THE EFFECT OF DIFFERENT ADDITIONAL WIRES ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AISI 304L AND AISI 430 STAINLESS STEELS COMBINED WITH TIG WELDING

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THE EFFECT OF DIFFERENT ADDITIONAL WIRES ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AISI 304L AND AISI 430 STAINLESS STEELS COMBINED WITH TIG WELDING

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MURAD AYAD M. DEBESKI

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I certify that in my opinion the thesis submitted by Murad Ayad M. DEBESKI titled "THE EFFECT OF DIFFERENT ADDITIONAL WIRES ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AISI 304L AND AISI 430 STAINLESS STEELS COMBINED WITH TIG WELDING" is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

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This thesis is accepted by the examining committee with a unanimous vote in the Department of Computer Engineering as a master thesis. December 12, 2017

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The degree of Master of Science by the thesis submitted is approved by the Administrative Board of the Graduate School of Natural and Applied Sciences, Karabük University.

Prof. Dr. Filiz ERSÖZ ....
Head of Graduate School of Natural and Applied Sciences

“I declare that all the information within this thesis has been gathered and presented in accordance with academic regulations and ethical principles and I have according to the requirements of these regulations and principles cited all those which do not originate in this work as well.”

Murad Ayad DEBESKI

ABSTRACT

M. Sc. Thesis

THE EFFECT OF DIFFERENT ADDITIONAL WIRES ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AISI 304L AND AISI 430 STAINLESS STEELS COMBINED WITH TIG WELDING

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The increase in the diversity of developing industrial materials requires the use of different materials where different characteristics are required and the combination of materials with different properties. Ferritic stainless steels, heat resistant instruments, turbine blades, heat exchangers and boiler pipes etc., which are the most used stainless steels in the industry, austenitic stainless steels can find themselves in areas such as coal and petroleum industries where high intergranular corrosion resistance is required and parts that are difficult to heat treat. Although different metals can be welded in many ways, it is an advantageous way to obtain high quality welds with TIG weld, smooth surface and excellent welds. In this study, the most commonly used AISI 304L austenitic stainless steel and AISI 430 ferritic stainless steel materials in the stainless steel group were combined by TIG welding methods. During the assembly, three additional wires, ER308, ER309 and ER347, were used. After joining these two different stainless steel with different additive metals, tensile, impact and microhardness tests were performed on the joined materials to determine the effects on the weld zone, and microstructure studies were carried out.

Key Words : TIG welding method, ferritic and austenitic stainless steels, microstructure, mechanical properties.

Science Code : 914.1.092

ÖZET

Yüksek Lisans Tezi

TIG KAYNAĞI İLE BİRLEŞTİRİLMİŞ AISI 304L VE AISI 430 PASLANMAZ ÇELİKLERİN MİKROYAPI VE MEKANİK ÖZELLİKLERİNE FARKLI İLAVE TELLERİN ETKİSİ

Murad Ayad M. DEBESKİ

Karabük Üniversitesi
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Yrd. Doç. Dr. Harun ÇUĞ
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Gelişen endüstride malzeme çeşitliliğinde artış, farklı özelliklerin gerekli olduğu yerlerde farklı malzemelerin kullanılmasını ve farklı özelliklere sahip malzemelerin kombinasyonunu gerektirmektedir. Endüstride en çok kullanılan paslanmaz çeliklerden olan ferritik paslanmaz çelikler, ısıya dayanıklı alet, türbin kanatları, ısı değiştirici ve kazan boruları vs. gibi birçok alanda kullanım imkanı bulurken, östenitik paslanmaz çelikler ise yüksek taneler arası korozyon direncine ihtiyaç duyulan kömür ve petrol endüstrisi ve ısıl işlem uygulaması zor olan parçalar gibi alanlarda kendilerine yer bulabilmektedirler. Farklı metallerin kaynağı birçok yöntemle yapılsa da TIG kaynağı, düzgün yüzeyli ve mükemmel kaynaklara sahip yüksek kaliteli kaynaklar elde edilmede avantajlı bir yöntemdir. Bu çalışmada, paslanmaz çelik grubunda en çok kullanılan AISI 304L östenitik paslanmaz çelik ve AISI 430 ferritik paslanmaz çelik malzemeler TIG kaynak yöntemleriyle birleştirilmiştir. Birleştirme sırasında ER308, ER309 ve ER347 kalite olmak üzere üç farklı ilave tel kullanılmıştır. Bu iki farklı paslanmaz çeliğin farklı ilave metaller ile birleştirilmesi işlemi sonrasında kaynak bölgesi üzerindeki etkileri belirlemek için, birleştirilen malzemeler üzerinde çekme, darbe ve mikro sertlik testleri yapılmıştır, mikroyapı incelemeleri gerçekleştirilmiştir.

Anahtar Kelimeler : TIG kaynak yöntemi, ferritik ve östenitik paslanmaz çelikler, mikroyapı, mekanik özellikler.

Bilim Kodu : 914.1.092

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SYMBOLS AND ABBREVITIONS INDEX

SYMBOLS

Creq : Chromium equivalent
Nieq : Nickel equivalent
Al : Aluminum
Ar : Argon
H_2 : Hydrogen
He : Helium
Mo : Molybdenum
Ni : Nickel
TS : Turkish Standards

ABBREVITIONS

AISI : American Iron and Steel Institute
ASTM : American Society for Testing and Materials
DIN : Deutch Industrie Normen
HAZ : Heat Affected Zone

CHAPTER 1

INTRODUCTION

It is very difficult to establish a date at which anything in engineering can be said to be truly invented. All electric fusion welding can be classified as arc welding but, as near as can be established, TIG welding originated in the USA, probably before 1939 where it was used mainly to facilitate the then rather difficult process of welding aluminum. As the less dense than air inert gas helium occurred naturally in the USA and was readily and cheaply available, it was used as an inert shield to prevent undue oxidation of the aluminum during melt down. It was known as the Heliarc process.

TIG welding appears to have become commercially available in the UK and Europe after development by BOC around 1948. However, helium was (and still is) very expensive in Europe so BOC turned to argon (an inert gas denser than air) which was produced by BOC as a by-product of air liquefaction for oxygen production. BOC continued to develop both gas and equipment and put on the market a commercial TIG welding process known as Argonarc; argon having certain advantages over helium, other than cost. In passing, it should be mentioned that both the Heliarc and Argonarc methods operated on AC at that time because the arc acted as an electrical rectifier. However, the DC component of the welding current caused dirty welds with oxides entrapped in the weld bead. To counteract this so-called rectifier, manufacturers in the USA used an extremely high voltage with a high frequency (HF) spark injector. This system was only partially effective in cleaning the weld and caused considerable radio frequency interference (RFI).

BOC's method eliminated the DC component by using a suppressor, a large capacitor connected in series with the arc, which gave excellent results for DC welding of aluminum but still gave some RFI. Use of argon as a shielding gas gave many advantages over helium, not least of which was a reduction in arc voltage to below 20

V. Argon also gave a smoother and much less fierce arc and cost was about 30% the cost of helium.

BOC also developed a surge injection system for arc starting and main- tenancy in which the original spark injection was used in short bursts for starting only and, because of this, HF and RFI were considerably reduced but not eliminated.

A useful application of the Argon-arc process at that time was for arc spot welding of thin sheet metals. It soon became obvious that DC TIG welding was highly suitable for joining most bright rolled steels, and particularly for many grades of stainless steel up to about 1.6 mm (1/16 in) thickness. A special spot welding gun was designed and introduced giving the facility to apply pressure and make welds from one side only where access was restricted. Development of high efficiency resistance spot welding systems seems now largely to have phased out the TIG spot welding process although it is still to be found, often using the same hard-wearing original equipment which was being sold up to the mid 1960s.

It is probably true to say that the most extensive current use of TIG is in seam welding of stainless steels, where the DC mode is usually most suitable (precision TIG welding is almost exclusively DC). Aluminum, apart from a few suitable alloys, is still almost exclusively welded using AC, so many combined AC/DC sets have been developed. The efficiency of such units is well illustrated by the fact that many 25-30-year-old TIG sets are still in use today, some of these not even having open -gap automatic arc strike but relying on the skill of an operator briefly to touch down and retract the electrode from the workpiece to initiate an arc before the electrode tip is deformed (touch start). Ever since its inception, equipment and consumables e.g. gas, wire, filler rods, etc. have been refined and improved although the basic principles of TIG welding have remained unchanged. A wide range of inert gas mixes has become available together with many varied alloyed tungsten electrodes. Power sources, mainly through advanced electronics, have become lighter, more accurate, and have greatly improved arc stability. This has enabled an increase in the use of TIG welding to be made, particularly for ultra -low current and precision applications. Control of weld sequences and programs by computer or microcomputer is now widely used and development in this field is still continuing [1].

The increase in the types of materials used in today's industry necessitates the use of different metals and different connections in places where different properties are required and in particular the economic factors have become increasingly important in recent years, necessitating the combination of materials with different properties. Although the source of different metals is usually made by solid state welding methods, it can be done with electric arc, TIG and MIG welding methods.

Among these welding methods, the TIG welding is a welding method in which the heat energy required for welding is protected by a tungsten electrode and inert gas supplied by an arc formed between the workpiece and a nozzle surrounding the welding region. In this welding method, high quality welds with smooth surface and perfect welds can be obtained.

In this study, AISI 304L austenitic stainless steel and AISI 430 ferritic stainless steel materials, which are most widely used in the stainless steel group, are combined by TIG welding methods. Three different filler materials were used during assembly, ER308, ER309 and ER347 quality. In order to determine the effects on the weld zone, tensile, impact and microhardness tests were performed on the joined materials, and microstructure studies were performed on the welded joints.

CHAPTER 2

LITERATURE REVIEW

Of all the welding processes Tungsten Inert Gas (TIG) welding is one of the most versatile. Since its inception, it has been improved and refined in terms of equipment, consumables and application and is capable of still further improvements [1].

In this thesis intends this to be a practical on TIG containing advice on such items as power sources, ancillary components, torches, gases, electrodes, fixtures and heat sinks, etc. In short, an extensive guide to its use. The thesis sets out to explain in clear language the various processes, equipment and associated terminology without reaching into the worlds of advanced electronics or metallurgy [2,3].

Some of the information provided may be obvious to experienced welders. However, it is hoped that even for experts some useful extra knowledge will be gained from reading the thesis which in most cases gives the author's considered opinions on the subject; not necessarily in agreement with other peoples views [4-6].

Certain passages in this thesis have been quoted almost verbatim from literature supplied by some of the companies listed. This is not for any reason other than that the passages quoted are definitive and could not significantly be improved to any great extent, as the basic TIG welding principles still apply. Also, some extra tabulated information has been included, as such data can often be difficult to find for someone not totally involved in a particular industry, e.g. pipeline welding and pipe sizes [6-8].

CHAPTER 3

GENERAL INFORMATION ABOUT STEELS

3.1. STEELS

Steels are alloys of iron and other elements, primarily carbon, widely used in construction and other applications because of their high tensile strengths and low costs. Carbon, other elements, and inclusions within iron act as hardening agents that prevent the movement of dislocations that otherwise occur in the crystal lattices of iron atoms. Figure 3.1 shows steel classification chart [2].

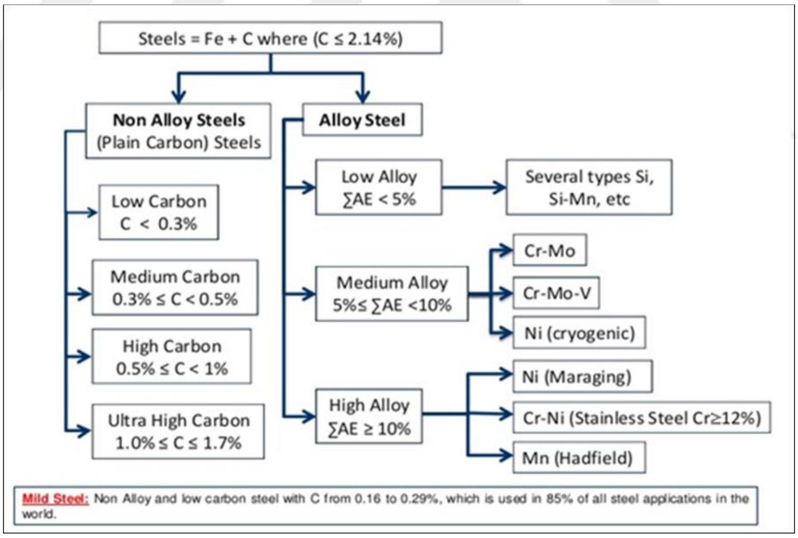


Figure 3.1. Steel classification chart [2].

There are few iron-carbon alloys in the construction that contain elements from steelmaking methods such as manganese, silicon, sulfur and phosphorus. They are also known as manufacturing steels because of their use in the building and manufacturing industries.

All properties of carbon steels are directly related to their structure, depending on the amount of carbon they contain. With increased carbon content, ductility (% elongation and% section shrinkage) and impact resistance properties decrease while the hardness, yield and tensile strength of steels increase. The increase in the amount of carbon (depending on these properties) plays a role in reducing the plastic deformation capabilities of steels. However, as a very important and effective element in the martensitic transformation, it makes it possible for the steels to be hardened by the mechanism we call water quenching. The increase in the amount of carbon has an adverse effect on the ability of the steel to absorb water and weldability. Varying the amount of alloying elements, their formation in the steel either as solute elements, or as precipitated phases, retards the movement of those dislocations that make iron comparatively ductile and weak, and thus controls qualities such as the hardness, ductility, and tensile strength of the resulting steel. Steel's strength compared to pure iron is only possible at the expense of ductility, of which iron has an excess. Although steel had been produced in bloomer furnaces for thousands of years, steel's use expanded extensively after more efficient production methods were devised in the 17th century for blister steel and then crucible steel. With the invention of the Bessemer process in the mid-19th century, a new era of mass-produced steel began. This was followed by Siemens-Martin process and then Gilchrist-Thomas process that refined the quality of steel. With their introductions, mild steel replaced wrought iron. Figure 3.2 show Fe-Fe_3C diagrams in which steels and cast-iron parts can be seen [3].

Further refinements in the process, such as basic oxygen steelmaking (BOS), largely replaced earlier methods by further lowering the cost of production and increasing the quality of the metal. Today, steel is one of the most common materials in the world, with more than 1.3 billion tons produced annually. It is a major component in buildings, infrastructure, tools, ships, automobiles, machines, appliances, and weapons.

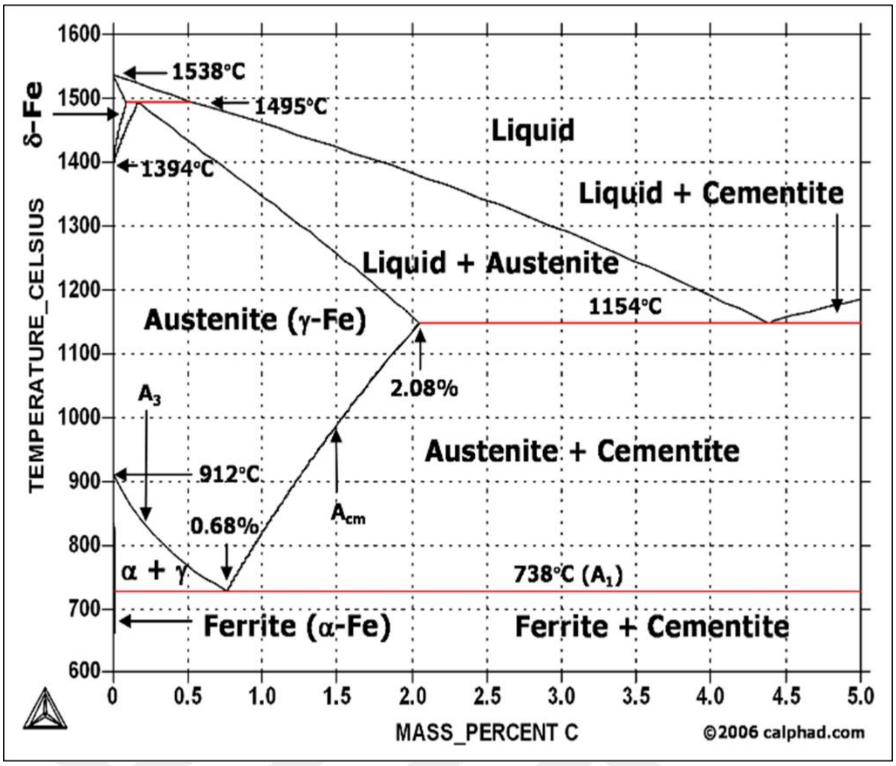


Figure 3.2. Fe-Fe3C phase diagrams.

Modern steel is generally identified by various grades defined by assorted standards organizations according to the American Iron and Steel Institute (AISI), steels can be broadly categorized into four groups based on their chemical compositions:

- Carbon Steels
- Alloy Steels
- Tool Steels
- Stainless Steel

3.1.1. Carbon Steels

Carbon steels contain trace amounts of alloying elements and account for 90% of total steel production. Carbon steels can be further categorized into three groups depending on their carbon content:

- Low Carbon Steels/Mild Steels contain up to 0.3% carbon
- Medium Carbon Steels contain 0.3 – 0.6% carbon
- High Carbon Steels contain more than 0.6% carbon [3].

3.1.2. Alloy Steels

They are steels whose composition exceeds the ratios specified in plain carbon steels or contains one or more of the other alloying elements in their own right. Steels which do not exceed 5% of alloying elements in the composition are of low alloy, steels exceeding 5% are high alloy steels [3].

3.1.3. Tool Steels

Tool steels are noble steels used for processing and shaping materials. The use of tool steels, which have 8% of total steel production, increases every year shows. Classification of steel materials as tool steel is only for the purpose of use. It is not possible to classify or limit chemical compositions in tool steels, such as other steel groups, because the chemical composition can vary widely and can intersect with other steel groups. For this reason, steels of the same chemical composition (production methods) changes can have different properties, so that materials with the same chemical composition in different areas of use can be named with different names [3].

3.1.4. Stainless Steels

Stainless steels are generally preferred due to their excellent corrosion resistance. In their chemical composition, steels having at least 12% chromium are called "stainless steel". Stainless steels are widely used in the food, pharmaceutical, chemical and petrochemical industries.

Stainless steels have not been discovered in recent years. In 1822, Faraday showed that there was an alloy that was highly resistant to atmospheric oxidation when chromium was added to the iron. In 1838, Mallet discovered that chromium steels appear corrosion-resistant properties in some environments. Until the late 19th century, chrome steels were only used for hot sulfuric acid containers. In 1904, Monnartz found that the addition of chrome-added steels to the oxidizing atmosphere made the passivating property more pronounced. It proved that the corrosion resistance of these metals came from the passive layer formed on the metal surface [3]. However, the formation of passive filming is not sufficient for the alloys to be resistant to corrosion in all environments. One of the ways to make stainless steels more resilient is to increase the proportion of the main alloying elements such as chromium and nickel to reduce carbon content [4].

The resistance to corrosion and staining of the stainless steel makes it an ideal and indispensable material because stainless steel is commercially cheaper in a wide range of applications, cheaper than other steels and has a striking appearance. Though there are a total of more than 150 stainless steel types, 15 of them are very common and very popular in the market.

Stainless steels are shaped by cold and hot rolling methods in many different ways such as flat products, plates, rods, wires, pipes, especially petro-chemistry, chemistry, like other similar steels. Cast parts are widely used in the food industry, in cigarettes, in surgical equipment’s, in industrial equipment's, in automotive, in the production of white goods, in constructions and construction elements. One of the areas where stainless steel is used is the products we have never separated in our everyday life like jewelry and watches. The most common quality used in jewelry is 316L austenitic stainless. Stainless steel does not oxidize and darken over time like silver. In addition, the density of stainless steel is slightly lighter than silver, so it is easier for designers.

The most important feature distinguishing stainless steels from other steels is that the chromium content is very high (12%). Due to the increased amount of chromium, oxidation resistance increases at high temperatures.

Stainless steels are classified in five groups according to their microstructure at room temperature:

- Austenitic Stainless Steels
- Ferritic Stainless Steels
- Martensitic Stainless Steels
- Duplex Stainless steel
- Precipitation Hardened Stainless Steels

3.1.4.1. Ferritic Stainless Steels

Ferritic stainless steels generally do not contain nickel. It is a stainless steel base containing high chromium (between 10.5% and 30%), molybdenum, titanium vanadium, carbide builder and ferritic steady breaking alloy elements. Thanks to their high chromium content, they provide a very high corrosion resistance to ferritic stainless steels. Ferritic stainless steels, which have mechanical and physical properties close to those of other similar carbon steels, are magnetic in contrast to austenitics. Due to their low carbon content they are not heat-treated and can be easily shaped.

