



T.R.
EGE UNIVERSITY
Graduate School of Applied and Natural Science



OPTIMIZATION OF PRETREATMENT PROCESS FOR THE IMPROVEMENT TEST PERFORMANCE

PhD Thesis

Mümin Yağız Altınörs

Chemical Engineering Department

İzmir
2019

T.R.
EGE UNIVERSITY
Graduate School of Applied and Natural Science

**OPTIMIZATION OF PRETREATMENT PROCESS
FOR
THE IMPROVEMENT OF TEST PERFORMANCE**

Mümin Yağız ALTINÖRS

Supervisor : Prof. Dr. MUSTAFA DEMİRCİOĞLU

Chemical Engineering Department
Chemical Engineering Second Cycle Programme

İzmir
2019

Mümin Yağız ALTINÖRS tarafından Yüksek Lisans tezi olarak sunulan “Optimization of Pretreatment Process for the Improvement of Test Performance ” (Test Başarımını İyileştirmek için Önışlem Sürecinin Eniyileştirilmesi)başlıklı bu çalışma EÜ Lisansüstü Eğitim ve Öğretim Yönetmeliği ile EÜ Fen Bilimleri Enstitüsü Eğitim ve Öğretim Yönergesi'nin ilgili hükümleri uyarınca tarafımızdan değerlendirilerek savunmaya değer bulunmuş ve 20/08/2019 tarihinde yapılan tez savunma sınavında aday oybirliği/oyçokluğu ile başarılı bulunmuştur.

Jüri Üyeleri:

İmza

Jüri Başkanı:

Prof. Dr. Kadir YURDAKOÇ

Raportör Üye:

Dr. Öğr Üyesi Canan CAN URAZ

Üye :

Prof. Dr. Mustafa DEMİRCİOĞLU

.....
.....

.....
.....

.....
.....

EGE ÜNİVERSİTESİ FEN BİLİMLERİ ENSTİTÜSÜ

ETİK KURALLARA UYGUNLUK BEYANI

EÜ Lisansüstü Eğitim ve Öğretim Yönetmeliğinin ilgili hükümleri uyarınca Yüksek Lisans Tezi olarak sunduğum “Optimization of Pretreatment Process for the Improvement of Test Performance ” başlıklı bu tezin kendi çalışmam olduğunu, sunduğum tüm sonuç, doküman, bilgi ve belgeleri bizzat ve bu tez çalışması kapsamında elde ettiğimi, bu tez çalışmasıyla elde edilmeyen bütün bilgi ve yorumlara atıf yaptığımı ve bunları kaynaklar listesinde usulüne uygun olarak verdiğimi, tez çalışması ve yazımı sırasında patent ve telif haklarını ihlal edici bir davranışımın olmadığını, bu tezin herhangi bir bölümünü bu üniversite veya diğer bir üniversitede başka bir tez çalışması içinde sunmadığımı, bu tezin planlanmasından yazımına kadar bütün safhalarda bilimsel etik kurallarına uygun olarak davrandığımı ve aksinin ortaya çıkması durumunda her türlü yasal sonucu kabul edeceğimi beyan ederim.

22/ 08 / 2019

İmzası

Adı-Soyadı

M. Yeğen

ACTIVONS

ÖZET

TEST BAŞARIMINI İYİLEŞTİRMEK İÇİN ÖNİŞLEM SÜRECİNİN ENİYİLEŞTİRİLMESİ

ALTINÖRS, Mümin Yağız

Yüksek Lisans Tezi, Kimya Mühendisliği Anabilim Dalı

Tez Danışmanı: Prof. Dr. Mustafa Demircioğlu

Haziran 2019, 60 sayfa

Bu çalışmanın amacı boya test performansına etkisi olan alüminyum jant üretiminin alt süreçlerinden biri olan yüzey hazırlama sürecini incelemektir. Alüminyum alaşımlı jantlar seri üretim öncesi bir dizi boya testlerine tabi tutulmaktadır. Bu testler uluslararası standartlarca belirlenmiş ve araç üreticileri tarafından da onaylanmıştır. Jant üreticileri, proje süresi boyunca müşteri şartnamelerinde yer alan boya testlerini başarılı bir sonuca ulaştıracak boya sürecini sağlamak durumundadır.

Bu çalışma boyunca alüminyum alaşımlı jantların üretimi, işlem temelli olarak, şekiller ile pekiştirilerek aktarılmış; bunun yanında boya işlemi içinde yer alan yüzey hazırlama süreci ile bu yüzey hazırlamada kullanılan kimyasallar tanıtılmıştır.

En uygun süreç parametrelerinin bulunması için deney tasarımı yöntemi kullanılmış, deneyler boya testleri ile doğrulanmıştır. Deney sonuçları istatistiksel olarak incelenmiştir.

Anahtar sözcükler: Alüminyum Alaşımlı jant, Yüzey Hazırlama Süreci, Boya testleri, TAC testi, Deney tasarımı.

ABSTRACT**OPTIMIZATION OF PRETREATMENT PROCESS FOR THE
IMPROVEMENT OF TEST PERFORMANCE**

ALTINÖRS, Mümin Yağız

MSc in Chemical Eng.

Supervisor: Prof. Dr. Mustafa Demircioğlu

June 2019, 60 pages

The purpose of this study is to examine the pretreatment process, one of the sub-processes in aluminum wheel production, which has an effect on coating test performance. Before mass production, aluminum alloy wheels undergo a series of coating tests. These tests are determined by international standards and approved by vehicle manufacturers. Wheel manufactures must provide the paint process that will ensure successful test results of the coating test according to customer specification within project period.

In this study, production of aluminum wheels, are explained with figures, based on operations; beside that the pretreatment process, a part of the coating process, and the chemicals used in the pretreatment process are introduced.

In order to find the most suitable process parameters DOE (Design of Experiment) method was applied, and the experiments were verified according to the coatings. Also, the experimental results were statistically analyzed.

Keywords: Aluminum alloy wheel, Pretreatment Process, Paint Test, TAC test, Design of Experiment.

ÖNSÖZ

Yüksek lisans tezimin konusu, halen çalıştığım kurumda, ortaya çıkan sorunların çözümünde kullanılan, ancak, zaman ve kaynak kaybına neden olan, deneme yanılma yöntemi yerine, bilimsel bir temeli dayalı yeni bir yaklaşım geliştirmektir. Bu çalışmanın sonucunda, işletme parametrelerinin önem sırası ortaya çıkarılmış, doğru olarak kabul edilen kimi işletme koşullarının, önem sırası ya da değerlerinin yanlış olduğu, istatistiksel çözümlene ve deneysel doğrulama ile görülmüştür. Tezim sayesinde tanışmış olduğum ve mühendislik uygulamaları için ne kadar önemli bir araç olduğunu öğrendiğim DOE yönteminin, somut bir sorunun çözümünde başarılı bir şekilde uygulandığı bu çalışmanın, bu ya da benzer alanda çalışanlar için teşvik edici ve yol gösterici olacağına inanıyorum.

İZMİR

07/07/2019

M. Yağız ALTINORS

TABLE OF CONTENT

ÖZET	VII
ABSTRACT	IX
ÖNSÖZ	XI
LIST OF FIGURE	XV
1. INTRODUCTION	1
1.1. WHEEL PRODUCTION	4
1.1.1. PRODUCTION BY FORGING METHOD	4
1.1.2. PRODUCTION BY COLD FORMING METHOD	5
1.1.3. PRODUCTION BY ALUMINUM LOW PRESSURE CASTING METHOD	5
2. PRETREATMENT PROCESS	17
2.1. DEGREASING	17
2.2. DEOXIDATION	19
2.3. PASSIVATION	20
2.4. FILIFORM CORROSION	21
2.4.1. MECHANISM OF FILIFORM ATTACK	24
2.4.1. FILIFORM CHEMISTRY	24
3. METHODS AND APPLICATION	26
3.1. DESIGN OF EXPERIMENT	26
3.2. TITRATION METHOD AND TEST SPECIFICATION	38
3.1.1 TOYOTA SPECIFICATION	39
3.1.2. FILIFORM CORROSION TEST (TAC) SPECIFICATION (TSH1552G)	43
4. RESULTS AND DISCUSSION	48
5. CONCLUSION	55
REFERENCES	56
CURRICULUM VITAE	60

LIST OF FIGURE

<u>Figure</u>	<u>Page</u>
Figure 1.1 Evolution of wheels (Steidl, 2019).	1
Figure 1. 2 Aluminum alloy wheels (Cms, 2019).	3
Figure 1.3 Dimensions used in the classification of aluminum alloy wheels (Cms, 2019).	3
Figure 1.4 Cross- section of Aluminum wheels (Cms, 2019).	3
Figure1. 5Aluminum blocks for Forged (Arconic, 2019).	4
Figure 1. 6 Forging operation (Arconic, 2019).	5
Figure 1.19 Paintshop operation for standard wheel.	14
Figure 2.1 Mechanism of particle removal from surfaces. (Streitberger & Dössel, 2008).....	18
Figure 2.2 Mechanism of oil removal from surfaces (Streitberger & Dössel, 2008).	18
Figure 2. 3 Bonderite 6706 conductivity versus time (Henkel, 2014).	19
Figure 3.1 CTQ of process.	26
Figure 3.2 SIPOC diagram of process.	28
Figure 3.3 Detailed process diagram.	28
Figure 3.4 Process capability of deoxidation conductivity.	32
Figure 3.5 Process capability of deoxidation temperature.	32
Figure 3.6 Process capability of passivation temperature.	33
Figure 3.7Process capability of passivation conductivity	33
Figure 3.8 Process capability of DI 2 conductivity.	34
Figure 3.9 Gage R &R titration of total acid.	35
Figure 3.10 Gage R &R temperature.	36
Figure 3.11 Example cutter knife (Unit: mm).	42
Figure 3.12 Holding the cutter knife.	43
Figure 3.13 Salt spray test apparatus (Toyota).	44
Figure 3.14 Relations between The temperature and the Specific Gravity of Salt Water (Toyota).....	47
Figure 4.1 Test result of Std Order 5. Figure 4.2Test result of Std Order 81.....	50
Figure 4.3 Test result of Std Order 21. Figure 4.4 Test result of Std Order 8.....	50
st result of Std Order 1. Figure 4.6 Test result of Std Order 5.	51
Figure 4.7 Effect of Pareto Diamond Tac1_8.	51
Figure 4.8 Interaction Plot for CS Tac1_8.	52
Figure 4.9 Optimization Plot for Cs Surface.	53
Figure 4.10 Effect of Pareto Diamond Tac1_8.	53
Figure 4.11 Interaction Plot for Diamond Cut Tac1_8	54

LIST of TABLES

<u>Table</u>	<u>Page</u>
Table 2.1 Filiform Corrosion growth rates on coated aluminum alloys.	24
Table 3.1 C&E Matrix.....	30
Table 3.2 Remark of Cp.	31
Table 3.3 Design run order 1 to 64 and condition.....	37
Table 3.4 Coating quality.	40
Table 3.5 Working Conditions of salt spray test apparatus (Toyota).....	46
Table 4.1 Test parameter & TAC test result.	48

SYMBOLS and ABBREVIATIONS

Symbols	Definition
Al	Aluminum
Ar	Argon
°C	Celsius
Fe	Iron
H	Hydrogen
N	Nitrogen
Mg	Magnesium
Si	Silicon
Ti	Titanium
Zn	Zinc
µm	micron

Abbreviations

ASTM B117

BC Before Christ

CMS CMS Jant Makina Sanayi A.Ş.

CNC Computer Numerical Control

ET Einpresstiefe

SYMBOLS and ABBREVIATIONS (continued)

ETRTO European Tire and Wheel Technical Organization

Abbreviations

ISO 6363-2 Reagents for Chemical Analysis - Part 2: Specifications

OEM Original Equipment Manufacturer

DMADV Define Measure Analyze Design Verify

ppm parts per million



1. INTRODUCTION

Wheels are parts of a vehicle, that directly affect the safety of a vehicle, and are strictly regulated. Wheels have the greatest important part in a car since on which tires are mounted and works under whole load of a car. Mechanically, wheels are rotating parts that move forward an object on a surface. In order for the wheel to rotate on the surface, it must be exposed to the external forces that will contact with it.

A Sumerian pictograph from about 3500 BC shows a pictogram of a wheel in Figure 1.1, so researchers agree that, the wheel was invented at about 3500 BC. The idea of wheeled transportation may have come from the use of logs for rollers, but the oldest known wheels were wooden disks consisting of three carved planks clamped together by transverse struts. Spoked wheels were invented about 2000 BC and allowed for the production of lighter wheels, but capable of handling more load (Tudor, 2009).



Figure 1.1 Evolution of wheels (Steidl, 2019).

The automobile wheels have started with Karl Benz's 1885 Benz Patent Motorwagen. The three-wheel vehicle used bicycle-like wire wheels, which were fitted with hard rubber. The style, material, method of production of wheel changed day by day. It has evolved at the beginning of invention.

For the development of less fuel-consuming vehicles without compromising both safety and comfort; the development of alloys with low density, hence low weight but high strength is the most important goal of Original Equipment

Manufacturers (OEM's) and automotive suppliers manufacturers. Therefore, the most important materials that come the forefront for OEM's and automotive supplier industry are light construction material and alloys such as titanium, aluminum, magnesium. When the classification of material is made according to the disadvantage and advantages of these alloys, the advantages of aluminum in terms of cost, machinability, corrosion resistance and recycling have caused the increasing of its usages in automotive industry every year. Another reason for the increase in the use of aluminum alloys is the importance of passenger safety which is important than consumption of fuels. The energy generated during the collision must be absorbed by shock absorber. Aluminum alloys are most suitable alloys for this purpose. In addition to the low density and high impact absorption properties of aluminum; high corrosion resistance, electrical conductivity, reproducibility and aesthetic properties of aluminum alloys has provided to common in the wheel production (Başer, T. A. 2012).

According the sector report of Association of Turkey Casting Industry, domestic aluminum alloy production wheels increased 400 times from 20000-25000 wheels per year to 9 million wheels per year in 25 years. There are six manufacturers of aluminum wheels, two of which are foreign investor. The facilities employed over 2500 qualified employees. In 2011, those six plants have reached an installed capacity of 9,500,000 units per year and production was made 95% capacity. In this year, 80% of production was for OEM's and the others was for aftermarket. Also, 90% of production was exported (Dal, 2012). Aluminum alloy wheel is shown in Figure 1.2.

The dimensions and characteristics used for the definition and classification of wheels, is shown in Figure 1.3, have been determined by the European Tire and Wheel Technical Organization (ETRTO). These dimensions and features are nominal width, nominal diameter, flange type, offset depth, number of wheel bolts and wheel axis diameter (Figure 1.4). In passenger cars, wheels whose a nominal width are 4 to 10 inches, and nominal diameter is 10 to 22 inches are used (Manuel, 2014).



Figure 1.2 Aluminum alloy wheels (Cms, 2019).

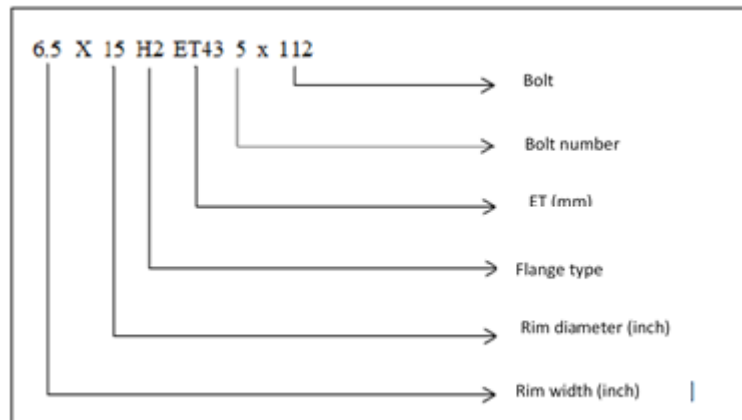


Figure 1.3 Dimensions used in the classification of aluminum wheels (Cms, 2019).

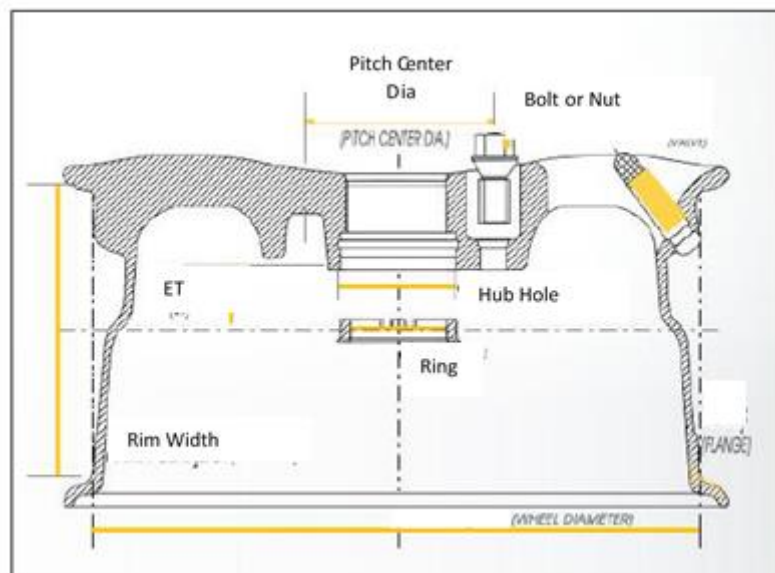


Figure 1.4 Cross- section of Aluminum wheels (Cms, 2019).

1.1. Wheel Production

This section provides the information about different production method of aluminum wheels. Pretreatment process is to be examined within the scope of the thesis, and the casting, machining and other processes are explained.

