RESISTANCE SPOT WELDING OF ALUMINUM ALLOY TO CARBON STEEL USING RED PURE COPPER AS FILLER METAL

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Master Thesis

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“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.”

Hamzah Hasan Younus YOUNUS

ABSTRACT

M. Sc. Thesis

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The Department of Mechanical Engineering

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In this study, resistance spot welding process of dissimilar metals AA6061 (1.0 mm thickness), and light carbon steel AISI- SAE 1005 (0.7 mm thickness) were investigated. During the welding process, pure red coppers were used in several different thicknesses (0.2, 0.3, 0.02, 0.03 mm), and choose the best among them. As an interlayer was added to improve welding conditions and solve the problem of anisotropy, to discuss optimization techniques, and include it between aluminum alloys and carbon steels to overcome the problem of different electrical and thermal properties, and more metal energy generated from electric current.

The following are some of the advantages that suit the labor market, using carbon steel and aluminum alloys, the inclusion of the best thickness of pure red copper strips between them, and using spot welding technology in the welding process between different metals. The main benefit of RSW is that it can be used to bind materials that are different from each other. In various manufacturing and food and beverage manufacturing industries, the joining of aluminum alloys and carbon steels to produce equipment such as furnaces, vessels, and containers has emerged as a great contender for joining carbon steels and aluminum alloys of equivalent grades. The combination of copper, carbon steel, and aluminum alloy leads to the improvement of many mechanical and metallic properties due to the good electrical and thermal conductivity properties and their affinity with some of their properties. Desired qualities include great corrosion resistance, a distinct decorative appearance, and excellent weldability. Resistance spot welding is suitable for service conditions including corrosive environments and high-temperature cycles when joining dissimilar metals in a weld.

The idea of this type of welding depends on the pressure of the two pieces to be welded with the two copper electrodes where a constant electric current passes through the metal. The main challenge in bonding two pieces of metal is the resistance presented by the air located at the boundary between them. This can prevent the pieces from adhering completely, which generates high levels of heat and causes the metal to melt. When they melt, the electric current is separated, and compressed electrodes are drawn in opposite directions, leading to fusion in the molten region. In this study, the strength of the current, its applied period, and the amount of pressure based on the type and thickness of the base metal material, several currents were used. The current ranged between 8500 kA and 12300 kA and was applied for several durations between 0.8 and 1.6 seconds. The test was performed on four thicknesses of red copper to determine the best thickness and used as a filler metal. The best current was determined to be 12300 kA, and the best duration was found to be 0.8 seconds.

Keywords : Resistance spot welding, carbon steel, aluminum alloy, pure copper, dissimilar welding

Science Code : 91415

ÖZET

Yüksek Lisans Tezi

BAKIR FOLYO DOLGU METALİ KULLANILARAK ALÜMİNYUM ALAŞIMININ KARBON ÇELİĞİNE DİRENÇ PUNTA KAYNAĞI

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Bu çalışmada, farklı metaller olan AA6061 (1,0 mm kalınlık) ve hafif karbon çeliği AISI-SAE 1005 (0,7 mm kalınlık) direnç punta kaynağı prosesi incelenmiştir. Kaynak işlemi sırasında birkaç farklı kalınlıkta (0.2, 0.3, 0.02, 0.03 mm) yüksek saflıkta kırmızı bakır folyolar kullanılmış ve aralarından en iyisi seçilmiştir. Kaynak koşullarını iyileştirmek ve anizotropi problemini çözmek, optimizasyon tekniklerini tartışmak, farklı elektriksel ve termal özellikler ve elektrik akımından üretilen daha fazla metal enerjisi sorununun üstesinden gelmek için alüminyum alaşımları ve karbon çelikleri arasına dahil etmek için bir ara katman eklenmiştir.

Karbon çeliği ve alüminyum alaşımlarının kullanılması, aralarına en iyi kalınlıkta saf kırmızı bakır şeritlerin dahil edilmesi ve farklı metaller arasındaki kaynak işleminde punta kaynağı teknolojisinin kullanılması işgücü piyasasına uygun avantajlarından bazılarıdır. RSW'nin ana faydası, birbirinden farklı malzemeleri bağlamak için kullanılabilmesidir. Çeşitli imalat ve yiyecek ve içecek imalat endüstrilerinde, fırınlar,

gemiler ve kaplar gibi ekipmanların üretilmesi için alüminyum alaşımları ve karbon çeliklerinin birleştirilmesi, karbon çelikleri ve eşdeğer derecelerdeki alüminyum alaşımlarının birleştirilmesi için büyük bir rakip olarak ortaya çıkmıştır. Bakır, karbon çeliği ve alüminyum alaşımının kombinasyonu, iyi elektriksel ve termal iletkenlik özellikleri ve bunların bazı özellikleriyle yakınlığı nedeniyle birçok mekanik ve metalik özelliğin gelişmesine yol açar. Arzu edilen nitelikler arasında yüksek korozyon direnci, belirgin bir dekoratif görünüm ve mükemmel kaynaklanabilirlik yer alır. Direnç nokta kaynağı, farklı metalleri bir kaynakta birleştirirken aşındırıcı ortamlar ve yüksek sıcaklık döngüleri dahil olmak üzere servis koşulları için uygundur. Bu tür kaynak yöntemi, metalden sabit bir elektrik akımının geçtiği iki bakır elektrot ile kaynak yapılacak iki parçanın basıncına bağlıdır. İki metal parçasının yapıştırılmasındaki ana zorluk, aralarındaki sınırda bulunan havanın sunduğu dirençtir. Bu, parçaların tamamen yapışmasını önleyebilir, bu da yüksek düzeyde ısı üretir ve metalin erimesine neden olur. Metaller eridiklerinde elektrik akımı ayrılır ve sıkıştırılmış elektronlar zıt yönlerde çekiler ve erimiş bölgede füzyon oluşur. Bu çalışmada, akımın şiddeti, geçiş süresi, ana metal malzemenin cinsine, kalınlığına ve uygulanan basınç miktarına göre akım 8500 kA ile 12300 kA arasındaydı ve birkaç kez 0,8 - 1,6 saniye arasında değişme göstermiştir. En iyi kalınlığı belirlemek için dört kalınlıkta kırmızı bakır folyo dolgu metali olarak kullanıldı ve test edildi. Seçim, 12300 kA'lık en iyi akım ile en iyi süre olan 0.8 saniye arasında olduğu tespit edilmiştir..

Anahtar Kelimeler: Direnç punta kaynağı, karbon çeliği, alüminyum alaşımı, saf bakır, farklı kaynak

Bilim Kodu **:** 91415

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SYMBOLS AND ABBREVITIONS INDEX

SYMBOLS

H : Heat generated
T : The average sheet thickness
ST : Shear Tension Strength
S : Base Metal Ultimate Tensile Strength
T : Material Thickness
I : Welding Current
R : Electrical resistance
T : Time of current flow
ST : Shear Tension Strength
S : Base Metal Ultimate Tensile Strength
T : Material Thickness

ABBREVIATIONS

RSW : Resistance spot welding
Al : Aluminum
ASTM : American Society for Testing and Materials
AWS : American Welding Society
DOE : Design Of Experiments
EDS : Energy Dispersive Spectroscopy
C.ST : Carbon steel
CU : Copper
FEM : Finite Element Method
SEM : Scanning Electron Microscope
AISI : American iron and Steel institute
XRD : X-ray diffraction
OM : Optical Microscope

IMC : Intermetallic Compound
IF : Interfacial Failure
PF : Pullout Failure
GTAW : Gas Tungsten Arc Welding
IC : Integrated Circuit
ESD : Electro Spark Deposition
IC : Integrated Circuit
ESD : Electro Spark Deposition
BM : Base Metal
NZ : Nugget Zone
HAZ : Heat Affected Zone
RWMA : Resistance Welder Manufactures Association
TST : Tensile Shear Test
SORPAS® : Simulation & Optimization of Resistance Projection & Spot Welding
HAZ : Heat Affected Zone

PART 1

INTRODUCTION

E. Thompson of Philadelphia's Franklin Institute was the first person to demonstrate how to successfully weld metals together using resistance. His research, which was completed in 1886, gave rise to the incredibly complex processes that are useful in the construction many of our contemporary structures. Numerous devices for electrodes, seam welding tools, and welding guns are used today on production lines at industrial sites to complete hundreds of welds. Modern resistance welding equipment enables process control in mechanical and electrical (current, voltage, or power) devices. A subset of fusion welding known as resistance welding uses pressure and heat to accomplish coalescence with the work surface. The required heat is produced at the intersection of the weldable parts by electrical resistance to current flow. These processes have several advantages, including the ability to join metals of different thicknesses and compositions without the use of flux, shielding gases, or consumable electrodes. Resistance welding differs from fusion welding techniques still more since it forges the heated components together using mechanical force. Before the electrode force is applied, during, and after the current period. A force system that can move one or both electrode holders toward and away from the workpiece while also producing the required welding force is attached to one or both electrode holders. A weld often has physical properties that are equivalent to or even better than those of the parent metal because the force has the effect of fine-tuning the grain structure. When high-quality welds come together quickly and smoothly, it may be challenging for beginners to comprehend how resistance welding machines operate. Resistance Spot welding is frequently used in the production of sheet metal for a long time. It has been employed as a connecting technique for vehicle builds because of its adaptability, durability, and high strength.

Process effectiveness along with excellent joints that are reasonably priced. This method's advantages include automatic possibility and speed. Resistance spot welding

(RSW) is performed between 2000 and 5000 different places on every passenger vehicle, and tens of millions of cars are built globally each year. Every weld point is important for manufacturing production and quality as a result. The production of other forms of transportation (such as railroads, ships, planes, and aerospace) also makes substantial use of it. The use of sheet metal in furniture, appliances, and other products. This method can also be used to join different sheet metals with different thicknesses.

1.1. Material used in Resistance Spot Welding

Copper and copper alloys are preferred due to their corrosion resistance and electrical and thermal conductivity. In order to construct copper components that maintain their mechanical or corrosion-resistant features without adding faults into the welds, advice is given on the best practices and techniques to use [1]. Copper has a high electrical and thermal conductivity, but it can still be joined together via resistance spot welding. Its electrical and thermal conductivities, among other factors, have a big impact on how resistant it is to weld [2].