The only heat treatment applied to such steels is annealing. The most commonly known ferritic qualities are AISI 430 and 442. Ferritic stainless steels are volume based cubic [3].

3.1.4.2. Austenitic Stainless Steels

The AISI 300 series or austenitic stainless steels account for approximately 60% of the total stainless-steel production in the world. A maximum of 0.15% carbon and a minimum of 16% chromium contain sufficient amount of nickel and / or manganese to stabilize the austenitic build up from very low temperatures to the melting temperature. The most well known type is steel, which is 18/10 (304 quality) known as stainless steel, containing 18% chromium and 8% nickel.

AISI 316L contains 12-25% chromium, 8-25% and 2.2% molybdenum in the composition. They are used in chlorinated environments where AISI 304 is inadequate. Steels known as "super-austenitic" stainless steels, such as AL-6XN and 254SMO, exhibit high molybdenum (> 6%) and a high stress corrosion resistance with nitrogen additives and high nickel. The high alloy content of the "super-austenitic" causes the costs to increase significantly. For this reason, a similar performance can be obtained from ferritic or duplex stainless steel groups at a lower cost. The most commonly known austenitic qualities are AISI 304 and 316. Austenitic stainless steels can easily be cold-formed. Because of these properties, it can be used as interior and exterior architectural by making it into sheet and sheet [4].

Austenitic chrome nickel stainless steels are most commonly used in stainless steels containing 12-25% Cr and 8-25% Ni in their composition. The sum of chromium, nickel and manganese in austenitic stainless steels is 24% or more. Typically the chromium content is 16% or more. Chromium provides oxidation and corrosion resistance, while nickel and manganese ensure that the austenite phase is stable even at room temperature, despite high cooling rates. Crystal structures are surface-centered cubic [4].

3.1.4.3. Martensitic Stainless Steels

Martensitic stainless steels are similar to ferritic steels and similar to low alloy, high strength steels or carbon steels.

However, due to the excess carbon depletion it contains, it can be hardened by heat treatment, such as carbon steels, and its strength can be increased. Basic alloying elements: chromium from 12% to 15%, molybdenum from 0.2% to 1.0% and carbon from 0.1% to 1.2%. Except for several martensitic grades, nickel is not included in the content. Martensitic stainless steels are magnetic. Depending on the increased carbon content, hardening and strength increases, toughness and ductility decrease. Depending on the high carbon content and other alloying elements, they can be hardened by heat treatment up to 60 HRC. After heat treatment called tempering or tempering, the most appropriate corrosion resistance is reached after the stress relieving process. Compared to ferritic and austenitic grades, corrosion resistance is slightly lower than martensitic grades. Machinability and formability are high. Depending on the alloying elements and ratios they contain, there may be a small amount of residual austenite phase in the constructions. It is also used as a tool steel.

The application area is very wide. The crystal structures are the volume central cubic tetragon.

3.1.4.4. Duplex Stainless Steels

Duplex stainless steels contain high chromium (18-28%) and medium nickel (4.5-8%). The amount of nickel is at most 8%, and it is insufficient to make the whole internal structure austenitic. The biaxial microstructure is obtained by tempering the steel at 1000-1050 °C and then rapidly cooling it. Duplex stainless steels have a higher strength than austenitic stainless steels. The most important limiting feature of duplex stainless steels is that they become brittle at high and very low temperatures. The most widely known duplex stainless steel is of AISI 2205 quality. Requires higher power for cold forming. It is generally used in chemical apparatus manufacturing, treatment plants, heat exchangers, petrochemical and paper industries and marine technologies. The crystal structures consist of a volume center cubic ferrite and a surface centered cubic austenite phase. The disadvantage of duplex stainless steels is; (HAZ) ferrite-austenite balance in favor of ferrite due to the weakening of the pitting corrosion resistance and the brittleness resulting from thermal aging limits the operating temperatures to 260-300 °C.

3.1.4.5. Precipitation Hardening (PH) Stainless Steels

Also called "aged hardened stainless steels". Precipitation stainless steels mainly contain chrome and nickel. It is a type of stainless steel that combines the properties of both martensitic and austenitic qualities in a proper manner. Like martensitic stainless steels, they have high resistance to heat treatment and corrosion resistance like austenitic qualities. The hardening is achieved by the addition of one or more alloying elements such as copper, aluminum, titanium, niobium and molybdenum. The most commonly known quality in this group is 17-4 PH. This quality is also known as AISI 630. This grade, which takes its name from 17% chromium and 4% nickel content, also contains 4% copper and 0.3% niobium [4].

3.1.5. Stainless Steel Usage Areas

Stainless steel is used in our homes, in our cities and in the industry. This product has been given a fan below;

At home:

- Cutlery, meals and other tableware
- Kitchen sinks
- In pots and pans
- In the oven and barbecues
- Garden equipment and furniture's

In the city:

- Bus stops, telephone clubs and another street furniture
- On building facades
- Elevators and escalators
- Subway, train and station infrastructure

Industry:

- In food products and pharmaceutical production equipment
- Drinking and wastewater treatment equipment and equipment
- Chemical and petrochemical plants
- Automotive and aircraft engines components
- It is used in fuel and chemical tankers [3].

CHAPTER 4

TUNGSTEN INERT GAS (TIG) WELDING

The TIG arc welding is also referred to as the "Argon-Arc" welding, since argon gas is often used as the shielding gas. In the TIG arc welding method, which is an electric arc welding method, the heat required for welding is provided by the electric arc formed between a non-melting tungsten electrode and the workpiece. The arc zone is often protected by sending argon gas. It is decided whether or not to use the welding additional metal according to the base metal to be welded. This method was developed in the US in 1940-1944 for the welding of light metal alloys such as aluminum and magnesium, especially in the aerospace industry, and helium gas, which was obtained in abundance from natural gas weldings in the United States at that time, was used.

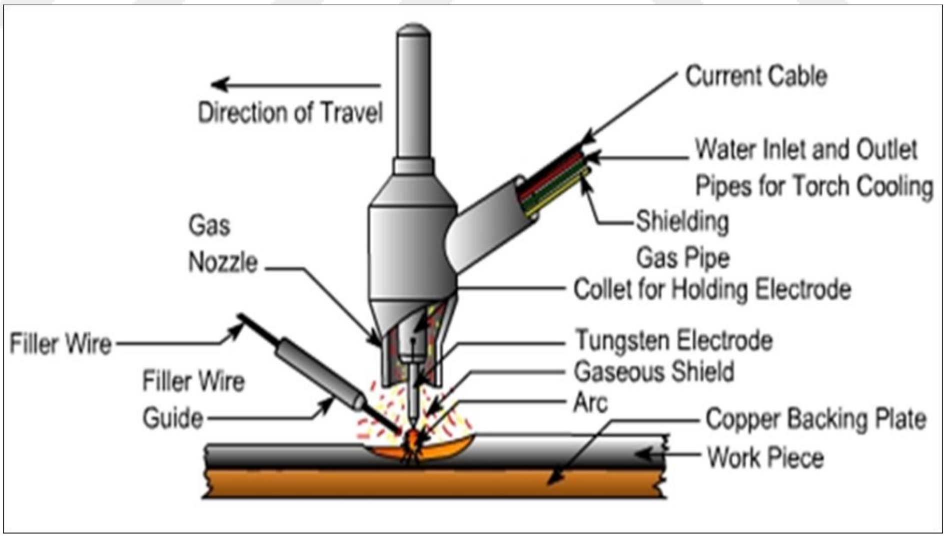


Figure 4.1. The TIG welding process.

The TIG arc welding method has found wide application range in the industry. In this welding method, the welder does not have much work. It is similar to the method of welding with acetylene, but the flame is different but the heat produced by the electric arc, there is no flammable gas and burning. It can be used at the welding of some special steel materials, but it is mostly made by this method at every position of non-ferrous metals. TIG, which is much more successful at the welding of fine metals, is also used at the welding of medium thickness metals.

In the TIG arc welding, the arc and welded joint can be easily seen by the welder. The slag layer does not come into effect and there is no problem of slag cleaning and slag remnants. TIG arc welding has become increasingly important and it is presently antagonistic as a welding method that can be applied in space, aviation, food, automotive sectors [2, 7, 8].

The TIG arc welding method is seamlessly applied in combination with steel, stainless steel, nickel alloys, copper alloys, titanium alloys, aluminum and magnesium alloys. These materials are frequently used in maintenance and repair works, automotive industry, shipbuilding industry, aircraft and space industry, chemical industry, metal manufacturing industry, food industry, pipelines, boilers and pressure vessels.

4.1. FOUNDATION OF TIG WELDING

The foundation of the process is schematically represented in Figure 4.2.

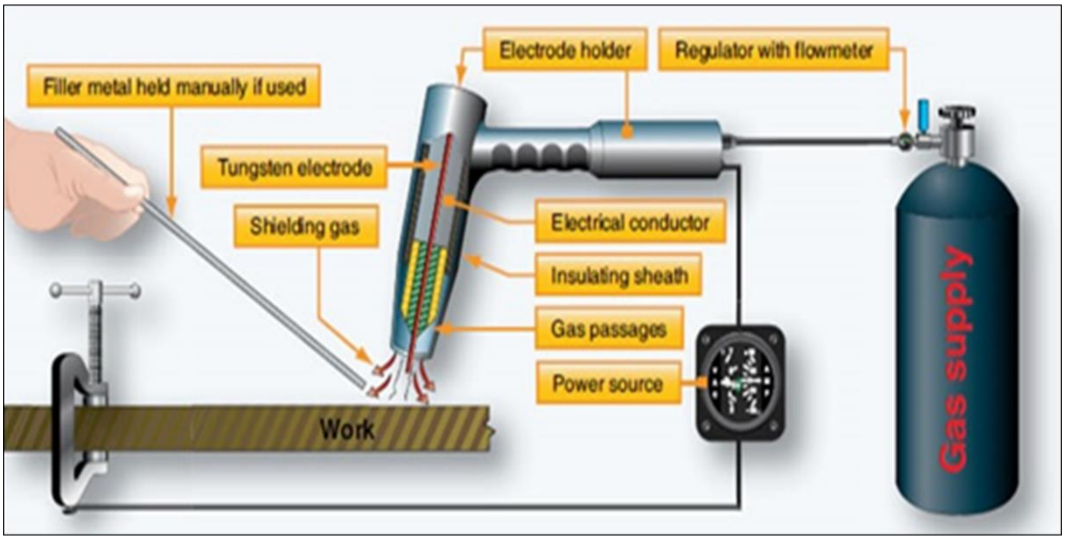


Figure 4.2. Foundation of TIG Welding.

A plasma arc is created between electrode tip and work piece to be welded by power source machine. Ignition pulse is produced with power source with a high frequency generator that is large up to several MHz. The frequency and voltage generates strong electrical interference around welding cell. The electrical energy is converted to thermal energy that provides to melt base and the filler material.

Depends on the material; base metal surface temperature is 1430 ˚C to 2230 ˚C Since the high temperature exists on the welding pool, it tends to react with oxygen and creates oxidation on the surface of the base metal. In order to prevent oxidation gas shielding is applied into the process [3, 9].

The shielding gas is fed into the gas nozzle at a preset flow rate. Also, the shielding gas is useful to prevent overheating of the welding torch.

4.1.1. Characteristic of the Arc

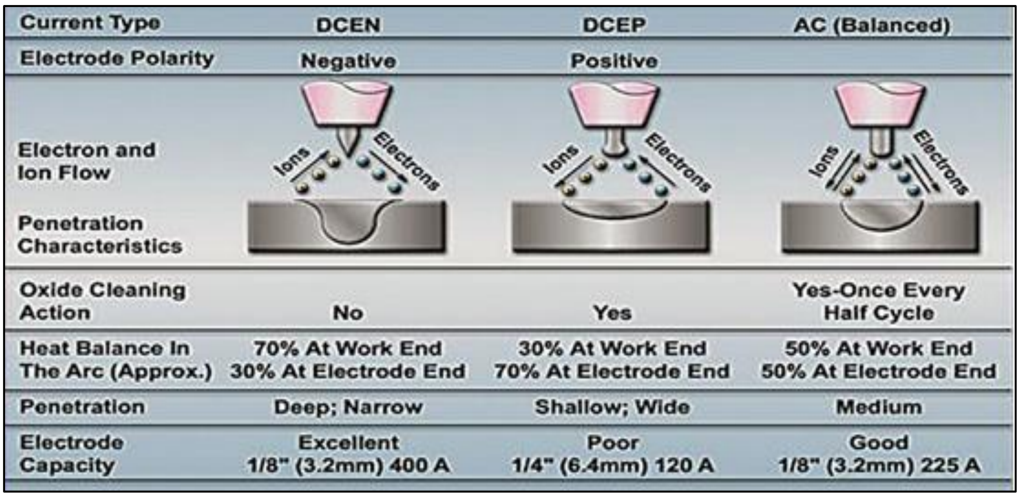
When an arc is to be formed between the tungsten electrode and the part, this space must be made electrically conductive. Thanks to the high temperature generated during arc ignition, the shielding gas becomes electrically conductive. In the TIG welding method, ignition of the arc while starting welding is one of the important subjects, the methods applied in this matter are; the most important advantage of the ignition by touching the applied electrode only in direct current operation is the simplicity and no additional equipment is needed in the welding current generator. Particularly disadvantages are the contamination of the electrode tip in pure tungsten electrodes and the method of tungsten conduction to the workpiece.

In this way, tungsten residues may occur in the weld metal during ignition. The electrode is alloyed and thus the arc becomes unstable. The copper can be avoided from tungsten residues by igniting it on an auxiliary plate. This method is only possible in direct current.

A new ignition technique is also ignited by the raised arc. In this method, the tungsten electrode, which is loaded with very low current intensity, is in contact with the part.

Therefore, there is no tungsten residue at the ignition point. First, the electrode is raised a little and a weak arc is burned, then the current intensity is adjusted to the full power by means of a special switch in the control unit.

In ignition with both direct current and high frequency used in alternating current applications, the high voltage arc ionizes the gas between the electrode and the workpiece and the welding arc occurs immediately. This event is repeated every cycle in the alternating current. In the ignition of the arc with a high voltage impulse, a high voltage current impulse ionizes the gas between the electrode and the workpiece when the electrode is brought close to the workpiece, thereby providing a welding arc. This method is usually used in automatic TIG welding equipment which is welding with direct current. There are systems that use TIG, plasma and laser welding methods or plasma cutting machines with a constant voltage welding machine to control the arc voltage change between the torch and the workpiece and to keep the arc length constant. Welding current generators used in the TIG method are constant currents, such as those used in arc welding with a shielded electrode, and special current generators falling with another definition. Fixed current welding current generators have a falling type voltamper characteristic, so that the current can remain constant when the arc length changes. Variations in the current are very small, depending on the arc voltage variations in the welding operation range in a volts-amp curve with a large gradient [6].



Current Type	DCEN	DCEP	AC (Balanced)
Electrode Polarity	Negative	Positive	
Electron and Ion Flow Penetration Characteristics			
Oxide Cleaning Action	No	Yes	Yes-Once Every Half Cycle
Heat Balance In The Arc (Approx.)	70% At Work End 30% At Electrode End	30% At Work End 70% At Electrode End	50% At Work End 50% At Electrode End
Penetration	Deep; Narrow	Shallow; Wide	Medium
Electrode Capacity	Excellent 1/8" (3.2mm) 400 A	Poor 1/4" (6.4mm) 120 A	Good 1/8" (3.2mm) 225 A

Figure 4.3. Three different polarities in GTAW.

Figure 4.3 shows schematically the movements of the load carriers in the background. The electrons are displaced towards the cathodic anchor, where the impactor produces heat. ions move in the opposite direction. However, the kinetic energy of the ions can only be applied to the surface of the welding substrate when the electrode is the anode and the cathode is also the cathode. However, the cleaning effect in this way is significantly lower because the positive polarity of the electrode is strongly heated, weakening the current intensity [10].

The use of an alternating current results in a good average of this condition. The change in the polarity allows the oxide layer to break down (cathodic cleaning) when the electrode is positive and to cool again when the electrode is negative. This is why the two half waves are called the cleaning half-wave and the cooling half-wave. In this context, a significant increase in the shelf-life of the bath surface and sufficient cleansing of the oxide from the shelf is achieved [10].

When the main metal is melted, the oxide layer on the surface, which is considerably higher than the melting point of aluminum, remains unmelted. Since there is no debris in the TIG welding, the oxide layer must be removed by the action of the arc. The disadvantage of this connection is the excessive heating of the electrode due to the fact that a large part of the generated heat is turned on in the electrode. The way to solve the problem of heating in the aluminum welding is to use an alternating current arc. During half cycles where the electrode is positive the oxide is scattered out of the molten aluminum. During negative half-cycles, the electrode cools while generating heat in the welding chamber. In this way uniform distribution of heat is provided and the electrode is inhibited in some measure. Usually a tungsten sphere melts at the tip of the electrode [10].

4.2. ADVANTAGES AND LIMITATIONS

4.2.1. Advantages of GTAW Include

- It does not form slag and does not require cleaning.
- No additional metal is required at all times.

- It can be welded in every direction.
- Perfect temperature control at the welding of fine parts, heat source and additional metal can be controlled separately.
- The arc and welded joints are visible.
- It is possible to send as many metal inserts as requested in the welding housing [11].

4.2.2. Limitations of GTAW Include

- The welding speed is slow.
- The tungsten electrode gets dirty.
- Low fill ratio. Therefore, time and cost are excessive.
- Particles from the tungsten electrode can enter the source chamber
- Less economical than consumable electrode arc welding for thick sections greater than 9.5 mm (3/8 in.) [12, 13].

4.3. APPLICATIONS

TIG welding can be used to weld many metal and metal alloys. Examples include all carbon-containing metals, steel alloys, stainless steels, heat-resistant alloys, bright metals, aluminum, nickel, titanium and zirconium alloys.

It is difficult to weld lead and zinc. The low melting temperature of these metals makes it extremely difficult to control the process. Steels and other metals allow high temperature process control. Welding can also be done using multiple passes and additional metal. Other welding methods should generally be preferred over 6 mm thick. However, it can also be used as a welding of thick parts with the multi-pass method. The positions of the electrode and additional metal in the manual TIG welding are given below. The arc heads are first moved in both the torch and the weld metal at the angle and positions shown, without additional metal or additional metal. During metal addition, care must be taken to ensure that the protective atmosphere does not dissipate and that the torch is added to the metal and not contaminated.

Figure 4.4. Some applications on TIG welding.

4.4. BASIC TIG WELDING REQUIREMENTS

The basic requirements for all TIG welding processes are similar, i.e. a power source, a hand held or machine manipulated torch, a pressurized supply of a suitable inert gas from cylinders or bulk containers and cables of the correct size to conduct welding current from the power source to the torch, Figure.4.5 [1].

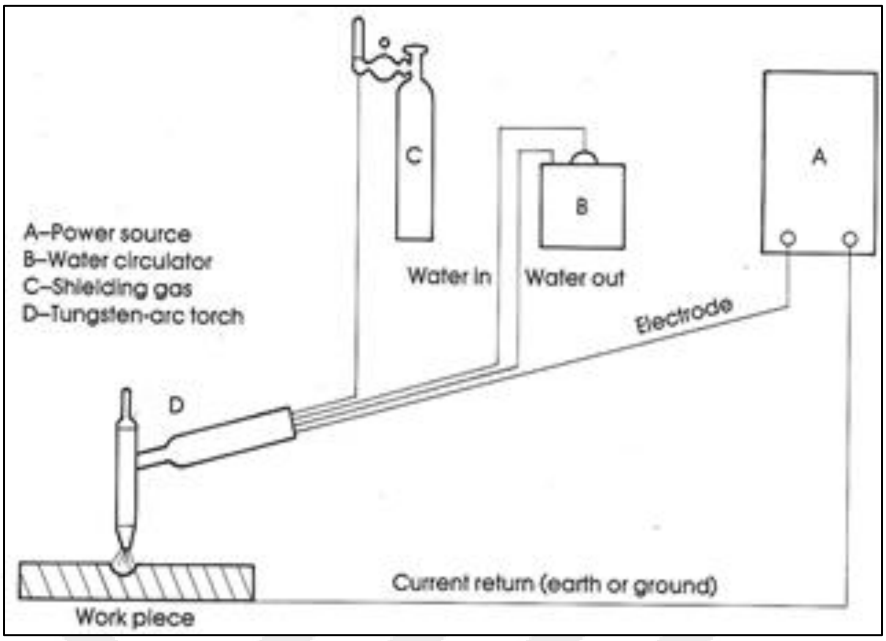


Figure 4.5. Basic TIG welding requirements.