1.1.1. Production by Forging Method

Forging process shapes the molecular texture of aluminum according to geometry of wheels. Forged aluminum wheels are often used when strength values need to be very high, as for trucks, buses and trailers.

Production by forging method, which is similar to casting process, has been dramatically reduced, because of high total cost.

The forging process and production steps involve similar steps with the casting method. However, they differ in the raw material preparation stage. In the casting method, the continuously melted raw material is kept ready as a charge and in the production approximately 15-20 wheels are made from one charge. In the forging method, the production process is started with a wheel which is prepared as a single Al block (Figure 1.5).



Figure1.1Aluminum blocks for Forged (Arconic, 2019).

With an 8000 tons press, the block is forged into a wheel shape. Once forged, the wheels are heat-treated to maximize overall mechanical strengths.



Figure 1.2 Forging operation (Arconic, 2019).

Forging process, is shown in Figure 1.6, aligns the grain flow of aluminium with the shape of the wheel. As the result of process, homogeneous strength is obtained on throughout the wheels. Precision machining in the production line ensures that each wheel is perfectly round. This eliminates any runout in a turning wheel. The ventilation and mounting holes are drilled. Then different pretreatment methods are applied the wheels (Arconic, 2019).

1.1.2. Production by Cold Forming Method

The material most commonly used in cold forming is steel sheet. The process steps begin with sophisticated laser-cutting workshop. Discs and rims are produced in this step. Then, discs of the wheel are produced by CNC machines using flowform method. Then at the disc and the rim assembly line, welding is performed either by robots or manually, with both utilizing inert gas and arc welding. Wheels are controlled for run-out and eccentricity. Final operation is anti-corrosion process which are zinc- phosphate and e-coat (electro-cathodesis) processes (Maxion wheels, 2019).

1.1.3. Production by Aluminum Low Pressure Casting Method

Low pressure casting method is a casting method which is based on the principle of filling the liquid metal with the aid of pressure. Since the mold used in casting is expensive, low pressure casting production is an economic method only in mass production. Before the low pressure casting methods, wheels had been produced by gravity casting method. However the gravity casting method were not able to pass the mechanical strength and wheel surface properties

requirements, which were increased by OEMS's demands (Dispinar, 2012). Nonmetallic and slags are present on the surface of the molten alloy in the crucible and heavy metals are deposited at the bottom. In the low pressure casting method, the material is taken form the clean part of the melt with aid of the riser tube (Figure 1.7).

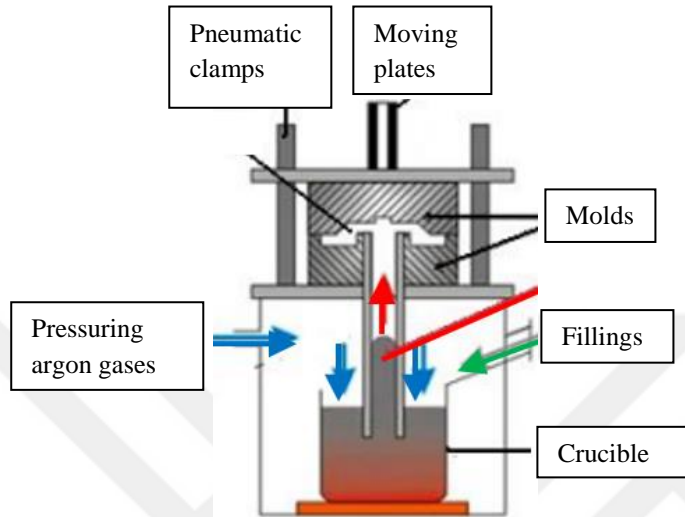


Figure 1.7 Low pressure casting device (Cms, 2019).

In gravity casting process, filling clean material method in low pressure casting can be inapplicable; therefore, due to not casting clean metal, the desired properties cannot be obtained as much as required. High pressure casting is more advanced than low pressure casting and is used in the production of smaller and more complex parts. This method, which is preferred for the production of parts which cannot be filled by low pressure casting method, is more expensive than low pressure casting method and low pressure casting method meets today's expectations in order to meet wheels requirements (Aran, 2007).

In this section, CMS Jant Makina Sanayi Industry Inc.'s plant, which produces alluminum alloys, the mass production steps of wheels with low pressure production methods is explained. The main process is shown in Figure1.8.



Figure 1.8 Main process of wheel production.

Raw Material Quality Control

Aluminum ingots, which are taken in blocks, are subjected to input quality control process. Microstructure control, visual control and chemical composition analysis are performed for aluminum ingots according to the related specification. After color coding on the basis of corresponding alloy, suitable ingots are conveyed to the raw material preparation section.

Raw Material Preparation

The raw material preparation stage starts with the melting of the alloy ingots. AlSi7 and AlSi11 alloys are melted in different furnaces. Melting of AlSi7 and AlSi11 chips from these materials is also performed in different furnaces. After the melting process is completed, certain amounts of metals are taken from chips and ingot furnaces. Ideally, a 100% AlSi7 or AlSi11 alloy should be used, but the chips from these materials are also reused in production for cost reduction and recycling (Figure 1.9).

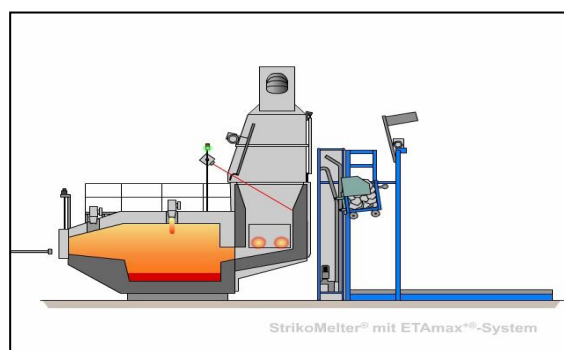


Figure 1.9 Melting furnaces (striko) (foundry, 2019).

Molten metal is taken to the degassing process in ladles before casting. In this stage additions are required for grain refining, modification and alloying.

These additions include Mg addition for alloying, Sr addition for modification, and AlTi 5B addition for grain thinning (Manual, 2002) , (Gautam Krishnan, 2013), (Gruzleski & Closset, 1990). These alloys are made prior to degassing to make the mixture more homogeneous (In Figure 1.10)



Figure 1.10 Sr, AlTi5B and Mg rod (Cms, 2019).

Degassing, is shown in Figure 1.11, can be done in three different ways in different production methods. These methods include degassing using N_2 gas, degassing using N_2 flux, and controlled H_2 addition with N_2 flux degassing. The purpose of using gases in degassing process is to clean the metal by removing oxides, foreign particles and H_2 flotation from the surface. Ar can be used instead of N_2 for the same purpose, but the use of N_2 gas is more common due to high cost of Ar.

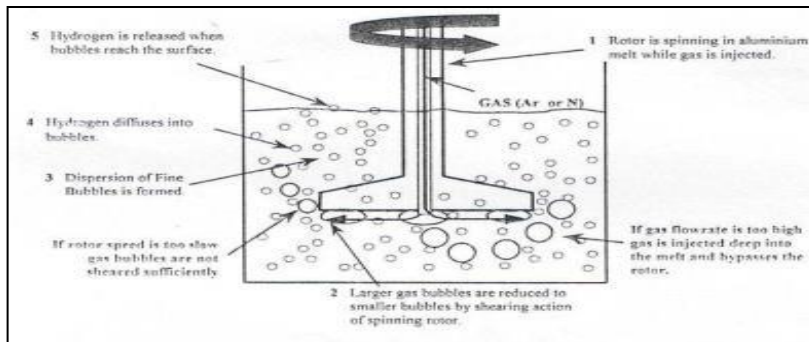


Figure 1.11 Degassing process.

Casting Process

After the degassing process is completed, the metal is transferred to the casting machine. At the beginning of the operation, a certain period of time is required for the temperatures of the furnace and the metal to come to a balance. After the temperature values have reached the desired level, casting starts, and then the production continues without interruption.

The basic elements used in the production of rims with low pressure casting method are the upper core, the lower core, runner and side walls (Figure 1.12). In the production of upper cores and lower cores, it is generally preferred to use mold steels and in the production of side blocks GG28 cast iron is used. The runner material is ceramic.

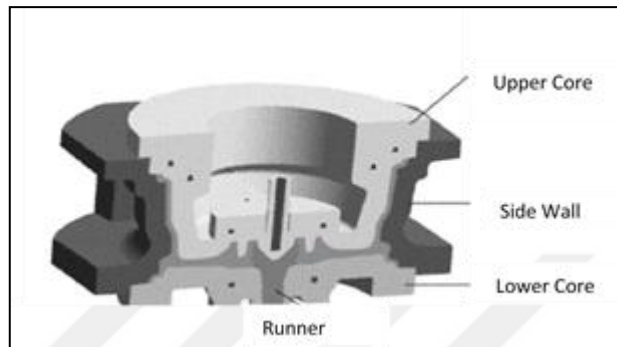


Figure 1.12 Mold and core.

Metal transfers from furnace to the mold by vertical runner (riser tube) (Figure 1.13). With runner, the material is taken from the clean part of the metal and delivered to the mold. The metal is conveyed to the mold by pressurized air, Ar or N₂ gases. Either Ar or N₂ gas is used, depending on the fluidity value of the alloy to be produced.

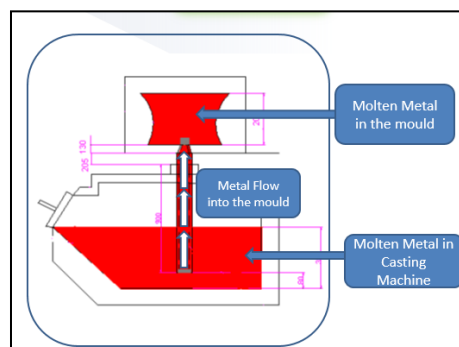


Figure 1.13 Casting process.

The casting cycle time includes metal filling and solidification time. The metal fills into the mold in approximately 30-40 seconds. This time does not differ significantly between both alloys. The production of AlSi7Mg and AlSi11Mg is noticed during the solidification stage, AlSi11Mg about 240 - 260 seconds, AlSi7Mg alloy 300 - 320 seconds solidifies in the range.

After the filling of the metal into the mold is completed, coolings are placed in such a way that directional solidification is provided in the mold. The solidification takes place in the opposite direction to the casting direction. Figure 1.14 shows the casting and solidification directions on the casting section.

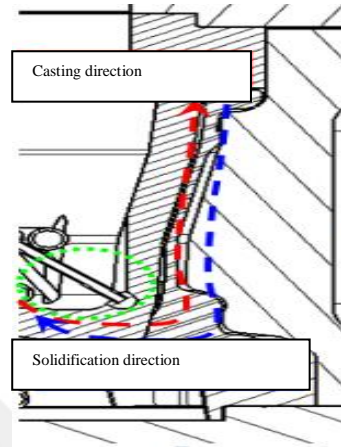


Figure 1.14 Casting process (Ercan, 2012).

When solidification is complete, the wheels are removed from the mold and immersed in the cooling pool located next to the device. The purpose of this cooling pool is not to improve mechanical properties of the product, but to reduce the temperature of the rim to prevent damage to the machine and the operator in subsequent processes.

X-ray Control of Casting

Due to fluctuations in casting process, defects such as blowholes, shrinkage and porosities can't be cleared up even with the use of advanced production methods. When all of the wheels produced are controlled by X-ray inspection, which is a safety requirement, any defect on a wheel can be detected easily. There are two types of this method. One of them is radiographic control, which is not suitable for mass production because the evaluation has to be done on the film. The other type, radiosopic control, is applied in wheel industry. Real-time control is done by this method; improper wheels with defects are not approved and are automatically separated into the scrap area at the exit of X-ray control (Akın Ü., 2008).

The types and sizes of conformity permitted on the wheels are defined by the customer specifications. These errors are identified on the X-Ray controllers and the improper wheel is automatically discarded. Wheels that are safely separated from this control are transferred to the next process. The next step after the X-ray control process depends on the material to be used. If the material is AlSi7Mg, heat treatment process has to be done.

Heat Treatment Process

Aluminum alloy wheels are subjected to heat treatment by artificial aging method indicated by T6 in order to reach the desired strength values (In Figure 1.15). T6 heat treatment consists of three stages: solution removal, quenching and artificial aging. In the solution step, the growth of the Mg and Si grains occurs and a homogeneous solid solution is obtained (Demir C. & Menteşe E.B., 2019). The solution takes place for about five hours in the sub-eutectic temperature range of 535 - 545 °C. During quenching, grains are formed by rapid cooling. By quenching, it is ensured that the Mg component does not remain in the grain and is formed at the grain boundaries, which requires diffusion and time. To accelerate diffusion, artificial aging occurs at an ambient temperature of 150 - 200 °C. Here, Mg₂Si precipitation, which is the active component of diffusion and heat treatment, occurs at the grain boundaries, which are high energy regions, and strength increase is achieved. There should be no more than 30 seconds between the descaling and the quenching furnace, otherwise the desired mechanical properties may not be achieved.

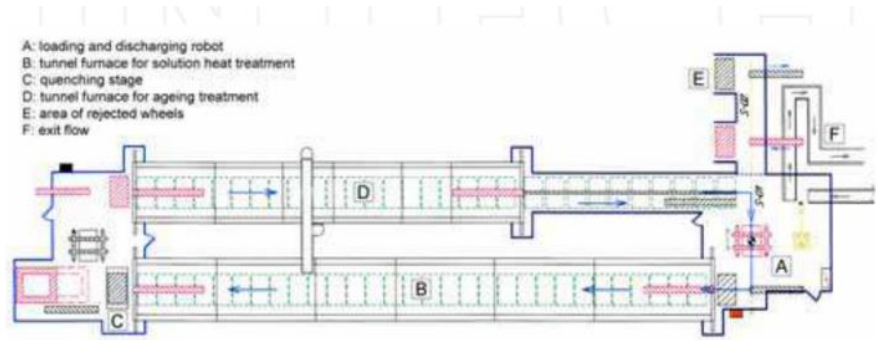


Figure 1.15 Heat treatment process.

Machining Operation

Construction of the desired tire cross-section form, drilling of cap, wheel bolt and valve of the wheels produced by low pressure casting method are performed in this operation. For these operations, it is necessary to provide the necessary tools and machines, to prepare appropriate machine processing programs, to prepare operational instructions and control plans. The dimensions of inner diameter, outer diameter, hole and offset edges of the wheel, are produced at the first machining operation (Figure 1.16). The cover, style, bead and outer diameter are afterwards machined. The wheel and valve holes are drilled (Figure 1.17).

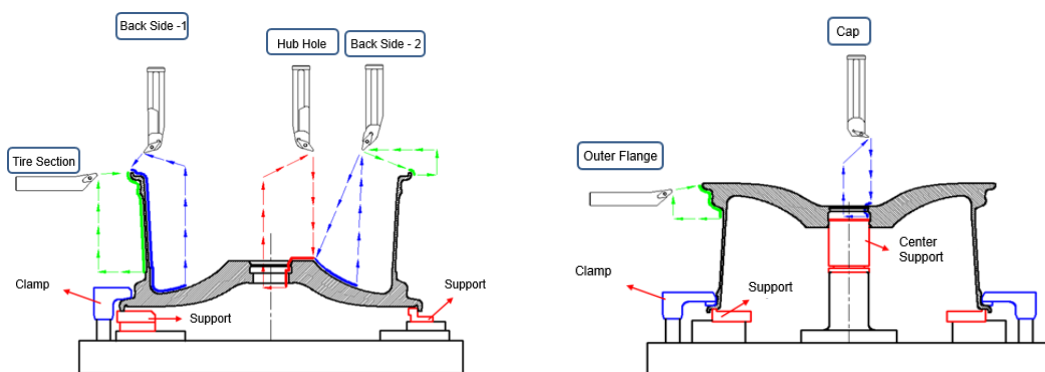


Figure 1.16 Main machining operation a) First step b) second step.

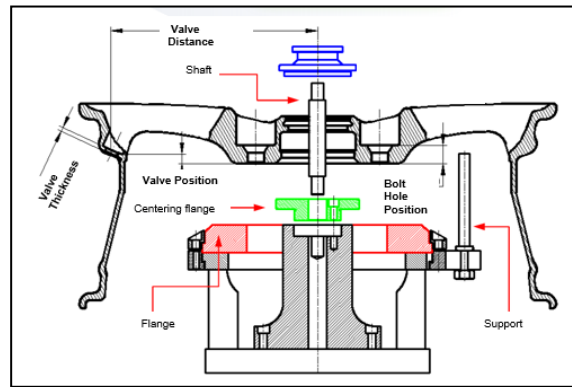


Figure 1.17 Drilling operation.

Balance Control, Sealing and Deburring Operations

Wheels whose machining operations are completed are subjected to balance and leakage (sealing) tests. Sealing is a safety characteristic, so it must be 100 % checked.

After a wheel has been injected with a gas containing helium up to a specified pressure, the helium leak tester uses mass spectrometry to measure leakage into the chamber and then determines whether that leakage is under or above a leakage threshold. If it is above, the wheel has to be separated as scrap. After these controls, deburring operation is done; burrs on the rim, surface defects and sharp corners are removed. Wheels that complete this process are put into production in the paintshop.

Bright Machine Process

Bright machine operation, also known as diamond-cut, is an optional process, applied to pre-painted wheels (In Figure 1.18). The first step is the mounting of the alloy wheel on the lathe. Then the machining tool machines off the entire painted surface to leave a shiny alloy. Wheels produced by this method are gaining popularity.



Figure 1.18 Diamond cut operation.

Paintshop

The purpose of the paintshop process in wheels production is to protect the wheels from the corrosive effects of environmental conditions, to provide aesthetic appearance and to extend the lifetime of the equipment with special coatings. The paintshop process steps are surface treatment (pretreatment), powder coating (primer) application, liquid paint application, varnish application and final control. According the type of wheels, the paintshop process is changed. These are shown in Figure 1.19 and Figure 1.20.