Cu and Cu- alloys; copper salts have a wide range of industrial uses in addition to their numerous applications in biology and agriculture, many of which are specialized and hardly ever go unused in any industry. In the pages that follow, the more well-known copper compounds are briefly discussed, along with an overview of some of their applications, with a focus on copper sulfate.

Rameters, including its electrical and thermal conductivities [2], copper plays a critical function in sustaining the health and growth of both plants and animals in addition to being a necessary component of all living tissues. It must be applied in places where it is absent.

The precise proportions of copper required for human health are frequently obtained through regular consumption of food and water. Contrary to several other metals like lead or mercury, copper and its derivatives are not toxic.

People who have worked with copper or its salts for a long period have not been found to have any occupational concerns related to copper.

These individuals have regularly been seen to appear healthier and to experience colds and other illnesses less frequently. Legend has it that wearing copper jewelry, such as bangles, will lessen and even prevent rheumatic pain. Kettles, water storage containers, and cooking equipment made of copper have been around for a while[1].

- Common Purposes
  The history of copper compounds would have to be studied much earlier than the fourth millennium BC.
- Uses in Agriculture
  In agriculture, where copper compounds were first used in 1761, they are particularly common.
- Sulfate of copper Common names include copper sulfate, blue stone, and blue vitriol.
- Agriculture and Copper Sulfate
  The following uses of copper sulphate in agriculture are the most significant ones.
- Other Compounds of Copper
  Verdigris, a basic copper acetate, was once produced in France.
- Copper Sulphate Uses Copper sulphate's uses
- Copper fungicides

Plant diseases that copper fungicides can control.

Copper-Base Alloy Metallurgy; the characteristics of copper itself have a significant impact on the fundamental qualities of copper alloys. Copper is the ideal technical material for bearing applications because it is recognized to have a few special characteristics. Which are: Excellent thermal conductivity. Excellent toughness and ductility over a wide temperature range.

The atomic structure and behavior of copper are directly related to each of the three properties listed above. The atoms of copper and in the periodic table of elements, copper and gold or silver together form a group, are remarkably like one another. The exceptional electrical conductivity of copper, which is a function of copper's atomic structure, is well known. A cloud of free electrons that is exclusively available for the passage of electrical current exists within the copper atom lattice. Additionally, the efficient transport of thermal energy is improved by the same electron cloud. Copper the arrangement of atoms is a face-centered cubic (Fcc) shape to form solid copper.

The atomic attractions between the atoms keep them fixed in place within the structure thanks to their energy. Copper's extraordinary ductility and endurance are due to the face-centered cubic arrangement of its atoms [2].

Photomicrographs of copper and copper alloys and processing that are both commercially significant and/or of interest from a metallurgical perspective. As a result, spot welding joints were made during the variation of welding current, electrode strength and the influence of process factors [3].

Aluminum is used extensively due of its corrosion resistance and low weight. At 2.7679 g/cm3, it is around one-third the density of steel or copper. By air, water, oils, or numerous chemicals, it is not easily corroded. This is caused by the resilient, refractory oxide coating, which readily recovers on a clean surface in the air. This oxide stops molten metal filler from soaking since it scarcely dissolves in the metal. The thermal and electrical conductivities of aluminum are roughly four times larger than those of steel.

For resistance spot welding, aluminum requires a higher current density and a faster weld time than steel of an identical thickness. Aluminum resists welding quite differently than other metals because of its unique physical and chemical characteristics [1].

Numerous physical and chemical characteristics of aluminum have made it a crucial component in industry across the board, including non-toxic, durability and resistance to fracture. The hue is either dark gray or lustrous silver. Conductor of heat and electricity retractable and knock able. It is easy to manufacture because it can be cast, machined, and extruded. 2.7 g/cm^3 is a low density. Because exposure to air instantly generates a coating of aluminum oxide, it is resistant to corrosion and, to a lesser extent, acid, and alkali resistance. It dissolves in water in certain patterns but not in alcohols. The union of atoms with one another takes the shape of a cube with its face in the center (FCC). There are nine isotopes of aluminum. Because aluminum powder has a silver reflective quality, it is utilized to create silver coatings and highly reflective mirrors. Combining pure aluminum with other elements like copper, silicon, and magnesium to create aluminum alloys, which increase the tensile strength of the metal. 80% reflectivity for both heat and light. The most important source of aluminum ore is the recyclable and reusable mineral Bauxite Al2O3. Extremely reactive to oxygen. Aluminum, Al, a non-metallic element with the symbol Al and atomic number 13, reacts both acidically and alkalinely. It is a member of the elemental family called Boron [1].

Due to passivation and its low metallic density, aluminum has a remarkable capacity to withstand corrosion. From the general properties (Name, number, symbol, aluminum, 13, p., chemical series: metal, group, session, sub-level: 13, 3, p, appearance silver, atomic number 5, Mass number: 811.10 g/mol), some physical and atomic properties about the aluminum are solid, Heat capacity is 087.11 joules/ (mol., density at dHg is 70.2 g/cm, melting point is 32.660 °C, boiling point is 2519 °C. Atomic diameter: 125 (pm), cube-centered face, oxidation state: 3, amphoteric oxide, electronegativity [4].

Due to its qualities, Aluminum is one of the essential chemical elements that modern industry is based on because of its properties that are infrequently found in one element, such as light weight, durability, rigidity, formability, and resistance to outside forces like corrosion. Military vehicles with armor plating. Manufacturing of vehicles and communication equipment including trains, ships, and railroads. The application of aluminum alloys in the building and construction industry. Manufacturing of door and window frames as well as household equipment. Packaging industry for chips. Industry of electrical connectors. Industry of jewelry. Fireworks and explosives industry. Paint. Create coins. Access to heights and surfaces, installation tools, and ladders [5].

In nature, aluminum is a common element that is widely distributed and ranked third among the most abundant elements in the world. It is found in combination with other elements to form silicon and oxygen, as well as in natural raw materials like bauxite (hydrated aluminum oxide), cryolite (sodium aluminum fluoride), and clay, where it can be found in the form of complex silicates.

Transport (vehicles, trucks, planes, trains, cars, and ships) as castings, paper, tubes, etc., a wide range of domestic objects, such as kitchenware, baseball bats, and electronics Laptop (Apple), streetlight poles, ship masts, strolling poles, etc. External levels of consumer electronics, and in cases of equipment also such as equipment Photography, electricity transmission lines for power distribution.

Ultra-pure aluminum (980.99%, 999.99% Al), used in the field of CDs, heat sinks for electronic devices like transistors and central units, and the original material of the main element covers the copper with a thin layer used in high light intensity for LED light[6]. Aluminum powder is also used in paint and pyrotechnics like solid rocket fuel.

The melting point of Aluminum is defined as the temperature at which a substance melts, or, to put it another way, the point at which a substance changes from a solid to a liquid state. Melting happens when a solid substance is heated or when the substance absorbs heat from its surroundings, at which point the molecules start to obtain enough energy. Knowing that the inner section of the sample is initially cold and that aluminum has a melting temperature of 660 ° C [7].

Aluminum Alloy AA6061 is a potential reinforcement for aluminum matrix composites (AMCs) that could improve characteristics and lower production costs is fly ash. By using a forging technique, fly ash particles were converted into the reinforced aluminum alloy AA6061 in various weight percentages (0, 4, 8, and 12 wt %). The semi-solid aluminum smelt included fly ash particles in it. Fly ash particles were detected in the generated AMCs' X-ray diffraction patterns, but no other intermetallic compounds were created. The microstructures of AMCs were analyzed using electron microscopy [8] .

1.2. STEEL AND RESISTANCE SPOT WELDING

One of the beneficial materials utilized in the RSW process is mild steel or low carbon steel. The complete mild steels are easily weld able when the right tools, systems, and techniques are applied. Some low carbon steels need to be post-heated. When an approximate post-heating method is not followed, the amount of carbon in the weld increases. This results in brittle and hard welding. When the nugget cools quickly, there is also a potential that the likelihood of forming a hard and brittle microstructure of the weld will increase. Depending on the magnetic material present in the tong loop, the welding current varies significantly when welding magnetic materials such as mild steel. There is a sizable difference in welding current based on the magnetic material. Because of the mill scale on their surface, hot-rolled steels are not suited for resistance spot welding procedures. However, RSW might be doable with some effort [2].

By preventing the buildup of carbon in the electrode tips, the life of the electrode can be extended. However, excessive oil concentration in the sheet metal might cause carbon content to develop in the electrode tips during welding. Therefore, it is advised that the severely oiled sheet stock's oil content be reduced or cleaned. The RSW welding procedure can be used to join low carbon steels. The rated capacity of the RSW machine, which should be determined based on the entire thickness of the selected material, should be used for the optimum results. Their score is fifty. The fifty percent duty cycle is defined as the unit welding in 5 out of 10 second's variation without overheating. There are some clear distinctions between low alloy and medium carbon steels and low carbon or mild steels when it comes to resistance spot welding. Low alloy and medium carbon steel both have larger resistance factors than high carbon steel, which marginally reduces the required current for efficient joining. These alloys have greater metallurgical changes during welding. Setting the time and temperature is therefore quite important. Hot-rolled steels are not appropriate for resistance spot welding techniques because of the mill scale on their surface[9]. RSW, though, might be doable with a little work. If the creation of carbon content in the electrode tips is avoided, the life of the electrode can be extended. However, if the sheet metal has an excessive amount of oil concentration, carbon content production in the electrode tips is conceivable during the welding process. Consequently, it is advised to reduce or wipe the oil content in the severely oiled sheet material. The RSW method can be used to weld low carbon steels. The rated capacity of the RSW machine should be chosen based on the entire thickness of the chosen material to achieve the optimum results. For all uses of this equipment, a duty cycle of 50% is adequate based on their rating. Based on a window of 10 seconds, duty cycle, there are several noticeable variations between low carbon or mild steels and low alloy and medium carbon steels when it comes to RSW [3].Since the increased resistance factor of low alloy carbon steel.