4.4.1. Torches

Welding torches are an element developed to fulfill the tasks of transmitting the current from the current wire to the electrode and delivering the protective gas over the welding chamber in order to be able to form the electric arc required for welding between the workpiece and the end tungsten electrode. Generally, torches are divided into two main groups as air-cooled and water-cooled. Cooling in air-cooled torches is carried out by means of air on the outside of the torche and by protective gas flowing on the inside, therefore they are also referred to as gas-cooled torches. These are lightweight torches with less current than 200 amps, easier to manipulate and cheaper than water cooled ones.

They are only suitable for welding thin parts with the limitation of current capacities. The angle between the tungsten electrode and the torch stalk, defined as the head angle, is normally 120 °, with perpendicular torches with this angle of 90 °, pen torches with 180 ° and rotary torch torches with adjustable tip angle.

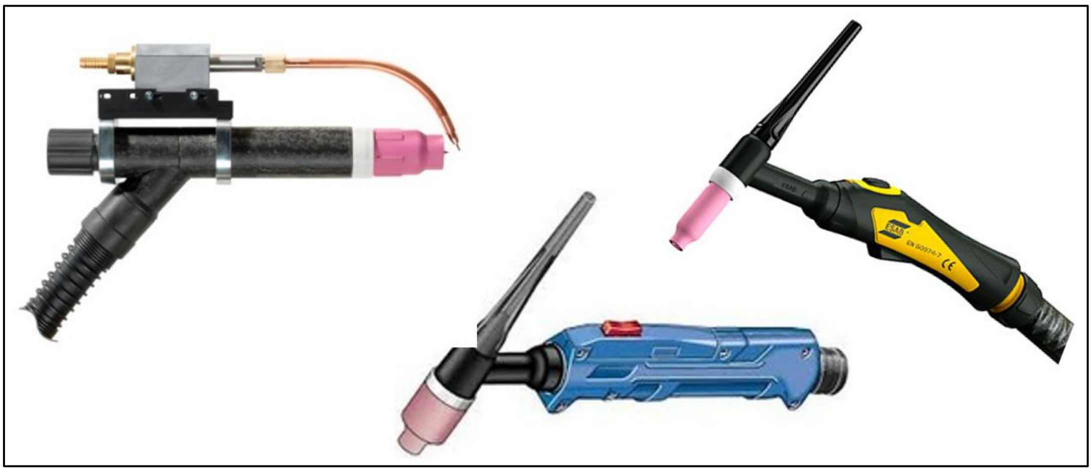


Figure 4.6. The most common types of torch used in TIG welding.

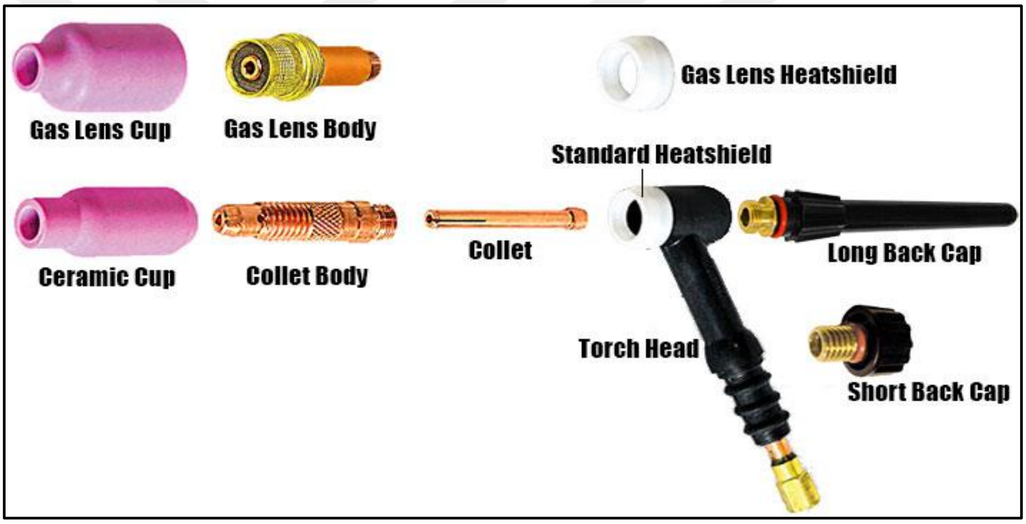


Figure 4.7. The Basic pieces of welding TIG Torch.

Pen-type torches are so named because they look like a lead pencil, and while they use it, they are held down like pencil writing with the head down. These are torches that can be used in places where other species can not enter. Because they are light and easy to manipulate, they are especially preferred by manufacturers using thin sheets.

A very common use of these torches is in the airplane industry, particularly in the combustion chambers and other parts of jet engines, where such torches provide a great deal of manipulation in the recording and welding of the sleeves. Rotary cap torches resemble pen torches in form, in which the torch nozzle and electrode holder are connected to the handle in spherical joints, in which the torch angle is altered to enlarge the handle and enlarge the torso universality.

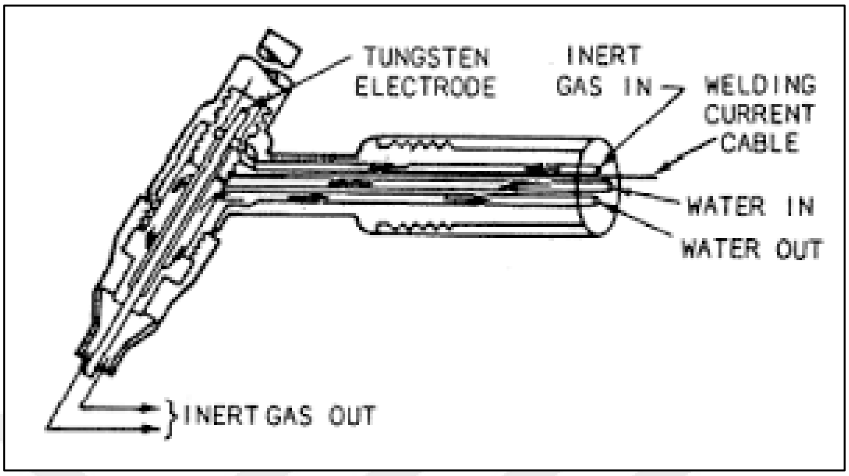


Figure 4.8. Torch design since the inception of the commercial TIG process.

Water-cooled torches are produced up to 1000 ampere current capacity as standard with the condition to be used with water-cooled metallic gas nozzles at high current intensities; only such torches are used in automatic TIG welding systems. If the sealing gaskets are broken, the water vaporizes during operation and the protective gaskets break the quality of the mixed gaskets, causing pores and cracks.

4.4.2. Electrodes

The most important difference between the TIG welding method and other electric arc welding methods is that the additional welding metal is not supplied by the electrode and the electrode only assumes the role of arc forming; in which tungsten, whose melting temperature is around 3500 °C, is selected as the electrode material. In addition to its high melting temperature, tungsten is a very strong electron emitter, which emits a strong electron current in the arc column and ionizes the atoms in the arc column to ensure arc stability.

In today's industry, tungsten (99.5% W) in commercial purity and electrodes alloyed with thorium, zirconium and lanthanum are used. In practice, it is possible to collect the TIG welding electrodes under three groups: pure tungsten electrodes, alloyed electrodes and striped electrodes. TIG welding electrodes are classified according to their composition in AWS A5.12 and DIN 32528 and color codes are used to easily distinguish them from each other [1].

Table 4.1. TIG electrode current carrying capacity.

Diameter, mm	DCEN or DCSP	DCSP or AC	Popular sizes
	Current capacity, A	Current capacity, A	
0.25	Up to 5	N/A	
0.5	Up to 15	N/A	✓
1.0	15-50	Up to 20	✓
1.6	50-100	20-50	✓
2.0	50-150	50-100	✓
2.4	50-200	50-150	
3.2	200-300	150-200	✓
4.8	250-400	200-300	✓
6.4	400-600	300-400	✓

Table 4.2. Nominal weight of standard length tungsten electrodes.

Standard diameters	Nominal weight per electrode in grams for standard lengths of		
mm	75 mm	150 mm	175 mm
1.0	1.1	2.3	2.7
1.2	1.6	3.3	3.8
1.5	2.6	5.1	6.0
1.6	2.4	5.8	7.0
2.0	4.5	9.1	10.6
2.4	6.5	13.1	15.3
3.0	10.2	20.5	23.9
3.2	11.7	23.3	27.2
4.0	18.2	36.4	42
4.8	26.2	52	61
5.0	28.4	57	66
6.0	41	81	95
6.4	47	93	109
7.0	56	111	130
8.0	73	145	170
10.0	114	227	256

Those longer than seven inches are only used in mechanized and automatic welding methods. In practice, the electrode diameter should be selected taking into consideration the maximum current loading capacity of the electrode. As this value is approached, the heat density of the arc increases and a weld seam with a stiffer arc and penetration higher than the stitch height can be obtained.

4.4.2.1. Identification of Electrode Type

Electrodes are identified by color and a DIN standard has assigned a color code. However, some of the colors, particularly orange and the pinks and reds (marked*) are often difficult to distinguish one from the other, so be very careful when a particular type must be used. Table 4.3 shows the col- ours suggested in the DIN standard which, however, is not as yet universally accepted.

The attempt to color code electrodes by a standard is an excellent idea but for this to become universally used some acceptable international standard should also be assigned to the various colors to avoid confusion [1].

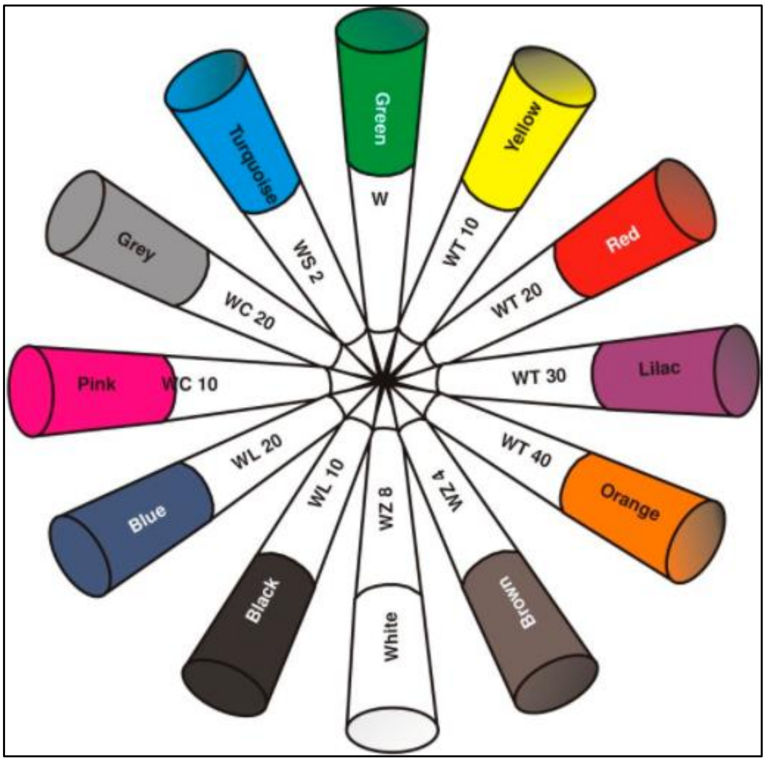


Figure 4.9. Electrodes are identified by color and a DIN standard.

Table 4.3. Electrode data to DIN 32528 specification.

General use	Composition %	DIN	Material No.	Color
AC	Tungsten, pure	W	2.6005	Green
AC and DC	Tungsten + 1 thorium	WT10	2.6022	Yellow
DC	Tungsten + 2 thorium	WT20	2.6026	Red*
DC	Tungsten + 3 thorium	WT30	2.6030	Lilac
DC	Tungsten + 4 thorium	WT40	2.6036	Orange*
AC	Tungsten + 0.8 zirconium	W28	2.6062	White
DC	Tungsten + 1.0 lanthanum	WL10	2.6010	Black
DC	Tungsten + 1.0 cerium	WC10	--	Pink*
DC	Tungsten + 2.0 cerium	WC20	--	Grey
* *color not easy to distinguish.*				

Table 4.4. Electrode uses and performance.

TYPE OF TUNGSTEN	COLOR	USES AND PREFORMANCE
Pure	Green	Provides good arc stability for AC welding. Reasonably good resistance to contamination. Lowest current carrying capacity. Least expensive. Maintains a balled end.
Ceriated CeO_2 1.8% to 2.2%	Orange	Similar performance to thoriated tungsten. Easy arc starting, good arc stability, long life. Possible replacement for thoriated.
Thoriated ThO_2 1.7% to 2.2%	Red	Easier arc starting. Higher current capacity. Greater arc stability. High resistance to weld pool contamination. Difficult to maintain balled end on AC.
Lanthanated La_2O_3 1.3% to 1.7%	Gold	Similar performance to thoriated tungsten. Easy arc starting, good arc stability, long life, high current capacity. Possible replacement for thoriated.
Zirconiated ZrO_2 0.15% to 0.40%	Brown	Excellent for AC welding due to favorable retention of balled end, high resistance to contamination, and good arc starting. Preferred when tungsten contamination of weld is intolerable.

4.4.3. Shielding Gas Types and Mixtures

In the TIG welding, helium was initially used and then argon gas was used. Both gases are single-atom and inert gas. For this reason, they do not join with other elements; they are colorless and odorless and do not burn. Helium gas is heavier than air while argon is heavier. Therefore, helium is volatile and the ability to maintain is low. However, argon protects molten metal better because it is heavier than air. Where higher current intensities are required, helium gas is used to provide higher arc voltage.

The argon gas used in the welding of light metals and alloys must be very pure. Factors such as water vapor, oxygen and nitrogen that may be present in it reduce the quality of the welding. Argon gas is transported at 150-180 atmospheres pressure and in tubes containing 6 to 9 m^3 of gas. The ionization energy of the helium is very high (24.5 eV) and therefore requires a long arc length. This increases the arc tension.

Increasing the amount of heat applied to the weld will affect the formation of the weld and the behavior of the weld in the following way:

- Penetration, typical argon finger loses form and stitch widths
- No pretreatment is required or is applied in very small quantities
- Welding speed increases.
- A hot and well-drained welded base is obtained.
- Welding scar is not calm; TIG welding is difficult to ignite in alternating current.

On the various gases now follow: Argon and Helium.

4.4.3.1. Argon

The reduction of heat input after low arc voltage gives a great advantage in manual welding of 1.5 mm dense parts. The effect of cleaning in the welding of materials covered with a refractory oxide layer such as aluminum and its alloys is more intense. The ignition of the back is much easier. The arc is calmer and more airy. Provides more effective protection with less protective gas because it is heavier than air. Even though the gas consumption is high in the vertical and ceiling welds, the weld can be easily dominated by the smaller weld bands resulting from the lack of heat input. Increasing the speed of automatic welding causes pore formation. Better results are obtained at the welding of different metals [14, 15].

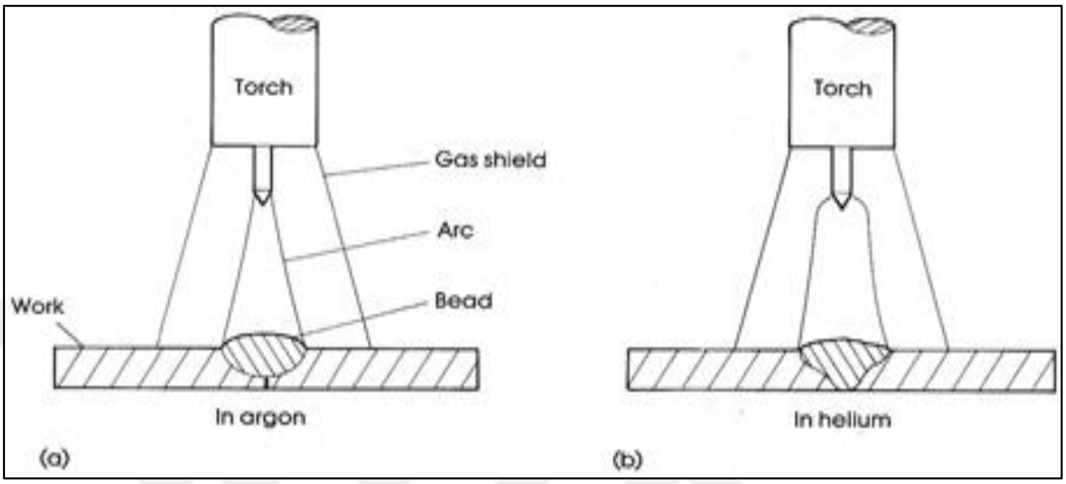


Figure 4.10. Arc shape using: a) Argon, b) Helium.

A range of argon mixes is available combined with hydrogen additions of between I - 5%. These gases concentrate the arc and can increase welding speed but they are more often used to give a better appearance to the finished weld. Hydrogen is classed as a reducing gas. It should be noted that inclusion of hydrogen can give rise to weld porosity, so the rule here is to use the lowest ratio of hydrogen to argon consistent with a good weld both for strength and appearance, Table 4.5. Your gas supplier will assist with the choice of mix [1, 16, 17].

4.4.3.2. Helium

Helium is an ideal shielding gas but more expensive in the UK and Europe and not therefore so widely used, in particular for hand welding. Its ionization potential is 24.5 electron volts, with excellent thermal conductivity, and it gives deeper penetration than argon for a given current and arc gap. Figure 4.14 shows the general TIG arc forms obtained with argon and helium when used for mechanized welding.

The higher arc voltage resulting from the higher arc voltage gives better results at the welding of thicker parts with high thermal conductivity materials. The high heat input and high welding speed create a narrower HAZ and as a result, the mechanical properties of the welded joint improve. Thus, the impact and self-attraction are reduced. Since it is much lighter than air, the resulting shielding gas consumption is high and the gas stream from the torch tube is sensitive to air movements.

Table 4.5. Shielding gases for various metals.

Gas mix %	Mild steels	Low alloy steels	Stain less steels	Nickel alloys	Aluminium and alloys	Copper and alloys	Remarks
Commercial argon 99.995	*	*			*	*	General use
High purity argon 99.998	*	*	*	*	*	*	Fine precision welding
Ar 75/He 25	*	*	*		*	*	Very suitable for Aluminium
Ar 70/He 30	*	*	*	*	*	*	
Ar 50/He 50	*	*	*	*	*	*	
Ar 99/ H_2 1	*		*				Not for use with martensitic
Ar 98.5/ H_2 1.5	*		*				
Ar 98/ $H_2$2	*		*	*			
Ar 97/ H_2 3			*	*			
Ar 95/ $H_2$5			*	*			
Special Ar / H_2 mixes			*	*			
Commercial He 99.993				*	*	*	Not for use with any steel
Ar/N						*	

In automatic welding processes, formation of pores and combustion notches in high welding speeds can be controlled. In automatic welding processes, formation of pores and combustion notches in high welding speeds can be controlled. Lighter than air, it provides better protection for finisher ceiling welds and is therefore suitable for use as a base [18, 19].

4.4.3.3. Back Purging

The finish of the underside of a weld bead is as important as the top surface and can be improved by back purging using the same gas as that flowing through the torch [1].