Figure 1.19 Paintshop operation for standard wheel.

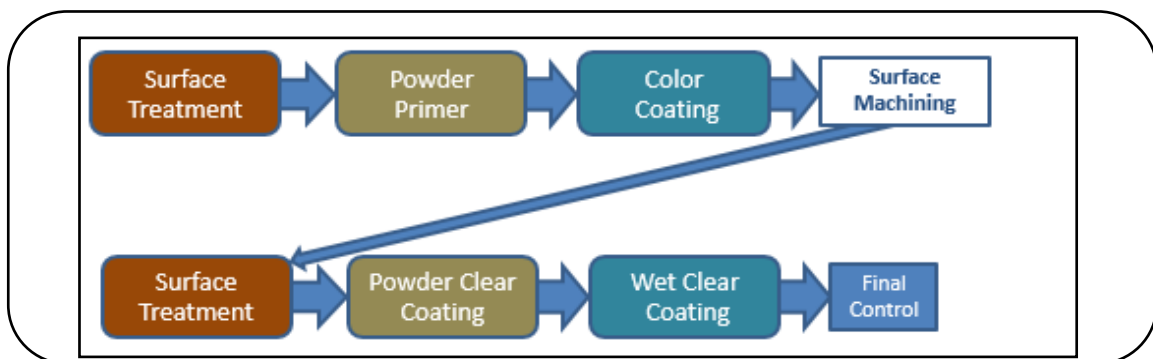


Figure 1.20 Paintshop process for diamond cut wheels.

Pretreatment is the most important application in the paintshop process. Pretreatment process eliminates the impurities on the wheel surface formed during machining process, and improves the adhesion of the paint on the surface. Several chemicals with different functions are used in pretreatment process. In CMS, there are ten bath in pretreatment line (Figure 1.21). The functions of these chemicals are explained in detail in the following section.

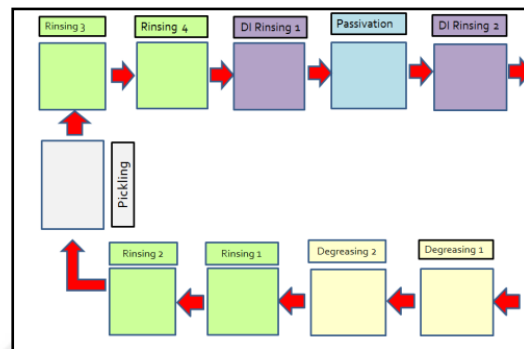


Figure 1.21 Pretreatment operation in CMS.

After pre-treatment process, powder coating is applied. This is a process where electrostatically charged dry powder coating and resin mixture is applied on an electrically grounded piece of metal with guns. The powder is drawn to the metal during the spraying process. The purpose of the application of a thick layer of powder coating is to provide corrosion protection and to give a smooth surface on which liquid paint is to be applied.

Powder coatings application includes large volumes of air because paint is transported with air on the wheels. (In Figure 1.22) This air has to be removed during melting and before crosslinking. Benzoin and its derivatives are suitable as additives for this purpose. Aluminum oxides also have an impact on the chargeability of the powder particles. After application of coating, the wheels are transferred to the curing oven where the coating is cured. Curing is the process of transformation of an organic coating film to a rigid film of thermosetting character as a result of polymerization reactions.



Figure 1.22 Powder paint booth.

During the transfer, montage and cap surfaces are brushed to remove the powder dust, because the montage surface must be free of any paint or dust particles.

Wet paint and wet clearcoat are applied with spray guns. In Çiğli plant, HVLP (high volume low pressure) type of spray gun is used. It permits a compromise between an optically attractive coating and reduced overspray formation.

The pigmented topcoat is usually applied in two steps; “wet on wet” with a basecoat and a clearcoat. “Wet on wet” means that the two coatings are applied in rapid succession without baking the basecoat so that they can be baked and crosslinked together. This basecoat system must then provide the correct color and a high appearance after interaction with the substrate and the other coating layers. After the flash off zone where a highly adhering, hard and enduring film forms as a result of solvent evaporation, wheels pass through the curing oven.

Final Inspection and Packaging

The wheels that are subject to 100% visual inspection according to the customer failure catalogue are packaged according to customer demand and delivered to the warehouse for shipment.

2. PRETREATMENT PROCESS

The standard pretreatment process for wheels comprises the following four operations for optimum preparation of the aluminum surface:

- Precleaning (optional)
- Degreasing
- Pickling
- Passivation

Depending on the degree of cleanliness of the wheels entering the coating line, the legislation demands with respect to cascade rinsing, and the existence of a post rinsing stage, the pretreatment line can have up to 14 stages for a safe and reproducible process. In CMS, spray (nozzle) application is used for the pretreatment. This method is suitable for parts with simple geometries. The advantages of spraying application are:

- short treatment time
- requires only small bath volume less investment cost
- less space, low capital cost
- excellent for particle removal

2.1. Degreasing

The purpose of degreasing is to remove all kinds of contaminations from the metal surface, to achieve a water-break free surface, that is, a continuous water film on the surface after rinsing off excessive degreasing chemicals with water and to obtain a reactive surface which is able to build up the zirconium coating that is, the conversion layer, within a reasonable period of time.

Alkaline degreasers, are composed of inorganic salts, the 'builder', and organic compounds, the 'surfactants'. The predominant task of the builder is to remove inorganic and pigment contaminants like metal grains and welding pearls. The task of the surfactant is to remove oils, lubricants, soaps, and other organic contaminants. Typical builders used in alkaline cleaners are:

- NaOH, KOH, Na₂CO₃, K₂CO₃ → maintaining alkalinity
- Silicates → particle removal, inhibition, buffering
- Orthophosphates → degreasing
- Condensed phosphates → degreasing, complexing
- Complexing agents → complexing.

Surfactants contain a hydrophilic group, that is, a long chain of ethoxy (EO) and/or chain of propoxy (PO) molecules, and a hydrophobic group, which is typically a long chain alkyl. They are classified as anionic, cationic, nonionic, and amphoteric surfactants. In degreasing, typically nonionic surfactants are in use today owing to their better environmental compliance. The mechanism of particle removal from surfaces is shown in Figure 2.1. Owing to their amphiphilic characteristics, surfactants in solutions reduce interfacial tensions, adsorb at solid interfaces, and form micelles. The mechanism of oil removal from surfaces is shown in Figure 2.2. The surfactants first adsorb on the oil surface, and then reduce the surface tension and remove separated droplets containing the oil from the surface.

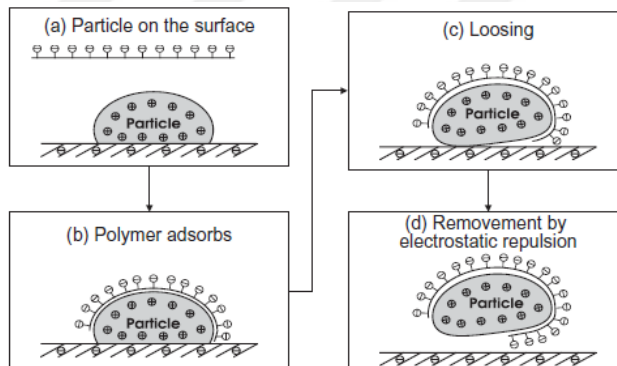


Figure 2.1 Mechanism of particle removal from surfaces. (Streitberger & Dössel, 2008)

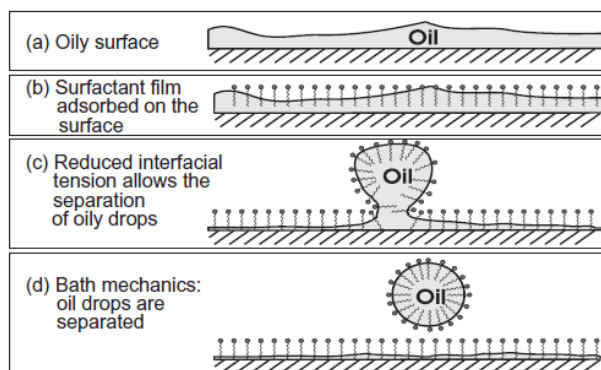


Figure 2.2 Mechanism of oil removal from surfaces (Streitberger & Dössel, 2008).

Degreasing is done in the degreasing bath. The level of the bath is kept constant by addition of city water. The degreasing baths is controlled mostly by titration method:

- Free alkalinity
- Total alkalinity
- Conductivity
- pH

Total and free alkalinity are defined by different titration methods instead of conductivity method, which are developed by Henkel which is supplier of Bonderite 6706. In practical terms, degreasing baths pick up oil and other contaminants that have to be either dumped at regular intervals, or need to be continuously passed through filtration systems in which other contaminants are removed (In Figure 2.3). Also, degreasing chemicals etch the aluminum oxide on the surface. Etching rate of the Bonderite 6706 is 0.2-0.4 g/m².

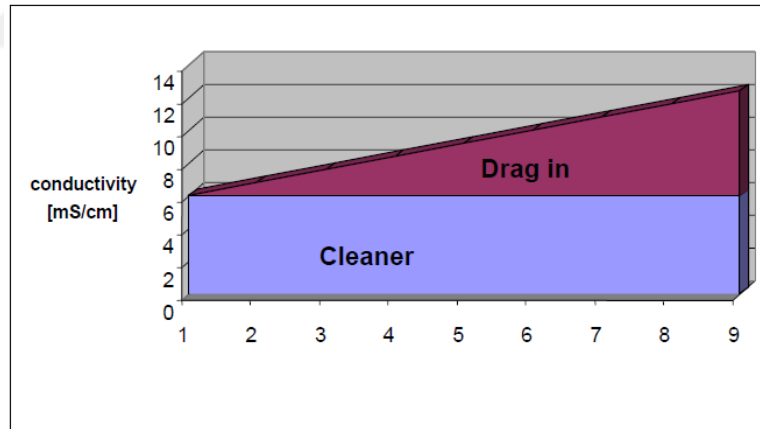


Figure 2.3 Bonderite 6706 conductivity versus time (Henkel, 2014).

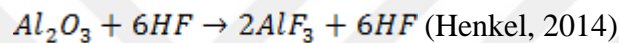
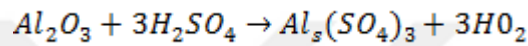
2.2. Deoxidation

In deoxidation process, the chemical removes aluminum oxide from the aluminum substrate via redox reactions. For aluminum, the deoxidation chemical must be a mixture of hydrofluoric, sulfuric or nitric acids (Henkel, 2014). If an alkaline chemical is used for deoxidation (pickling) a dark grey deposit forms on

the surface. The silica present in the alloy of wheels are insoluble in alkaline based media. The target of deoxidation are:

- Removal of metals that are not soluble in alkaline media, like Si, Cu, Zn, Fe
- Neutralization of the surface
- Removal of oxides form the surface

The chemical Bonderite 4902 consists of hydrofluoric acid and sulfuric acid. The reaction mechanism is



2.3. Passivation

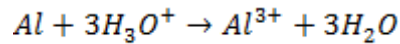
In order to improve the corrosion resistance of aluminum the conversion layer can be given a passivation as a chrome-free solution. Today, hexavalent chrome has been replaced by zirconium based solution due to the toxic danger of chromium-VI compounds. It is generally accepted that the effect of improved corrosion protection is mostly associated with reduction of the pore size by precipitation of insoluble compounds and removal of secondary phosphate crystals from the surface of the phosphate layer by the acidic solution of the passivating agent.

Zirconium-based coating chemicals typically operate under the following conditions:

- Zirconium concentration 50–150 ppm
- Fluoride concentration 50–200 ppm
- pH 3.5–5.0
- Conductivity(20 °C) <600 $\mu\text{S cm}^{-1}$
- Dump frequency 1–4 weeks, depending on contamination level and quality of preceding rinsing bath

Deionized water and a chrome-free passivation chemical, Bonderite 4850, is used for the preparation of the passivation bath. The coating thickness on the surface is 5-15 mg/m². The model of conversion is shown in Figure 2.4. Below, the reaction mechanism is shown; (Henkel, 2014)

Etching of the metal surface:



Zr-Oxide deposition

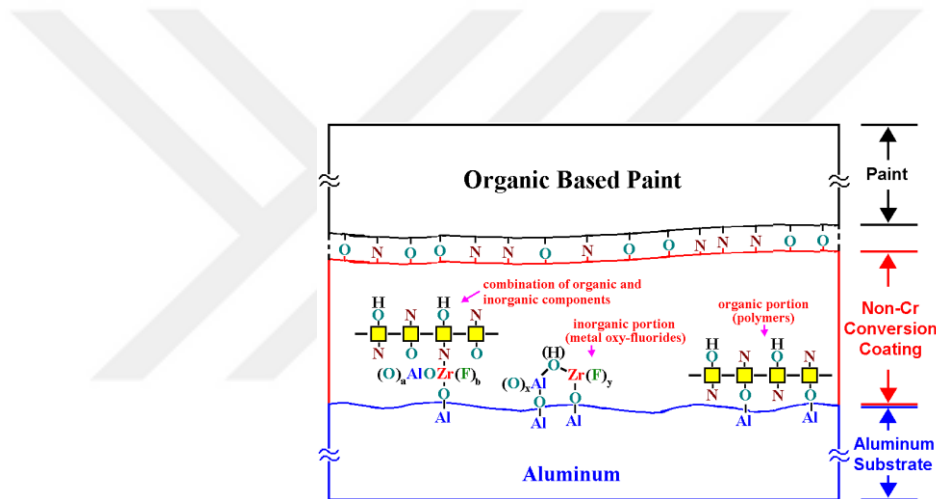
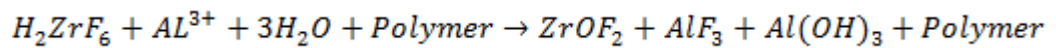


Figure 2.4 Model of conversion.

2.4. Filiform Corrosion

Filiform corrosion is another special case of crevice corrosion that can occur on an aluminum surface under a thin organic coating (typically 0.1 mm). The pattern of attack is characterized by the appearance of fine filaments spreading from one or more sources in semi random directions. Filiform corrosion takes place when the following conditions are present:

- The coating has defects
- The coating is permeable to water.
- Relative humidity is high, specifically in the range 80–95%.

- Contaminants are present on or in the coating or at the coating–substrate interface

The source of initiation is usually a defect or mechanical scratch in the coating. The filaments are fine tunnels composed of corrosion products underneath the bulged and cracked coating. Filiforms are visible at an arm's length as small blemishes. Upon closer analysis, they appear as fine stretches shaped like tentacles or cobweb like traces (Schweitzer, 1996). A filiform has an active head, and a filamentous tail (Figure 2.5).

Filiform corrosion is commonly observed on aluminum sheet, plate, and foil. The corrosion products are gelatinous and milky in color.

Filiform attack in aluminum is particularly severe in warm coastal and tropical regions that experience salt fall or in heavily polluted industrial areas. Filiform corrosion occurs only in the atmosphere, and relative humidity is the single most important factor. This type of attack is rare on aluminum below about 55% relative humidity or above 95%. In natural atmospheres, it occurs most readily on aluminum at relative humidity's between 85 and 95%. Although temperature and the thickness of the organic coating are minor factors, rising the temperature increases the rate of filament growth if the relative humidity stays within the critical range.

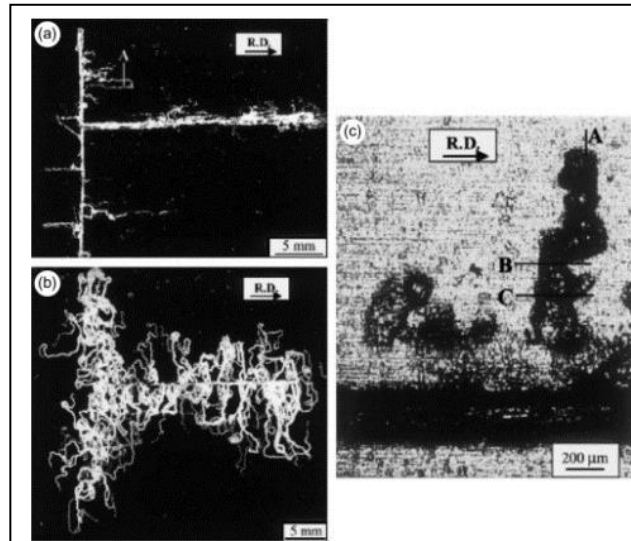


Figure 2.5 Filiform tracks on Al alloy 5005 (Al=0.89 mg-0.17 Fe) after constant humidity exposure (RH 65- 75%) for 1,000 h at 400 °C. Substrates were clear coated with a 15–45- μm thick acrylic resin.

The presence of oxygen is fundamental because it supplies the primary reactant for the cathodic reaction. Essentially, filiform corrosion is a type of oxygen concentration cell in which the anodic area is the head of the filament and the cathode is the area surrounding it, including the tail (Schweitzer, 2004).

Typical filament growth rates average about 0.1 mm/day. Filament width varies, with increasing relative humidity, from 0.3 to 3 mm. The depth of penetration can be as deep as 15 μm . Numerous coating systems used on aluminum are susceptible to filiform corrosion, including epoxy, polyurethane, alkyd, phenoxy, and vinyls. Condensates containing the chloride, bromide, sulfate, carbonate, and nitrate ions have stimulated filiform growth in coated aluminum alloys. Growth rates for filiform corrosion on aluminum with lacquers and various slower-drying resins are summarized in Table 2.1.

Table 2.1 Filiform Corrosion growth rates on coated aluminum alloys.