These alloys have greater metallurgical changes during welding. Setting the time and temperature is therefore quite important. It's important to predict the time and temperature. In comparison to mild steel, these types of steels are more susceptible to weld embrittlement. Low alloy and medium carbon steels often have greater compressive strength. As a result, these kinds of alloys typically have high electrode pressure. When longer welding is preferred, ductile welds may be achievable [2].

1.2.1. Steel Varieties

The best materials for resistance spot welding are those with higher resistance, like austenitic steel or chrome-nickel steel alloys. At critical temperatures for longer welding, however, there is a greater chance of carbide precipitation. Under this heading is the steel that has been zinc-coated or galvanized. With stronger electrode forces, steel to steel bonding is feasible in these materials. To move the zinc apart and strengthen the resistance spot welds, more electrode pressure is applied. Any surface damage sustained externally during welding can easily repaired. However, there is a problem with the loss of coating materials at interfaces that cannot currently be resolved. The expectation that zinc-coated materials will have superior TSS of the weld is generally unfounded [10]. examined the effects of process factors on the peak current, micro hardness, heat input, and tensile shear load bearing capability of dissimilar welds between interstitial free steel of grade 7114 and AISI 316L austenitic stainless steel. They claim that high heat input causes internal weldment faults, and martensite transformation has been observed to cause low electrode force fracture [11]. Investigated the mechanical properties and microstructure of an RSW-fabricated ASS Cold Rolled 301 LN weld joint and reported that interfacial fracture has been noticed as a result of martensite transformation[10]. Using the RSW approach and various welding currents, connected sheets of Mg and Al that were not compatible. Spot welds were put through a tensile shear test to look at how they fail and how strong they are. He noticed that the fracture tore in two separate ways [7]. The nugget diameter should be around 4t (t = Sheet thickness). They discovered that the nugget's bigger size caused its tensile strength to be higher [11].

They discovered that when welding time and welding current grew, the size of the nugget also increased in their study of the effects of welding duration and welding current on the resistance spot welding of AISI 304 SS. They also pointed out that welding current, rather than welding duration, dominated the nugget dimension [13]. Attempted to analyze the influence of RSW process parameters on nugget formation and concluded that as electrode tip diameter increased, electrode indentation and nugget size decreased [14]. Used the RSW procedure to combine SPA-H steel sheets and looked at how the length of the welding process affected the tensile shear strength. Mechanics were used to load the samples. For improved outcomes, it was claimed that the electrode indentation needed to be kept to a maximum of 30% of the sheet thickness[12].The failure specimens of resistance spot-welded lean steel and AISI 316L following the tensile-shear test. They discovered that the capacity for work hardening was lower in DSS than in ASS, and failure happened in the base metal of the Dissimilar. Investigated the effects of welding time and welding current on the spot weld tensile shear strength of 1.6 mm thick AISI 316L stainless steel sheet due to inappropriate nugget dimensions and heat input. Shearing type failure and tearing type failure were the two failure types used to produce the sheet.

1.2.2. Carbon Steel Types and Their Characteristics

According to its carbon content, carbon steel can be split into three categories: low-carbon steel (also known as mild carbon steel), medium-carbon steel, and high-carbon steel [16].

1.2.3. Low Carbon Steel

The most popular kind of carbon steel is low-carbon steel. The usual carbon content of these steels is less than 0.25 weight percent. Typically, cold work is required to harden them because heat treatment cannot make them martensitic. Carbon steels are often weak and brittle. [17].

1.2.4. Mid Carbon Steel

Medium-carbon steel has a manganese concentration of 0.60 to 1.65 weight percent and a carbon content of 0.25 to 0.60 weight percent. This steel is given a martensitic microstructure and improved mechanical properties using a heat-treatment procedure that includes automatizing, followed by quenching and tempering. Only extremely thin pieces of metal can be heated to harden them; however, the steel can be made to be more heat resistant by adding alloying metals like chromium, molybdenum, and nickel. Medium-carbon steels that have been hardened are stronger than low-carbon steels, but they are less ductile and tough [13].

1.2.5. Haigh-Carbon Steel

In high-carbon steel, which has a carbon content between 0.60 and 1.25 weight percent, manganese percentages range from 0.30 to 0.90 weight percent. Among carbon steels, it is the least ductile and has the highest hardness and toughness. High-carbon steels have a high wear resistance due to their regular hardening and tempering. High-carbon steels, such as tool and die steels, also include additional alloying elements like tungsten, molybdenum, vanadium, and chromium. These elements combine to form carbide compounds, such as tungsten carbide, which result in the production of the incredibly hard, wear-resistant steel. Steel that has been previously used, brand-new steel, or a combination of the two can be used to create carbon steel. New steel is produced by combining iron ore, lime, and coke, which is made by heating coal without air in a blast furnace at a temperature of about 1650 °C [18].

1.2.6. Applications & Examples

- **Lower carbon steel**

Food cans, I-beams, channel, and other structural elements, pipes, as well as building and bridge components, typically use low carbon steel.

- **Mid-carbon steel**

Due to their great strength, resistance to wear, and toughness, medium-carbon steels are frequently used for machinery parts like crankshafts, gears.

- **A high carbon steel**

Because of their exceptional hardness and wear resistance, high-carbon steels are used in cutting tools, springs, high-strength wire, and dies.

1.3. OBJECTIVES OF THIS WORK

The following summarizes the work's objectives:

- Research the bonding process and ideal copper interlayer thickness between carbon steel and aluminum alloy.
- The optimum welding conditions are obtained by studying the effects of welding parameters (welding current, welding time) on the mechanical properties and microstructure of carbon steel and aluminum alloy with the best thickness of copper as interlayer.
- 3. Using a metal interlayer and the best welding circumstances, carbon steel and aluminum alloy welding is optimized.

1.4. THE WORK'S SCOPE

Figure 1.1) shows the layout of this work's aims and the stages of experimental and testing work.

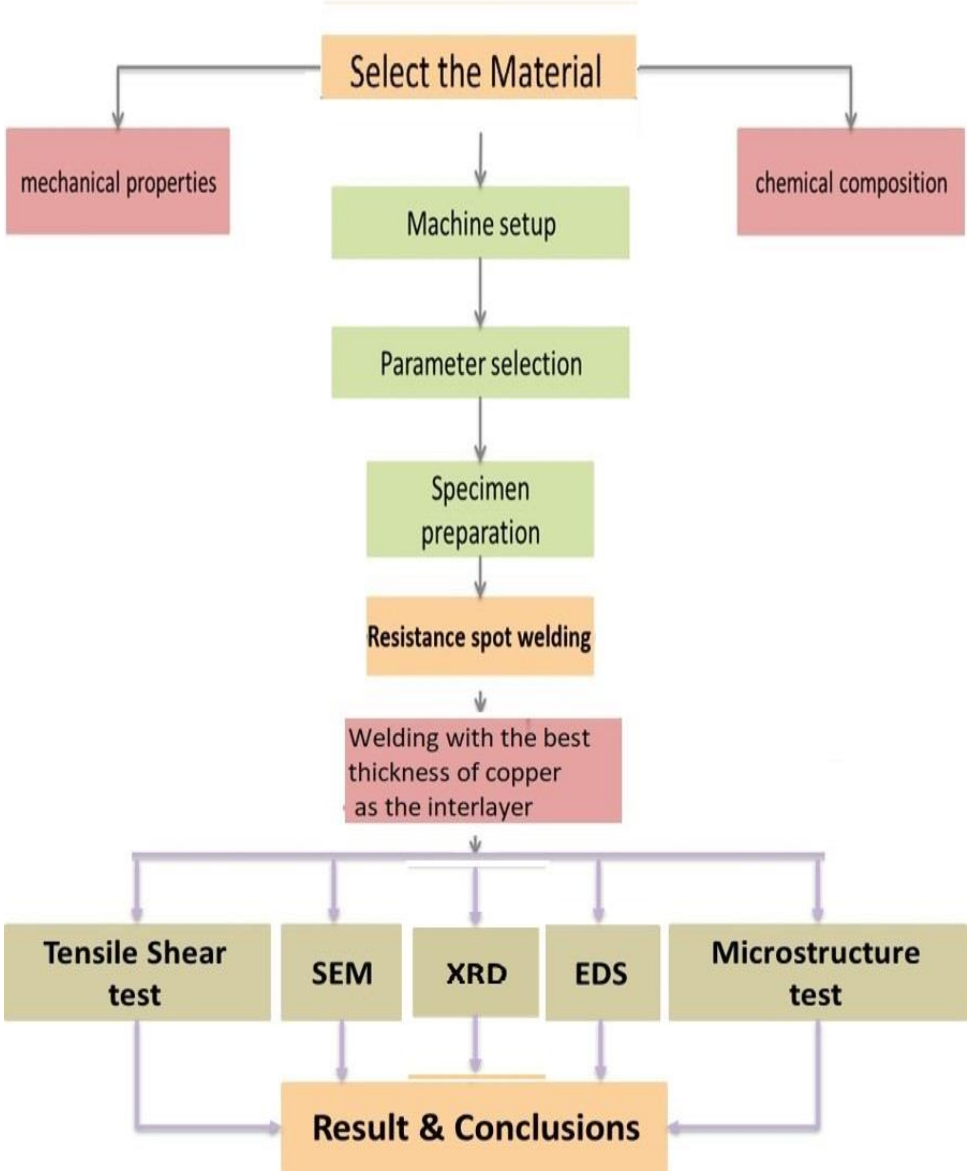


Figure 1.1. The Scope of the Work

PART 2

SURVEY OF LITERATURE

2.1. INTRODUCTION

Due to its high efficiency, one of the essential methods for bonding sheet metal for industrial components is resistance spot welding. RSW is a complicated process that involves simultaneous electrical, thermal, and mechanical interactions that are linked. Numerous studies on the resistance spot welding process have been done, concentrating on the impact of various welding parameters (weld current, weld duration) on the welding quality. Other scientists look at how metal interlayers affect the quality and mechanical properties of welds. The following earlier research is pertinent to this investigation:

Eli Hu Thompson, the first person to demonstrate that resistance welding could be used to unite metals was a professor at Philadelphia's Franklin Institute. His research, which was finished in 1886, produced extremely detailed and sophisticated methods that are helpful in putting together many of our current structures. Today's production lines move so quickly that manufacturing facilities must complete hundreds of welds using a variety of electrode machines, welding welders, and welding guns. Process control in mechanical and electrical (current, voltage, or power) is made possible by contemporary resistance welding apparatus. Resistance welding is a class of fusion welding methods that fuse materials together by applying heat and pressure to the seam surface. The electrical resistance to the current flow at the interface of the components to be welded produces the necessary heat. These procedures may bond metals of different thicknesses and textures and have significant benefits, such as not requiring consumer electrodes, shielding gases, or flux. Together. Before, during, and after the current interval, electrode force is applied.