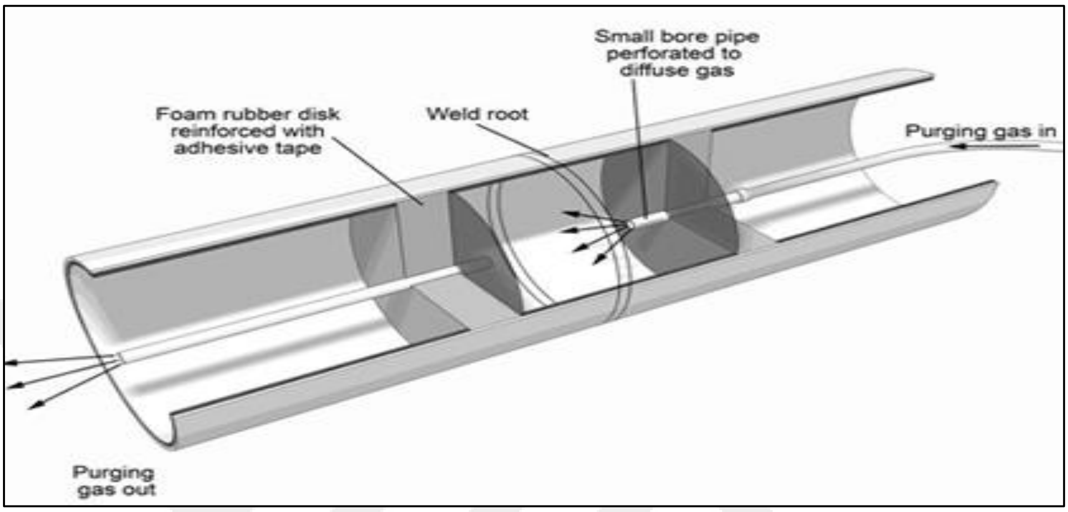


Figure 4.11. Back purging.

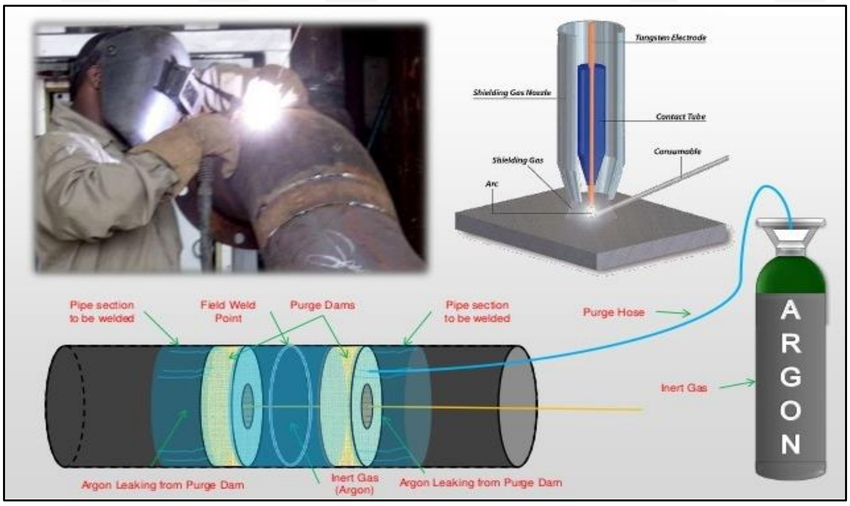


Figure 4.12. Back purging using the same gas as that flowing through the torch.

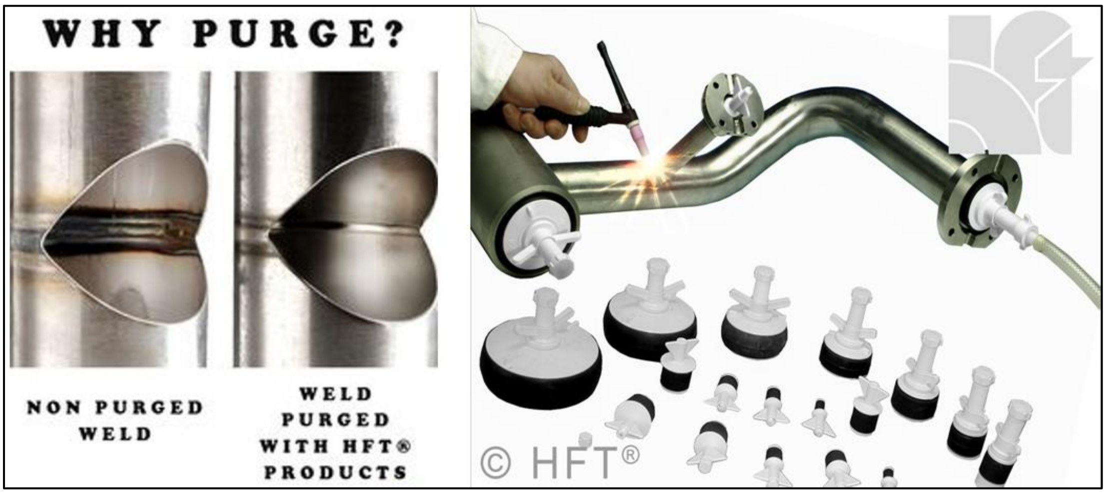


Figure 4.13. Why Back purging use.

4.5. CABLES

In general, the only independent cable used in TIG welding is the current return (earth) and by far the best for this purpose is stranded copper, covered with a natural or synthetic rubber (rather than plastic) which will remain flexible over a wide temperature range. Use good quality cable from a reputable manufacturer and keep to the maximum current capacity stated. Always ensure that the connectors at both ends are tight and will not work loose in use. Keep cables as clean as possible and away from possible damage by welders' boots, fork lift trucks or heavy components.

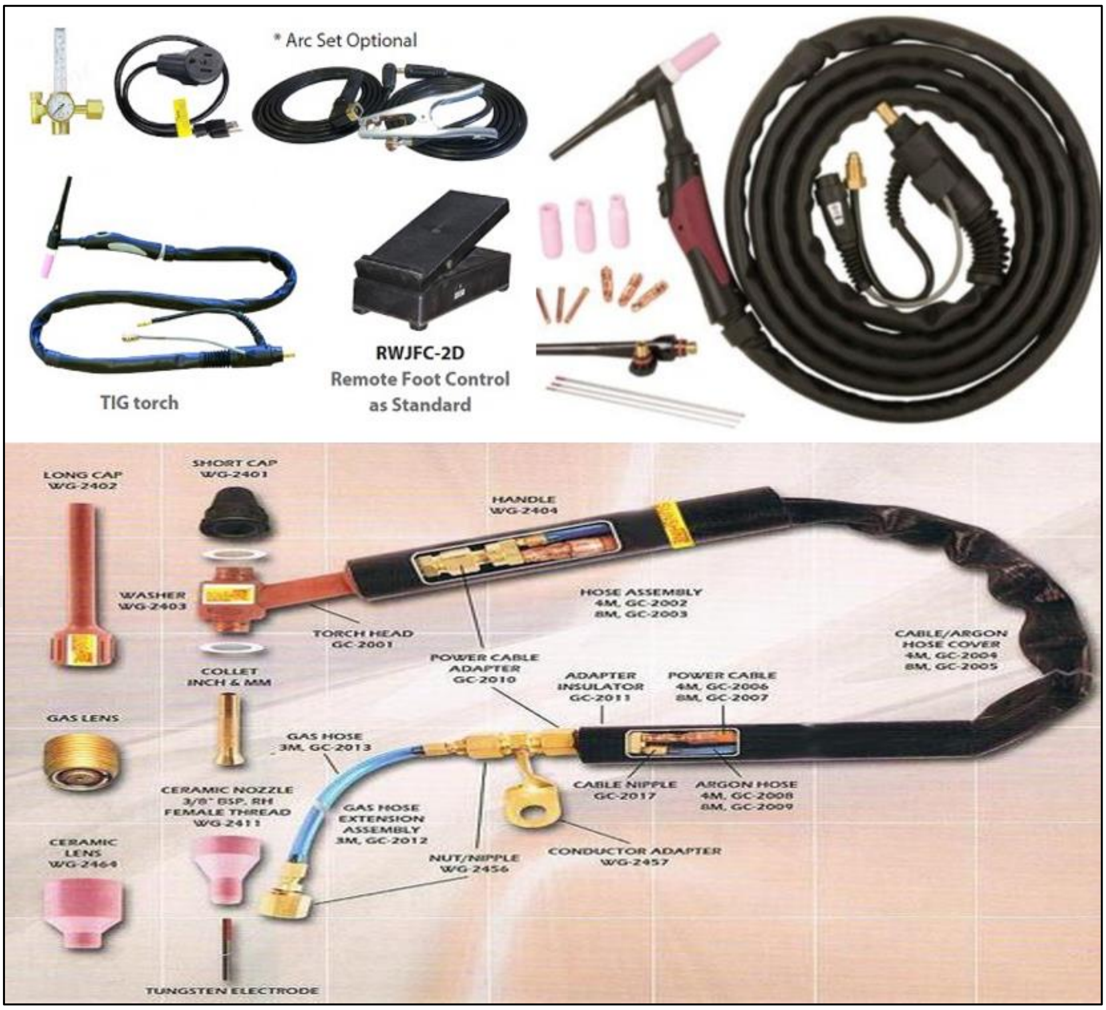


Figure 4.14. Some of the most popular cables are used in welding TIG.

4.6. TIG WELDING POWER SOURCES

The power source is the heart of all welding systems; reliability, accuracy and long life being the desirable characteristics governing the selection of a set. Price does, of course, enter into the choice but with TIG power sources, as with any electromechanical device, you get what you pay for. When considering purchase, pay great attention to duty cycle, spares availability and the speed with which servicing can be obtained if required. In small workshops, there is seldom a back-up set, so choose wisely.

Figure 4.15. TIG welding power sources.

The power source must convert mains electricity, with its inherent variations, into as stable a welding current as possible. It does this by using a transformer to reduce mains voltage and proportionally increase current through the secondary windings and convert this to welding current using a rectifier.

Modern power sources are much lighter and less bulky through use of solid state electronics, efficient cooling and modern materials such as plastics and light alloys in their construction. It is generally considered that the four main basic types are as follows:

4.6.1. Type 1 Transistor Series Regulator Power Sources - Dc Only

These use power transistors for current regulation, with analogue control from a low current signal. They are low in efficiency but give accurate and very stable control of the welding current and provide pulsing with varying waveforms and frequency [1].

Figure 4.16. TIG welding machine with full main fittings.

4.6.2. Type 2 Switched Transistorized Power Sources - Usually DC Only

Using power transistors with HF switching of the DC supply, these power sources give similar current control characteristics to Type 1, are more electrically efficient but give a smaller range of pulsing frequency and waveforms [1].

4.6.3. Type 3 Thyristor (SCR) Power Sources - AC/DC

Transformers are very advanced electronic devices that use thyristors instead of diodes on the output side. These power supplies provide very good current and welding time accuracy. It gives AC waveforms and can be used in pulsed mode even though there is limited pulse frequency response [1].

4.6.4. Type 4 AC rectifier plus inverter power sources - AC/DC

These sets are up and coming in the welding industry, very versatile, light in weight and can have many add-on features. Very cost effective and small in size with high efficiency. The response rate is generally lower than transistorized power sources, but then you can't have everything. Watch future progress in development of these undoubtedly commercially attractive sets [1].

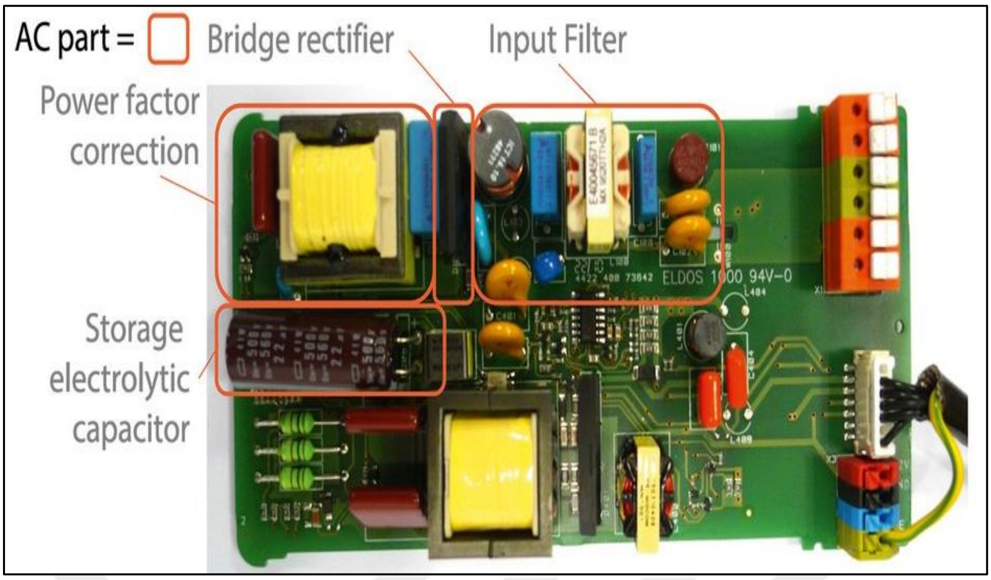


Figure 4.17. Electrical circuit of the rectifier current in the welding machine TIG.

4.7. FILLER WIRE AND RODS

Consumable wires or rods for TIG welding are obtainable compatible with most metals, and manufacturers will, on request, produce small batches of special materials. Table 4.6 lists a few popular proprietary filler rods sold by the main suppliers to the trade. The standards referred to are British and American, other countries have equivalents [1, 20].

For Example: ER308LSI is suitable for joining stainless steels of the 304 types and 308 types. Welding speed is higher than 308 or 308L due to improved weldability of the weld metal [21, 22].

Figure 4.18. Consumable wires or rods for TIG welding.

Table 4.6. Filler rods for manual TIG welding.

Material welded	Rod composition	British standard	Nearest AWS	Comment or application
Low carbon steel	Deoxidised steel rod	BS 2901 A17 Part 1 1983	A5.288 R.60	Mild and low alloy steels
Medium carbon steel	High strength rod	BS 2901 A16	A5.2.88 R65	Also low alloy steels
Super steels	Mild steel plus some aluminium, zirconium and titanium, also silicon and manganese	BS 2901 A15	A5.18.79 ER 70S.2	Excellent for high quality root runs
Creep prone steels	Steel alloy plus 1% chromium and 0.5% molybdenum	BS 2901 A32	A5.28.79 ER 80S B.2	Boiler and superheater tubes
Creep prone steels	2% chromium, 1% molybdenum	BS 2901 A33	A5.28.79 ER 90S B.3	Consult supplier Automotive and aircraft frame tubes
Cast iron	Plus silicon	BS 1453B2		Cast iron cladding and resurfacing
Stainless steels	Rods and wires containing nickel, chromium, molybdenum and other metals in various amounts as suitable	BS 2901 part 2 347 S96 316 S92 308 S92 308 S94	A5.9.81 ER 347 ER 316L ER 308L ER 309	Consult supplier Many variations, particularly for austenitic steels
Aluminium bronze	Zinc free aluminium bronze	BS 2901 Part 3 C13	A5.777 ER-Cu A1-A2	Marine fittings
Aluminium	(a) Pure aluminium (b) + 5% silicon (c) + 10% silicon (d) + 5% magnesium (e) also with larger proportions of silicon and magnesium	BS 1453 BS 2901 Part 4 1050A 4043A 4047A 5356 5556A	A5.10.88 ER 1100 ER 4043 ER 4047 ER 5356	Use Food and aerospace Repairs General purpose Domestic and automotive AiZnMg alloys Other general purpose rods are available

4.8. STATEMENT OF THE PROBLEM

The application of TIG Welding prosses at a global level in the field of oil and gas, petrochemical and marine fields because of the benefits regarding to productivity and high efficiency. This research on the development of finite elements that mimic the performance of longitudinal welds of the pipe lines used to transport natural gas models focus. The effect of temperature on the behavior of materials transmission is crucial in the process of welding. In this study, I will change the key variables for the best mechanical properties of welded connection.

CHAPTER 5

EXPERIMENTAL STUDY

5.1. MAIN MATERIAL AND WELDING SUPPLEMENTARY METAL

In this study; AISI 304L austenitic stainless steel with good corrosion resistance, high mechanical properties and good forming ability, and AISI 430 ferritic stainless-steel due to good corrosion resistance and good mechanical properties. The joining process was done by TIG welding method, 2mm 308L, 309L, 347L welding wire was used as additional wire. In order to ensure a good nuance, the sample mouth V was opened with a width of 1mm and 60º angle. Table 5.1 show the chemical composition of AISI 304L and AISI 430 stainless steels. Table 5.2 summarizes the chemical composition of the additional wires used in welding. Tables 5.3 and 5.4 mention the mechanical properties of AISI 304L and AISI 430 stainless steels.

Table 5. 1. Chemical composition of AISI 304L and AISI 430 stainless steel.

Material	C	Mn	P	S	Si	Cr	Ni	Fe
AISI 304L	0.03	2.0	0.045	0.03	0.75	18-20	8-10	Balance
AISI 430	0.12	1.0	0.045	0.03	1.0	16-18	0.75	Balance

Table 5. 2. Chemical composition of used additional fillers.

Filler	C	Si	Mn	Cr	Ni	Nb	Fe
ER308	<0.03	0.30-0.65	1.00-2.50	19.50-22.00	9.00-11.00	-	Balance
ER309	<0.03	0.30-0.65	1.00-2.50	23.00-25.00	12.00-14.00	-	Balance
ER347	<0.08	0.30-0.65	1.00-2.50	19.00-21.50	9.00-11.00	<1.0	Balance

Table 5.3. Mechanical and physical properties of AISI 304L and AISI 430.

Properties	AISI 304L	AISI 430
Breaking strength	485-670 MPa	520 MPa
Tensile strength (0.2%)	200 MPa (min)	250 MPa (min)
Hardness, Rockwell (HV)	155	165
Thermal Conductivity (W/mk)	15,7	25,1
Melting Range (ºC)	1375 - 1450	1425 - 1530

5.2. PRE-RESOURCE PREPARATION AND WELDING OF SAMPLES

For the experimental study, austenitic and ferritic stainless steel materials were prepared by cutting in dimensions of 250x180x1.5 mm, 60º V welding opening is opened to samples and pre-welding stainless steel wire brush, oxide, oil etc. cleaned from the waste. Welding was carried out in the inverter type TIG welding machine at the welding parameters given in Table 5.4. Coupled stainless steel pairs of different grades are shown in Figure 5.1.

Table 5.4. Welding Parameters.

Current (A)	Voltage (V)	Gas Flow Rate (lt/min)	Filler Diameter (mm)	Electrode Diameter (mm)	Protective Gas
65	13.5	12	2	2.4	Argon

Figure 5.1. TIG welding of different kinds of stainless steels.

5.3. SAMPLE PREPARATION FOR MICROSTRUCTURE

The welded specimens were cut with wire erosion and then divided into small pieces for microstructure work with the help of cutting machine. After the cutting process samples were taken with cold resin. The samples were sanded in 600, 800, 1000, 1200 mesh abrasive respectively and then polished with felt in 6 microns, 3 microns and 1 micron diamond pie respectively. After polishing process, the furnace is electrolytically packed in the furnace with oxalic acid - pure water mixture and power supply (Figure 5.2). The solution was prepared by dissolving 10 g of oxalic acid in 100 ml of purified water.

The power source (+) was exposed to the sample immersed in the prepared solution and the solution was left in solution with the polar (-) polar acid. The etching process was applied for 15 seconds at an average current of 2 Amps with 13.8 V DC voltage. Microstructure images were taken with 200X, 500X, 1000X magnification with the aid of a microscope in the metallography laboratory after the etching process.

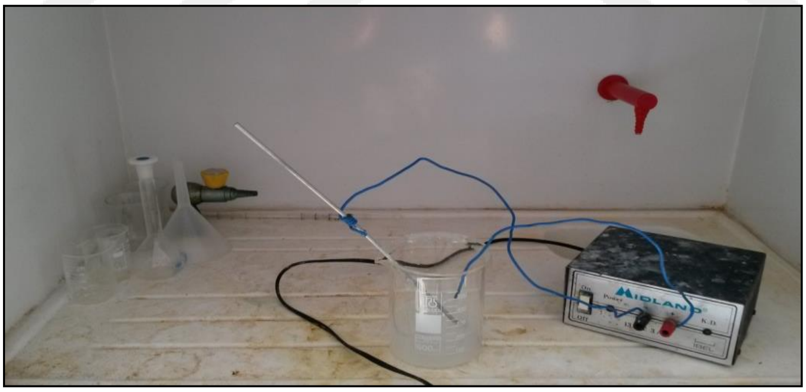


Figure 5.2. Power source 12,4 V DC.

Microstructure examination, tensile, impact notch and hardness measurements of the samples were carried out after these processes.

5.4. MICROSTRUCTURE ANALYSIS

The optical microscope images and SEM images of the samples were taken from the "Nikon Eclipse MA200" optical microscope device and "Carl Zeiss Ultra Plus Gemini Femme" brand SEM device (Figure 5.3 and Figure 5.4) available from Karabük University Iron and Steel Institute Research Laboratories.