Coating	Initiating environment	Typical rate		Relative humidity, %	Filament width	
		mm/day	mils/day		mm	mils
Alkyds	HCl vapor	0.1	4	85	0.5–1.0	20–40
Acrylic	HCl vapor	0.1	4	85	0.5–1.0	20–40
Polyurethane	HCl vapor	0.1	4	75–85	0.5–1.0	20–40
Polyester	HCl vapor	0.2	4	85	0.5–1.0	20–40
Epoxy	HCl vapor	0.09	3.5	85	0.5–1.0	20–40

2.4.1. Mechanism of Filiform Attack

Filiform corrosion on aluminum is a corrosion cell driven by differential aeration. The filiform cell consists of an active head and a tail that receives oxygen and condensed water vapor through crack and splits in the applied coating. The head is filled with flowing flocs of opalescent alumina gel moving toward the tail, where aluminum ion transport and gradual reaction with hydroxyl ion take place. The final corrosion products are partially hydrated and fully expanded in the porous tail. The head and middle sections of the tail are corresponding locations for the various initial reactant ions and the intermediate products of corroding aluminum in aqueous media. The mechanism of filiform corrosion initiation and activation in aluminum is shown in Figure 2.6. Aluminum has a greater tendency to form blisters in acidic media, with hydrogen gas evolved in cathodic reactions in the head region. As shown in Figure 2.7, the corrosion product in the tail is aluminum trihydroxide ($\text{Al}(\text{OH})_3$), a whitish gelatinous precipitate.

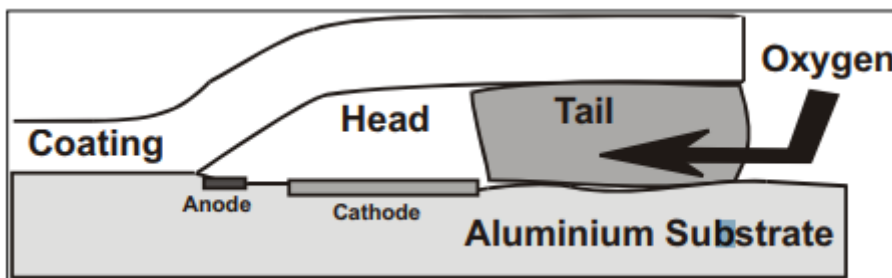


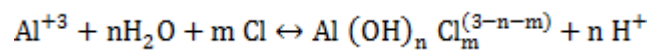
Figure 2.6 The cross section of a filiform on aluminum.

2.4.1. Filiform Chemistry

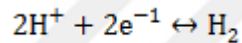
Schematic picture of filiform corrosion can be seen in Figure 2.7. This figure shows the cross section of the filiform, the oxygen diffusion path, and both

the anodic and cathodic sites. Schematic polarization curves are drawn for the two sites. According to Baes and Mesmer (Baes & Mesmer, 1976) the Al^{3+} ions are not hydrolyzed below pH 3. This means that pH of 3 should be the minimum pH obtainable by hydrolysis of Al^{3+} ions. Beck (Beck, 1984) has found a relationship between dissolved AlCl_3 and pH. This shows that the hydrolysis of Al^{3+} ions reaches a much lower pH in the presence of chloride ions. The reactions in the head of the filiform will be (Nguyen & Foley, 1980).

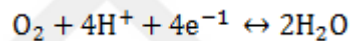
The dissolution and the hydrolysis of aluminum:



The cathodic reaction in the head:



The reaction in the tail consist of the cathodic reduction of oxygen:



The conductivity in the filiform head will be high enough that there will be a mixed potential throughout the filiform head. Both the anodic and cathodic currents will determine this mixed potential. Due to this mixed potential a current will flow from the anodic tip towards the cathodic back of the head. This current will be called the filiform current throughout this thesis.

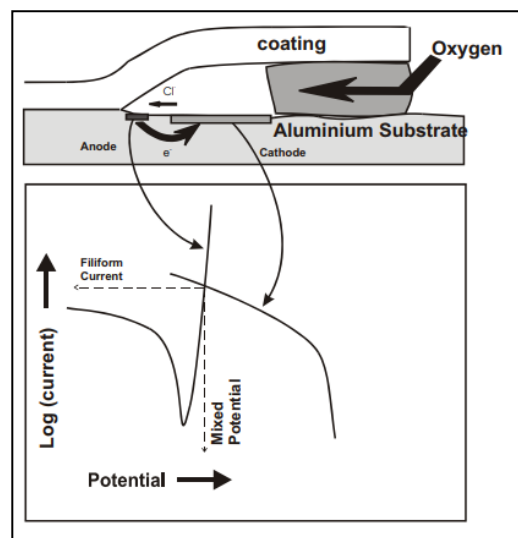


Figure 2.4.1 Schematic picture of the reactions that take place.

3. METHODS AND APPLICATION

3.1. Design of Experiment

Design of experiment is a tool used for analyzing the effects of input variables on an output of the process, identifying the inputs with important effects on the output, hence, helps to optimize the process parameters.

To perform a design of experiment, the process was investigated according to six-sigma, and DMADV, is an acronym that stands for Define, Measure, Analyze, Design and Verify, methodologies were used. These methodologies are typically used to create new processes and new products or services. The letters DMADV stand for:

- Define the project goals
- Measure critical components of the process and the product capabilities
- Analyze the data and develop various designs for the process, eventually sorting the best one
- Design and test details of the process
- Verify the design by running simulations and a pilot program, and then handing over the process.

First, CTQ (Critical to Quality) was done, which is a diagram-based tool that helps us develop and deliver high quality products and services (In Figure 3.1). Then they were used to translate broad customer needs into specific, measurable performance requirements.

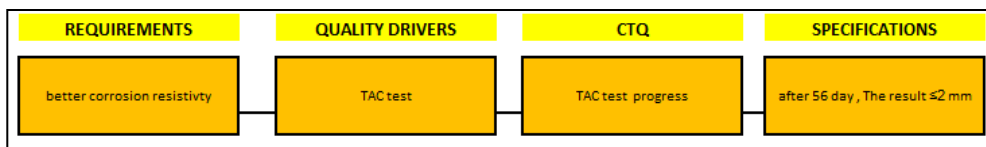


Figure 3.1 CTQ of process.

Then SIPOC, is an acronym that stands for Supplies, Inputs, Process, Outputs and Customers, and detailed process diagram were formed by the team (In Figure 3.2). After these, the team had a meeting to make a cause and effect

matrix (In Figure 3.3). At the meeting, all team members rated each input in the process. The ratings correspond to:

- 1: No relation between the Input and Output
- 3: Slight relation between Input and Output
- 5: Average relation between Input and Output
- 9: Direct relation between Input and Output



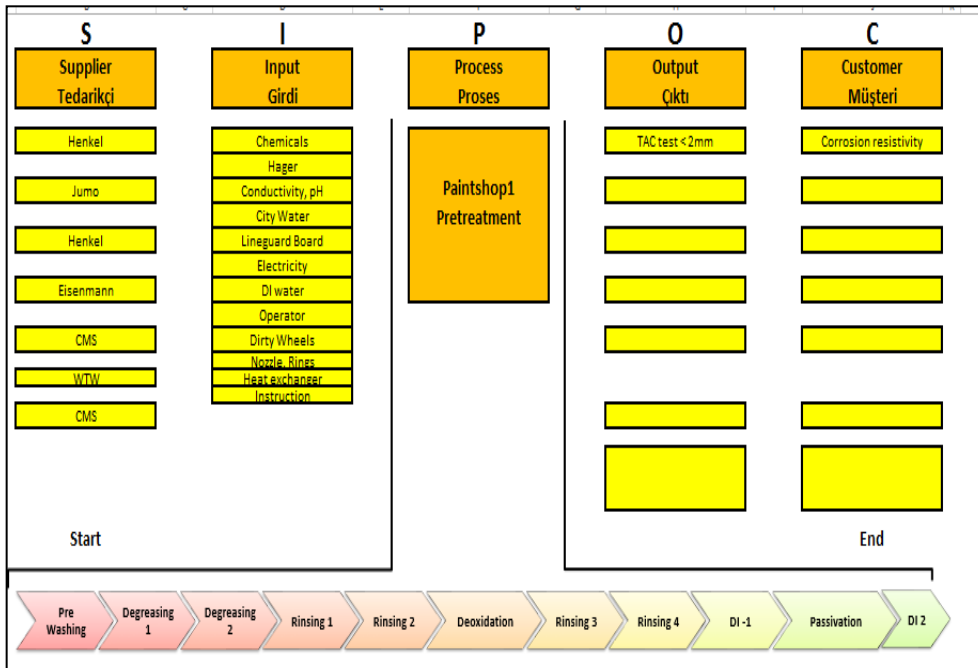


Figure 3.2 SIPOC diagram of process.

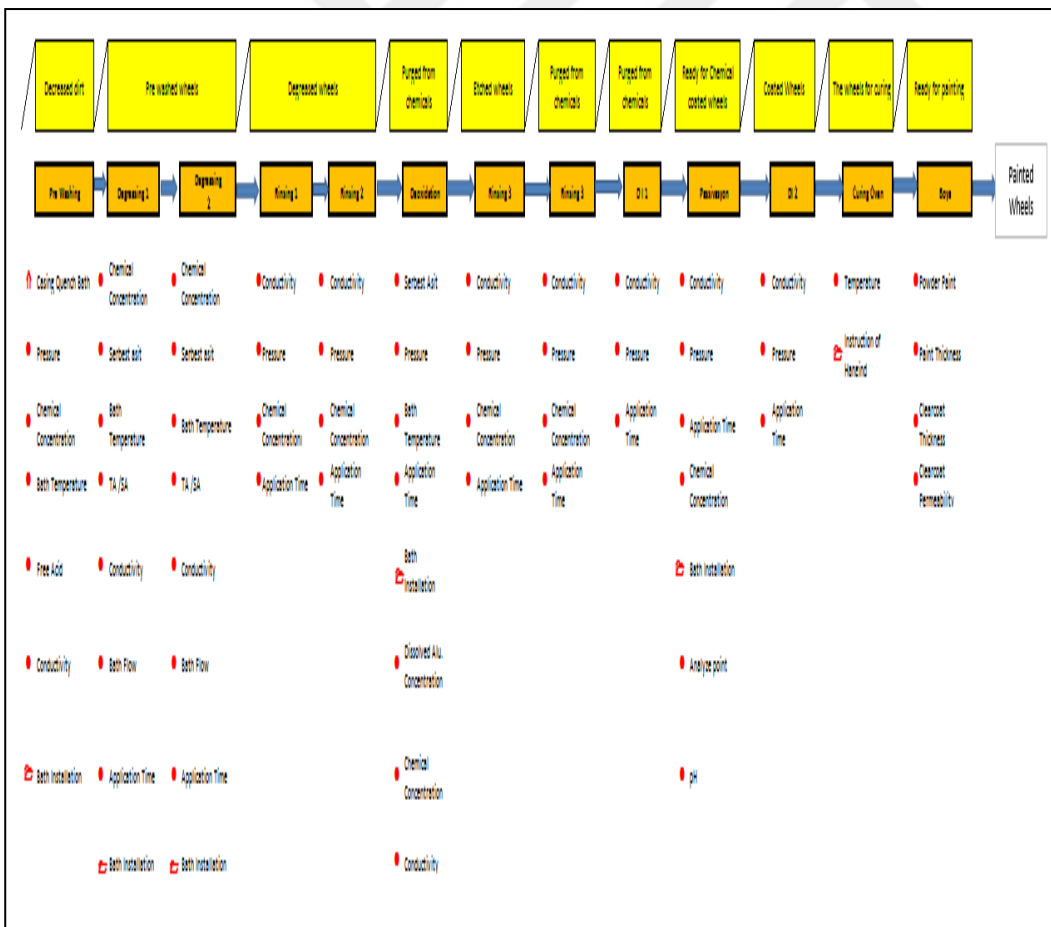


Figure 3.3 Detailed process diagram.

The main input parameters are determined according to their total ratings. These parameters of priority are:

- Deoxidation concentration
- Temperature of deoxidation
- Total acidity of pre-washing bath
- Temperature of passivation
- Conductivity of passivation
- Curing time of powder coating
- Conductivity of DI water 1
- Conductivity of DI water 2
- Saturation of Al in deoxidation
- Thickness of clearcoat
- Conductivity of dripping water

Table 3.1 C&E Matrix.

NO	0: yok 1: az 3: var 5: belirgin etki 9: Çok yüksek etki	Output	Paint test Performance	TOTAL	Priority	%
		GİRDİLER:				
1	Pre washing	Quench Bath Water	3	30	HAYIR	1%
2	Pre washing	Pressure	1	10	HAYIR	0%
3	Pre washing	Free Acid	5	50	HAYIR	2%
4	Pre washing	Chemical Concentration	9	90	EVET	3%
5	Pre washing	Bath Temperature	5	50	HAYIR	2%
6	Degrasing 1	Chemical Concentration	3	30	HAYIR	1%
7	Degrasing 1	Free Alkalinity	3	30	HAYIR	1%
8	Degrasing 1	Bath Temperature	3	30	HAYIR	1%
9	Degrasing 1	TA/SA	3	30	HAYIR	1%
10	Degrasing 1	Conductivity	3	90	HAYIR	3%
11	Degrasing 1	Flow	3	30	HAYIR	1%
12	Degrasing 1	Application Time	3	30	HAYIR	1%
13	Degrasing 2	Chemical Concentration	3	30	HAYIR	1%
14	Degrasing 2	Free Alkalinity	3	30	HAYIR	1%
15	Degrasing 2	Bath Temperature	3	30	HAYIR	1%
16	Degrasing 2	TA/SA	5	50	HAYIR	2%
17	Degrasing 2	Conductivity	3	90	HAYIR	3%
18	Degrasing 2	Flow	3	30	HAYIR	1%
19	Degrasing 2	Application Time	1	10	HAYIR	0%
20	Rinsing1	Conductivity	3	30	HAYIR	1%
21	Rinsing1	Pressure	3	30	HAYIR	1%
22	Rinsing1	Application Time	3	30	HAYIR	1%
23	Rinsing1	Chemical Concentration	3	30	HAYIR	1%
24	Rinsing2	Conductivity	3	30	HAYIR	1%
25	Rinsing2	Pressure	3	30	HAYIR	1%
26	Rinsing2	Application Time	9	90	EVET	3%
27	Rinsing2	Chemical Concentration	3	30	HAYIR	1%
29	Deoxidation	Pressure	5	50	EVET	2%
30	Deoxidation	Bath Temperature	9	90	EVET	3%
31	Deoxidation	Flow	9	90	EVET	3%
32	Deoxidation	Dissolved Alu. Concentration	9	90	EVET	3%
33	Deoxidation	Chemical Concentration	9	90	EVET	3%
34	Rinsing3	Conductivity	3	90	HAYIR	3%
35	Rinsing3	Pressure	3	30	HAYIR	1%
36	Rinsing3	Application Time	3	30	HAYIR	1%
37	Rinsing3	Chemical Concentration	3	30	HAYIR	1%
38	Rinsing4	Conductivity	3	30	HAYIR	1%
39	Rinsing4	Pressure	3	30	HAYIR	1%
40	Rinsing4	Application Time	3	30	HAYIR	1%
41	Rinsing4	Chemical Concentration	3	30	HAYIR	1%
42	D 1	Conductivity	9	90	EVET	3%
43	D 1	Pressure	3	30	HAYIR	1%
44	D 1	Application Time	5	50	HAYIR	2%
45	Passivation	Conductivity	5	50	EVET	2%
46	Passivation	Pressure	9	90	EVET	3%
47	Passivation	Application Time	1	10	HAYIR	0%
48	Passivation	Teperature	9	90	EVET	3%
50	Passivation	pH	3	30	HAYIR	1%
51	D 2	Conductivity	5	50	EVET	2%
52	D 2	Pressure	5	50	EVET	2%
53	D 2	Flow	9	90	EVET	3%
54	D 2	Application Time	5	50	EVET	2%
55	DI 2	Dropping Water Conductivity	9	90	EVET	3%
56	Curing Oven	Teperature	2	20	HAYIR	1%
57	Paint Curing Oven	Teperature	9	90	EVET	3%
58	Paint	TOZ Paint TÜRÜ	3	30	HAYIR	1%
59	Paint	Clear coat Thickness	3	30	HAYIR	1%
60	Paint	Powder Paint Thickness	5	50	HAYIR	2%
61	Paint	Clear coat Permeability	3	30	HAYIR	1%
Çıktılar için Toplam			262	2800		

After determining all the inputs of high priority, some of them are excluded from the design of experiment, in accordance with case studies investigated in literature, and others are selected to be examined.

In literature, filiform corrosion shows some characteristics, which are;

- Filaments grow along the rolling direction (Ruggeri & Beck, 1983)
- Filiform corrosion occurs in a specific range of relative humidity (Ruggeri & Beck, 1983)
- Filiform corrosion does not occur in atmospheres without oxygen (Ruggeri & Beck, 1983); (W.H. & Hoover, 1972))
- The speed of growth and size of the filiform are independent of the coating thickness
- Increasing amount of inter metallic in the substrate increases the filiform length
- Active layers on the surface can increase the length of filiform
- The filiform head is acidic and has a high chloride concentration

Cpk is an indication about the future capability of a process, and Ppk gives information about how the process has performed in the past. Table 3.2 shows how to evaluate Cpk values. The variations, Cpk and Ppk, of selected inputs were followed and analyzed (Figure 3.4- 3.8).

Table 3.2 Remark of Cp.

<u>Cpk</u>	Evaluation	Remark
$Cpk \leq 1$	insufficient	Process is insufficient. Process improvement must be done.
$1 < Cpk \leq 1.33$	acceptable	Process provides the specifications. Process must go on under the control.
$Cpk \geq 1.33$	good	Process provides the specifications.

