.000.000,00 €	1200tons price of CW625N	14.700.000,00 €
Sales profit added by the company for the 1200tons CW625N alloy	1.800.000,00 €	Sales profit added by the company for the 1200tons CW625N alloy	2.100.000,00 €
Sales price of the 1200tons final product	16.800.000,00 €	Sales price of the 1200tons final product	16.800.000,00 €
Net profit (Heat treatment cost of 1200tons CW625N alloy)		300.000,00 €	
Percentage of profit increase		$\frac{2.100.000,00 - 1.800.000,00}{1.800.000,00} \times 100 = 16$	

When the table above is examined; The rate of profit obtained without applying heat treatment is 16%.

5. CONCLUSIONS and FUTURE WORK

As a result of three different cooling methods applied to the samples with the three different forging temperature and three different forging pressure for the CW625N alloy studied;

- As determined in microstructure images, cooling methods caused differences on the alloy. Grain sizes and structural differences are observed.
- When the cooling curves of the groups and samples are examined; After the forging process, it has been determined that the fan is not as sudden as water, but needs to be cooled quickly. It is found that the cooling time increased when the forging temperature increased in the samples cooled in calm air and therefore the dezincification resistance decreased.
- The direct effect of forging temperature increase on the dezincification resistance decreased, whereas the direct effect of forging pressure on the dezincification resistance is not detected.
- Un-heat treated samples (in the groups); while the beta phase ratios are expected to be high, the beta phase ratio is obtained low in the samples because of the fast and control cooling with fan. So, the amount of dezincification depth is low. Thus, their values are in the scope of the standard.
- Surface hardness values, the direct effect of drilling force and surface roughness on the alloy is determined.
- Heat treatment process is application that directly increases the dezincification resistance. This solution (heat treatment process), which is the traditional method for the alloys cooled in calm air after forging, was applied. In this study; The dezincification depth values in some of the heat treated samples exceeded the standard scope. Therefore, a second time heat treatment process was applied. Although the element ratios determined for the CW625N alloy are within the scope of the standard; it is obtained different in element ratios cause high dezincification depth values.

When both statistical analyzes and traditional detailed experimental studies are evaluated within the scope of the thesis study;

- The direct effect of the cooling method on all parameters has been determined.
- It has been determined that there is an inverse proportion between dezincification resistance and forging temperature. Forging temperature increase decreases dezincification resistance.
- When the statistical analysis results of the heat treatment group are examined, error rates are found. The reason of this; It is caused by heat treatment application.
- The best forging parameter; It was determined as 750°C and 80 Bar for temperature.

There are 2 important factors in a brass alloy. One of these; dezincification depth values are obtained within the scope of the standard and the other is the machinability of the alloy. Although it is a lead-free brass alloy;

- When the chip structures, drilling forces applied to the parts and surface roughness values were compared, the results are obtained the close the values at the applied heat treated group which as the traditional method and the cooled with fan group. The other groups values are not prefer for the good machinability.
- In addition to all the above findings, the most important result of this study; cheaper alternative method is discovered instead of the traditional method of production. When both the dezincification test results and machinability test results were examined, it is found that; Instead of cooling the products in calm air and applying heat treatment (conventional method), cooling of alloy products with fan has been found as the cheapest a alternative method. The application of fan cooling method provides financial benefits and time savings in production time by removing the expensive heat treatment process in the traditional method.

This type of alloy called lead-free brass is open to research on both alloy's elements ratios and production parameters.