Figure 5.3. Nikon Eclipse MA200 optical microscope.

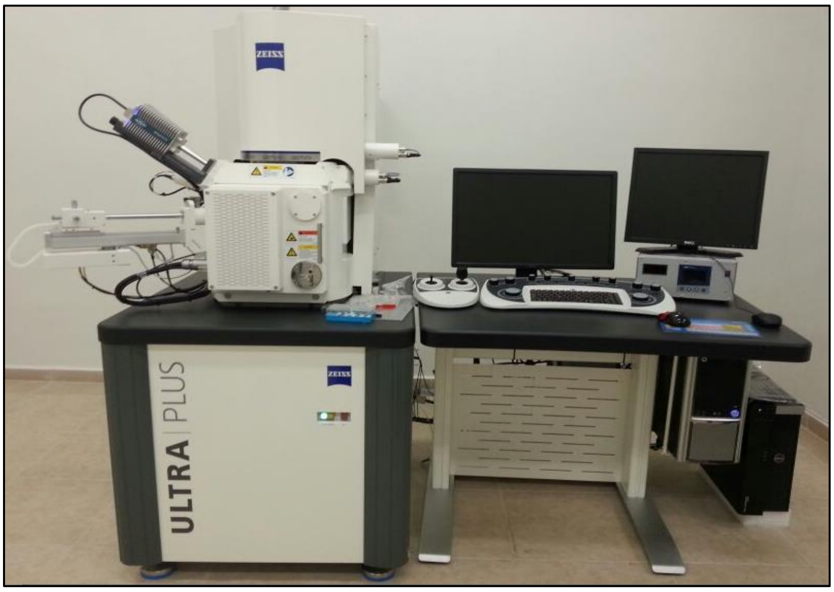


Figure 5.4. Carl Zeiss Ultra plus gemini femme SEM analyzer.

5.5. SAMPLES HARDNESS MEASUREMENTS

The hardness measurement of the test specimens was carried out using the Q250-M Universal Vickers microhardness tester with the same measurement line from the base metal and the base metal to the weld metal. A 500 g load was applied to the sinker. The microhardness device in which the hardness measurement is shown in Figure 5.5.

Figure 5.5. Q250-M Universal microhardness tester

5.6. TENSILE TEST

The specimens for the tensile test were prepared by cutting with wire erosion in two different sizes according to TS 287 EN 895 / tst T1 standards. These two different samples are coded as standard A and standard B, respectively (Figure 6 and Figure 7). The tensile test was carried out at a speed of 0.067 min/mm on a 100 kN MTS 370 Landmark (Fig. 5.8) tester.

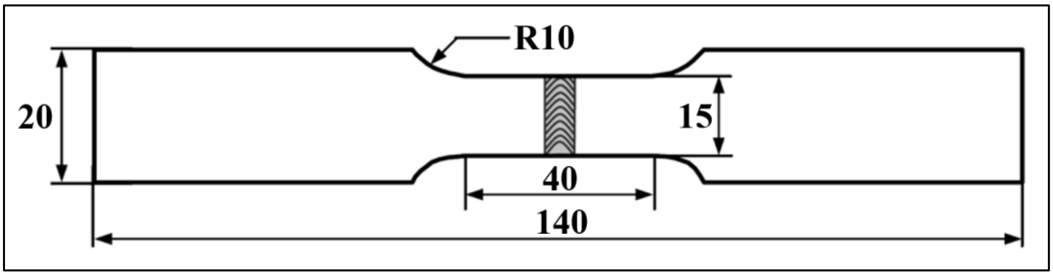


Figure 5.6. Measurements of the samples used in the tensile test (Standard A)

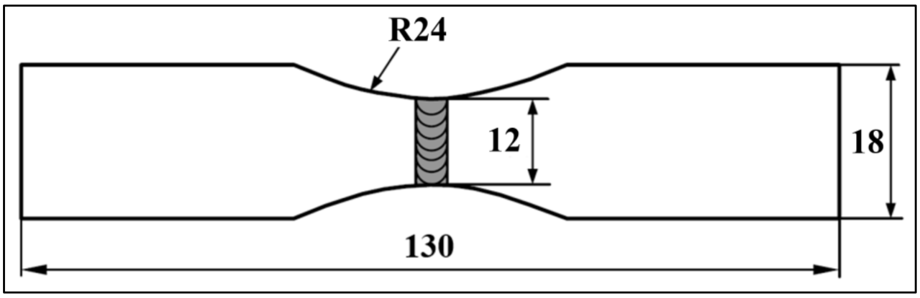


Figure 5.7. Measurements of the samples used in the tensile test (Standard B).

Figure 5.8. MTS 370 Landmark 100 kN brand towing device.

5.7. IMPACT NOTCH EXPERIMENT

The test specimens were subjected to the impact notch test. According to the EN 10045-1 standard of stainless steel assemblies of different grades, the notched specimens prepared below the standard were tested at 20 °C (RT), 0 °C and -20 °C. The specimens were tested on the Zwick / Roell RKP450 impact notch device (Figure 5.9).

Figure 5.9. Zwick / Roell RKP450 impact notch device.

CHAPTER 6

EXPERIMENTAL RESULTS

6.1. MICROSTRUCTURE RESULTS

The optical microstructure images of the combinations obtained using 304L austenitic and AISI 430 ferritic stainless steel double TIG welding and different types of supplementary wire are given in Figures 6.1 to 6.6.

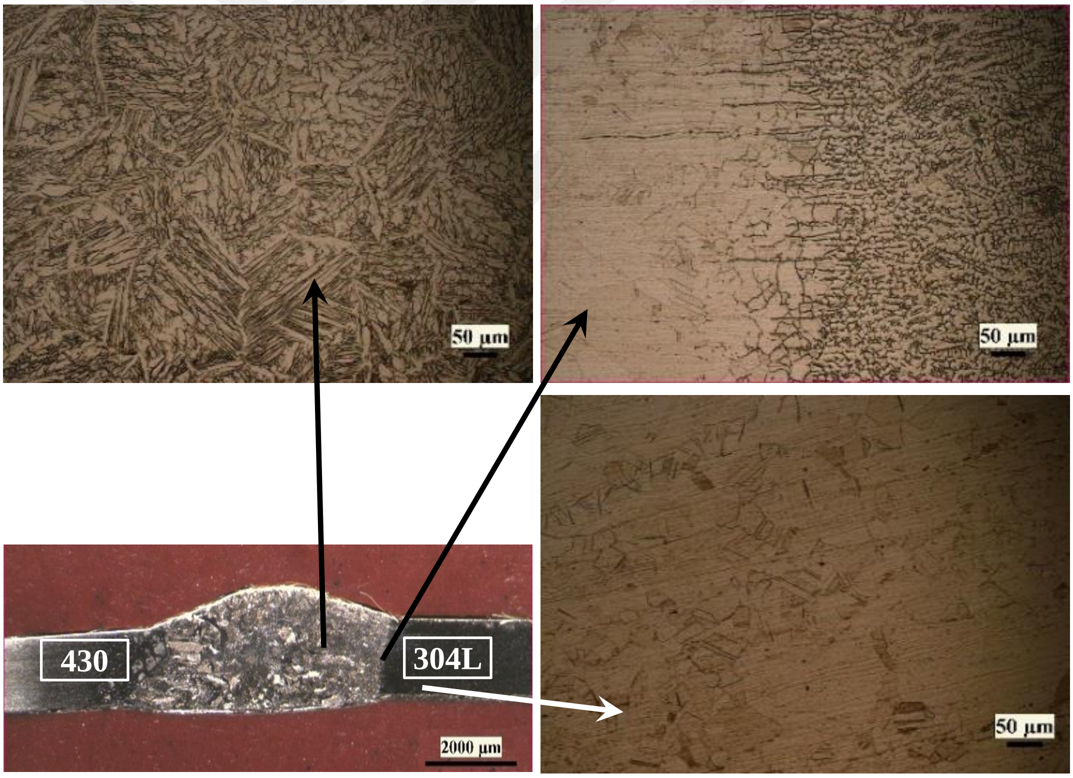


Figure 6.1. Microstructure image obtained by 304L stainless steel of welding zone combined with ER308 quality additive metal.

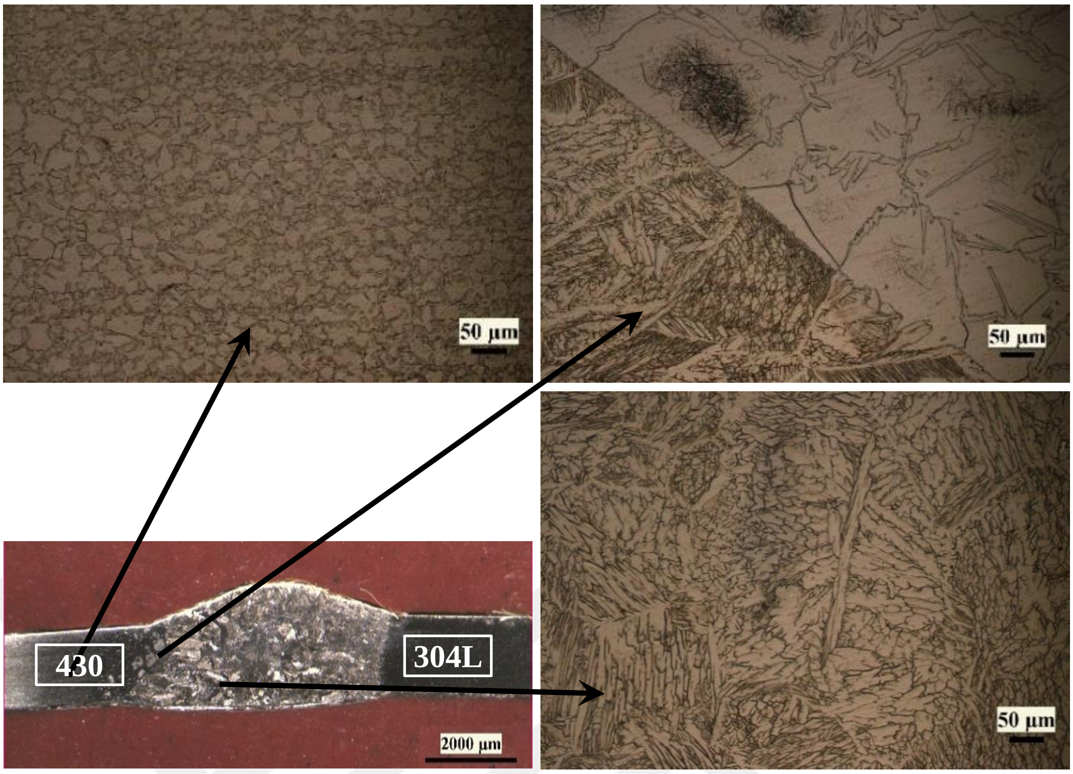


Figure 6.2. Microstructure image obtained by 430 stainless steel of welding zone combined with ER308 quality additive metal.

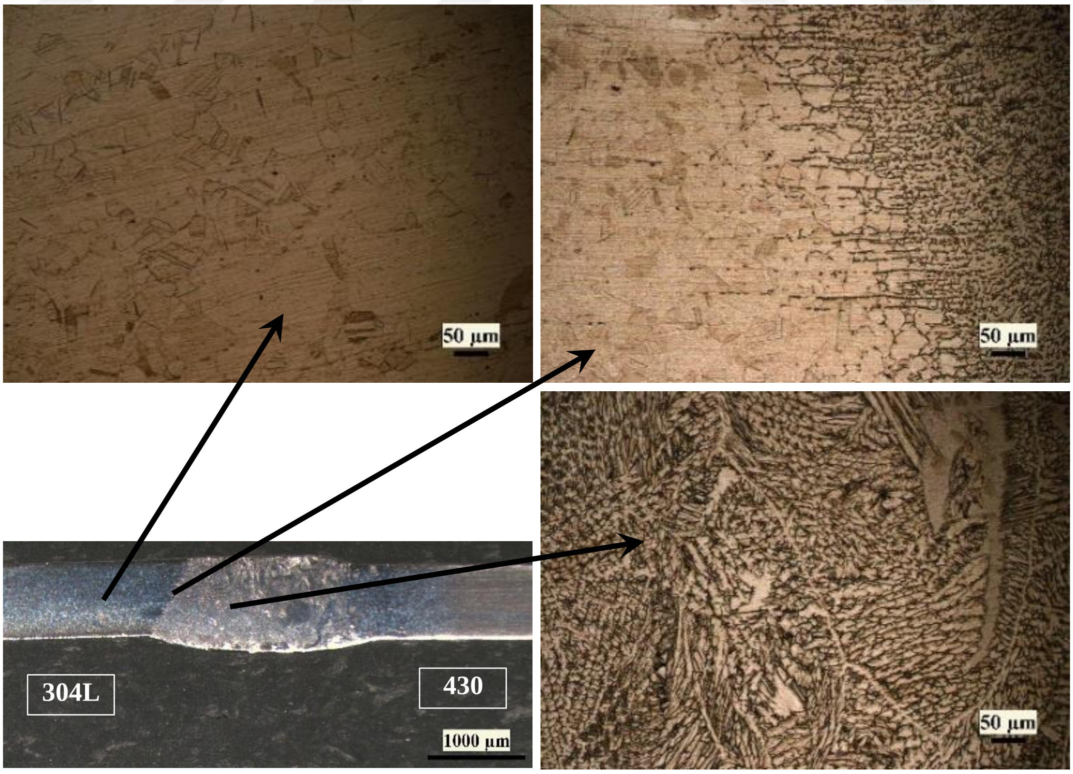


Figure 6.3. Microstructure image obtained by 304L stainless steel of welding zone combined with ER309 quality additive metal.

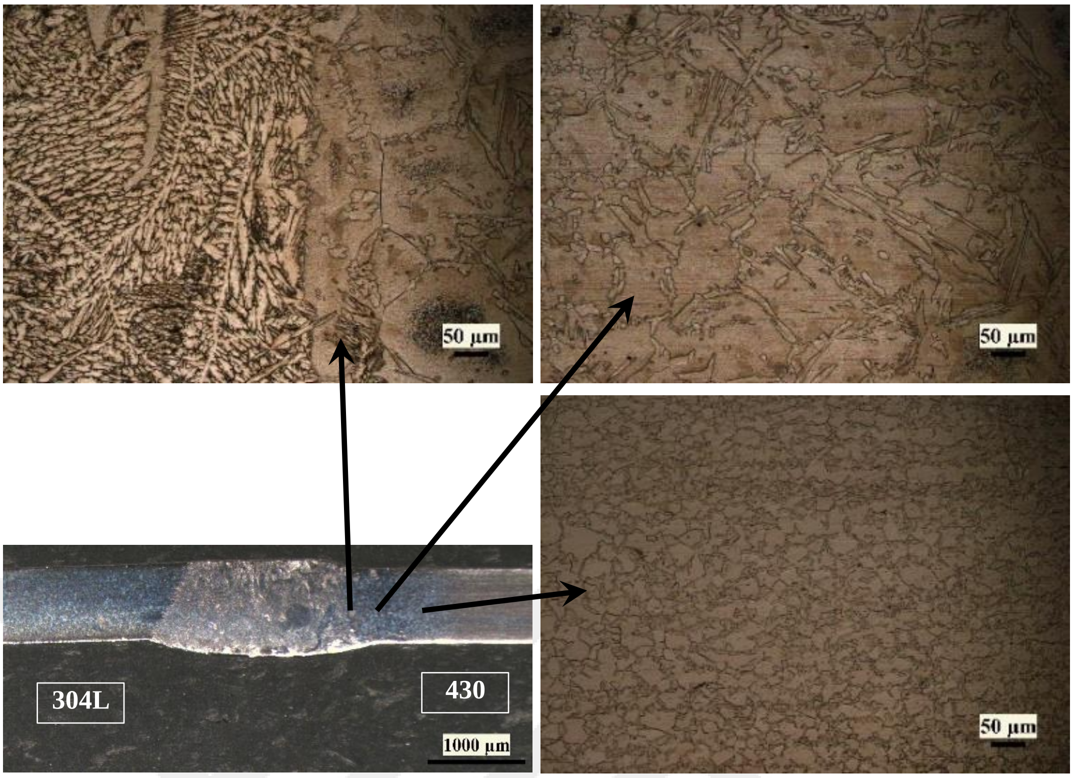


Figure 6.4. Microstructure image obtained by 430 stainless steel of welding zone combined with ER309 quality additive metal.

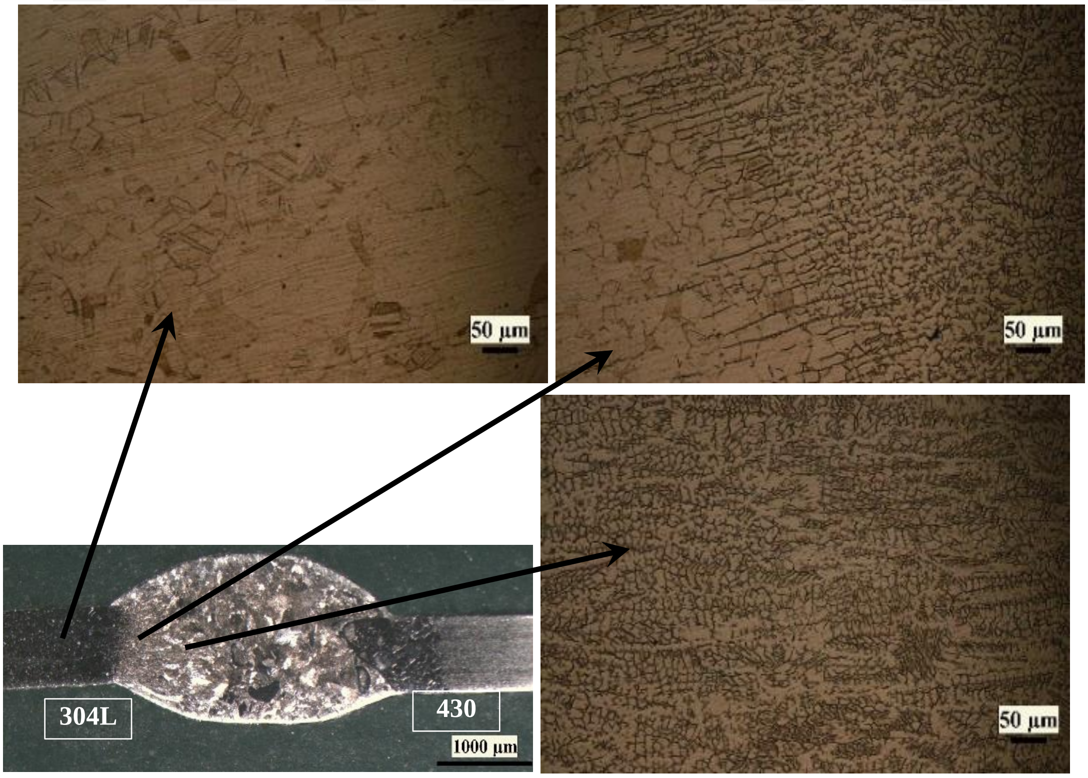


Figure 6.5. Microstructure image obtained by 304L stainless steel of welding zone combined with ER347 quality additive metal.