A force system that can move the electrode holders toward and away from the work piece and generate the necessary weld force is attached to one or both electrode holders. The effect of the force is to improve the grain structure, resulting in a weld with physical properties equal in most cases to or even better than those of the original metal. Resistance welding devices and their work sometimes seem incomprehensible to beginners when excellent welds are formed quickly and easily. Resistance spot welding has been widely used in sheet metal fabrication for many decades. It has been used as a jointing technology for automobile bodies due to its flexibility, durability, and high processing speed, along with inexpensive joints of extremely high quality.
The ability and speed to automatically are among the advantages of this process. Resistance Spot Welding (RSW) is performed on thousands of sites, approximately 2000-5000 per passenger vehicle, and annual production for vehicles worldwide is measured in the Tens of millions of units. Therefore, every welded spot count, not only for quality but also for production manufacturing.

It is also widely used in the manufacture of other transportation (trains, ships, aircraft, and aerospace), appliances, furniture, and other products made from sheet metal. In addition, dissimilar metal sheets and different sheet thicknesses can be joined by this procedure if the ratio does not exceed 4 to 1 [14]. Ibrahim et al. 2016, in this study, 2 mm thick stainless-steel sheets were bonded to aluminum alloy sheets by RSW with an interlayer of Al-Mg alloy. The melting point of the interlayer is lower than that of Al alloy. As a result, a successful joining occurred when the molten interlayer filled the space between the plates at a lower temperature. To confirm the fatigue fracture mechanism and gauge the fatigue strength, tensile shear stress experiments were carried out. Under the same welding conditions, dissimilar welds of aluminum and steel with interlayers displayed tensile shear strengths that were higher than those without interlayers, with an average value of 8400 N. A 2um-thick, homogenous thin IMC layer was created along the contact, resulting in a solid bond. Mg is discovered to be 5 mm away from the contact as it diffuses into the Al sheet from the Al-Mg interlayer. Where plug-type fracture occurred with high loads, shear fracture through the solid block with medium loads and thickness-induced stress-induced crack growth in the Al plate under low loads. The tensile and fatigue shear strengths of RSW Al/steel dissimilar welds were greater than those of FSSW [15].

In 2015, H. R. Rezaei Ashtiani and R. Zarandooz A 2D axisymmetric electro-thermo-mechanical finite element (FE) model was developed to investigate the effects of welding time, welding current, and electrode tip diameter on temperature distributions and nugget size during resistance spot welding (RSW) of sheets made of the Inconel 625 super alloy. Uncoupled thermal-mechanical analysis and coupled electro-thermal analysis are used in modeling. In order to improve the accuracy of simulation, researchers have looked into temperature-dependent material properties, including physical, thermal, and mechanical characteristics.

With a suitable variation of each process parameter, the thickness and diameter of calculated weld nuggets were compared to experimental data, and an excellent match was found. The FE model that was presented also predicted the quality and form of the weld nuggets as well as temperature distributions. Adjusting RSW parameters using the FE model helps to avoid using expensive experimental methods. The nugget size and electrode indentation increase with welding time and current intensity, whereas they decrease with electrode tip diameter [20]. S. K Hussein and O. S. Barrak (2015) The study intends to investigate the effects of RSW parameters on the shear strength of the spot weld for different metals (AA 6061-T6 and AISI 1010) with thicknesses of 0.5 and 0.7 mm. parameter (welding current, electrode force, squeezing will be utilized three values for each welding parameter (welding current, electrode force, squeeze time and welding time). Minitab has investigated the effects of these parameters by using the Taguchi method to design experiments (DOE). Each welding parameter (welding current, shear, Microhardness, and microstructure tests) will be used with three values. The maximum shear force used to weld metals that are not comparable is (1140N for t 0.7 mm). Using DOE, this value has been optimized to get (1240N). The shear force at the least was (250N in t 0.5 mm). Shear force was generally raised by increasing the welding current and sample thickness, whereas shear force was decreased by increasing the electrode force, squeezing time, and welding time. The center of the nugget zone has the highest hardness value, per Microhardness tests. Prior to reaching constant values outside of the nugget zone, it decreases a little. Until it achieves constant values outside of the nugget zone, it fluctuates significantly. Aside from that In addition, The NZ and HAZ of AISI 1010 include ferrite and bainite [20]. Tantalum was employed as an interlayer in laser welding to enhance the quality of the weld between nickel-titanium (NiTi) and AISI 316L stainless steel wires, according to

C. H. Ng et al. A Ta interlayer's presence and thickness had an impact on the chemical make-up, microstructure, and mechanical properties of laser-welded NiTi-316 SS joints. Brittle intermetallic compounds were less abundant in the weld joint as Ta was increased (TiFe4, TiCr2, TiFe). Boosted the production of TaCr2 and Ni3Ta. The microstructural analysis of both materials showed that from the weld boundary to the weld centerline, the solidification mode shifted from planar to dendritic. In comparison to laser-welded NiTi-316 SS (134MPa) without a Ta interlayer, the tensile stress and strain of the welded joints at fracture increased to 251MPa by adding a 50m Ta interlayer. By adding Ta to the weld joint extensively (> 50 m), the mechanical properties were weakened.

Consequently, a sufficient amount of Ta is required [21].2015, M. Sun, S. T. Niknejad, et al RSW was employed in the current work to examine the welding of different 2mm-thick alloys of magnesium (AA5754) and aluminum (AZ31). Introduced between the two base metals, a to stop the development of Al-Mg intermetallic complexes, a coating of pure nickel was added. Microstructural investigations were used to determine the Mg/Ni and Al/Ni interfaces using SEM/EDS and XRD techniques. effectively put an end Intermetallic layer that were continuous and a micron thick were created by the Al-Mg reaction at the numerous contacts (through Al- Ni and Mg-Ni reactions). In comparison to a joint without an interlayer, the results of the mechanical testing revealed a considerable improvement in joint strength. The nugget diameter and strength are improved by increasing the welding current up to 36000A.joint toughness However, the Mg/Ni has defected such cracks and porosity. [22].In 2016, M. R. Arghavani and colleagues examined how the zinc layer affected the microstructure and mechanical capabilities of RSW of aluminum to galvanized (GS-Al joint) and low carbon steel (PS-Al joint).In spite of the fact that the nugget's "volume" at the PS-Al connection was larger, the nugget's "diameters" at the PS-Al and GS-Al connections were almost the same size as the pushed molten zinc layer that was pushed outward from the nugget. Al-Fe intermetallic layer thickness was reduced by the melting and evaporation of zinc coating. Zinc also reduced the tension brought on by the fixture. When welding currents are higher than 12000A, GS-Al welds have A higher fracture load than PS-Al joints, which contrasts with the fact that PS-Al joints were stronger than GS-Al joints when welding currents were lower than 12000A.

Reduced welding currents above 12000A. Low welding current for GS-Al welds resulted in an incomplete joined. However, High welding currents improved the mechanical properties of GS-Al junctions by reducing produced tensile stress and forming an intermetallic layer with a thickness below the critical value (5.mm) [23].In this study by I. Ibrahim et al. (2016), 2 mm thick stainless steel sheets were bonded by RSW to sheets of aluminum alloy with an interlayer made of an Al-Mg alloy. The melting point of the interlayer is lower than that of the alloy of aluminum. As a result, interlayer molten at a lower temperature was injected into the area between the two sheets, resulting in a successful connecting. Tensile shear fatigue experiments were carried out to investigate the fatigue fracture process and measure fatigue strength. Al/steel dissimilar welds with interlayers displayed a larger tensile shear force than those without interlayers, with an average value of 8400N under the same welding parameters.

Along the Interface, a thin and homogeneous IMC layer with a thickness of 2mm was produced, resulting in a strong bond. Magnesium diffused into the Al sheet from the Al-Mg interlayer and was found 5 mm from the interface, high loads caused plug type fracture, medium loads caused shear fracture through the nugget, and low loads caused full-thickness fatigue crack development in the Al sheet. RSW Al/steel dissimilar welds had higher tensile shear and fatigue strengths than FSSW [24]. The structure, characteristics, and performance relationships of the RSW of Al/Al alloys, Al alloys/steel, Al/Mg alloys, and Al/Ti alloys were the main subjects of this work by S. M. Manladan et al. (2016). Additionally, the primary metallurgical flaws in Al spot welds, electrode deterioration, weld bonding, and the effect of welding conditions on joint quality. The RSW of Al alloys results in rapid electrode tip wear and uneven weld quality due to the high contact resistance and required high welding current, which is typically two to three times that of steel. According to studies, removing oxide buildup, boosting electrode force, and using a low-current pre-heating all considerably lower contact resistance and improve joint quality. For Al/steel dissimilar RSW, the use of optimized electrode morphology, the technique of RSW with cover plates, and the use of interlayers such as Al-Mg, AlSi12, and AlCu28 alloys to prevent the formation of brittle intermetallic compounds (IMC) and enhance the joint quality. It was also shown that interlayers made of pure Ni, Au-coated Ni, Sn-coated steel, and Zn-coated steel may be used to stop the formation of brittle IMCs during the RSW of Al/Mg alloys.