6. REFERENCES

- [1] Callcut V.; The Brass Properties&Applications; CDA Publication; 1996; No. 121, p. 42.
- [2] <https://cdn.bartın.edu.tr/metalurji/d7ee7cd9-f063-46698e1c393503ed6ffb/demir-disi-metaller-bakir.pdf> Date of Access: March 12,2020.
- [3] Caron R.N., Sharif A.; Alloy and Temper Designation; Materials Science and Materials Engineering, 2017.
- [4] https://www.simetric.co.uk/si_metals.htm Date of Access: February 24,2020.
- [5] Bodude, M.A., Momohjimoh I. and Nnaji R.N.; Mechanical and Microstructural Evaluation of Plastically Deformed Brass; Materials Sciences and Applications,2015; Volume 6, pages 1137-1144
- [6] Casting; ASM Handbook; 2008; Volume 15.
- [7] Madsen D. A.; Print Reading for Engineering and Manufacturing Technology;; Manufacturing Materials and Processs, 2004; Chapter 6.
- [8] Kesici T.; %70 Cu - %30 Zn Pirinç Alaşımlarında Tav Parametrelerinin Derin Çekilebilirliğe Etkileri; Kırıkkale University, Institute of Science and Technology, Thesis (M.Sc.); 2006 Kırıkkale-Türkiye.
- [9] Edward E. Igelegbai, Oluwaseun A. Alo, Adefemi O. Adeodu, Ilesanmi A. Daniyan; Evaluation of Mechanical and Microstructural Properties of α -Brass Alloy Produced from Scrap Copper and Zinc Metal through Sand Casting Process; January 2017; Journal of Minerals and Materials Characterization and Engineering, Vol. 5 pages 18-28.
- [10] Claesson. E., Rod. O.; The Effect of Alloying Elements on the Corrosion Resistance of Brass; Materials Science and Technology (United Kingdom);21 November 2016; 32 (17), pages 1794-1803.
doi.org/10.1080/02670836.2016.1254925
- [11] Tuck C.D.S., Powell C.A., Nuttall J.; Corrosion of Copper and Its Alloys; Shreir's Corrosion 2010; Volume 3, Pages 1937-1973.

- [12] Vilarinho C., Davim J.P., Soares D, Castro F., Barbosa J.; Influence of The Chemical Composition on the Machinability of Brasses; Journal of Materials Processing Technology. Volume 170. Issues 1–2. 14 December 2005. Pages 441-447. doi.org/10.1016/j.jmatprotec.2005.05.035
- [13] Metallography and Microstructures; ASM Handbook; 2004; Volume 9.
- [14] Kuyucak S., Sahoo M.; A Review of the Machinability of Copper-Base Alloys; Canadian Metallurgical Quarterly; January – March 1996.; Volume 35, Issue 1, Pages 1–15. doi.org/10.1179/cm.1996.35.1.1
- [15] Copper – The Vital Metal; Copper Development Association; 1998; 121,
- [16] Kalpakjian S., Schmid R. S., Manufacturing Engineering and Technology, Seventy Edition, 2014, p156.
- [17] Jin L, Sandström R; Machinability Data Applied to Materials Selection; Materials & Design; 1994; Volume 15, Issue 6, Pages 339-346. [doi.org/10.1016/0261-3069\(94\)90028-0](https://doi.org/10.1016/0261-3069(94)90028-0)
- [18] <http://www.nevoku.com/bakir-ve-alasimlarinin-kaynak-kabiliyetikaynak/viewdeck/e3016e73-99f4-4df5-b327-35b544793359>.
Date of Access: February 20,2020.
- [19] Meran C., Yüksel M., König R.; “CuZn37 Pirinç Malzemesinin Kaynak Edilebilirliği”; Kaynak Teknolojisi II. Ulusal Kongre ve Sergisi; Ankara 1999; pages 199-209.
- [20] Şentürk B. S., Pirinç Alaşımlarının Ekstrüzyonunda Meydana Gelen Üretim Hatalarının Tespiti Nedenleri Ve Çözüm Yolları, Yüksek Lisans Tezi, 2007.
- [21] KOÇAK H., Bakır ve Bakır Alaşımları, Sağlam Metal; Haziran 2013, İstanbul, pages 31-33.
- [22] Agrawall B. K.; Introduction to Engineering Materials; Tata McGraw-Hill Publishing Company; New Delhi 1993; s 234.
- [23] <https://commons.wikimedia.org/wiki/File:Cu-Zn-phase-diagram-greek.svg#/media/File:Cu-Zn-phase-diagram-greek.svg>
Date of Access: March 20, 2020.