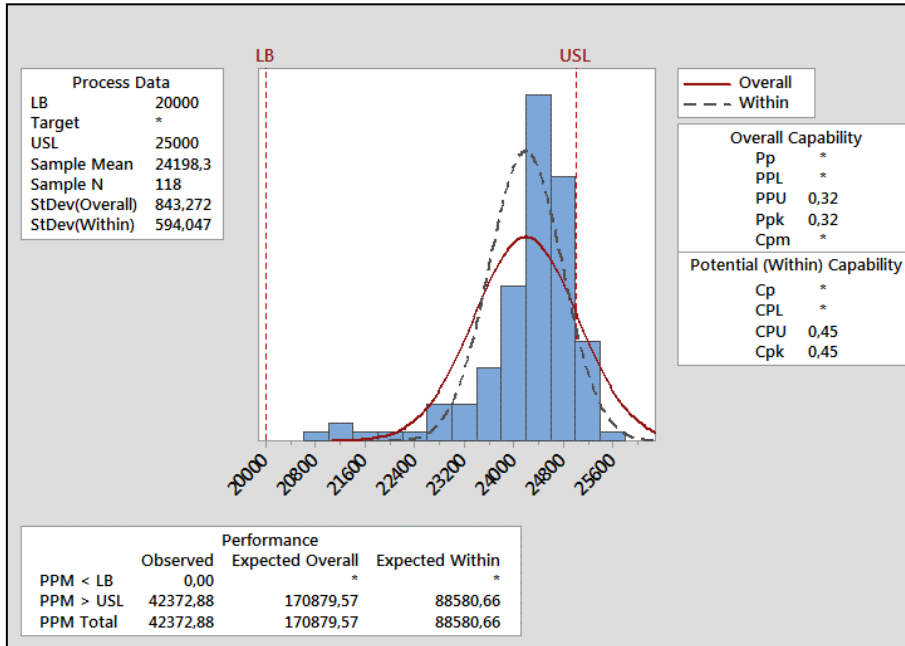


Figure 3.4 Process capability of deoxidation conductivity.

According to the graph in Figure 3.4, Cpk value is less than 1, which indicates that the process is insufficient; the process is likely to work at close to the upper limit of deoxidation conductivity.

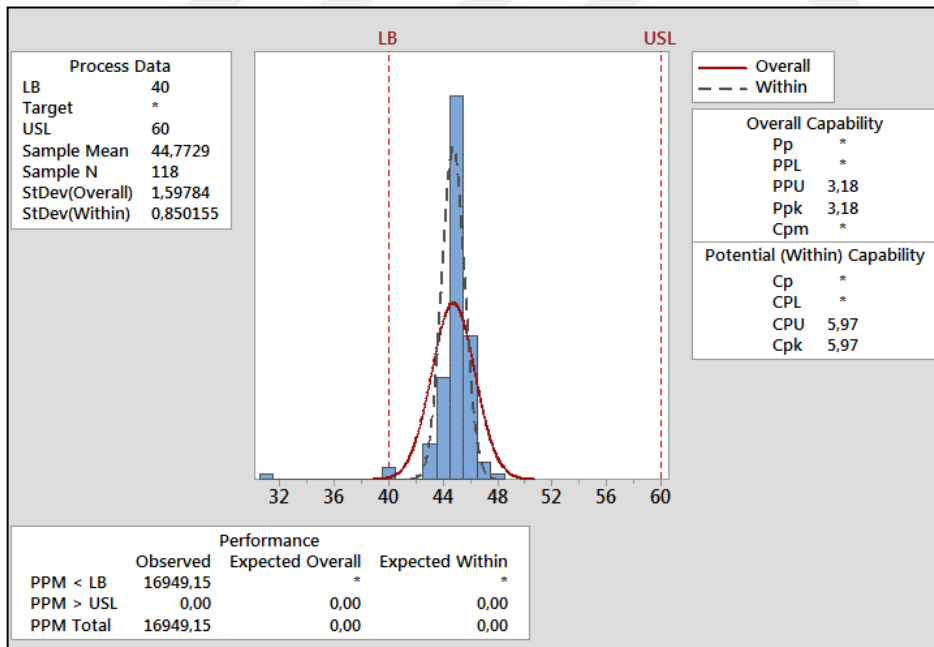


Figure 3.5 Process capability of deoxidation temperature.

For deoxidation temperature, Cpk value is more than 1,33, which shows that the process provides the specifications. Also, according to the graph in Figure 3.5, center point of the process is shifted to left (lower boundary). Ppk value above 1 shows that the process capability is far from the specification limits

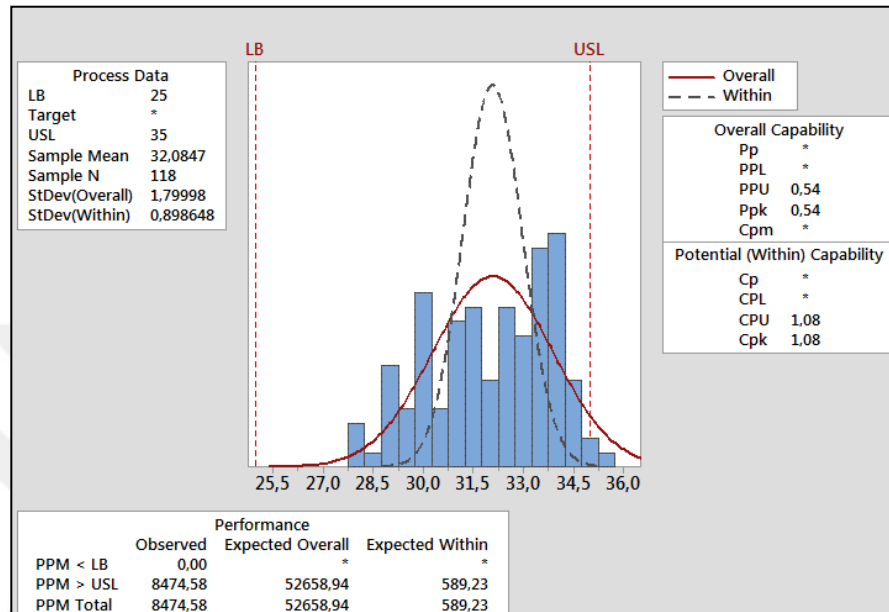


Figure 3.6 Process capability of passivation temperature.

In Figure 3.6, Cpk value is between 1 and 1,33, so process provides the specifications. The distance from the process mean to the nearest specification limit (USL) is less than the one-sided process spread. Therefore, Ppk is low (0.54), and the overall capability of the process is poor.

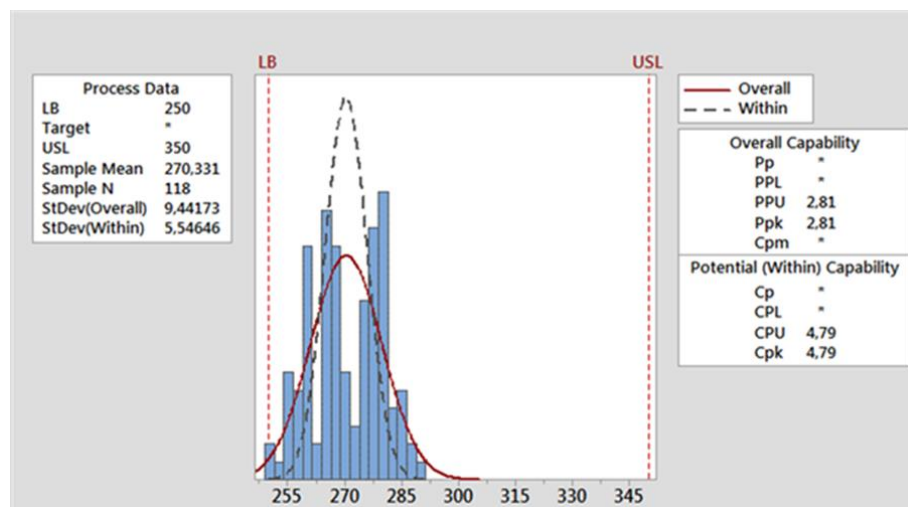


Figure 3.7 Process capability of passivation conductivity

In Figure 3.7, Cpk value is above 1,33, so the process provides the specifications. Also, according to the graph, central point of the process is shifted to left (lower boundary). Ppk value above 1 indicates that the process is far from the specification limits.

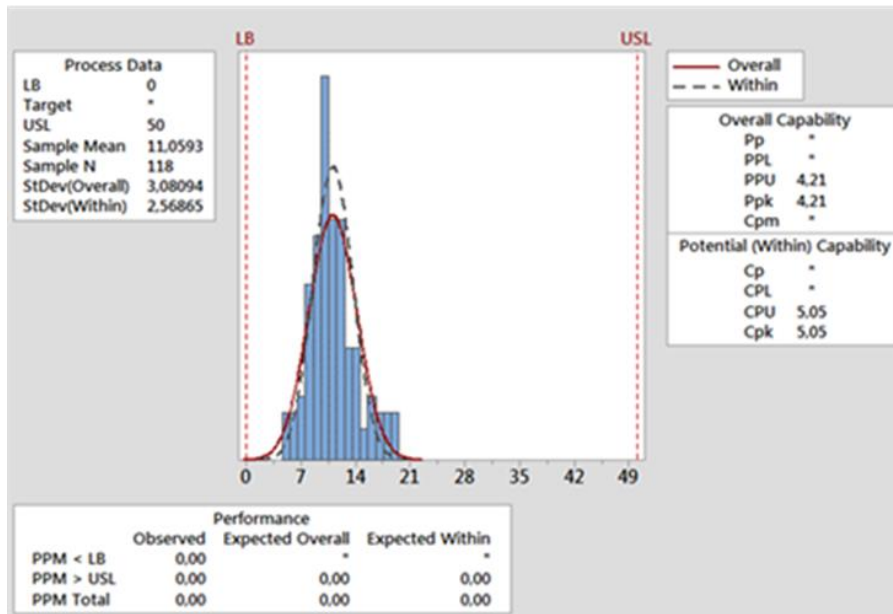


Figure 3.8 Process capability of DI 2 conductivity.

In Figure 3.8, The Cpk and Ppk measures will be very close when the process remains in a state of consistent statistical control, as both the actual sigma and estimated sigma will be similar. Cpk value is higher than 1,33, so the process provides specifications

According to the capability analyses, the priority was put on deoxidation conductivity and passivation temperature.

Also Gage R & R analysis was done for titration and temperature measurement, the results are shown in Figures 3.9 -3.10.

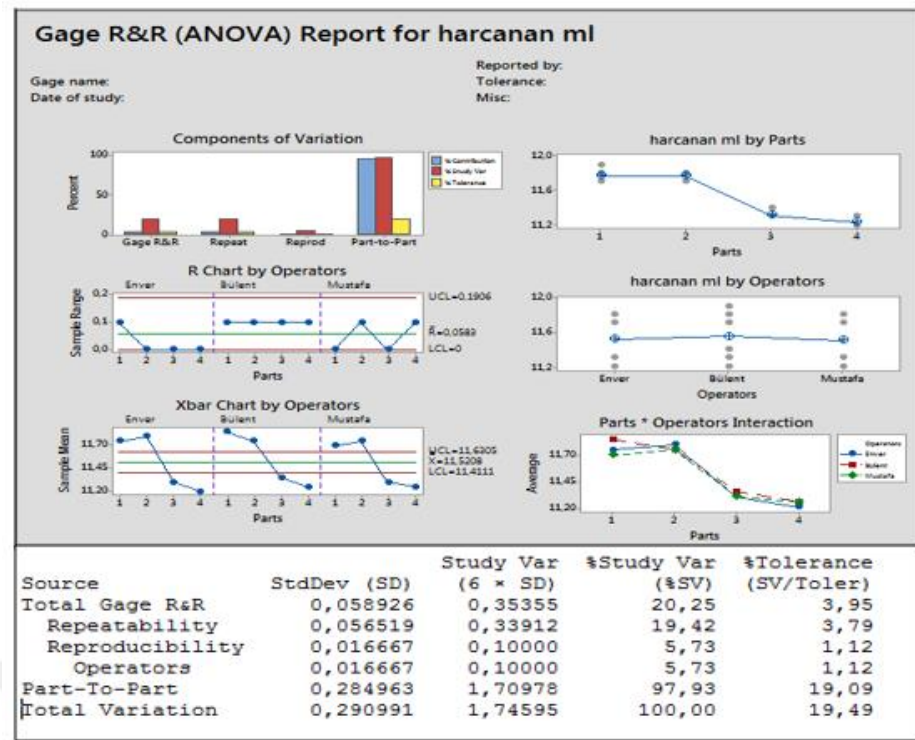


Figure 3.9 Gage R &R titration of total acid.

P/T above 30% means that the parameters within the specifications are not controlled by a measurement system, and there is no measurement system to distinguish the variances. In the graph in Figure 3.9, the %Study Var. (%SV) column gives the value of Gage R&R, and %Tolerance (SV/Toler) column gives the value of P/T. Gage R&R and P/T values are below 30%, so the system is suitable for data collection. The measurements vary negligibly between operators, i.e. are independent of the operators.

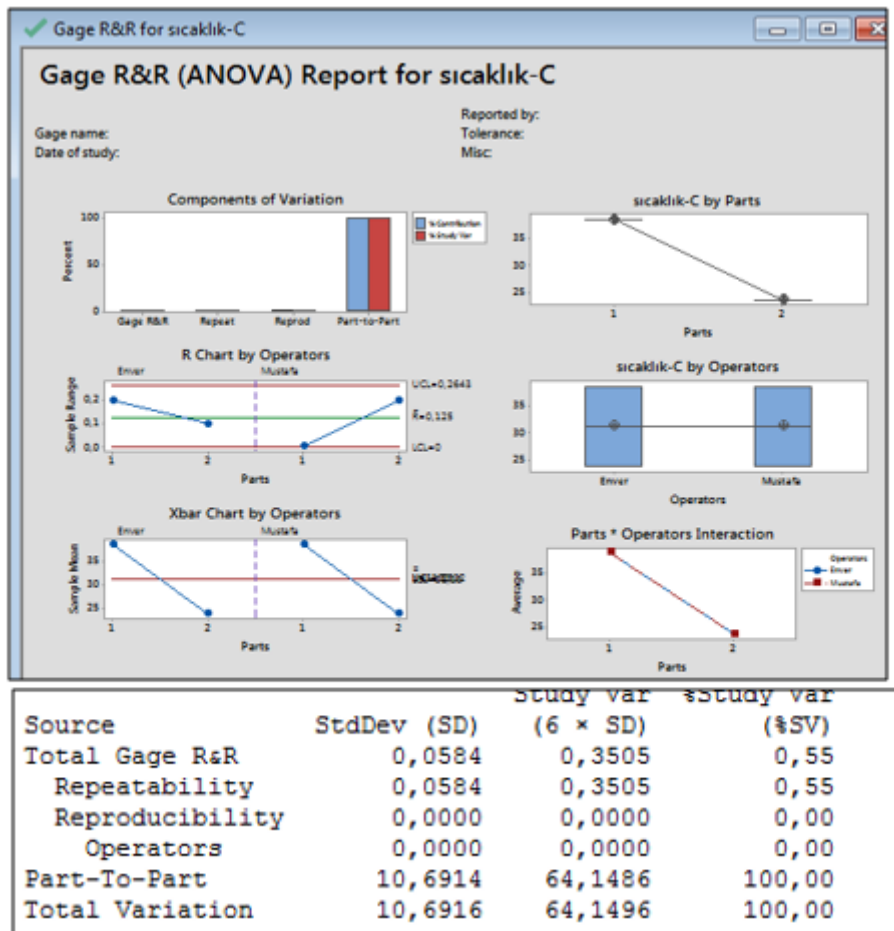


Figure 3.10 Gage R &R temperature.

The system in Figure 3.10 has Gage R&R and P/T values above 30%, which means the system is not suitable for data collection. The measurement results vary significantly depending on the operators. Here the measurement device was changed to digital thermometer.

Before the Design of Experiment (DOE), we chose these inputs,

- Temperature of deoxidation
- Conductivity of deoxidation
- Temperature of passivation
- Conductivity of passivation
- Curing time
- Total acidity of pre-washing bath.

For DOE, Minitab program was used. Factorial design of experiment was selected and every experiment was done twice. Also three central points were chosen. Eventually, the number of experiments was 131 in total (Table 3.3).

Table 3.3 Design run order 1 to 64 and condition.