The weldability of Al/Ti dissimilar alloys is also improved by the RSW processes with cover plates and RSW conducted with electromagnetic stirring [25].S. S. Rao, et al. 2017, investigated were how shear-tensile strength, nugget diameter, and failure mechanism were affected by resistance spot welding process parameters. The range of appropriate nugget formation parameters was established by taking into account the variation in dynamic contact resistance with the change in RSW parameters such as weld current, weld time, and electrode force. The ideal resistance spot welding conditions were found to be 8000A weld current, 0.25s weld duration, and 3500N electrode force for galvanized high-strength steel sheets with a thickness of 1.6 mm.The study also analyzed the transition from one failure mode to another due to varying process parameters. The shear–tensile strength of a weld improves as weld current increases. With the increase in heat input during welding, the shear–tensile strength increases within the adequate weld range. As the nugget diameter increases, the failure mode transitions from interfacial failure to pull–out failure.

The reported failure mechanism for interfacial failure is brittle at the majority of fracture locations and shear-ductile for pull-out failure [26]. J. Chen et al. 2017, the microstructure and mechanical properties of a resistance spot welding connection between DP 600 ultra-high strength steel and A5052 aluminum alloy with a 50 m Zn slice interlayer. A columnar crystal with a unique pattern was found to be the fusion zone (FZ) grain of A5052. The heat-affected zone (HAZ) and FZ microstructures of DP 600 were both composed of ferrite-fine martensite. Fe2Al5, Fe4Al13, and Fe11Zn40 made up the intermetallic compound (IMC) in the contact area. The primary IMC was set up in a spiral pattern, which improved its mechanical properties. The tensile-shear force achieved a maximum value (7060N), which was 28% higher than in the absence of the Zn slice interlayer. The fracture was preceded by clear plastic deformation and showed plug failure (PF) mode as opposed to interfacial failure (IF) mode. The fracture was discovered to have a plug failure (PF) mode as opposed to an interfacial failure (IF) mode, and it was clearly caused by plastic deformation. On the fracture surface, many dimples were discovered [27]. L. Shi, J. Kang, et al. 2019. Using a proprietary welding technique, General Motors Company produced resistance spot welds. It was made of low carbon steel that was 0.9mm thick and aluminum that was 0.8mm thick. It had three different coatings on it: hot-dipped galvanized (HDG), Zn-Ni coating, and Zn-Ni coating with a passive layer made of trivalent clear chromate (Zn-Ni-Cr). In contrast to welding to HDG coated steel, adding Ni or Cr to the Zn coating results in a distinctive microstructure by increasing porosity, producing agglomerated particles around the weld nuggets, removing the oxide film defect, and delaying the formation of the Fe2Al5 layer. The RSW-HDG samples improved the tensile strength for the coach-peel and tensile-shear specimens because they had the largest nugget size and the least amount of thinning. According to the structural stress concept employed [28], the shorter fatigue life of RSW-ZnNi and RSW-ZnNiCr relative to RSW-HDG was caused by defects around the weld nugget perimeter and a lower weld nugget diameter. The goal of Kumar, et al2020.'s study is to examine the mechanical characteristics, hardness, and microstructure of RSW's 304 Stainless steel. Find out how the welding current, welding time, electrode pressure, and holding time affected the nugget diameter, tensile strength, micro hardness, and microstructure of the joints during RSW of 1 mm-thick 304 stainless steel plates. 30 x 100 mm specimens with 30 mm overlaps were created using an RSW machine. The specimen was put through a tensile test, and the Vickers' tester was used to gauge the specimens' micro hardness.

To examine the important inputs for each output, Taguchi was used. The specimen's tensile strength has been discovered to be affected by the current intensity, weld time, and nugget diameter. Since an increase in either of these factors causes a rise in micro hardness, electrode pressure and holding duration have a considerable impact on micro hardness [29].

M.H.SAR, A.A.F, et al. 2020 conducted this study to measure the effects of welding current and time on the nugget size and tensile shear strength of the weldment, which revealed the characteristics of the weld joint. Resistance spot welding was used in two phases with and without filler materials to join 1.5mm thick sheets of carbon steel and the aluminum alloy A6061. Due to their strong affinity for welded metals and thus superior wettability, copper and zinc were utilized as filler materials. The results demonstrate that welding current gradually changes nugget size and tensile shear strength; welding current influences the joint's strength more significantly than welding time. Without filler, it is impractical to do steel-to-aluminum-alloy resistance spot welding, and the resulting structure has very little strength in comparison to the filler. Additionally, the results demonstrate that copper filler enhances weldments' strength more than zinc filler, which copper's greater affinity for both metals May explain the junction with the highest tensile shear strength for copper filler is achieved at 15000A welding current, whereas the joint with the lowest tensile shear strength is achieved at 13000A [30].

In order to achieve resistance spot welding of comparable AISI-1008 steel plates and various AISI-1008 and Al 1100 alloy welds, T. Das and J. Paul utilized a graphene Nano platelets interlayer in 2020. The strength of the RSW weld is influenced by the welding current and time used. A decrease in brittleness and the addition of a graphene interlayer, for both same and dissimilar joints, respectively, improved some measures by 49% and 124%. Microstructural characterization using optical, SEM, XRD, TEM and spectroscopy. Microhardness examinations of the weld nugget cross-section in both instances revealed an enhanced hardness in the fused zone. The increase in hardness was a result of intermetallic formation with a high AlFe content at the interfaces of various joints. In the interfacial zone of different weld joints, IMC formation was also observed. Elemental carbon peaks and a low-intensity Fe_2C peak were visible in identical weld joints' XRD spectra. The nugget's size changed as the welding current rose. Inspected and researched cracked surfaces Brittle fractures and shear dimples were the most common [31].

2020, P. D. Enrique et al. In this instance, a dissimilar resistance spot welding of an aluminum alloy (AA5052) to a galvanized dual phase steel is accomplished using an electro spark deposition AA4043 interlayer (GI DP600). This manufacturing process might make it easier to use aluminum alloys more frequently in applications for lightening vehicles. Interlayers are added using electro spark deposition (ESD) in order to resistance spot weld an AA5052 sheet to a DP600 sheet that has been galvanized. When an AA4043 interlayer is used, the tensile lap-shear strength of the weld increases by at least 30%, which may be due to a thinner iron-aluminum intermetallic at the faying surfaces, according to a study of weld strength with and without the interlayer. The initial weld and full weld strength of an interlayer were also strengthened. Paul, et al. 2020, Performed a comprehensive study of explosively welded (tantalum with 304

L stainless steel) copper M1E interfacial layer to analyze the mechanical and microstructural properties of the interlayer. Microstructures were examined using scanning (SEM). In contrast, bending tests and Microhardness measurements were performed to identify mechanical characteristics. The interfacial layers are prone to partial recrystallization because they are subject to considerable plastic deformation. Investigations at the tiny level revealed that connected sheets are present in the solid melt zones' (nano micro) crystal phases, which have a variety of chemical compositions. The molten zones are mostly made up of a mixture of Cu and Ta particles of varied sizes close to the Ta/Cu contact. In contrast, nanoparticle-sized compounds based on elements of both nearby linked sheets are present in the molten zones close to the Cu/SS contact. The Microhardness of the solidified melt regions produced close to both interfaces is significantly lower than that found inside the layers of strain-hardened stainless steel [33].

PART 3

THEORETICAL SIDE

3.1. RESISTANCE WELDING

By using pressure, heat, and two or more metal components, resistance welding is the process of joining them. The resistance that the welding materials present to an electrical current's flow is what produces the welding heat in the components to be welded. Without the use of extraneous components like fluxes, filler rods, etc., the metals are joined together during this procedure, which prevents the metallography of the weld from being complicated by their addition. By using mechanical force on the heated parts to generate the weld, resistance welding differs from fusion welding. As a result of the force, the grain structure is refined. It is quick and simple to generate good welds. A newcomer could assume the method is straightforward or more widely applicable because of the same traits. Is shown in figure 3.1. It should be observed from this scheme that resistance welding may be divided into two primary classifications based on the process of bonding the pieces [13].

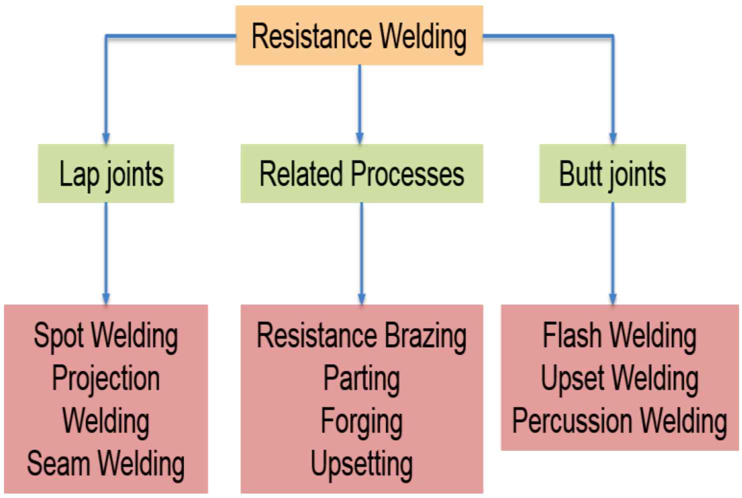


Figure 3.1. Resistance welding processes.

3.1.1. Lap joining

This is a method where the electrodes conduct the welding current and apply the welding force at the same time. This method includes not only any kind of lap joint but also any joint in sheets, plates, rods, and bars in which the weld is not made end-to-end or edge-to-edge [3]. Shown in figure 3.2.

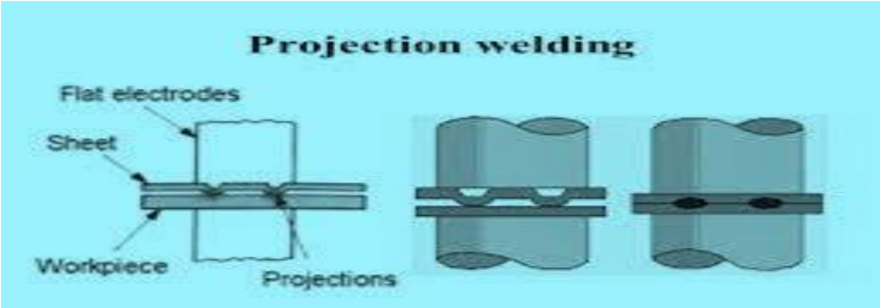


Figure 3.2. Projection welding process.