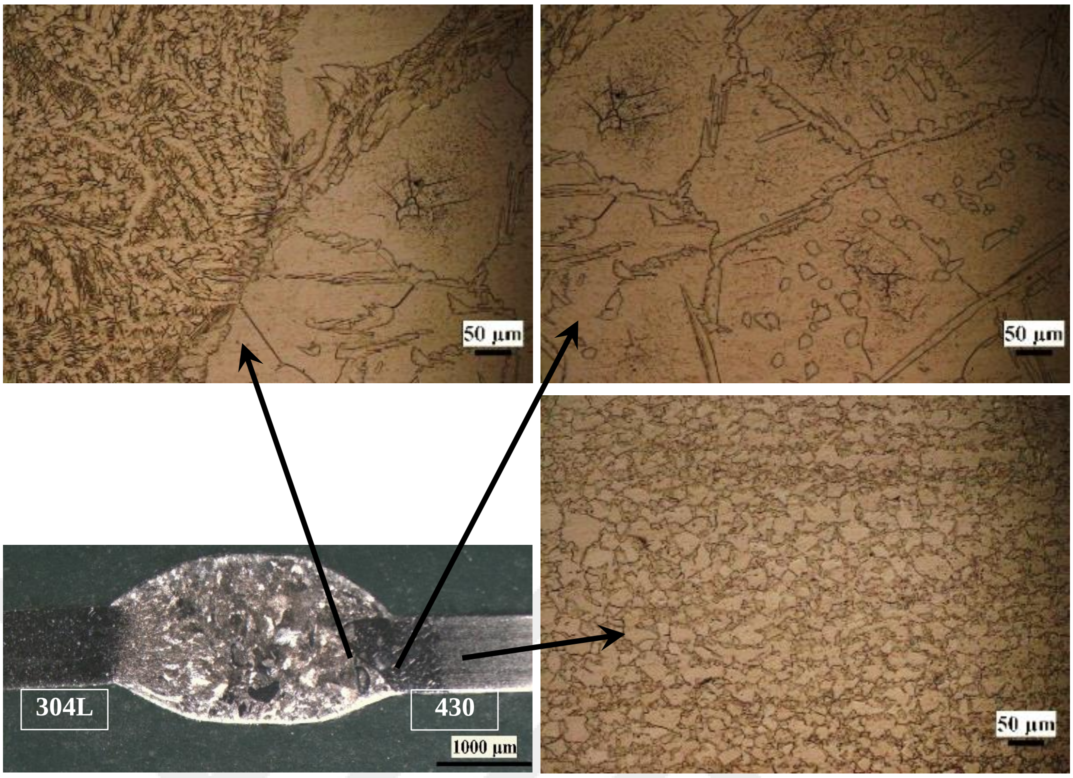


Figure 6.6. Microstructure image obtained by 430 stainless steel of welding zone combined with ER347 quality additive metal.

When microstructure images are examined in general; AISI 304L austenitic stainless-steel microstructure austenite, AISI 430 ferritic stainless steel microstructure ferrite. Different grades of stainless steel additive wire compositions, fusion and blend-dependent dilution, differing rates of cooling, are considered to be due to structural differences [23].

When examined in Figure 6.1 and Figure 6.2, it is seen that the sample weld metal microstructure joined by ER308 additional wire was formed from the lath ferrite phase, and the joint appeared to be grain refinement at HAZ microstructure on both ferritic and austenitic stainless-steel sides.

As can be seen in Figure 6.3 and Figure 6.4, when weld metal images of welded material pairs were analyzed using ER309L additive metal, the weld metal microstructure was found to be composed of austenite-type austenite from ferrite grain boundaries and secondary austenite phase in grains. When the melting band of the AISI 304L austenitic stainless steel is examined, it appears that a larger HAZ is formed compared to the ER308 additive metal. AISI 304L austenitic stainless steel interfacial transition with weld metal exhibits intertwined condition. It is seen that the welded joint has been found in the ferritic stainless steel HAZ. The most characteristic feature of stainless steels is; the growth of the grain in the weld metal and in the HAZ region, which leads to a decrease in the torsional strength of the weld metal [24]. Normally, austenitic and ferritic stainless steels have a fine-grained structure. However, ferritic and duplex stainless steels are particularly prone to grain growth at temperatures above the A_3 temperature. During welding, HAZ grows in the region where this temperature is reached. As stated in the literature, the coarse-grained ferrite phase occurs because there is no secondary austenite phase or precipitates in the part of the HAZ above which the ferrite solubility is overcome [25-29].

In Figure 6.6, when the microstructure of the sample combined with ER347 additional wire is examined, it is seen that the weld metal microstructure is in dendritic form and lath ferrite. Combination of both AISI 304L and AISI 430 stainless steel material is seen in HAZ as an increase in grain size. The AISI 304L austenitic stainless-steel side HAZ melting band exhibits a sharper transition, while the HAZ melting band of the AISI 430 ferritic stainless steel shows a wider range, while grain shrinkage is seen in the HAZ.

If the microstructures are evaluated in general, the HAZ maximum grain reduction on the ferritic stainless-steel side is found with the combination of ER308 of additional metal and ER309 of additional metal. If the weld metal microstructures are compared, the weld metal formed with ER308 of additional metal appears to have a ferritic grain structure. However, the weld metal formed with ER347 of additional metal appears to be an austenitic structure with a dendritic structure. As a result of the microstructures it can be hardened with hardness results [28-32].

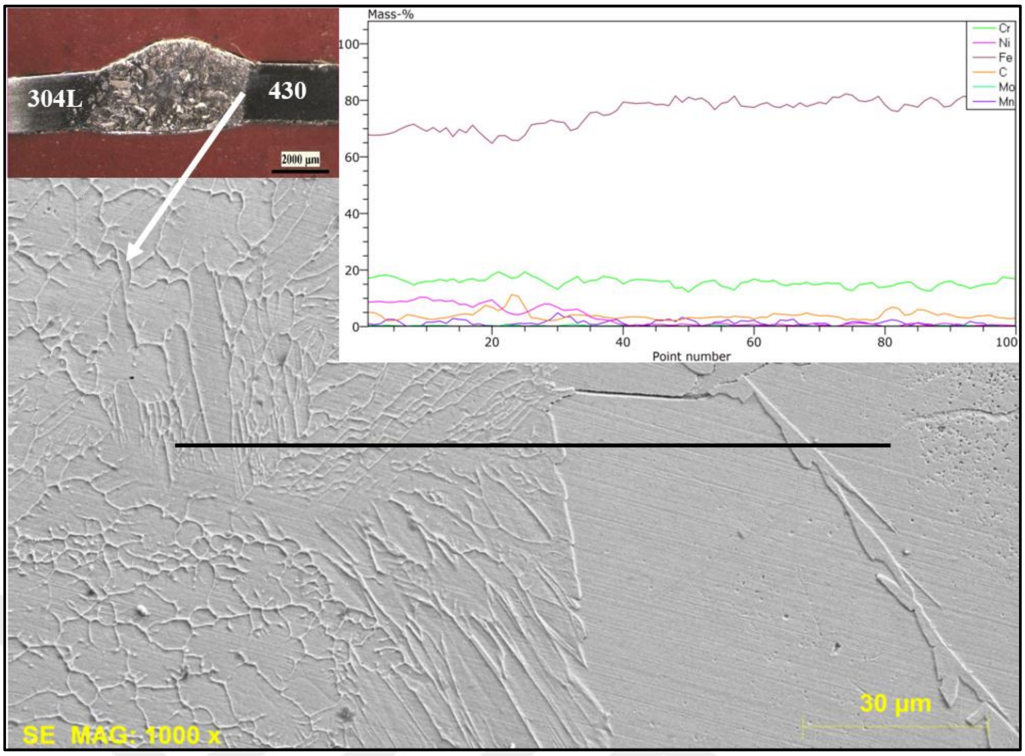


Figure 6.7. SEM image and linear EDS analysis from weld interface of 430 stainless steel part of stainless steels combined with ER308 filler metal.

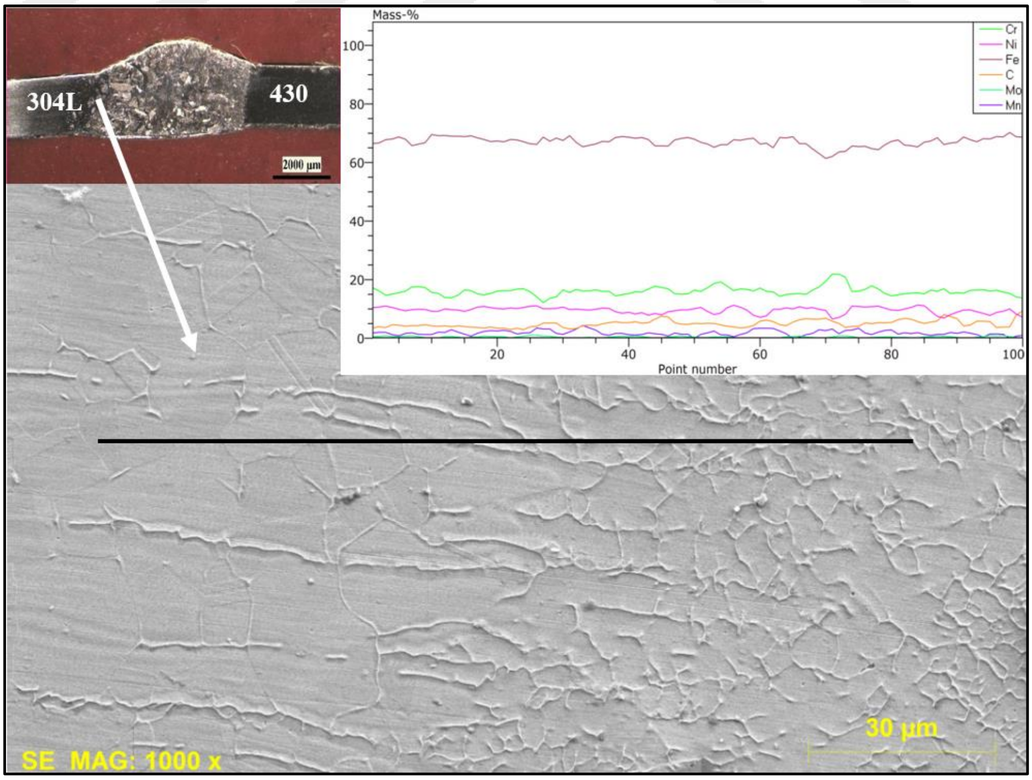


Figure 6.8. SEM image and linear EDS analysis from weld interface of 304L stainless steel part of stainless steels combined with ER308 filler metal.

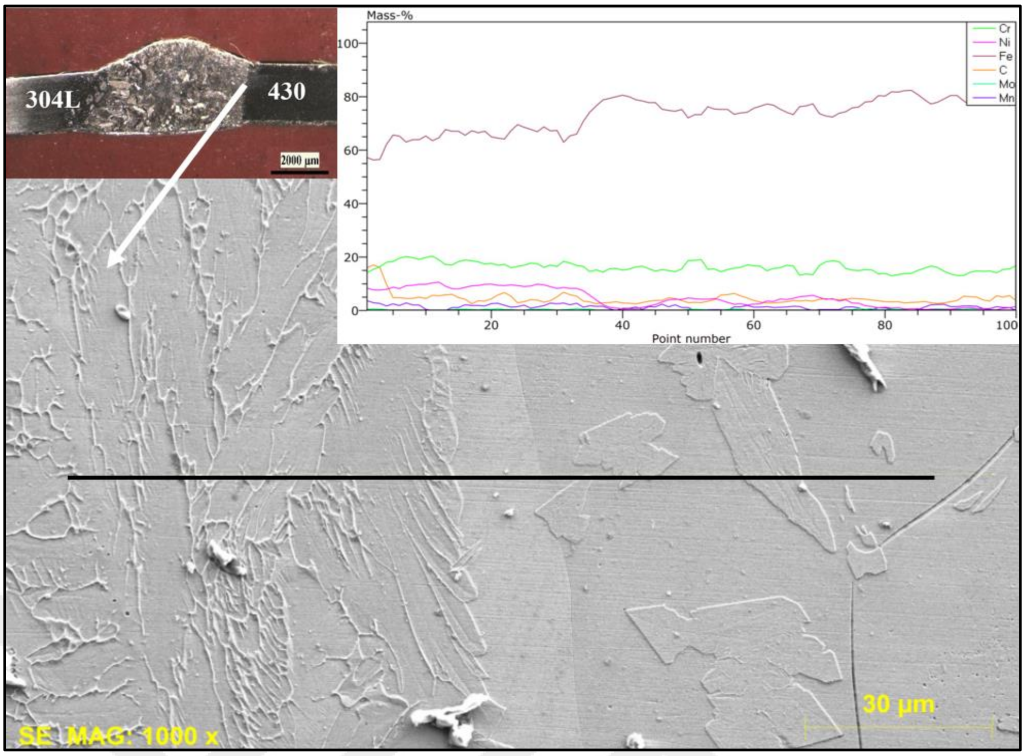


Figure 6.9. SEM image and linear EDS analysis from weld interface of 430 stainlesssteel part of stainless steels combined with ER309 filler metal.

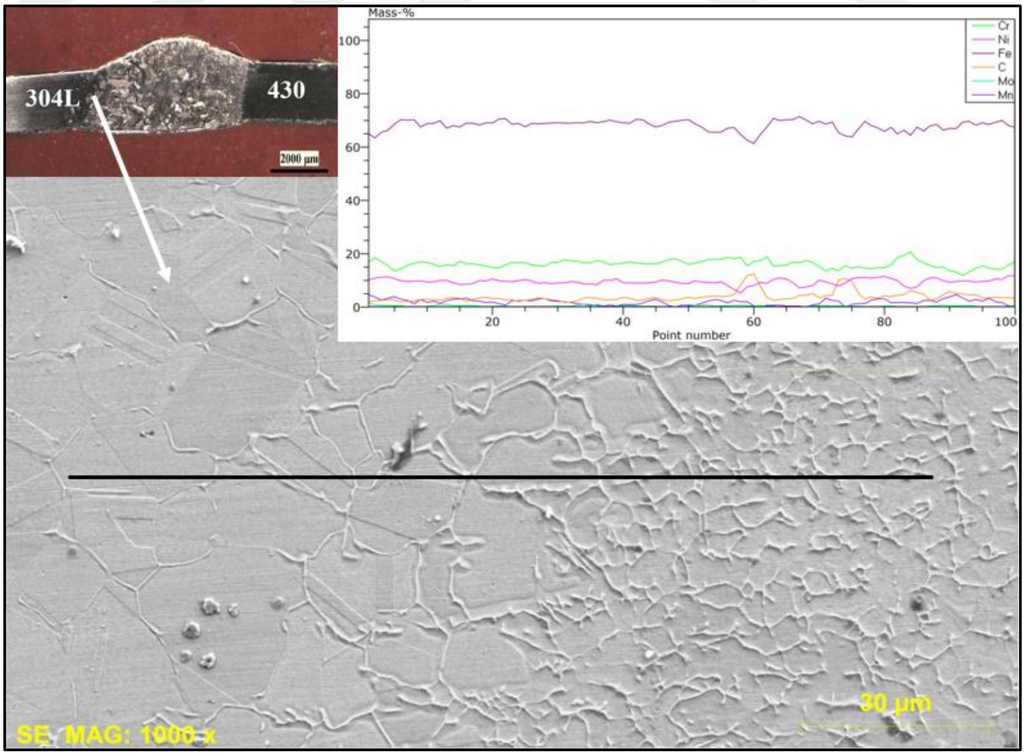


Figure 6.10. SEM image and linear EDS analysis from weld interface of 304L stainless steel part of stainless steels combined with ER309 filler metal.

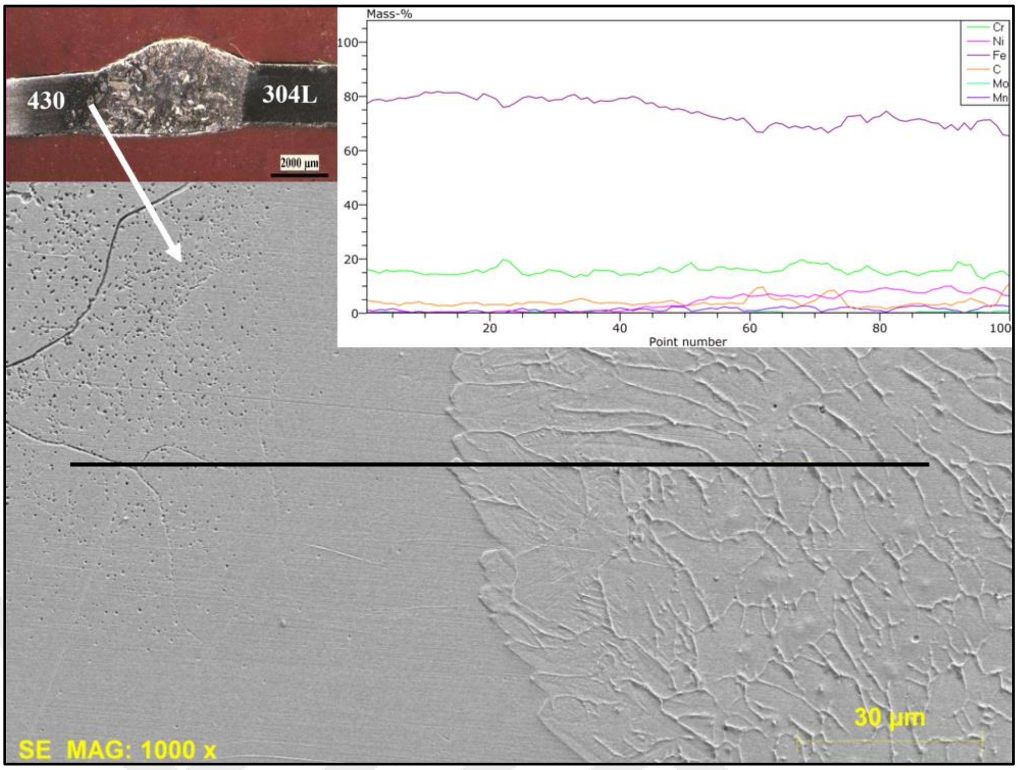


Figure 6.11. SEM image and linear EDS analysis from weld interface of 430 stainless steel part of stainless steels combined with ER347 filler metal.

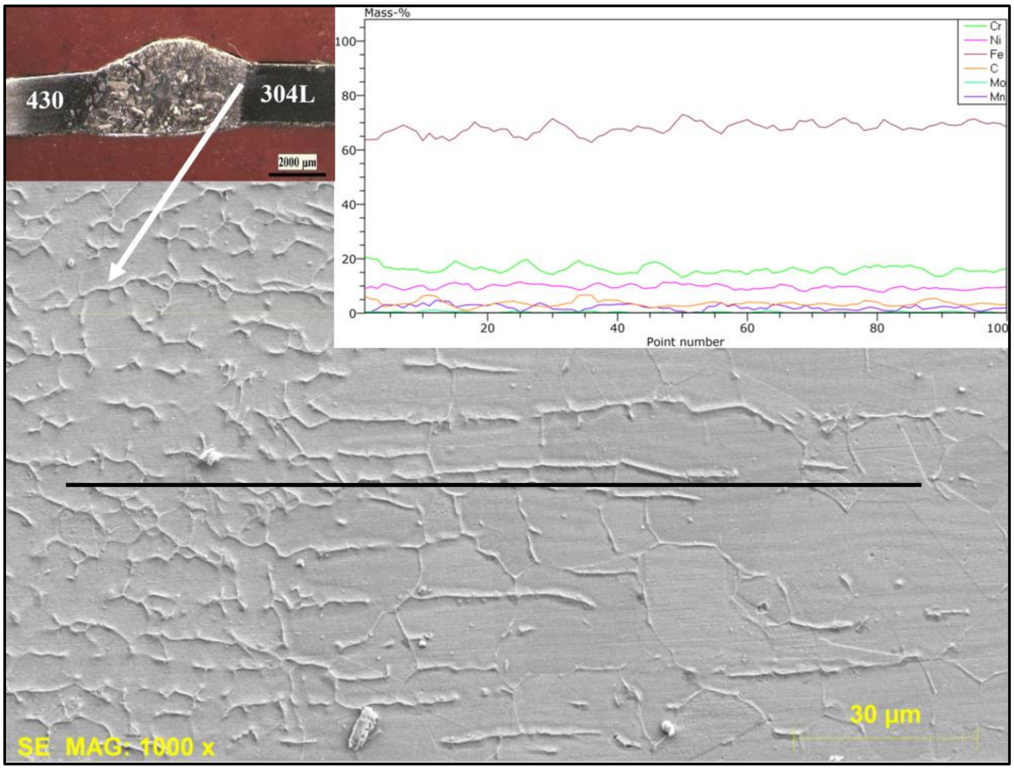


Figure 6.12. SEM image and linear EDS analysis from weld interface of 304L stainless steel part of stainless steels combined with ER347 filler metal.

As can be seen from the microstructure and SEM images, coarse grains are observed in the HAZ near the melting limit of ferritic stainless steel main material. Grain size increases as the melting limit is approached. No grain refinement was observed on the austenitic stainless steel side of the welded joint in the HAZ zone.

As can be seen from the images, the ferritic stainless steel side of the joining shows distinct grain refinement in HAZ, whereas the austenitic stainless side shows more grain refinement and grain refinement than grain refinement. This is the main reason why the welded joints are formed from the coarse-grained part on the completely ferritic stainless side of the splice in the tensile tests.