StdOrder	RunOrder	CenterPt	Blocks	Deox Konsantrasyon	Deox Sıcaklık	Ön Yıkama Toplam Asit	Pasivasyon Sıcaklık	Pasivasyon İletkenlik	Kürlenme Süresi
1	71	1	1	22	42	18	25	250	13
2	50	1	1	40	42	18	25	250	13
3	95	1	1	22	50	18	25	250	13
4	94	1	1	40	50	18	25	250	13
5	3	1	1	22	42	32	25	250	13
6	12	1	1	40	42	32	25	250	13
7	117	1	1	22	50	32	25	250	13
8	97	1	1	40	50	32	25	250	13
9	11	1	1	22	42	18	37	250	13
10	40	1	1	40	42	18	37	250	13
11	96	1	1	22	50	18	37	250	13
12	73	1	1	40	50	18	37	250	13
13	42	1	1	22	42	32	37	250	13
14	83	1	1	40	42	32	37	250	13
15	25	1	1	22	50	32	37	250	13
16	129	1	1	40	50	32	37	250	13
17	105	1	1	22	42	18	25	350	13
18	88	1	1	40	42	18	25	350	13
19	48	1	1	22	50	18	25	350	13
20	130	1	1	40	50	18	25	350	13
21	125	1	1	22	42	32	25	350	13
22	82	1	1	40	42	32	25	350	13
23	112	1	1	22	50	32	25	350	13
24	45	1	1	40	50	32	25	350	13
25	79	1	1	22	42	18	37	350	13
26	76	1	1	40	42	18	37	350	13
27	74	1	1	22	50	18	37	350	13
28	68	1	1	40	50	18	37	350	13
29	69	1	1	22	42	32	37	350	13
30	67	1	1	40	42	32	37	350	13
31	4	1	1	22	50	32	37	350	13
32	64	1	1	40	50	32	37	350	13
33	60	1	1	22	42	18	25	250	25
34	6	1	1	40	42	18	25	250	25
35	62	1	1	22	50	18	25	250	25
36	17	1	1	40	50	18	25	250	25
37	75	1	1	22	42	32	25	250	25
38	38	1	1	40	42	32	25	250	25
39	16	1	1	22	50	32	25	250	25
40	87	1	1	40	50	32	25	250	25
41	80	1	1	22	42	18	37	250	25
42	113	1	1	40	42	18	37	250	25
43	19	1	1	22	50	18	37	250	25
44	51	1	1	40	50	18	37	250	25
45	21	1	1	22	42	32	37	250	25
46	57	1	1	40	42	32	37	250	25
47	35	1	1	22	50	32	37	250	25
48	23	1	1	40	50	32	37	250	25
49	78	1	1	22	42	18	25	350	25
50	13	1	1	40	42	18	25	350	25
51	72	1	1	22	50	18	25	350	25
52	61	1	1	40	50	18	25	350	25
53	115	1	1	22	42	32	25	350	25
54	53	1	1	40	42	32	25	350	25
55	104	1	1	22	50	32	25	350	25
56	89	1	1	40	50	32	25	350	25
57	5	1	1	22	42	18	37	350	25
58	26	1	1	40	42	18	37	350	25
59	65	1	1	22	50	18	37	350	25
60	109	1	1	40	50	18	37	350	25
61	46	1	1	22	42	32	37	350	25
62	28	1	1	40	42	32	37	350	25
63	43	1	1	22	50	32	37	350	25

Table 3.3 Design run order 64 to 131 and condition.

StdOrder	RunOrder	CenterPt	Blocks	Deox Konsantrasyon	Deox Sıcaklık	Ön Yıkama Toplam Asit	Pasivasyon Sıcaklık	Pasivasyon İletkenlik	Kürlenme Süresi
64	47	1	1	40	50	32	37	350	25
65	59	1	1	22	42	18	25	250	13
66	24	1	1	40	42	18	25	250	13
67	20	1	1	22	50	18	25	250	13
68	108	1	1	40	50	18	25	250	13
69	63	1	1	22	42	32	25	250	13
70	77	1	1	40	42	32	25	250	13
71	110	1	1	22	50	32	25	250	13
72	15	1	1	40	50	32	25	250	13
73	118	1	1	22	42	18	37	250	13
74	107	1	1	40	42	18	37	250	13
75	2	1	1	22	50	18	37	250	13
76	101	1	1	40	50	18	37	250	13
77	127	1	1	22	42	32	37	250	13
78	7	1	1	40	42	32	37	250	13
79	54	1	1	22	50	32	37	250	13
80	9	1	1	40	50	32	37	250	13
81	122	1	1	22	42	18	25	350	13
82	111	1	1	40	42	18	25	350	13
83	32	1	1	22	50	18	25	350	13
84	120	1	1	40	50	18	25	350	13
85	37	1	1	22	42	32	25	350	13
86	92	1	1	40	42	32	25	350	13
87	81	1	1	22	50	32	25	350	13
88	114	1	1	40	50	32	25	350	13
89	29	1	1	22	42	18	37	350	13
90	1	1	1	40	42	18	37	350	13
91	66	1	1	22	50	18	37	350	13
92	91	1	1	40	50	18	37	350	13
93	93	1	1	22	42	32	37	350	13
94	86	1	1	40	42	32	37	350	13
95	70	1	1	22	50	32	37	350	13
96	34	1	1	40	50	32	37	350	13
97	85	1	1	22	42	18	25	250	25
98	18	1	1	40	42	18	25	250	25
99	52	1	1	22	50	18	25	250	25
100	119	1	1	40	50	18	25	250	25
101	44	1	1	22	42	32	25	250	25
102	55	1	1	40	42	32	25	250	25
103	98	1	1	22	50	32	25	250	25
104	121	1	1	40	50	32	25	250	25
105	41	1	1	22	42	18	37	250	25
106	93	1	1	40	42	18	37	250	25
107	103	1	1	22	50	18	37	250	25
108	126	1	1	40	50	18	37	250	25
109	124	1	1	22	42	32	37	250	25
110	84	1	1	40	42	32	37	250	25
111	30	1	1	22	50	32	37	250	25
112	100	1	1	40	50	32	37	250	25
113	58	1	1	22	42	18	25	350	25
114	116	1	1	40	42	18	25	350	25
115	36	1	1	22	50	18	25	350	25
116	10	1	1	40	50	18	25	350	25
117	99	1	1	22	42	32	25	350	25
118	14	1	1	40	42	32	25	350	25
119	33	1	1	22	50	32	25	350	25
120	131	1	1	40	50	32	25	350	25
121	90	1	1	22	42	18	37	350	25
122	27	1	1	40	42	18	37	350	25
123	123	1	1	22	50	18	37	350	25
124	106	1	1	40	50	18	37	350	25
125	128	1	1	22	42	32	37	350	25
126	22	1	1	40	42	32	37	350	25
127	31	1	1	22	50	32	37	350	25
128	102	1	1	40	50	32	37	350	25
129	49	0	1	31	46	25	31	300	19
130	56	0	1	31	46	25	31	300	19
131	8	0	1	31	46	25	31	300	19

3.2. Titration Method and Test Specification

Before the wheels were hung on the pretreatment line, number of the corresponding experiment was marked on each. Then, all of the test parameters were controlled by the operator. Total acidity was measured by titration, and if found to be lower than the threshold value, 2.4 kg of Bonderite C-IC 2000 TH Acid for each missing point in a volume of the tank was added to increase acidity.

The titration method is as follows:

- 10 mL of bath solution is put to an Erlenmeyer-flask and 50 mL of deionized water is added.

- 4 - 5 drops of indicator Phenolphthalein as 0.1 % solution is added.
- 5 g of NaF is added.
- The solution is titrated against 0.1 N NaOH. A color change from clear to pink indicates the point.
- The consumption of 0.1 N NaOH in mL is equal to points of total acidity.

After the trials, the wheels were tested in the laboratory according to TSH3122G, the specification of coating quality for aluminum wheels.

3.1.1 Toyota specification

Standard covers the quality to be applied aluminum wheels disks to enhance their design features and blister prevention (blisters which affect design). S –A, grades by Toyota with respect to regions, are described according to the level of blister required to prevent corrosion. Coating quality is specified as shown in Table 3.4 (Toyota).

Item			Requirement	Grade	
				S	A
Color tone			Actual color tone shall not differ from the color tone specified in drawings.	x	x
Appearance			There shall be no noticeable rough surface, pinholes, sagging, mottle, cissing and the like.	x	x
Hardness			HB or harder	x	x
Adhesion			0/100	x	x
Impact resistance			There shall be no cracks and peeling.	x	x
Chipping resistance			Grade 3 or higher	x	x
Water resistance			0/100 (40°C X240 h)	x	x
Spot resistance	Water discoloration resistance		Color difference ΔE shall be 0.8 max. without noticeable spots.	x	x
	Alkali discoloration resistance		Color difference ΔE shall be 1.5 max. without noticeable spots.	x	x
	Acid discoloration resistance			x	x
Hydrofluoric acid cleaning agent resistance			Report	x	x
Volatile oil resistance			There shall be no wrinkling, cracking, blisters and peeling on coated film immediately after and after 2 h of the test.	x	x
Accelerated weather resistance ⁽¹⁾	Xenon method	750 MJ	Gloss retention (60° GS): 85 % min. Color difference ΔE : 3 max. There shall be no abnormalities such as cracking, peeling or significant discoloration on coated film.	x	x
	SWOM method	800 h	Gloss retention (60° GS): 85 % min. Color difference ΔE : 3 max. There shall be no abnormalities such as cracking, peeling or significant discoloration on coated film.	x	x

Table 3.4 Coating quality.

Item		Requirement	Grade	
			S	A
Outdoor weather resistance	12 months	Gloss retention (60° GS): 85 % min. Color difference ΔE: 3 max.	x	x
	18 months	There shall be no abnormalities such as cracking, peeling or significant discoloration on coated film.	x	x
CASS test (Appendix 2 in JIS D 0201, ASTM B368-09)	240 h ⁽²⁾	Cut portion on design surface: Blister width at one side shall be 3 mm max.	x	x
		Back edge portion of window hole (Blister width toward design surface)	x	x
		Grade S: There shall be no blister. Grade A: 3 mm max. Portions other than above: There shall be no blister.	x	x
Filiform corrosion resistance (TAC test)	8 cycles	Blister width at one side from cut portion shall be 2 mm max.	x	x
		Edge portion of window hole: Blister width toward design surface shall be 2 mm max.	x	x
		Portions other than above: There shall be no blister.	x	x
CASS + TAC Test	8 cycles	Blister width from cut portion at one side shall be 10 mm max.	x	---
		Back edge portion of window hole: No blister	x	---
		Portions other than above: There shall be no blister.	x	---
Conduction		Edge portion (design surface, reverse surface) of window hole: There shall be no conduction. ⁽³⁾	x	x

Table 3.4 Coating quality (continued).

Notes:

1) Apply basically the Xenon method to the accelerated weather resistance test. If no Xenon tester is available, the SWOM (sunshine weather-o-meter) method may be applied instead.

2) 72 h for the bright cut portion on the design surface of grade A. (For that of grade S, 240 hours)

3) Exclude back edge portion of window hole of grade A. (Toyota).

Test Methods

Use a test plate that is cut out in necessary size from a product manufactured by regular process. Use a flat plane which is shot-blasted or machined using AC4W-T6 as specified, and coated in the same process as the product if the shape of the test plate is not suitable for the test. When the quality of product varies depending on the production process (condition), conduct the test by using two test plates each sampled from products that were made under the most or least suitable production condition (Toyota).

Adhesion

The shape of cutter knife shall be as shown in Figure 3.11. It shall be made of carbon tool steel with hardness of 820 ± 30 HV. Before use, the used blade tip must be replaced by a new tip. The blade must be housed in the holder, and the holder must be held as shown on Figure 3.12 (e.g Erichsen cutter and NT cutter type S and A, small size).

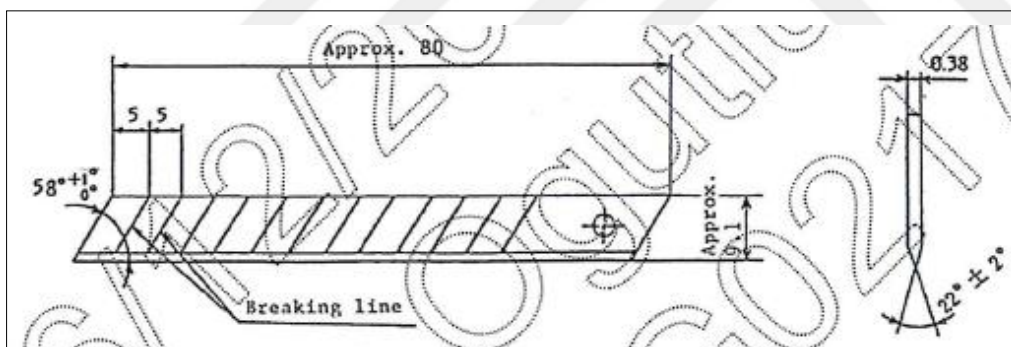


Figure 3.11 Example cutter knife (Unit: mm).

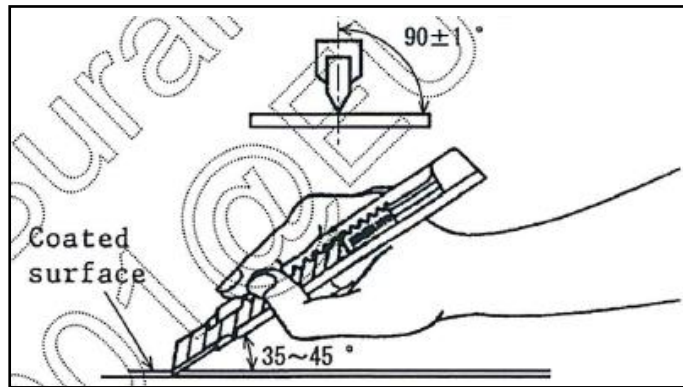


Figure 3.12 Holding the cutter knife.

Filiform Corrosion Test (TAC)

TAC test is the most challenging test among all customer specifications. The cyclic test, where one cycle consists of salt spray for 24 hours (TSH1552G), humidity test (40 °C, 85 % RH) for 120 hours, and exposure at room temperature (23 °C for 24 hours) is performed eight times. After the salt spray test and before conducting the humidity test, salt is removed from the sample by washing the sample with water. The maximum blister width is measured at one side from the "wheel back edge portion" and "a cut portion on the design surface". The length of the single cut portion shall be approximately 120 mm. It is evaluated excluding 10 mm from its both ends. A knife the same as the one specified in Adhesion must be used and a cut that reaches the base material at one stroke must be made.

3.1.2. Filiform corrosion test (TAC) specification (TSH1552G)

Test apparatus shall be in accordance with JIS Z 2371-or.ASTM B117 (see Figure 3.13). The salt water shall be cleaned by filtering, after having been adjustment of pH and concentration and heated. The salt water is sprayed through nozzles using heated, moistened and pressure-controlled compressed air to execute an accelerated corrosion test. Test apparatus shall satisfy to the conditions specified below and either the nozzle type or the spray tower type may be used. The spray chamber shall be made of heat insulating material and it's inside surface shall sufficiently withstand the working conditions.

- 1) Structure and performance of the test apparatus shall be regulatable to meet the specifications given in Table 3.5.
- 2) Drops of solution which accumulate on the ceiling of cover shall not be permitted to fall on the plates being tested.
- 3) Drops of solution which fall from the test plates shall not be returned to the solution reservoir for respraying
- 4) Salt spray shall not leak out of the test apparatus

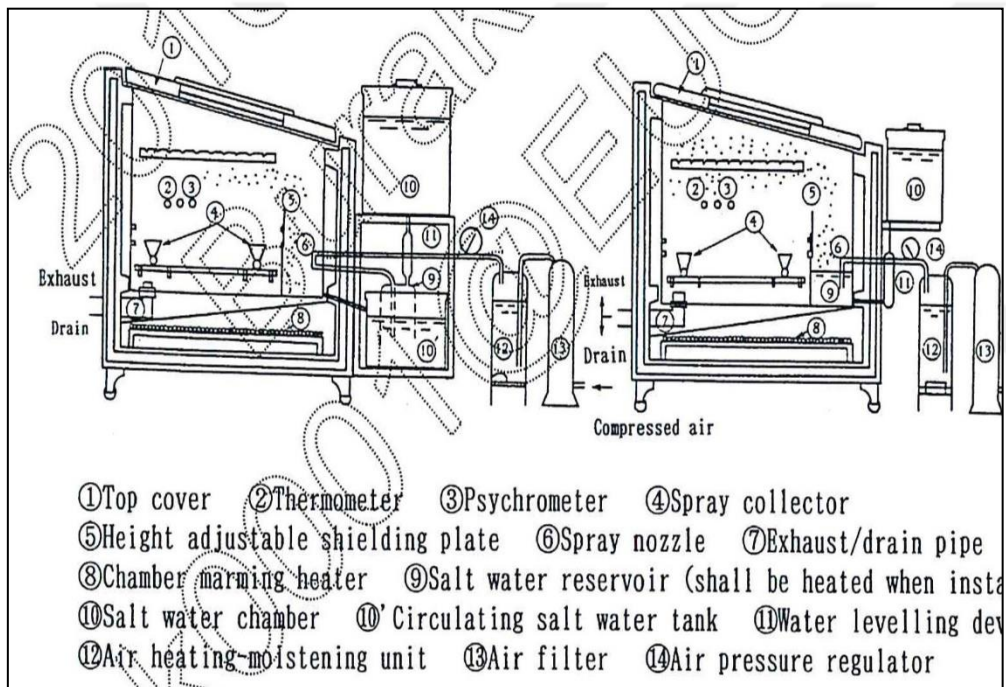


Figure 3.1.2 Salt spray test apparatus (Toyota)

Test Conditions

For the evaluation using test plates, coat the test plates in accordance with TSH 1550G in the case of electrodeposit coatings. Perform treatments on conditions specified in the coating standard and plating standard in the case of other kinds of coating, and plating film. The above conditions shall not be applied to the cut product.

If the test is performed on coatings, place a single edged razor or small cutter (ex. NT-cutter) vertically onto the coated test plate and scribe two lines diagonally crossing so as to expose the underlying metal. The cutting shall not be necessary if the test is performed on plating film.

Seal the cut edges of the test plate using appropriate sealing material (like zinc-rich paint, adhesive tape).

Position the test plate onto the salt spray test apparatus regulated to, satisfy the specifications given in Table 3.5 such that the following condition are met

- a. Position the test plate parallel to the principal direction of horizontal flow of salt spray through the chamber.
- b. Position the test plate with the surface to be tested facing up approximately 30° from the vertical line
- c. The test plate shall be so positioned as to be clear of anything but the supports
- d. Salt solution from one test plate shall not drip on any other test plates. Suitable materials for supporting test plates are glass, rubber, plastic or suitable coated wood. Test plate shall preferably be supported from to bottom or back face or fixed with slotted supports. Suspension from glass hooks or waxed strings may be used as long as specified position of test plate is obtained.