- [24] Karunakar D. B.; Metal Casting Lecture-3: Copper, Zinc And Titanium Cast Alloys;, Department of Mechanical and Industrial Engineering Indian Institute of Technology; Roorkee.
- [25] Tekin E.; Demirdışı Metaller ve Alaşımlarının Uygulamalı Optik Metalografisi; Ankara 1984.
- [26] Anulf B., Lindqvist D., Lundin C.; Comments on the Use of the Model-Material Technique in the Hot Forging of Brass; Journal of Mechanical Working Technology; December 1985; Volume 12, Issue 2, , Pages 149-152. [doi.org/10.1016/0378-3804\(85\)90131-7](https://doi.org/10.1016/0378-3804(85)90131-7)
- [27] Brock J., Zaroog O.S.; Copper Alloys: Corrosion; Encyclopedia of Materials: Science and Technology, 2001, Pages 1662-1664. doi.org/10.1016/B978-0-12-803581-8.02892-7
- [28] Marshakov I.K.; Corrosion Resistance and Dezincing of Brasses; Protection of Metals; May 2005; Volume 41, Issue 3, Pages 205-210. doi.org/10.1007/s11124-005-0031-2
- [29] Shraier L., Ed L.; Korroziya. Spravochnik (Handbook of Corrosion), Moscow: Metallurgiya, 1981.
- [30] Momeni A., Ebrahimi G.R., Faridi H.R.; Effect of Chemical Composition and Processing Variables on the Hot Flow Behavior of Lead Brass Alloys; Materials Science and Engineering; February 2015; Volume 626, Pages 1-8. doi.org/10.1016/j.msea.2014.12.016
- [31] TS EN ISO 6509-1 Bakır ve Bakır Alaşımları: Çinko bakır alaşımları Çinkosuzlaşma Direncin Tayini
- [32] Wright Roger N.; Relevant Aspects of Copper and Copper Alloy Metallurgy; Wire Technology (Second Edition), 2016, Pages 177-200.
- [33] Garcia P, Rivera S., Palacios M, Belzunce J.;Comparative Study of The Parameters Influencing The Machinability of Lead Brass; Engineering Failure Analysis; Volume 17, Issue 4, June 2010, Pages 771-776. doi.org/10.1016/j.engfailanal.2009.08.012

- [34] <http://www.matweb.com/reference/copper-alloys.aspx> Date of Access: March 20, 2020
- [35] Davis J.R.; Copper and Copper Alloys; ASM Specialty Handbook; ASM International Handbook Committee; 2001; Page 265.
- [36] Heat Treating of Nonferrous Alloys; 2016; ASM Handbook; Volume 4E.
- [37] Geçmen İ.; Alfa Pirinç Sacların Sürtünme Karıştırma Kaynak Özellikleri; Marmara University ,Institute of Science and Technology, Thesis Phd; 2015; İstanbul
- [38] W. Gale and T. Totemeier; ASM. Metals Handbook 2nd desktop edition; ASM 1999; Smithells Reference Book. 8th edition; Elsevier 2003.
- [39] http://www.actkaynak.com/upload/galeri/luchs-bakir-alasimlarinin-kaynagi_21131.pdf Date of access: march 25, 2020
- [40] Chang-Yu Hung, Chi-Ming Lin, Chih-Chun Hsieh, Chia-Chun Li, Paxon Ti-Yuan Wu, Kuan-Ting Chen, Weite Wu; A Novel Approach to Improving Resistance to Dezincification of Diphasic Brass; In Journal of Alloys and Compounds; 2016; 671:502-508. doi.org/10.1016/j.jallcom.2016.01.261
- [41] Yazan A.; Pirinç Alaşımlarının Çinkosuzlaşma Korozyonuna Alüminyum, Nikel Ve Kalay Alaşım Elementlerinin Etkileri; İstanbul Technical University, Institute of Science and Technology, Thesis (M.Sc.); 2014. hdl.handle.net/11527/9239
- [42] Nobel C., Klocke F., Lung D., Wolf S.; Machinability Enhancement of Lead-free Brass Alloys; Procedia CIRP; 2014; Volume 14, Pages 95-100. doi.org/10.1016/j.procir.2014.03.018
- [43] Jhansson J., Perrson H., Stahl J.E, Zhou M., Bushlya V.; Machinability Evaluation of Low-Lead Brass Alloys; Procedia Manufacturing; Volume 38, 2019, Pages 1723-1730 doi.org/10.1016/j.promfg.2020.01.102
- [44] Kroupa A.,Vrestal J., Boulet P., Dinsdale A., Watson A., Record M-Ch.; The Reassessment of The Al-Cu and Cu-Zn systems with respect to the γ –brasses phase; Calphad Volume 51; December 2015;page 369.