Due to the joining of two different stainless steel couples, there are different structures and different chemical compositions in the melting zone in the HAZ region. In order to observe how this chemical composition changes, a linear EDS analysis was made from these regions. The results are given in Figure 6.7 to 6.12. Linear EDS analyzes from the retention zone after the TIG welding process using three different additional wires yielded mutually accurate results. The fact that the additional metals used in the welding process generally have an austenitic structure is also reflected in the weld metal and a harmonization of the chemical composition between the weld metal and the austenitic base material has been observed. Ferritic stainless steel from its melting interface towards the ferritic stainless steel part has been found to have a decrease in nickel content and an increase in the amount of iron required by its chemical composition.

Overlapping results with this work have been obtained in the work of authors R. Kaçar and S. Gündüz in the point welding of dissimilar 304L and 430 stainless steel resistance welds, as well as in the study of TIG, MIG, and implanted electrode welding, in which Y. Kaya has also done with the same materials, they reported the results. In both studies, it was found that the grains in the region close to the half-melting point of the austenitic stainless steel on the austenitic stainless steel side were similar to the weld metal grains, but grain orientations were not uniform due to the heat complexity in this region. When the region near the melting point of the half-melting point on the ferritic stainless steel side of the assembly is examined, it appears that the particles formed in this region are not similar to weld metal grains because they are composed of austenitic supplemental weld metal + ferritic base metal mixture. On the other hand, it has been observed that there is not a lot of weeping on the austenitic side of the combination, but a significant increase in the ferritic side of the combination [31,33].

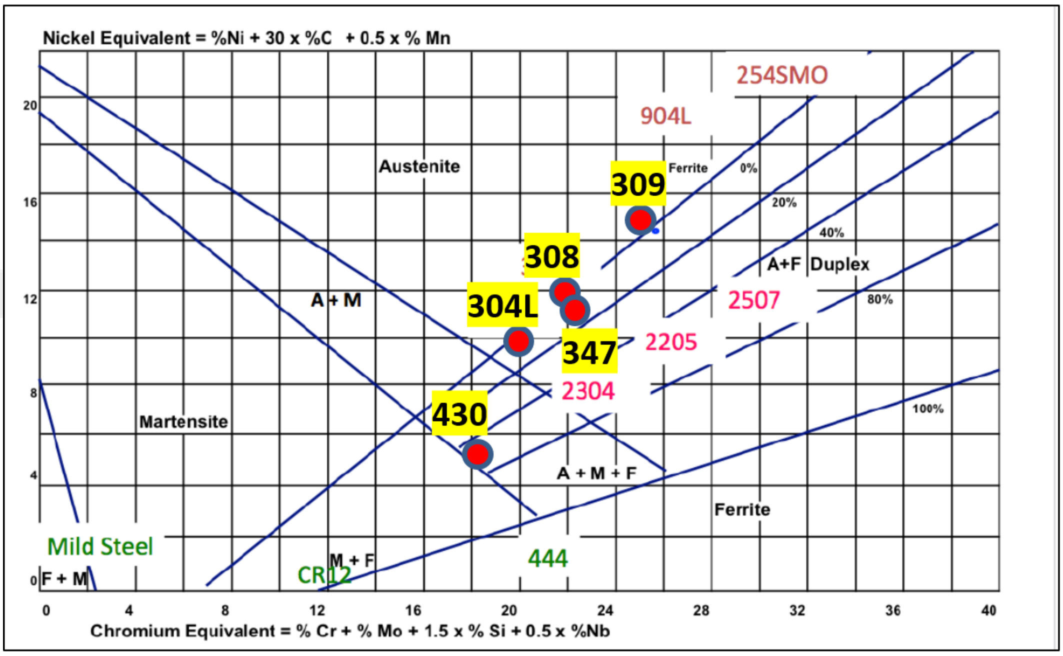


Figure 6.13. Location of alloys on the Schaeffler diagram.

Creq: Cr% + Mo% + 1.5xSi% + 0.5xNb% (6.1)

Nieq: Ni% + 30xC% + 0.5xMn% (6.2)

Table 6.1. Creq and Nieq values of base materials and filler materials to be welded.

	AISI 304L	AISI 430	ER308	ER309	ER347
Creq	20,1	18,5	21,75	24,75	22,0
Nieq	10,9	4,85	11,8	14,8	11,8

In the Scheafler diagram, two kinds of materials to be welded and three types of additional filler materials were identified by finding Creq and Nieq. Since it is a welding of dissimilar materials and it is a matter of combining with different additional wires, it is difficult to determine structures and it is difficult to make comments on the Scheafler diagram.

6.2. HARDNESS MEASUREMENT RESULTS

The hardness measurement results of the joints obtained by using the TIG welding method using different additional wires are shown in Figure 6.14, respectively. It is clear that AISI 430 stainless base metal hardness is higher than AISI 304L stainless base metal. The difference between the weld metal and HAZ hardness of the joints obtained with all three additional metals is striking. Weld metal hardness of stainless steel joints of different grades seems to be higher than hardness at both main metals. The reason for this increase is the dendritic solidification of stainless steels. The hardness of AISI304L quality material is measured as 158 HV and the hardness of AISI430 quality material is measured as 183 HV.

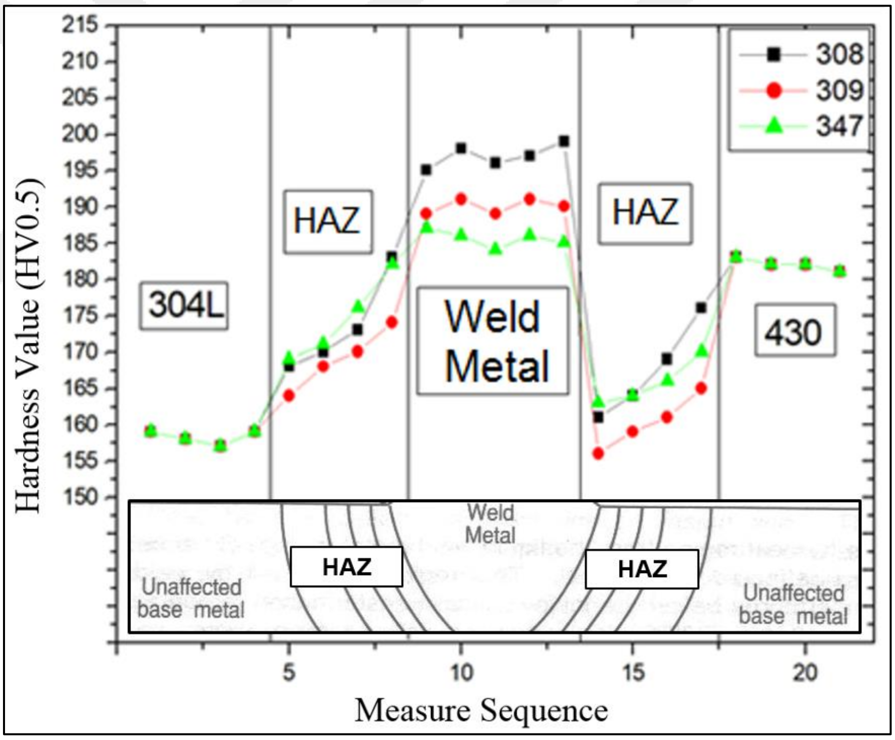


Figure 6.14. Stiffness distribution of stainless steel welded joint joined with different additional filler.

As seen in Figure 6.14, the weld metal and HAZ hardness of the austenitic and ferritic stainless steel assembly combined with ER308 were found to be higher than the ferritic stainless steel. It is thought that the cause of this is caused by the increase in favor of delta ferrite. The weld metal hardness of the samples combined with ER347 additional wire is found to be lowest. The chemical composition of the additive metals plays an active role in the hardness of the weld metal [31].

6.3. TENSILE TEST RESULTS

According to the test results, it was determined that the elongation and tensile strengths of the assemblies in which ER309 welding additive metal was higher than ER308 and ER347 weld metal additions, respectively. AISI 304L austenitic stainless steel HAZ was formed in tensile test specimens at all joints. This is due to the combination of AISI 304L austenitic stainless steel with higher HAZ hardness and yield strength. It has been reported that the austenitic stainless steels have a tendency to decrease in hardness due to grain growth at the weld, and therefore, in the tensile test, the weld metal is largely out of HAZ [24].

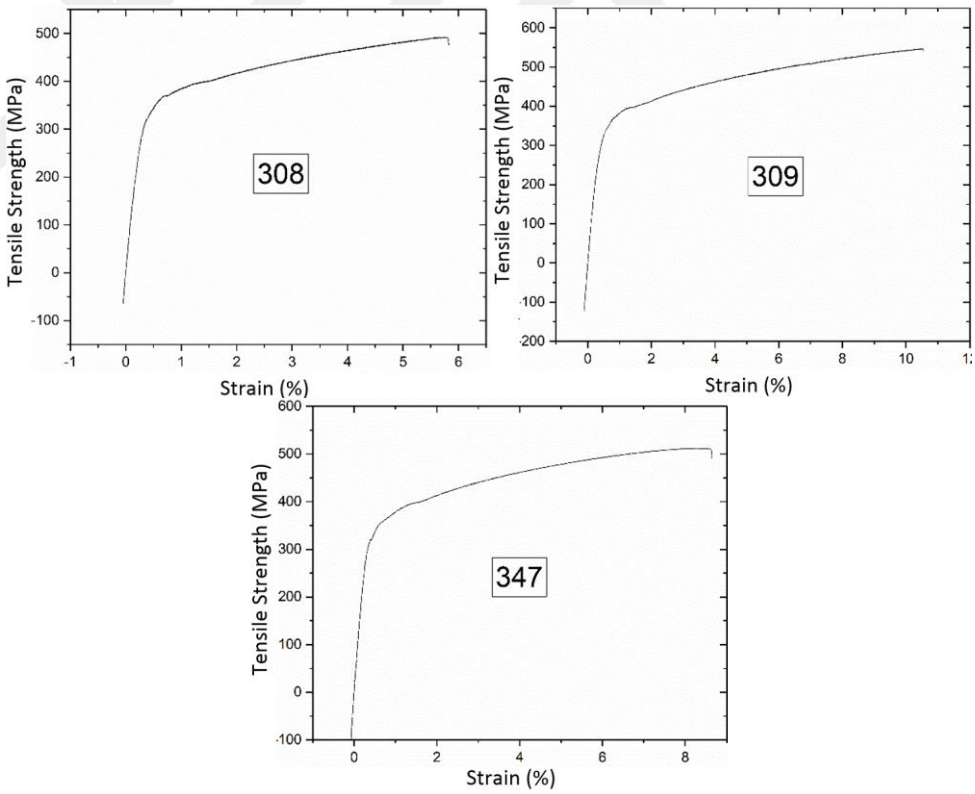


Figure 6.15. Tensile test results of samples joined by TIG welding method using different type filler.

The average tensile strength of the samples combined with ER308 additional wire was 491,83 MPa and the extension was 5,80%. The tensile strength of the samples combined with ER309 additional wire was found to be 538,380 MPa and the extension was 10,55%. the average tensile strength is 511,43 MPa, and the elongation is 8,52%. The tensile strength and elongation of the samples combined with ER309 additional wire were found to be higher than those combined with ER308 and ER347 additional wire. Under the influence of the welding thermal cycle, the HAZ region has been formed in this region by the cooling regime and by the thermal diffusivity, decreasing hardness cracks. The addition of additional austenite-forming chemical compound supports the results.

Macro photographs of the fracture zones of welded tensile specimens prepared according to TS 287 EN 895 / tst T1 standards and referred to in the thesis as Standard A and Standard B are given in Figures 6.16 to 16.21. In macro photographs, the samples on the left are AISI 304L and the samples on the right are AISI 430 stainless steel.

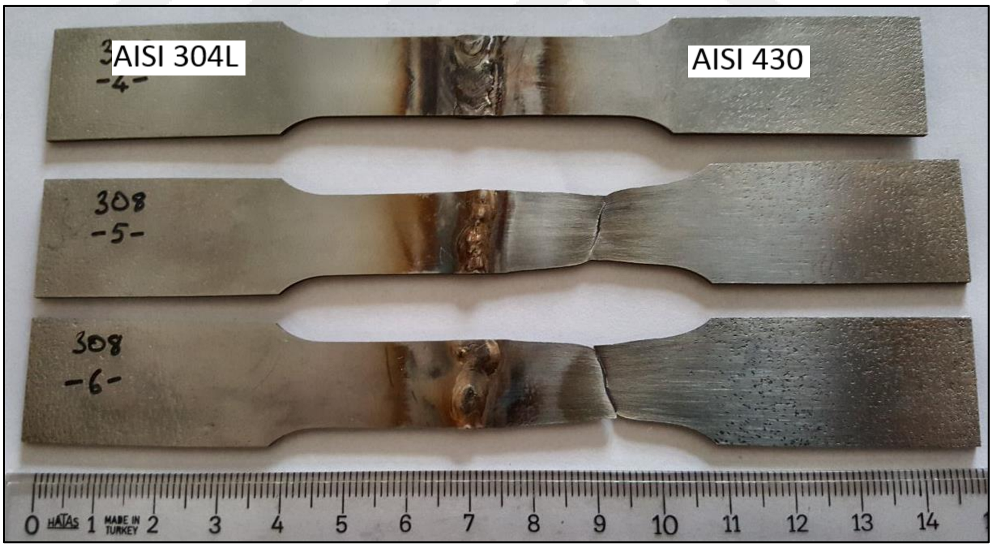


Figure 6.16. Macro photographs of the refraction areas of the Standard A welded tensile specimens combined with ER308 additional wire.

Figure 6.17. Macro photographs of the refraction areas of the Standard A welded tensile specimens combined with ER309 additional wire.

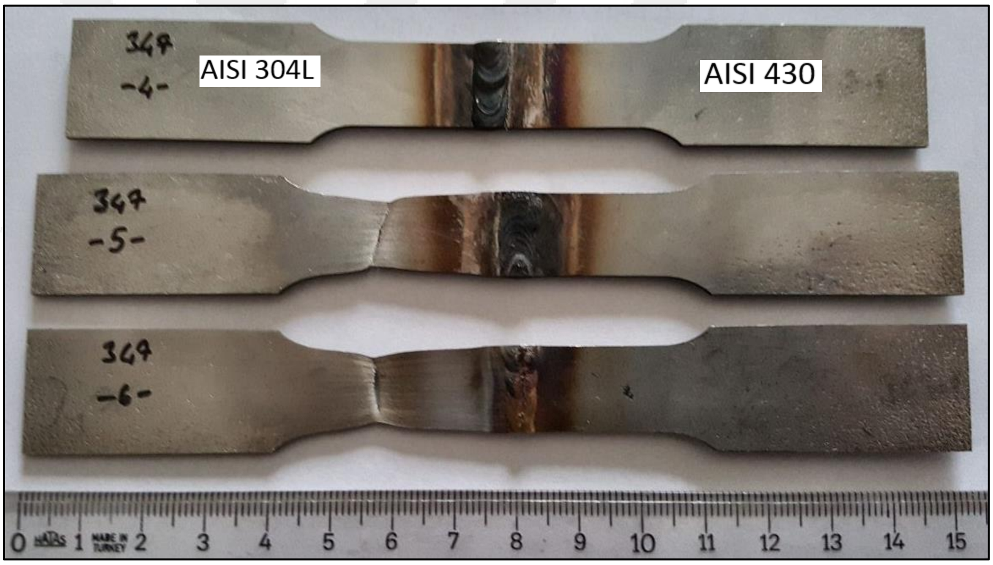


Figure 6.18. Macro photographs of the refraction areas of the Standard A welded tensile specimens combined with ER347 additional wire.

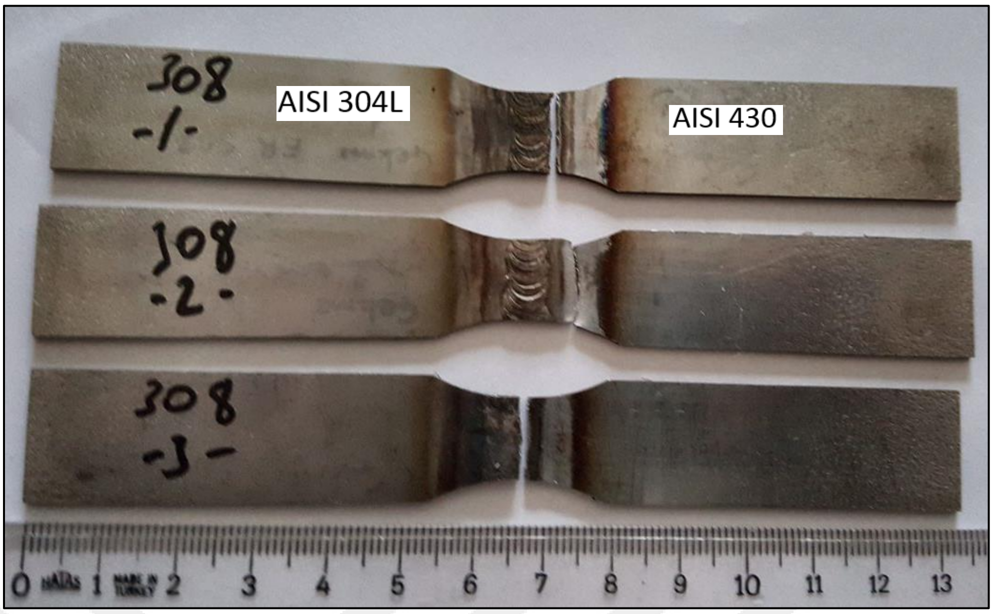


Figure 6.19. Macro photographs of the refraction areas of the Standard B welded tensile specimens combined with ER308 additional wire.

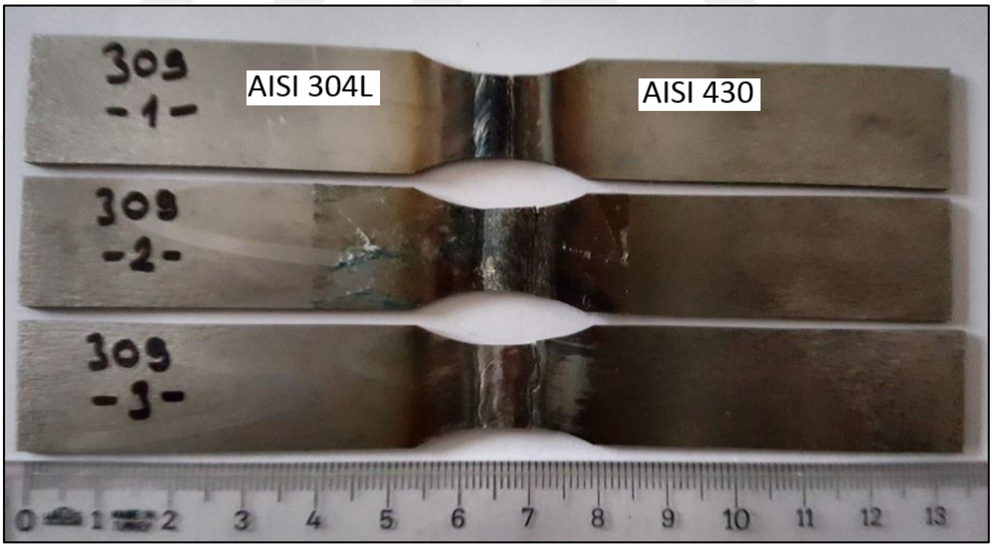


Figure 6.20. Macro photographs of the refraction areas of the Standard B welded tensile specimens combined with ER309 additional wire.

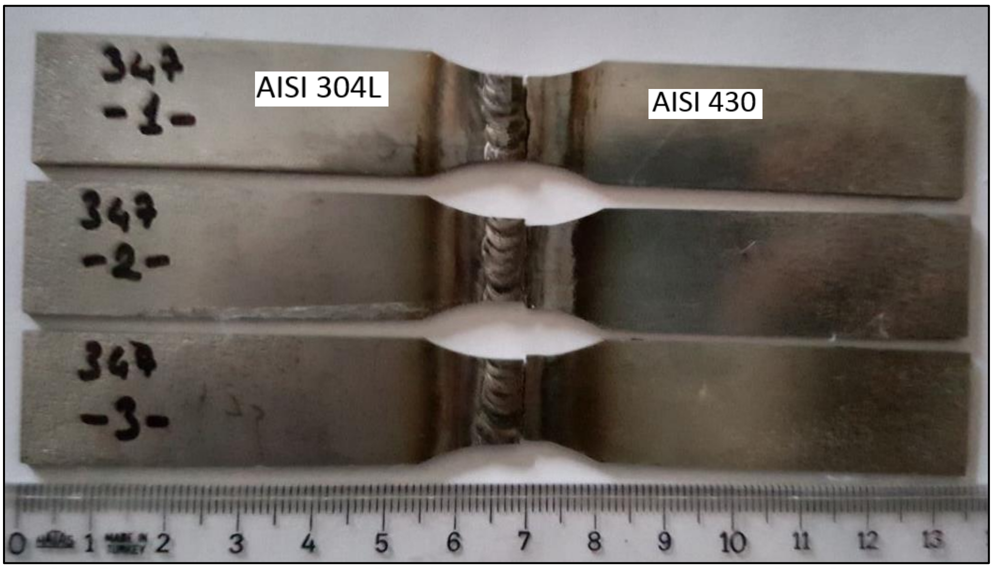


Figure 6.21. Macro photographs of the refraction areas of the Standard B welded tensile specimens combined with ER347 additional wire.