Carry out the test continuously for specified period of time or until the test plate reaches the specified state. When carrying out a life test, observe the state of the test plate once a day at designated time of a day. The time required to remove the test plate out of the test apparatus for such observation shall not exceed 30 minutes as a rule and this period of the time shall be considered as comprising a part of the test period.

Randomize the position of the test plate with appropriate frequency to make the amount of water spray uniform.

Table 3.1.2 Working Conditions of salt spray test apparatus (Toyota)

Item		Working condition		Remarks
		Test for specified period of time	Life Test	
Spray salt water	Quantity (mL/h/80cm ²)	1.4±0.6	1.4±0.4	Average of two spray collecting containers ⁽¹⁾
	Concentration	5		
	Specific Gravity ⁽²⁾	35 °C 1.0245 to 1.0400		Measured on the solutions collected in the spray collecting container ⁽¹⁾
	pH	(RT) 6.5 to 7.2		
Salt water pre-heater	Temperature °C	35		
	Water level	Within marked line of level ages		
Salt water level in reservoir		20		
Compressed air pressure (kPA)		98±2,45		
Moistening device	Temperature °C	47±1		
	Water level	Within marked line of level ages		
Spray chamber	Temperature °C	35±1		
	Relative Humidity	95 to 98%		

Notes:

- 1) Funnel having a cross section of 80 cm² at its top shall be used as the spray collecting container
- 2) Measure the specific gravity by a hydrometer and convert the measured value into the specific gravity at 35 °C using the graph shown in Figure 3.14.

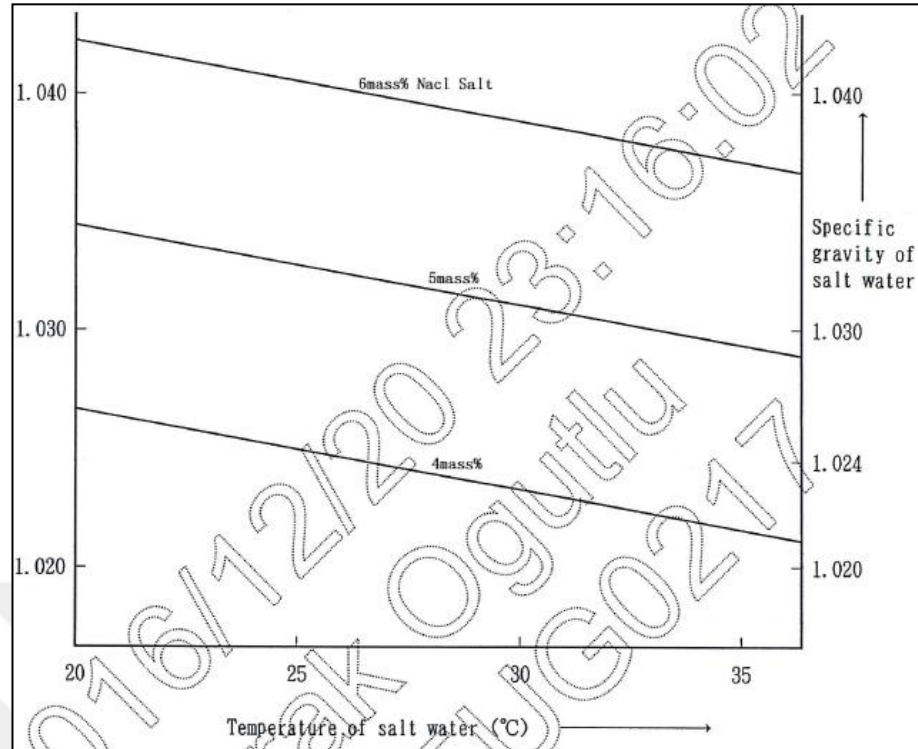


Figure 3.1.2 Relations between The temperature and the Specific Gravity of Salt Water (Toyota)

Preparation of Salt Water

Prepare the salt water to the concentration of $5.0 \pm 0.5\%$ and pH 6.5 to 7.2 by dissolving refined salt specified in JIS K 8150 or ISO 6353-2 or other refined salt of equivalent standard into the distilled water or deionized water with the electrical conductivity of $20 \mu\text{S}/\text{cm}^{-1}$. The pH can be adjusted by addition of diluted hydrochloric acid or sodium hydroxide solution of approximately 0.1 mol/L (0.1 N). When the pH of salt solution is not easily stabilized, adjust the pH after leaving the salt solution stand indoor for 16 hours or more.

4. RESULTS and DISCUSSION

The results of TAC test, shown in Table 4.1, were interpreted in Minitab 18.

Table 4.1 Test parameter & TAC test result.

StdOrder	RunOrder	CenterPt	Blocks	Deox Concentration	Deox Temperature (°C)	Pre-Degreasing Total Acid (ml)	Passivation Temperature (°C)	Passivation Conductivity (µs/cm ²)	Curing Time (minute)	CS Tac 1_8(mm)	Diamond Tac 1_8 (mm)
1	71	1	1	22	42	18	25	250	13	3	4
2	50	1	1	40	42	18	25	250	13	2	2
3	95	1	1	22	50	18	25	250	13	0,5	4
4	94	1	1	40	50	18	25	250	13	1,5	2,5
5	3	1	1	22	42	32	25	250	13	1	2
6	12	1	1	40	42	32	25	250	13	1	7
7	117	1	1	22	50	32	25	250	13	1,2	1
8	97	1	1	40	50	32	25	250	13	1	3
9	11	1	1	22	42	18	37	250	13	5	1
10	40	1	1	40	42	18	37	250	13	1,5	1,5
11	96	1	1	22	50	18	37	250	13	0,5	1
12	73	1	1	40	50	18	37	250	13	1	1,5
13	42	1	1	22	42	32	37	250	13	2,5	4,5
14	83	1	1	40	42	32	37	250	13	3,5	1,5
15	25	1	1	22	50	32	37	250	13	1	1
16	129	1	1	40	50	32	37	250	13	1	1
17	105	1	1	22	42	18	25	350	13	0,5	2,5
18	88	1	1	40	42	18	25	350	13	1,5	8
19	48	1	1	22	50	18	25	350	13	1	5
20	130	1	1	40	50	18	25	350	13	0,5	2
21	125	1	1	22	42	32	25	350	13	1	3
22	82	1	1	40	42	32	25	350	13	1,5	2
23	112	1	1	22	50	32	25	350	13	0	4
24	45	1	1	40	50	32	25	350	13	1	3
25	79	1	1	22	42	18	37	350	13	1,5	2
26	76	1	1	40	42	18	37	350	13	0	1,5
27	74	1	1	22	50	18	37	350	13	1	1
28	68	1	1	40	50	18	37	350	13	1	1
29	69	1	1	22	42	32	37	350	13	1,5	1
30	67	1	1	40	42	32	37	350	13	0,5	1
31	4	1	1	22	50	32	37	350	13	0	0,5
32	64	1	1	40	50	32	37	350	13	0,5	0,5
33	60	1	1	22	42	18	25	250	25	1,5	1
34	6	1	1	40	42	18	25	250	25	1,5	2,5
35	62	1	1	22	50	18	25	250	25	2,5	3
36	17	1	1	40	50	18	25	250	25	3,5	2,5
37	75	1	1	22	42	32	25	250	25	1	2,5
38	38	1	1	40	42	32	25	250	25	1	2,5
39	16	1	1	22	50	32	25	250	25	1,5	2,5
40	87	1	1	40	50	32	25	250	25	1,5	2
41	80	1	1	22	42	18	37	250	25	2,5	1,5
42	113	1	1	40	42	18	37	250	25	2	4
43	19	1	1	22	50	18	37	250	25	1,5	3
44	51	1	1	40	50	18	37	250	25	1,5	3
45	21	1	1	22	42	32	37	250	25	3	2
46	57	1	1	40	42	32	37	250	25	2	3,5
47	35	1	1	22	50	32	37	250	25	2	2,5
48	23	1	1	40	50	32	37	250	25	1	1,5
49	78	1	1	22	42	18	25	350	25	1,5	3,5
50	13	1	1	40	42	18	25	350	25	1,5	2
51	72	1	1	22	50	18	25	350	25	2	2
52	61	1	1	40	50	18	25	350	25	1	1
53	115	1	1	22	42	32	25	350	25	0	1
54	53	1	1	40	42	32	25	350	25	0,5	2
55	104	1	1	22	50	32	25	350	25	0,5	1,5
56	89	1	1	40	50	32	25	350	25	2,5	1
57	5	1	1	22	42	18	37	350	25	6	2,5
58	26	1	1	40	42	18	37	350	25	1,5	1
59	65	1	1	22	50	18	37	350	25	3	1,5
60	109	1	1	40	50	18	37	350	25	1,5	2,5
61	46	1	1	22	42	32	37	350	25	3	1,5
62	28	1	1	40	42	32	37	350	25	2	1

Figure 4.1 Test parameter & TAC test result (continued).

StdOrder	RunOrder	CenterPt	Blocks	Deox Concentration	Deox Temperature (°C)	Pre-Degreasing Total Acid (ml)	Passivation Temperature (°C)	Passivation Conductivity (µs/cm ²)	Curing Time (minute)	CS Tac 1_8(mm)	Diamond Tac 1_8 (mm)
63	43	1	1	22	50	32	37	350	25	3	3
64	47	1	1	40	50	32	37	350	25	2	1,5
65	59	1	1	22	42	18	25	250	13	1	4,5
66	24	1	1	40	42	18	25	250	13	0,5	5
67	20	1	1	22	50	18	25	250	13	2,5	2
68	108	1	1	40	50	18	25	250	13	0,5	5
69	63	1	1	22	42	32	25	250	13	0,5	4
70	77	1	1	40	42	32	25	250	13	1	3
71	110	1	1	22	50	32	25	250	13	1	2,1
72	15	1	1	40	50	32	25	250	13	1,5	2
73	118	1	1	22	42	18	37	250	13	1,5	1
74	107	1	1	40	42	18	37	250	13	1	1
75	2	1	1	22	50	18	37	250	13	1	0,5
76	101	1	1	40	50	18	37	250	13	1	1
77	127	1	1	22	42	32	37	250	13	1,5	3
78	7	1	1	40	42	32	37	250	13	1,5	2
79	54	1	1	22	50	32	37	250	13	2	1
80	9	1	1	40	50	32	37	250	13	1	1
81	122	1	1	22	42	18	25	350	13	0,5	2
82	111	1	1	40	42	18	25	350	13	1,5	1,5
83	32	1	1	22	50	18	25	350	13	1,5	1,5
84	120	1	1	40	50	18	25	350	13	0,5	3
85	37	1	1	22	42	32	25	350	13	4	2
86	92	1	1	40	42	32	25	350	13	2	5
87	81	1	1	22	50	32	25	350	13	0,5	2
88	114	1	1	40	50	32	25	350	13	1,5	4
89	29	1	1	22	42	18	37	350	13	1	2,5
90	1	1	1	40	42	18	37	350	13	1,5	1
91	66	1	1	22	50	18	37	350	13	0,5	1
92	91	1	1	40	50	18	37	350	13	0,5	1
93	39	1	1	22	42	32	37	350	13	1	1,5
94	86	1	1	40	42	32	37	350	13	1,5	1,5
95	70	1	1	22	50	32	37	350	13	0,3	0,5
96	34	1	1	40	50	32	37	350	13	0,5	1
97	85	1	1	22	42	18	25	250	25	1,8	1
98	18	1	1	40	42	18	25	250	25	3,5	2,5
99	52	1	1	22	50	18	25	250	25	0,5	3
100	119	1	1	40	50	18	25	250	25	2	3
101	44	1	1	22	42	32	25	250	25	1	2
102	55	1	1	40	42	32	25	250	25	1,5	1,5
103	98	1	1	22	50	32	25	250	25	1,5	1,5
104	121	1	1	40	50	32	25	250	25	0,5	3
105	41	1	1	22	42	18	37	250	25	0,5	1
106	93	1	1	40	42	18	37	250	25	2	1
107	103	1	1	22	50	18	37	250	25	3	1
108	126	1	1	40	50	18	37	250	25	1,5	2
109	124	1	1	22	42	32	37	250	25	2,5	2
110	84	1	1	40	42	32	37	250	25	2	1,5
111	30	1	1	22	50	32	37	250	25	1,5	2,5
112	100	1	1	40	50	32	37	250	25	1	1
113	58	1	1	22	42	18	25	350	25	1	2
114	116	1	1	40	42	18	25	350	25	2	3
115	36	1	1	22	50	18	25	350	25	1	1,5
116	10	1	1	40	50	18	25	350	25	1	1,5
117	99	1	1	22	42	32	25	350	25	1,5	1,2
118	14	1	1	40	42	32	25	350	25	1,5	1
119	33	1	1	22	50	32	25	350	25	0,5	1
120	131	1	1	40	50	32	25	350	25	2,5	2
121	90	1	1	22	42	18	37	350	25	3	1,5
122	27	1	1	40	42	18	37	350	25	3	1,5
123	123	1	1	22	50	18	37	350	25	1	3
124	106	1	1	40	50	18	37	350	25	2	3
125	128	1	1	22	42	32	37	350	25	5	3
126	22	1	1	40	42	32	37	350	25	1,5	1
127	31	1	1	22	50	32	37	350	25	2,5	1,5
128	102	1	1	40	50	32	37	350	25	1,8	3
129	49	0	1	31	46	25	31	300	19	1	1
130	56	0	1	31	46	25	31	300	19	2	0,5
131	8	0	1	31	46	25	31	300	19	2	1,5



Figure 4.1 Test result of Std Order 5.



Figure 4.2 Test result of Std Order 81.



Figure 4.3 Test result of Std Order 21.



Figure 4.4 Test result of Std Order 8.

Figures 4.1 to 4.6 show examples of test panels. The panels that failed the TAC test are shown in Figures 4.5 and 4.6 (because $TAC > 2$; $TAC = 3$ and $TAC = 4$ respectively). The panels that underwent diamond cut process passed the test, whereas the corresponding cast surfaces with the same experimental parameters failed, which proves the dependency of filiform formation on the surface, diamond-cut or cast, besides other parameters.

108 of 131 cast surface and 93 of 131 diamond-cut surface test panels passed the TAC test. This shows that the parameters of the test matrix were chosen accurately.



Figure 4.5 Test result of Std Order 1.



Figure 4.5 Test result of Std Order 5.

There are cases that both surfaces painted with different parameters failed the TAC test. To understand which parameters have the greatest effect on test results, the results were analyzed using Minitab.

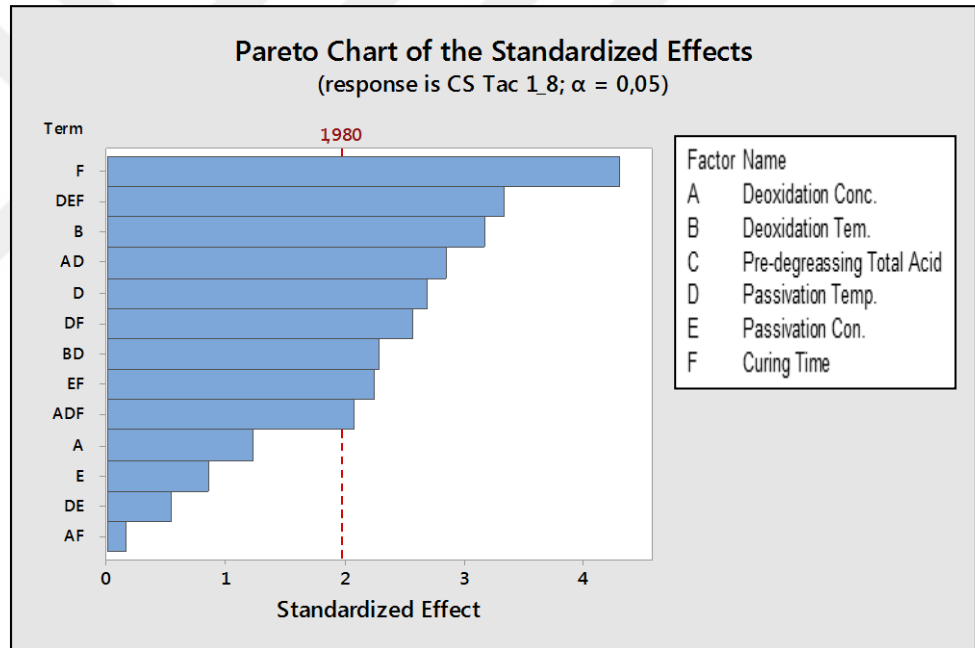


Figure 4.6 Effect of Pareto Diamond Tac1_8.

The relative effects of parameters and combinations of parameters on TAC test on cast surface are shown on Figure 4.7. Curing time of powder coating, deoxidation temperature and their combination have the highest effect on TAC test, among other parameters. Interaction of passivation and deoxidation temperatures affects the TAC test results.