- [45] Atsumi H., Imai H., Li S., Kondoh K., Kousaka Y., Kojima A.; High-strength, lead-free machinable α - β duplex phase brass Cu-40Zn-Cr-Fe-Sn-Bi alloys; Materials Science and Engineering-A; 25 November 2011; Volume 529, Pages 275-281. doi.org/10.1016/j.msea.2011.09.029
- [46] Copper Casting Alloy; Non-Ferrous Founders' Society and Copper Development Association.
- [47] Brooks C.R.; Heat Treatment, Structure and Properties of Non-ferrous Alloys; American Society for Metals 1982; pages 275-327.
- [48] Heat Treatment; ASM Metals Handbook 1990; 9th Edition; Ohio
- [49] Mindivan H.; Yüksek Mukavemetli Pirinçlerin Mikroyapı ve Aşınma Özelliklerine Isıl İşlemin Etkisi; İstanbul Technical University, Institute of Science and Technology, Thesis (M.Sc.); 2001 İstanbul.
- [50] Forging and Casting; ASM Handbook 1961; Volume 5, 8th Edition.
- [51] Kenworthy L., O'Driscoll W.G.; Dezincification of Brasses; Anti-Corrosion Methods and Materials 1955; Volume 2, Issue 8, pages 247-249.
- [52] Estelle A.A.; Drinking Water Lead Regulations: Impact on the Brass Value Chain; Materials Science and Technology; 1 August 2016; Pages 1763-1770.
- [53] TS EN 12420 Copper and Copper Alloys: Forging Standard
- [54] TS EN 12164 Copper and Copper Alloys: Free Machining Rod
- [55] TS EN 12165 Bakır ve Bakır Alaşımları: Biçimlendirilmiş ve Biçimlendirilmemiş Dövme Taslağı
- [56] Rojas-Rodríguez I., Lara-Guevara A., Salazar-Sicacha M., Mosquera-Mosquera J.C., Robles-Agudo M., Ramirez-Gutierrez C., Rodríguez-García M.; The Influence of the Precipitation Heat Treatment Temperature on the Metallurgical, Microstructure, Thermal Properties, and Microhardness of an Alpha Brass; Materials Sciences and Applications, 2018; Issue 9, pages 440-454.
- [57] Lovisek M., Liptakova T., Dundekova S., Milkova K.; Characteristics of Al-Brass Affecting Degradation Process; In 32nd Danubia Adria Symposium 2016;