3.1.2. Spot Welding

Spot welding is the most widely used example of lap joining, and it is accomplished with shaped electrodes held essentially stationary while the weld is made. Shown in figure 3.3.

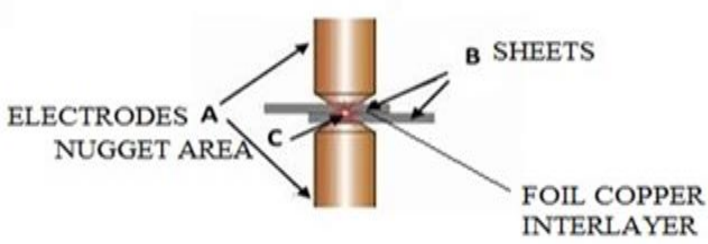


Figure 3.3. Spot welding process**.**

3.1.3. Projection Welding

Projection welding by forming projections in one or both workpieces, the current path is localized at the projections. Permits the use of flat electrodes, thus producing projection welds. Shown in figure 3.4.

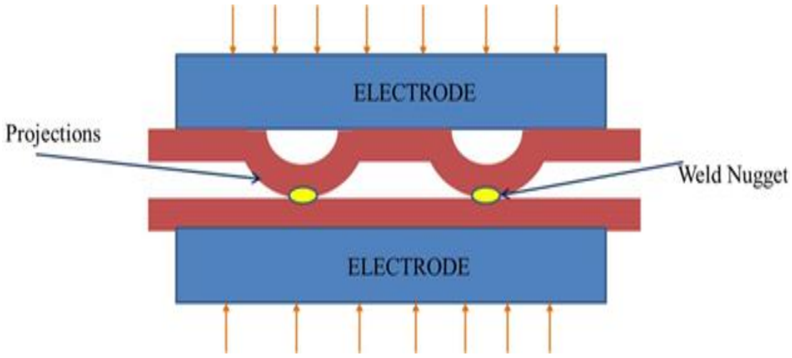


Figure 3.4. Projection welding process.

3.1.4. Pulsation Welding

Pulsation Welding (normally a spot or projection weld) is made with a single application or impulse of current. However, if the current flow is interrupted and reapplied one or more times without the release of electrode force, a pulsation weld results. Shown in figure 3.5.

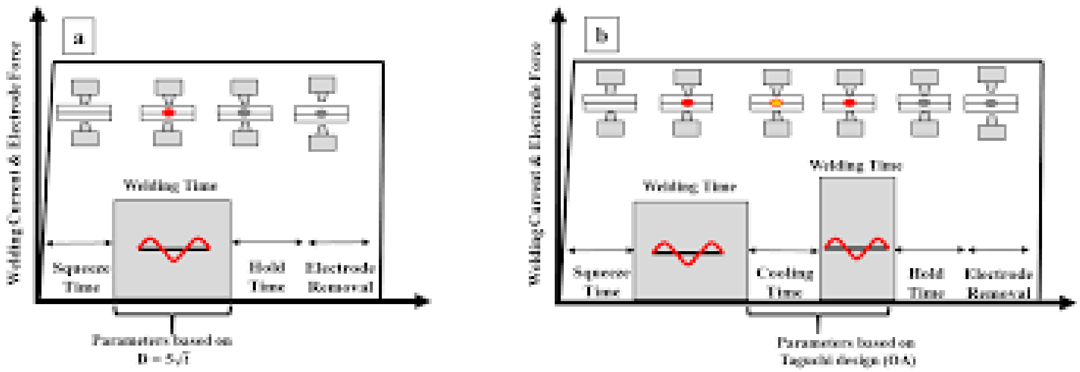


Figure 3.5. Pulsation Welding process.

3.1.5. Seam Welding

Seam welding is quite similar to spot welding, but the electrodes revolve and are actually in motion while the weld is being made. Shown in figure 3.6.

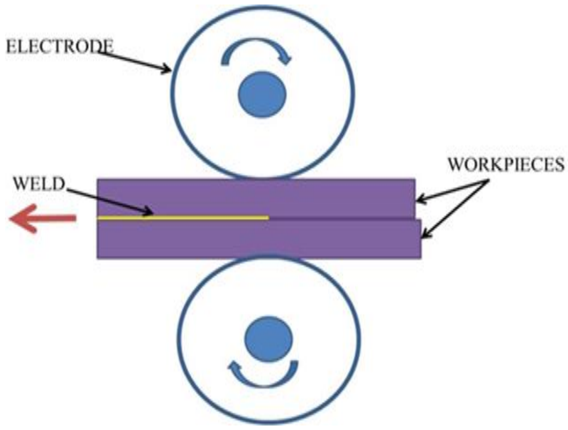


Figure 3.6. Seam welding process.

3.1.6. Roll Spot Welding

The resulting joint is called a roll spot weld, if the interrupted electric current is used regardless of whether the wheels rotate continuously or intermittently and if the timing suitable is such that the welds do not overlap. Figure 3.7.

Figure 3.7. Roll spot welding process.

3.1.7. Butt Joining

Butt joining is the method in which the weld takes place on the ends of bars or the edges of sheets or plates. The electrodes deliver current to the two workpieces and may or may not be used to transmit the upset force. If they are utilized to transfer the upset force, it is accomplished through the gripping action of the electrodes or clamp jaws; otherwise, upset force is given by further used clamp members or backup members [3]. Shown in figure 3.8.

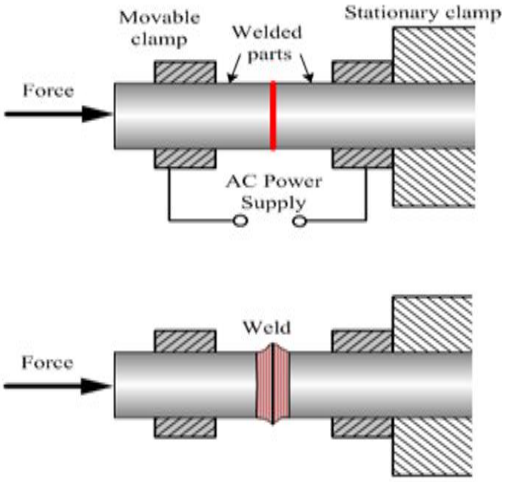


Figure 3.8. Butt welding process.

3.1.8. Flash Welding

When two rods or bars are clamped end-to-end, they make electrical contact, which causes flashing when current is applied. As the flashing continues, the metal is burned away, necessitating the movement of one piece toward the other to keep the flashing process going. As this happens, the two parts' ends reach welding temperature. At this point, an upset force is applied to finish the weld depicted in figure 3.9.

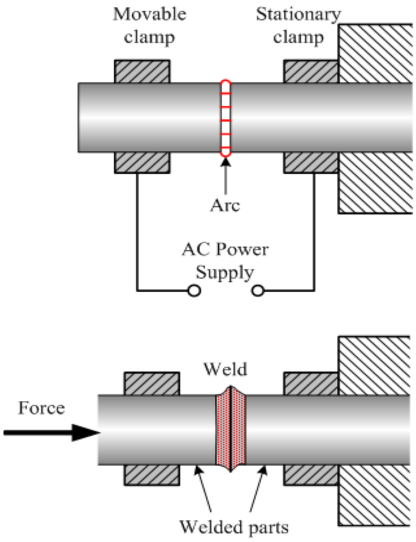


Figure 3.9. Flash welding process.

3.1.9. Upset Welding

If two rods or bars are clamped end to end in a copper electrode, held in contact with one another as welding current and force are applied, the resultant joint is an upset weld. Shown in figure 3.10.

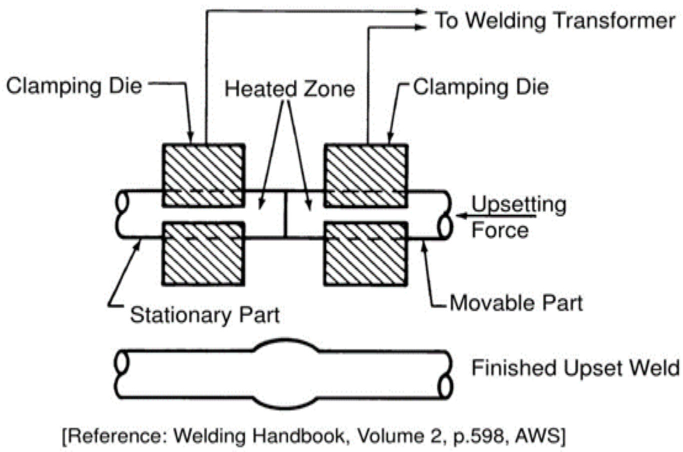


Figure 3.10. Upset welding process.

3.1.10. Percussion Welding

Despite the fact that the resistance of the workpieces doesn't generate any heat, it is often categorized as a resistance welding technique. The two components act as spark-gap electrodes, and an arc heated by a quick electrical discharge is used to weld them together. Percussion-like application of force during or immediately following an electrical discharge during this process, coalescence is produced simultaneously over the entire region of abutting surfaces. As shown in figure 3.11.

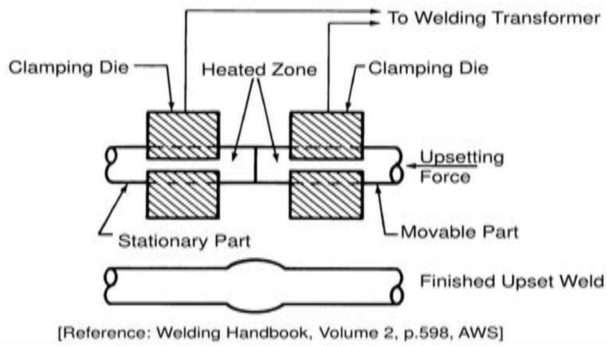


Figure 3.11. Percussion welding process

3.2. RESISTANCE SPOT WELDING

It is frequently referred to as a resistance welding technique even though the resistance of the workpieces doesn't produce any heat. The two parts serve as spark-gap electrodes for a welding arc that is heated by a brief electrical discharge. Coalescence is produced concurrently throughout the whole region of abutting surfaces during this process, which applies force in a percussion-like manner during or soon after an electrical discharge.