As shown in Figure 6.15 and Figure 6.21, it has been found that peeling in tensile specimens is usually carried out on the ferritic stainless steel side. It is also seen that the steel of the braid is in the HAZ. It is thought to be especially in the coarse-grained region, because this region has a coarse-grained and brittle structure.

The specimens prepared as standard A were found to be scratched on the base metal side of the ferritic stainless steel. This means that the weld metal and the mechanical properties of HAZ are higher than the base metal. According to these results, when the mechanical properties of the welded joint are examined, it can be concluded that it has succeeded.

It is seen that the HAZ width in the welding process varies in two samples. This is because of the difference between the heat transfer coefficient and the melting temperatures. As is known, the Thermal Conductivity of austenitic stainless steels (15, 7 W/mK) is 25.1 W/mK in Ferritic Stainless Steels. Also austenitic stainless steels are 1375 - 1450 $^{\circ}$C and ferritic stainless steels are 1425 - 1530 $^{\circ}$C. According to this result, it is expected that the austenitic 304L stainless steel will penetrate more in the weld metal.

6.4. IMPACT NOTCH EXPERIMENT RESULTS

The notch-impact experiment was carried out at 20 °C (RT), 0 °C and -20 °C. The notch-impact test result is shown in Table 6.2 and the post-test images of the impact notch test specimens are given in Figure 6.22.

Table 6.2. Impact-notch test result table of bonded samples using TIG welding.

Number	Specimen Designation	Dimensions in notch base (mm)	Test Temperature (°C)	Nominal Energy of Pendulum (J)	Impact absorbed Energy (J)	Impact Toughness (KJ/M²)
1	ER308	1.5x10x8	+20 (RT)	450,33	10,84	904,01
2					17,06	1422,00
3					17,43	1452,95
	Average				**15,11**	**1259,65**
4	ER309				23,54	1961,73
5					7,50	624,83
6					20,64	1720,10
	Average				**17,22**	**1435,55**
7	ER347				19,69	1640,78
8					21,6	1800,03
9					15,31	1276,34
	Average				**18,86**	**1572,38**
10	ER308		0		12,08	1006,64
11					9,11	759,59
12					7,16	596,76
	Average				**9,45**	**787,66**
13	ER309				21,31	1775,99
14					10,67	889,45
15					7,92	660,06
	Average				**13,30**	**1108,50**
16	ER347				15,86	1322,09
17					6,91	575,77
18					19,21	1601,35
	Average				**14,00**	**1166,40**
19	ER308		-20		7,92	660,06
20					3,7	308,44
21					4,84	403,24
	Average				**5,49**	**457,25**
22	ER309				4,11	342,15
23					2,42	201,76
24					10,32	860,41
	Average				**5,61**	**468,11**
25	ER347				4,38	581,6
26					4,46	388,3
27					6,57	447,89
	Average				**5,13**	**472,60**

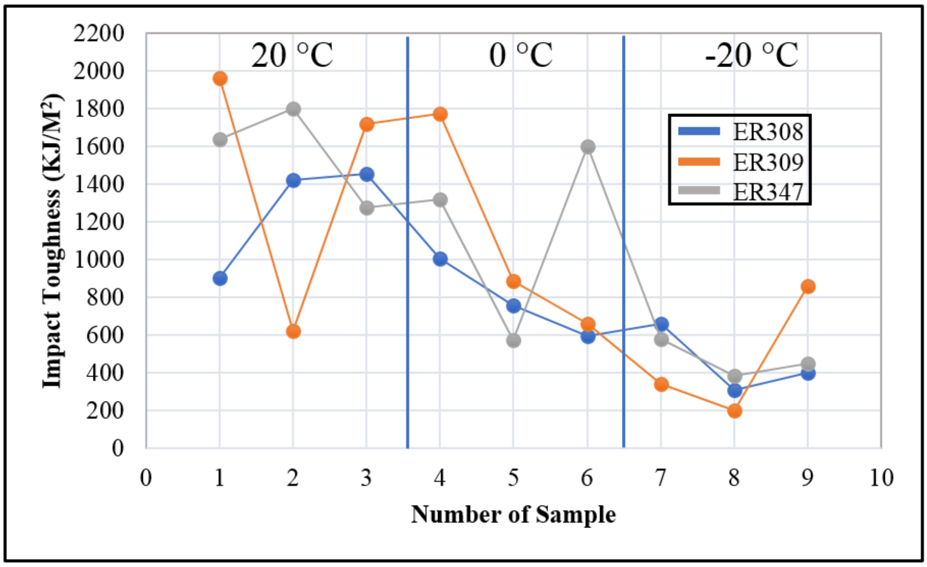


Figure 6.22. Impact-notch test result graphic of bonded samples using TIG welding.

When the results are analyzed, the impact-notched toughness of the samples combined with ER308, ER 309 and ER347 additive metals in average room temperature was found to be 125,96 J/cm^2, 143,55 J/cm^2 and 157,23 J/cm^2, respectively. The impact-to-notch shear strengths of the samples combined with ER308, ER309 and ER347 ER309 additive metals, respectively, at 0 ^{o}C were found to be 78,76 J/cm^2, 110.85 J/cm^2 and 116.64 J/cm^2, respectively. The impact-notched toughness of the samples combined with ER308, ER309 and ER347. ER309 additive metal on average at -20 ^{o}C was found to be 45.72 J/cm^2, 46.81 J/cm^2 and 47.26 J/cm^2, respectively.

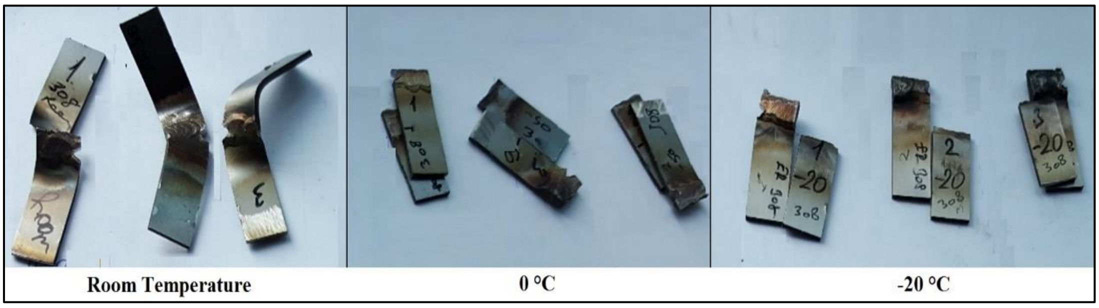


Figure 6.23. Macro images after impact notch test of samples with ER308 coded filler.

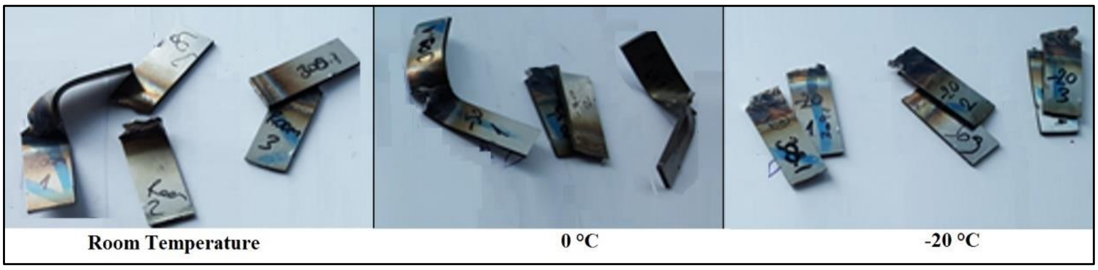


Figure 6.24. Macro images after impact notch test of samples with ER309 coded filler.

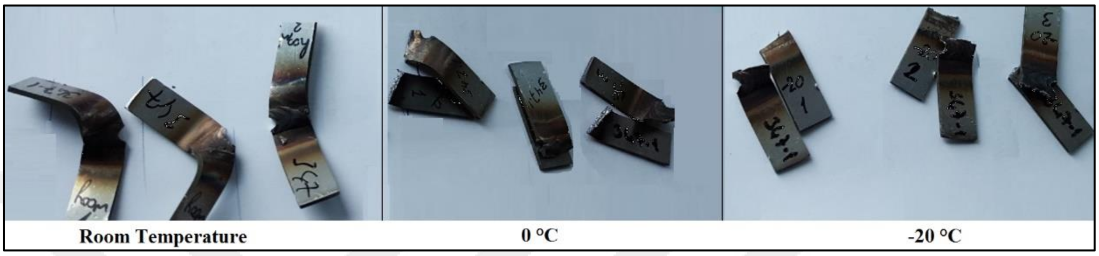


Figure 6.25. Macro images after impact notch test of samples with ER347 coded filler.

As shown in Figure 6.23, Figure 6.24 and Figure 6.25, no rupture has occurred in all three parameters at room temperature. It may be said that the impact strength is good. The joints made at 0 ^{o}C indicate that in all three parameters the fracture zones are realized in a brittle fracture mode by the AISI 304L austenitic stainless steel. The consolidations made at -20 ^{o}C indicate that the fracture zones in all three parameters are realized in a brittle fracture mode by AISI 430 ferritic stainless steel. The reason for the fracture is that ferritic stainless steels have low impact strength at low temperatures.

CHAPTER 7

RESULTS

7.1. GENERAL RESULTS

The sample weld metal microstructure joined by ER308 additional wire was formed from the lath ferrite phase, and the joint appeared to be grain refinement at HAZ microstructure on both ferritic and austenitic stainless-steel sides.

The weld metal images of welded material pairs were analyzed using ER309L additive metal, the weld metal microstructure was found to be composed of austenite-type austenite from ferrite grain boundaries and secondary austenite phase in grains.

The microstructure of the sample combined with ER347 additional wire is examined, it is seen that the weld metal microstructure is in dendritic form and lath ferrite.

The HAZ maximum grain reduction on the ferritic stainless-steel side is found with the combination of ER308 of additional metal and ER309 of additional metal. If the weld metal microstructures are compared, the weld metal formed with ER308 of additional metal appears to have a ferritic grain structure. However, the weld metal formed with ER347 of additional metal appears to be an austenitic structure with a dendritic structure. As a result of the microstructures it can be hardened with hardness results.

As can be seen from the microstructure and SEM images, coarse grains are observed in the HAZ near the melting limit of ferritic stainless steel main material. Grain size increases as the melting limit is approached. No grain refinement was observed on the austenitic stainless steel side of the welded joint in the HAZ zone.

As can be seen from the images, the ferritic stainless steel side of the joining shows distinct grain refinement in HAZ, whereas the austenitic stainless side shows more grain refinement and grain refinement than grain refinement. This is the main reason why the welded joints are formed from the coarse-grained part on the completely ferritic stainless side of the splice in the tensile tests.

It is clear that AISI 430 stainless base metal hardness is higher than AISI 304L stainless base metal. The difference between the weld metal and HAZ hardness of the joints obtained with all three additional metals is striking. Weld metal hardness of stainless steel joints of different grades seems to be higher than hardness at both main metals.

The weld metal and HAZ hardness of the austenitic and ferritic stainless steel assembly combined with ER308 were found to be higher than the ferritic stainless steel. It is thought that the cause of this is caused by the increase in favor of delta ferrite. The weld metal hardness of the samples combined with ER347 additional wire is found to be lowest. The chemical composition of the additive metals plays an active role in the hardness of the weld metal.

The average tensile strength of the samples combined with ER308 additional wire was 491,83 MPa and the extension was 5,80%. The tensile strength of the samples combined with ER309 additional wire was found to be 538,380 MPa and the extension was 10,55%. the average tensile strength is 511,43 MPa, and the elongation is 8,52%. The tensile strength and elongation of the samples combined with ER309 additional wire were found to be higher than those combined with ER308 and ER347 additional wire. Under the influence of the welding thermal cycle, the HAZ region has been formed in this region by the cooling regime and by the thermal diffusivity, decreasing hardness cracks. The addition of additional austenite-forming chemical compound supports the results.

The specimens prepared as standard A were found to be scratched on the base metal side of the ferritic stainless steel. This means that the weld metal and the mechanical properties of HAZ are higher than the base metal. According to these results, when the mechanical properties of the welded joint are examined, it can be concluded that it has succeeded.

The joints made at 0 ^oC indicate that in all three parameters the fracture zones are realized in a brittle fracture mode by the AISI 304L austenitic stainless steel. The consolidations made at -20 ^oC indicate that the fracture zones in all three parameters are realized in a brittle fracture mode by AISI 430 ferritic stainless steel. The reason for the fracture is that ferritic stainless steels have low impact strength at low temperatures.

REFERENCES

1. Hall, A., "***Cambridge CBI 6AH***", 1st Published, Abington Publishing, England, (1991).

2. Krauss, G., "***Steels Processing, Structure, and Performance***", ASM International, (2005).

3. Pickering, F.B., "Physical Mettallurgical Developments of Stainless Steels", ***Stainless Steels,*** 84:2–28, (1985).

4. Ehrnstén, U., Yagodzinskyy, Y., Hänninen, H., Karlsen, and W., Ivanchenko M., "Microstructural Manifestation of Dynamic Strain Aging in AISI 316 Stainless Steel", **Journal of Nuclear Materials**, 395:156–161, (2009).

5. Jeffus, L., "***The Essential Welder: Gas Tungsten Metal Arc Welding***", 1st Edition, pp 1-3, December 15, (1999).

6. Ericsson, M., "Simulation of Robotic TIG-Welding, Dissertation", ***Department of Technology University of Trollhättan/Uddevalla***, (2003).

7. Boran, N., "TIG Punta Kaynağı ile Birleştirilen Az Karbonlu Çelik Malzemelerin Mekanik ve Metalografik İncelenmesi", Yüksek Lisans Tezi, ***MarmaraÜniversitesi Fen Bilimleri Enstitüsü***, İstanbul, (2002).

8. Kurt, H. İ., "TIG Kaynak Yöntemi ile Birleştirilen Östenitik Paslanmaz Çeliklerin Mikroyapı ve Mekanik Özelliklerinin İncelenmesi", Yüksek Lisans Tezi, ***Marmara Üniversitesi Fen Bilimleri Enstitüsü***, İstanbul, (2006).

9. Gürcan, M., "TIG Kaynağı", ***Sinai Eğitim ve Geliştirme Merkezi Genel Müdürlüğü***, Ankara, (1987).

10. Kou, S. and Willey, J., "***Welding Metallurgy***", pp.11- 16 and pp.37-60, 2nd Edition, November 1, (2002).

11. Myers, T., "Why the Growing Interest in Gas Tungsten Arc Welding?" ***The Fabricator***, Vol. 22 (NO. 9), pp 38 -39, November, (1992).

12. ***American Welding Society***, "Welding Handbook", 8th Edition, Vol 2, pp. 74-107, (1991).

13. Oğuz, B., "***Paslanmaz Çeliklerin Kaynağı***", Oerlicon Yayını, İstanbul, (2001).

14. Odabaş, C., "***Paslanmaz Çelikler Temel Özellikleri Kullanım Alanları Kaynak Yöntemleri***", 2. Baskı, Ilı Eczacıbaşı, Lincoln Elektrik, Kaynak Tekniği Sanayi ve Ticaret A.Ş., İstanbul, (2004).

15. Ural, M., ve Kaluç, E., “Paslanmaz Çeliklerin TIG Yöntemi ile Kaynağı”, ***Metal ve Makine***, 76, İstanbul, 12-21 Mart, (1996).

16. Suban, M. and Tusek J., “Dependence of Melting Rate in MIG-MAG Welding on the Type of Shielding Gas Used”, ***Journal of Materials Processing Technology***, 119, pp. 185-192, (2001).

17. Yılmaz, R. and Barlas, Z., “Paslanmaz Çeliklerin Gazaltı Kaynak Yöntemi ile Birleştirilmesinde Koruyucu Gaz Kompozisyonunun Mikroyapı ve Mekanik Özelliklere Etkisi”, ***Pamukkale Üniversitesi Mühendislik Fakültesi Mühendislik Bilimleri Dergisi***, 11 (3): 391-400, (2005).

18. Tülbentçi, K., “***Paslanmaz Çeliklerin Kaynağı, MIG-MAG Ergiyen Elektrot ile Gazaltı Kaynağı***”, Gedik Holding, 137-142, İstanbul, (1990).

19. Grant, K. H., “***Gas-Tungsten Arc Welding***”, ASM Handbook, Welding,Brazing, and Soldering, London, 6:590-602, (1998).

20. Kaluç, E. ve Tülbentçi, K., “Paslanmaz Çelikler ve Kaynaklanabilirliği”, Seminer Notları***, Kocaeli Üniversitesi Kaynak Teknolojisi Araştırma Eğitim ve Uygulama Merkezi***, Kocaeli, (1995).

21. Committee., “Gaz Metal Arc Welding Guide”, The Lincoln Electric, America, (1986).

22. Internet: Kaynak Sanatı Bilgi Formu “Tıg Kaynağı”, **http://www.anatamir.com/kaynak,** (2009).

23. Kaya, Y., Kahraman, N., Durgutlu, A. and Gülenç, B., “Ferritik Paslanmaz Çelik ile Düşük Karbonlu Çelik Malzemelerin Farklı Kaynak Yöntemleriyle Birleştirilebilirliğinin Araştırılması”, ***International Iron & Steel Symposium***, pp. 77-78, Karabük, Türkiye, (2012).

24. Lippold, J. C. and Kotecki, DJ., “***Welding Metallurgy and Weldability of Stainless Steels”,*** pp. 168-223, Wiley-Interscience, A. Jhon Wiley & Sons Inc., (2005).

25. Çalık, A., “Elektron Işın Kaynağı ile Birleştirilmiş İki Farklı Çelik Malzemenin Kaynak Bölgesinin İncelenmesi”, Doktora Tezi, ***Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü***, Isparta, (2004).

26. Hayat, F., “Resistance Spot Weldability of Dissimilar Materials: BH180-AISI304L Steels and BH180-IF7123 Steels”, ***J. Mater. Sci. Tech***., 27(11), 1047-1058, (2011).

27. Lippold, J. and Kotecki, D., “***Welding Metallurgy and Weldability of Stainless Steel***”, John Wiley and Sons, USA, (2005).

28. Easterling, K., “Introduction to the Physical Metallurgy of Welding”, ***Butterworks Monographs in Materials***, UK, (1983).

29. Granjon, H., "***Fundamentals of Welding Metallurgy***", Woodhead Publishing Ltd, UK, pp. 123-130, (1991).

30. Çörten, N. Şener, A., Kaya, Y., and KAHRAMAN, N., "AISI 304 ve AISI 316 Östenitik Paslanmaz Çeliklerin TIG Kaynağıyla Birleştirilebilirliğinin İncelenmesi", ***4th International Conference on Welding Technologies and Exhibition (ICWET'16)***, Gaziantep, Turkey, 11-13 May, (2016).

31. Kaya, Y., "An Investigation on Joinability of the AISI 304 and AISI 430 Stainless Steel by TIG, MIG And Shielded Metal Arc Welding Methods", ***J. Fac. Eng. Arch. Gazi Univ***, Vol. 25, No 3, 549-557, (2010).

32. Durgutlu, A., "Experimental Investigation of the Effect of Hydrogen in Argon as a Shielding Gas on TIG Welding of Austenitic Stainless Steel", ***Materials and Design***, 25, 19–23, (2004).

33. Kaçar, R. ve Gündüz, S., "AISI 304-AISI 430 Paslanmaz Çeliklerin Direnç Kaynak Kalitesine Soğuk Deformasyonun Etkisi" ***Demir Çelik Store Sanayi Dergisi***, (2016).

RESUME

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