- on Advanced in Experimental Mechanics; Materials Today:Proceedings 3(4): 1051-1055
- [58] Bagherian E.R., Fan Y., Abdulvand A., Cooper M., Frame B.; Investigation of the Distribution of Lead in Three Different Combinations of Brass Feedstock; International Journal of Metalcasting; April 2016; Issue 10 (3), pages 322-328; Scotland UK. [doi.org/ 10.1007/s40962-016-0055-1](https://doi.org/10.1007/s40962-016-0055-1)
- [59] Reetz B., Reimers W.; Hot Extrusion of α and α/β -brass Alloys; International Journal of Materials Research; July 2008; Volume 99, Issue 7, pages 787-794. doi.org/10.3139/146.101694
- [60] Pantazopoulos G.A., Toulfatzis A.I.; Fracture Modes and Mechanical Characteristics of Machinable Brass Rods; Metallography, Microstructure, and Analysis; 15 August 2012; Volume 1, pages106–114. doi.org/10.1007/s13632-012-0019-7
- [61] Jha S., Balakumar D., Paluchamy R.; Experimental analysis of microstructure and mechanical properties of copper and brass based alloys; June 2015; International Journal of Automotive and Mechanical Engineering 11(1), pages 2317-2331. doi.org/10.15282/ijame.11.2015.14.0195
- [62] Johansson J., Gutnichenko O., Ståhl J. –E., Bushlya V., Schultheiss F.; Determining process parameters for successful material reclamation of lead-free brass chips using hot forging operations: Lubrication; Procedia CIRP 2019; Volume 80, Pages 108-113. doi.org/10.1016/j.procir.2019.01.086
- [63] Schultheiss F., Johansson D., Bushlya V., Zhou J., Nilsson K., Ståhl J-E.; Comparative study on the machinability of lead-free brass; Journal of Cleaner Production; 15 April 2017; Volume 149, Pages 366-377. doi.org/10.1016/j.jclepro.2017.02.098
- [64] Machining; ASM Handbook; 1989; Volume 16.
- [65] Kalppakjian S., Schmid S.; Manufacturing Engineering and Technology; 8th. Edition; 2014.
- [66] IPCS (1998) Copper. Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 200.

- [67] <https://en.wikipedia.org/wiki/Brass> Date of access March 24, 2020
- [68] Ünlü B.S.; Bakır Esaslı CuSn10 ve CuSn30 Yataklardaki Alaşım Elementlerinin Aşınma ve Mekanik Özelliklere Etkisi; Makine Teknolojileri Elektronik Dergisi; 2006; Pages 11-17.
- [69] Klocke F., Nobel C., Veselovac D.; Influence of Tool Coating, Tool Material, and Cutting Speed on the Machinability of Low-Leaded Brass Alloys in Turning; Materials and Manufacturing Process; 2016; Volume 31, Issue 14, Pages 1895-1903. doi.org/10.1080/10426914.2015.1127944
- [70] Choucri J., Zanotto F., Grassi V., Balbo A., Touhami M. E., Mansouri I., Monticelli C.; Corrosion Behavior of Different Brass Alloys for Drinking Water Distribution Systems; Metals; 2019; Volume 9, Issue 6, Pages 649. doi.org/10.3390/met9060649
- [71] http://www.almag.it/uploads/leghe/CZA25CW625N_TN_EN.pdf Date of Access: March 25, 2020
- [72] Özhan Doğan S., Ekici B.; The Effect of Hot Forging Pressure and Heat Treatment on CW625N Lead Free Brass Alloy Dezincification Resistance; Acta Physica Polonica A; April 2020; Volume 137 Pages. doi.org/10.12693/APhysPolA.137.545

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- 2 Anık B.G., Eren Ş., Özhan Doğan S, Kanpara G.; 50.000 Ton Kaldırma Kapasiteli Yüzer Havuzun Denize İndirilişinin Ele Alınması; 5. Uluslararası Mühendislik Mimarlık Ve Tasarım Kongresi; December 46/ 2019; Page 1435.
- 3 Anık B.G., Eren Ş., Özhan Doğan S, Kanpara G.; Türkiye Tersanelerinde Yaşanan 2008 Krizi Ve Son 20 Yıllık Gemi İnşa Sanayisinin Gelişimi; 5. Uluslararası Mühendislik Mimarlık Ve Tasarım Kongresi; December 46/ 2019; Page 1595.

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