The squeeze, weld, hold, and off steps' timings are all regulated steps. One of the early electric welding methods still in use today is resistance welding. Figure illustrates the pressure welding technique of resistance spot welding Figure 3.12. The weld is produced by combining time, pressure, and heat. During resistance welding, the material's resistance to current flow causes localized heating of the component. The pressure exerted by the tongs and electrode tips through which the current travels keeps the workpieces together before, during, and after the welding current time cycle. The cross-sectional area of the welding tip contact surfaces, the thickness, and the type of material all have an impact on how long current flows in the joint [47] [48]. By passing electrical current through the workpieces positioned between electrodes for a predetermined amount of time, a resistance spot weld is produced.

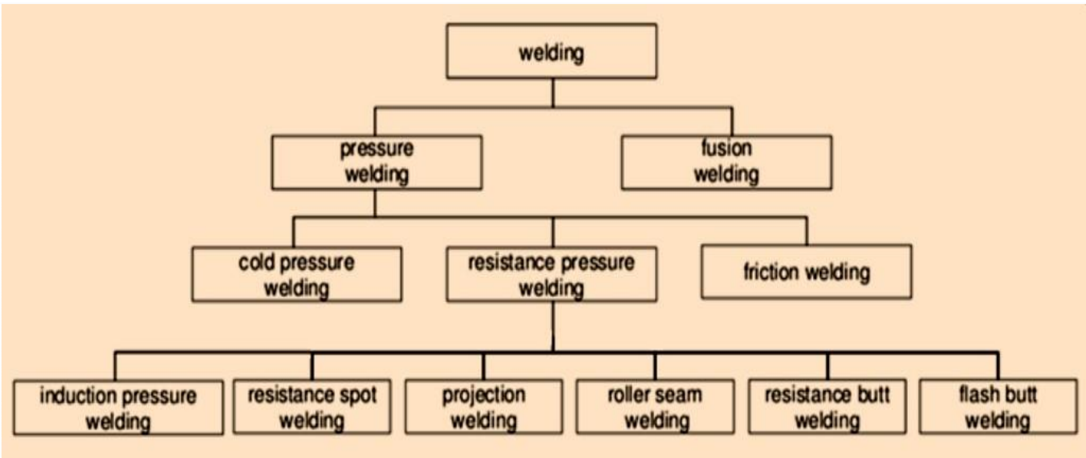


Figure 3.12. Classification of the welding methods [16].

A complicated interplay between the physical and metallurgical characteristics of the material being welded and the electrical/mechanical phenomena of the welding process or welding machine is resistance spot welding. [50]. By using copper alloy electrodes to apply the welding current and force to the workpieces, the necessary current density and pressure are created at the welding site. [51] [52]. A weld is a focused coalescence of metal that has been heated to the proper temperature. This term is all-inclusive and does not take into account the method or caliber of the weld. The molten metal must first liquefy before solidifying once more in order for fusion welding to be accomplished without the use of force.

As opposed to a resistance weld, which is formed under minimal stress and maintained until the weld zone hardens, cast structure forms. In comparison to the cast structure present in fusion welds, the resulting grain structure is of a higher order. Shows a figure 3.13. A condensed form is A. An illustration of the absolute minimal required gear. The quantity (3.13). B, a schematic showing the welding process. Both or any of the electrode holders have a force mechanism attached that can move the electrodes. The holders are attached to a force system that allows for both forward and backward movement [3].

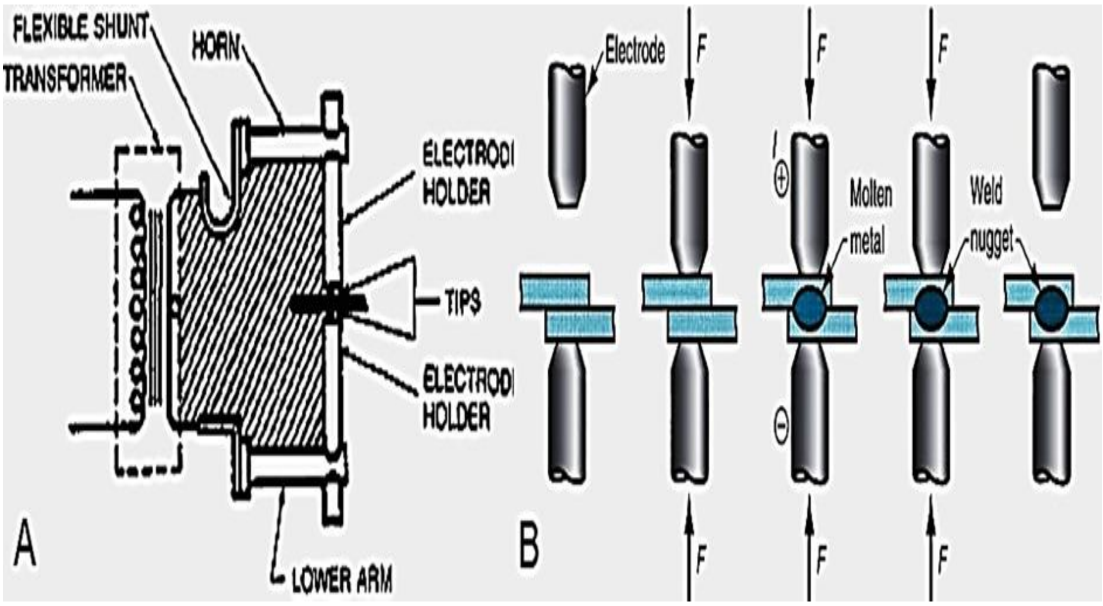


Figure 3.13. A Typical spot-welding secondary circuit [3] and B Resistance spot welding process [53].

3.2.1. Machine of Resistance Spot Welding

Resistance welding machines can be divided broadly into three groups: standard, special and miscellaneous. Standard machines meet the electrical and mechanical capabilities specified in standards written by the Resistance Welder Manufacturers' Association (RWMA), depending on their physical sizes. The rocker arm type is the most versatile and commonly used stationary machine, which is generally made for foot or air operation. Both machines have a fabricated steel frame, complete with a welding transformer and tap switch. Typical foot-operated rocker arm spot machine. The upper rocker arm assembly, which includes the horn, is pivoted at the top front of the frame. The lower horn holder is usually mounted on a front vertical column by means of which the assembly can be changed for job clearance. The throat gap is the overall area inside the secondary loop with the electrodes in the closed position. The throat depth is the horizontal distance between the electrodes and the nearest machine obstruction.

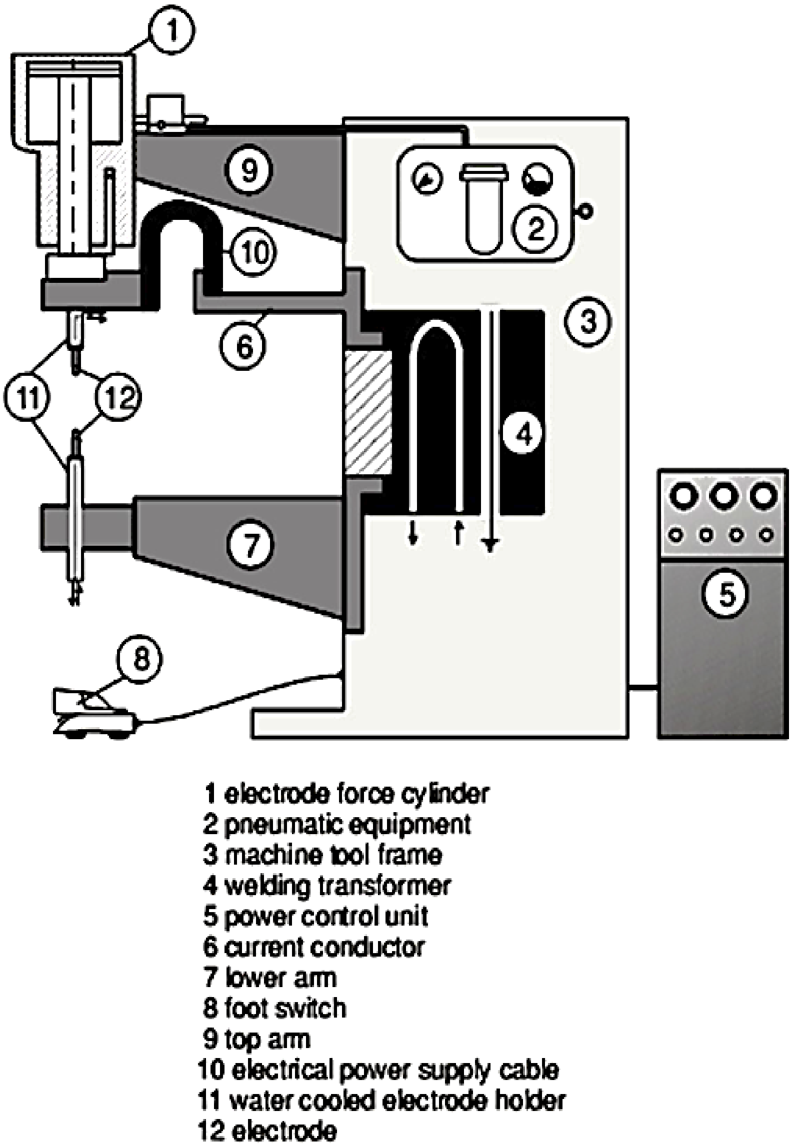


Figure 3.14. Schematic assembly of spot-welding machine.