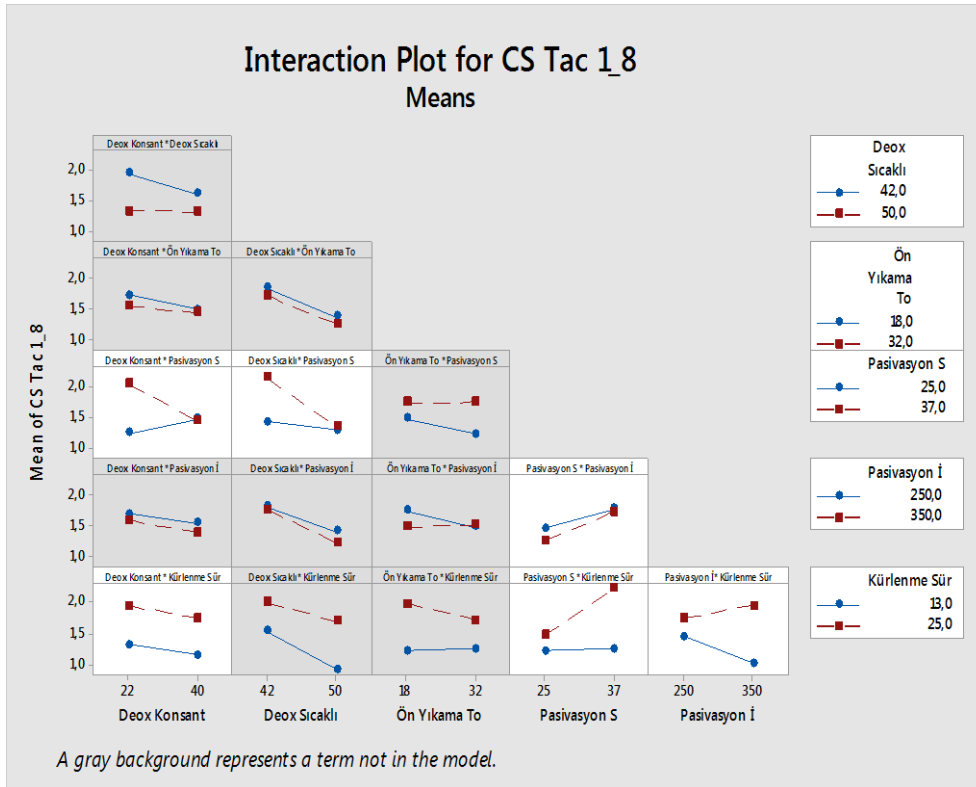


Figure 4.7 Interaction Plot for CS Tac1_8.

The interaction of parameters on TAC test for cast surface are shown on Figure 4.8. At 22 ml/L constant deoxidation concentration, increasing curing time increases the value of TAC test result, leading to failure. At constant passivation temperature, the value of TAC test result increases with increasing passivation conductivity. Passivation conductivity and temperature affect the coating film thickness. Film thickness above an acceptable threshold value results in failure at TAC test.

The optimization module of Minitab was used to minimize the value of TAC test result, as shown on Figure 4.9.

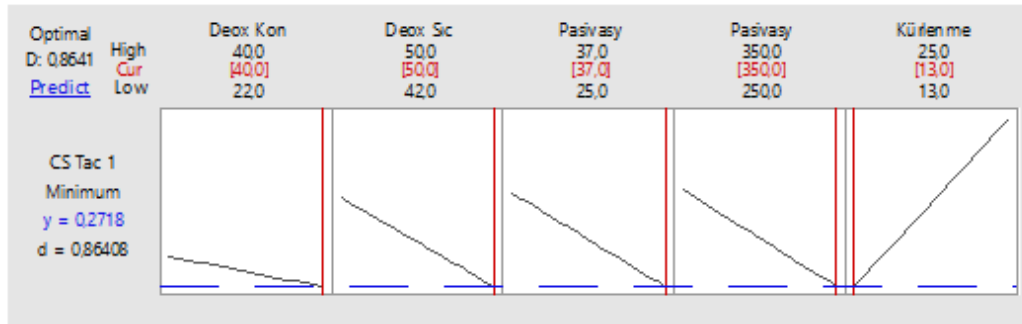


Figure 4.8 Optimization Plot for Cs Surface.

For diamond cut wheels, curing time of powder coating, passivation temperature and their combination have the highest effect on TAC test, similar to the case of cast surfaces (Figure 4.10),

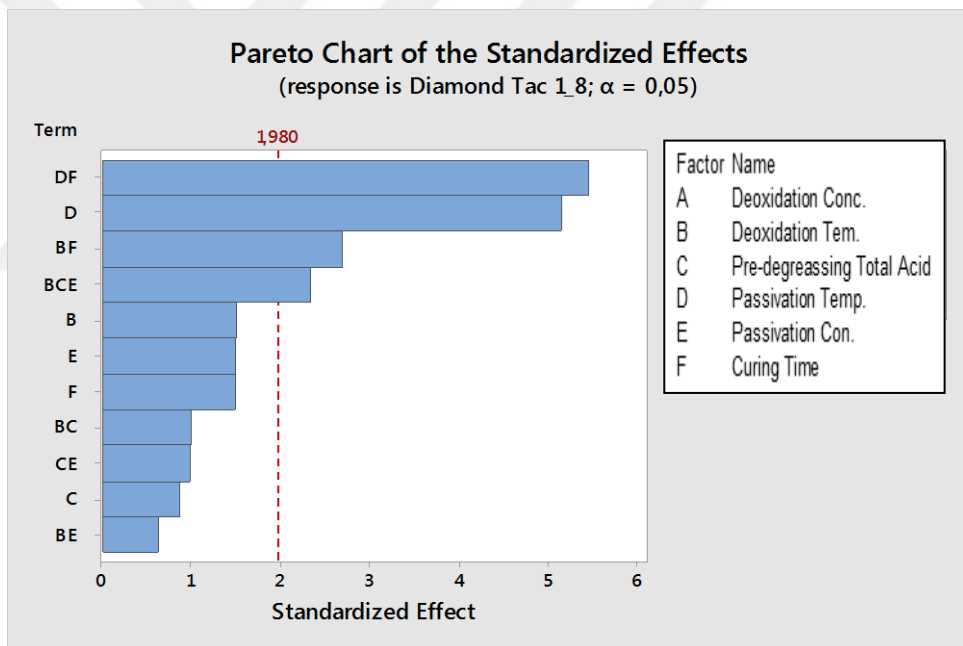


Figure 4.9 Effect of Pareto Diamond Tac1_8.

The interaction of parameters on TAC test for diamond-cut surface are shown on Figure 4.11 At 42 °C constant deoxidation concentration, decreasing curing time increases the value of TAC test result.. At 42 °C constant deoxidation temperature, increasing passivation conductivity improves TAC test results. But, when the both deoxidation and passivation temperatures increase simultaneously, increase in passivation temperature has less effect on the results. Increase of passivation temperature increases the etching of the surface, and increase of

passivation conductivity increases the coating thickness; so TAC test results improve with increasing the values of these parameters.

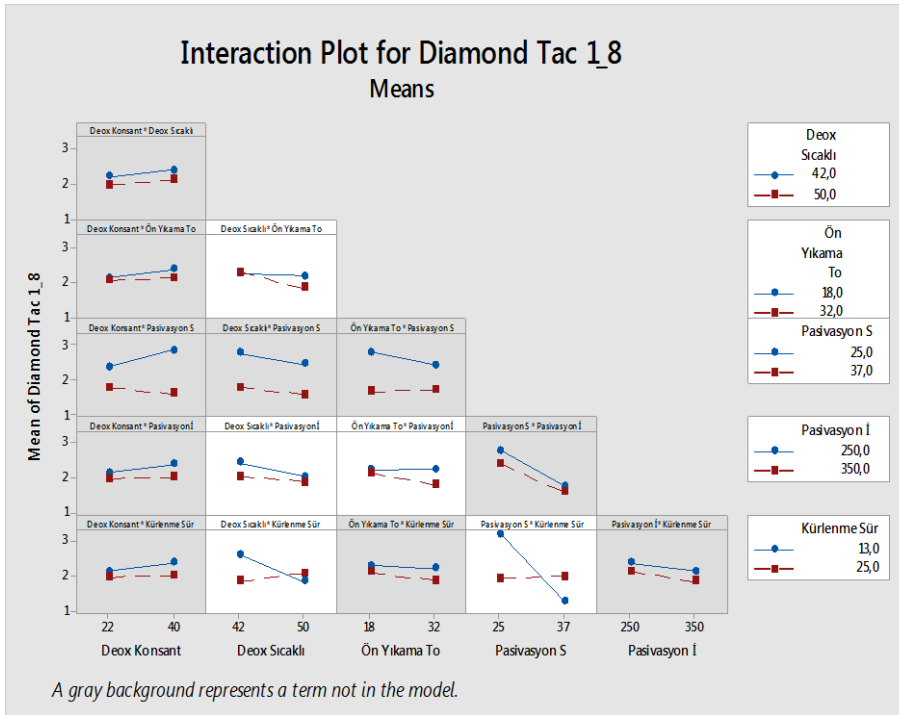


Figure 4.10 Interaction Plot for Diamond Cut Tac1_8

Using the optimization module of DOE of Minitab, the parameters that give the best TAC test results are determined (In Figure 4.12)

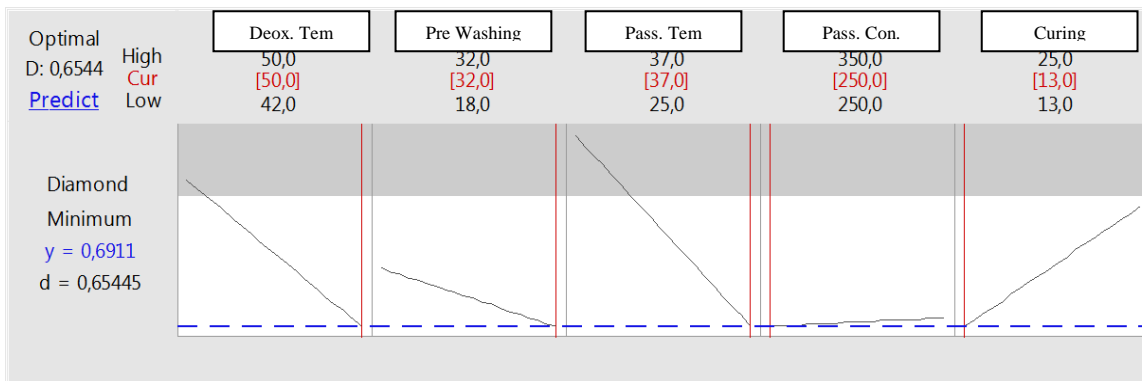


Figure 4.11 Optimization Plot.

5. CONCLUSION

The purpose of this study was to investigate the effect of process parameters on TAC test results, and make improvements accordingly. The mode and level of effect of process variables were examined according to pareto analysis, which showed the positive effect of passivation temperature and conductivity on TAC test, and the interaction between deoxidation and passivation baths.

The wheels coated according to the resulting parameters passed the TAC test but failed the adhesion test. Here, it was discovered that increasing the coating film thickness, while improving TAC test results, had a negative effect on adhesion. The next study to be done would concentrate on this subject.

Each test in the scope of customer specifications is affected from the changing parameters in a contradicting way; increasing one parameter results in failure in one test, and improvement in another.

After interpreting the results of this study and applying them to the process in practice, the passivation conductivity has been increased from 260 $\mu\text{S}/\text{cm}$ to 270 $\mu\text{S}/\text{cm}$ and deoxidation temperature from 40 °C to 45 °C. So then, the ratio of passing the TAC test has improved from 25% to 75%.

REFERENCES

- Akın Ü., N. M.**, 2008, SİRİRAL KAYNAKLI ÇELİK HAT BORULARININ KAYNAK DİKİŞLERİNİN RADYOSKOPIK TEST YÖNTEMİ İLE MUAYENESİ, 3rd International Non-Destructive Testing Symposium and Exhibition, s. 1-12, İstanbul
- Aran, A.**, 2007, Döküm Teknoloji İmal Usülleri Ders Notları, İstanbul.
- Arconic.** , www.arconic.com: <https://www.arconic.com/alcoawheels/europe/en/benefits.asp>. (data acces:10 June 2019).
- Baes, C., Mesmer, R.** ,1976, "The hydrolysis of Cations", New York, John Wiley & Sons.
- Başer, T. A.**, 2012, Alüminyum Alaşımaları ve Otomotiv Endüstrisinde Kullanımı, Mühendis ve Makina Cilt 53 Sayı 635, 51-58.
- Beck, T. R.**,1984, Salt film formation during corrosion of aluminum., Electrochim, Acta Vol 24, 485-491.
- Cms**, <http://www.cms.com.tr/tr/urunler/urun-katalogu>, data access 20 June 2019.
- Dal, K.** , " Türkiye Döküm Sanayicileri Derneği Sektör Rapor", <http://www.subconturkey.com/2012/Eylul/haber-Turkiye-Dokum-Sanayicileri-Derneği-Sektor-Raporu.html>, (data access 6.6.2019)
- Demir C., Mentеше E.B., T. M.**, "Aluminyum Isıl İşleminde Su Verme Uygulamaları Ve Kalıntı Gerilme Etkisi", <https://docplayer.biz.tr/1202371-Aluminyum-isil-isleminde-su-verme-uygulamalari-ve-kalinti-gerilime-etkisi.html>, data acces 6 June 2019
- Dispınar, D.A.**, 2012," Correlation between Mechanical Properties and Porosity Distribution of A356 in Gravity Die Casting and Low Pressure Die Casting,Advanced Materials Research Vol 445, 283-288.
- Ercan, Y.**, 2012, Al-Si ötektik alaşımaları, İzmir, CMS Jant ve Makina Sanayii A. Ş.
- Foundry.** <https://www.foundry-planet.com/fileadmin/redakteur/Material/14-06-10-striko-bild06.jpg> (data access 6 June 2019).

REFERENCES (continued)

- Foundry**, <https://www.foundry-planet.com/fileadmin/redakteur/Material/14-06-10-striko-bild06.jpg> (data access 5 June 2019).
- Gautam Krishnan, D. E.**, 2013, Study of Strontium Modification in Aluminium Alloy, Vol,3, Issue 10.
- Gruzleski, J. E., Closset, B. M.**, 1990, The treatment of liquid aluminum-silicon alloys, Illionis, Des Plaines, American Foundrymen's Society.
- Henkel**, 2014, Preatment o Aluminum Wheels, Henkel Company.
- Hoar, T.**, 1952 November, Discussion on Filiform Corrosion, Chem. Ind.
- Manual, A. A.**, 2002, Aluminium Automotive Manual, Products-Cast Alloys and products. European Aluminium Association data acces <https://www.european-aluminium.eu/media/1544/aam-products-6-cast-alloys-and-products.pdf>.
- Manuel, S.**, 2014, Rims, Brüksel, European Tyre and Rim Technical Organization.
- Maxion Wheels**, <https://www.maxionwheelsturkey.com/en/why-maxion-jantas-wheels> (data access 5 June 2019).
- Nguyen, T. H., Foley, R.**, 1980, The Chemical Nature of Aluminum Corrosion, Journal of the Electrochemical Society, 2563-2566.
- Ruggeri, R. T., Beck, T. R.**, 1983, An Analysis of Mass Transfer in Filiform Corrosion, Corrosion, 452-465.
- Schweitzer, P. A.**, 1996, Encyclopedia of Corrosion Technology, New York, Marcel Dekker Inc.
- Schweitzer, P. A.**, 2004, Encyclopedia of CORROSION TECHNOLOGY 2. Edition, New York, Marcel Dekker.
- Steidl, J.**, Illustration showing the evolution of the wheel starting from a stone wheel and ending with a steel belted radial tire", <https://www.shutterstock.com/g/jamesgroup> (data acces 5 June 2019.)
- Streitberger, H.-J., Dössel, K.-F.**, 2008, Automotive Paints and Coatings, Weinheim, Wiley-VCH Verlag GmbH & Co.
- Toyota, A. E.** TSH3122G.

REFERENCES (continued)

Tudor, R., "History of wheels", <https://www.autoevolution.com/news/history-of-the-wheel-7334.html>, data access 5 June 2019.

W.H., S., Hoover, S., 1972, Filiform Corrosion of Aluminium. *Paint Technology*, 76.



TEŞEKKÜR

Bu çalışma süresince gerekli verilerin sağlanmasında kolaylık gösteren CMS firmasına, TAC testinin yapılmasında yardımcı olan Zihşan Akgözlü'ye, kıymetli görüşlerinden yararlandığım, yardımlarını esirgemeyen Hakan Erdoğan'a tezin biçimlenmesinde değerli katkılarını aldığım Ece Özütatlı'ya ve Profesör Doktor Mustafa Demircioğlu'na ve CMS Jant Makina Sanayii A.Ş.'ne teşekkürü bir borç bilirim.



... / ... / 20..

İmzası

Adı-Soyadı

CURRICULUM VITAE

M. YAĞIZ ALTINÖRS

GSM : 05372191531

e-mail : muminaltinors@gmail.com

Address: 1771 Sok No: 13 /9 Bostanlı/ İzmir

Education

2005- 2010 (Bachelor'sDegree) Ege University, Chemical Engineering Department

Experience

01.2016-

CMS JANT MAKİNA A.Ş.

Paintshop Process Chief

Installation of the paintshop, carrying out projects to improve production efficiency, taking part in approval of new projects, responsible to quality audits such as ISO 1694 & VDA and customer, adaption new paint and chemicals on daily production ,

04.2012-11.2015

HAYES-LEMMERZ ALÜMİNYUM JANT A.Ş.

Paintshop Engineer

Installation of the paintshop, planning and following daily production, carrying out projects to improve production efficiency, taking part in approval of new projects, planning periodic and preventative maintenance activities.

07.2011-04.2012

OLGUN ÇELİK A.Ş.

Paintshop Engineer

Installation of cataphoresis and wet paint units, preparing the documentation related to the paintshop according to ISO/TS 16949 standards, taking part in approval of the units by OEM, planning and following daily production, carrying out projects to improve production efficiency, planning periodic and preventative maintenance activities.

06.2011-07.2011

EKİNOKS KİMYA SAN. PAZ. LMTD. ŞTİ.

Technical Service Engineer

Technical support to customers, following the chemical stocks and planning the shipments accordingly