3.2.2. Spot Welding Electrodes

During the resistance welding process, electrodes are brought into contact with the workpieces in order to transport electricity and provide electrode force. Resistance spot welding electrodes are roughly divided into the following groups: (tips or caps). In all resistance welding procedures, resistance welding electrodes carry out the following three essential tasks; by transporting the welding current, they function. The best electrode may be selected based on an electrode's electrical and thermal conductivity as well as its own resistance and the resistance at the point where it meets the work surface [3].

It has a mechanical purpose, to start. They have the necessary electrode force or pressure to produce a good weld. The load placed on the welding electrodes is force (pounds). The force is multiplied by the electrode's contact surface area to get pressure (psi). We'll use the more precise technical term, force. The electrodes are frequently subjected to significant strains during the welding process. They must endure these stresses at elevated temperatures without unduly deforming. This is so that the current can be conducted and localized in a certain location in order to function. The heated work parts are forged together by the transmitted electrode force, which also focuses the welding current in a small area.

3.2.3. Spot Welding Electrodes

They support the process of removing heat from the weld zone. The electrodes' thermal conductivity ought to be higher than the metals being welded together. The electrical and thermal conductivities of various metals are often inversely proportional. The electrodes transfer heat away from the material's outer surfaces because of their superior thermal characteristics. When various metals are welded, which is necessary or desired to achieve thermal equilibrium, the function may assume significant importance. In these situations, it may be best to choose an electrode with a lower thermal conductivity to avoid an excessively quick heat dissipation from one component of a different combination.

Any resistance welding process, simple or complex, depends on the electrodes' appropriate operation to be successful Any resistance welding procedure, no matter how straightforward or intricate, depends on the proper operation of the electrodes. The welding equipment's electrodes are made to conduct current, withstand strong forces, maintain a constant contact area, and ensure the right relationship between current, time, and force. Care should be made in the selection and design of electrodes when satisfactory welds are required. For this reason, even the best electrodes cannot produce high-quality welds unless the welding equipment properly controls the required welding current, weld time, and force.

3.2.4. Electrode Material

Electrode mechanical and physical characteristics vary depending on the application. The only electrode material available during the early stages of resistance welding's development was pure copper, but as welding currents and forces rose, it became clear that better electrode materials were needed to keep up with the advancement. This need sparked the continued development of a number of electrode materials intended to improve upon the drawbacks of pure copper.

With greater compressive strength and wear resistance, electrode materials now have higher annealing or softening temperatures than pure copper, however conductivity has unavoidably suffered [3]. For welding various metals, RWMA advises using different electrode materials. The analysis of electrode alloy, electrode hardness, strength, and conductivity are identified by these numerous categories and classes [2]. The three groups of electrode materials are as follows:

Alloys with a copper base are in Group A. Refractory Metals and Refractory compose Group B. Group C Specialty Materials
Group A base alloys for copper

RWMA Category 1.
Class 1 material is advised for welding aluminum alloys, magnesium alloys, some coated materials, brass, bronze, and low carbon steel coated with tin, chromium, or zinc due to its high electrical and thermal conductivity and inability to be heated. These electrode materials are more resistant to deformation at significantly greater temperatures than hardened pure copper [3] [48] [54] and have good mechanical qualities.

RWMA Category 2.
Compared to Class 1 materials, Class 2 materials are more durable and have a somewhat lower conductivity. This electrode material can be used to spot and seam weld the majority of materials. The characteristics of these electrode materials are a result of their copper-based alloys [3] [54].

RWMA Class 3.

Class 3 material is suitable for projection welding electrodes, flash welding electrodes, and upset welding electrodes because it has better mechanical qualities than Class 2 material. Class 3 material is recommended for structural welding current that is operating under extremely high stress. It is advised for spot welding and seam welding high electrical resistance steels, such as stainless steel. These electrode materials should be used in hot conditions [3].

RWMA Class 4

Compared to Class 3 materials, RWMA Class 4 materials are significantly stronger and less conductive. For flash, upset, and projection welding applications, it is advisable to use it as an electrode material when stresses are exceptionally high, wear is severe, but heating is not extreme. It is employed in the production of flash welding electrodes and seam welding bushings. These electrode materials need to be used in heated environments. [3].

RWMA Class 5

Consists of aluminum and copper. It is suggested to utilize it since it is a low-cost, high strength backing material. Flash welding electrodes, secondary circuit welder arms, and other current-carrying fixtures are typical examples of applications where high strength, wear resistance, and nonmagnetic properties are required [3].

Group B materials are not solid solution alloys but pressed and sintered powered materials. The Group B electrode materials are mixtures of copper and tungsten. They are recommended for applications where extremely high deformation resistance is more important than electrical conductivity. Their mechanical characteristics and conductivities depend on the proportions of copper and tungsten used. When copper-based alloys would quickly deteriorate due to high heat, prolonged welding, or high pressure, these electrode materials are used [3] [54].

RWMA Class 10

When reasonably high electrical and thermal conductivity is necessary, Class 10 material is advised as a face material or insert material for projection welding electrodes as well as flash and upset welding electrode.

RWMA Class 11

Class 11 material is more durable and has a lower conductivity than Class 10 material. It is advised as a face material or insert material for flash and upset welding electrodes as well as all-purpose projection welding electrodes for moderate welding pressures. Additionally, bearing inserts and upheaval facings can be seam-welded with it. High-resistance steels like stainless steel should be spot welded.

RWMA Class 12

Materials in Class 12 are more durable and less conductive than those in Class 11 materials. It is specifically indicated for heavy-duty electrode facings and projection welding electrodes in upsetting applications. It is suitable as a material for an electrically disruptive electrode.

RWMA Class 13

The conductivity of Class 13 and Class 14 materials is lower than that of Class 12 materials. Class 13 has a very low degree of elasticity and is extremely hard.

RWMA Class 14

Less difficult than Class 13. It can be drilled or machined. When resistivity brazing or welding non-ferrous metals with a high electrical conductivity, both are used. Joining copper and brass wires across and connecting copper wire braid to brass and bronze terminals are two common applications. Typically, this kind of activity necessitates particular settings. This category includes all substances that are neither copper alloys, refractory metals, nor refractory metal composites. As a result, they cannot be classed as Group A or B materials.

RWMA Category 20. Class 20 material is more mechanically robust than Class 2 and has equivalent conductivity. For usage on coated materials, it is frequently advised.

3.2.5. Electrode Design

Numerous factors, including specific applications and climatic conditions, have influenced the general design of electrodes. Straight, threaded, and tapered are the three typical shank designs [3]: Tapered designs are most frequently used since they are so easy to install and remove. Applications with consistent height adjustment and high stresses are threaded. Straight is used to make positioning easier. An electrode design is made up of four structural parts: the face, the body, the way it is attached to the electrode holder, and the cooling system. Direct contact is made between the face of a spot-welding electrode and the workpiece either above or below the fusing point.

The electrode face's proportions are affected by the assembly's size, shape, and desired weld nugget size, as well as the thickness of the work metal. RWMA [48] [54] has set the electrode face's shape, as seen in Fig 3.15.

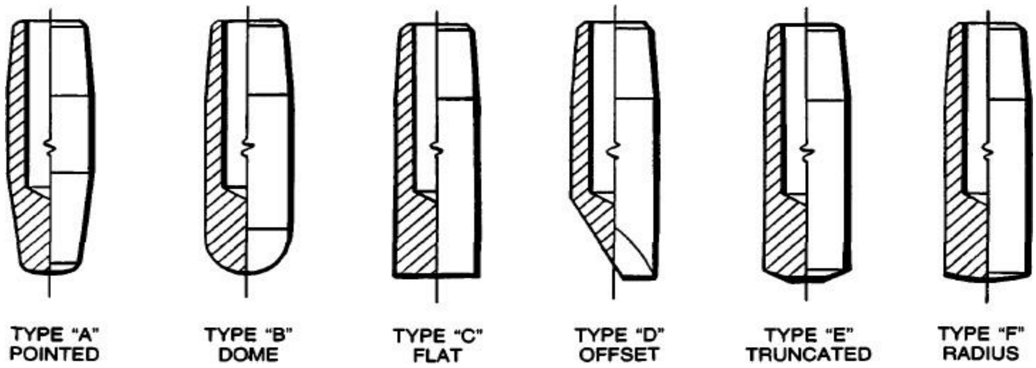


Figure 3.15. Standard spot-welding electrode nose geometries [3].

Figure 3.15 displays six common electrode nose configurations. Pointed A, a dome in B, a flat C, an offset D, a truncated E, and a rounded F (Radius). The most popular varieties for general welding applications are Types A, B, and E. When only limited surface marking is needed, Types C and F are utilized. Projective welding is yet another application for type C. To weld close to an inverted flange or corner, Type D welding is necessary [3]. Large-diameter electrode faces may overheat due to insufficient electrode pressure, especially when welding current is high. This might result in voids, blowholes, or an unattractive surface finish. Figure 3.16. In addition to being displayed are RWMA alloy classes and a traditional straight description.

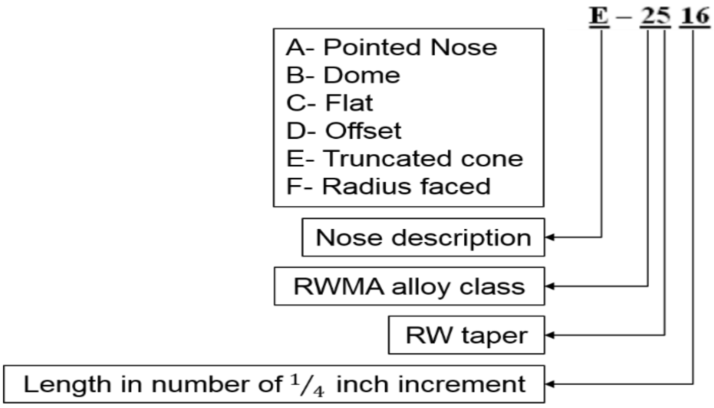


Figure 3.16. Spot welding electrode's tips description [3].

3.2.6. Electrode Defect

During welding, pressure and heat alter the electrode's profile. Deformation-induced lower current density can lead to shoddy spot welding. When welding coated material, electrode wear, which may cause weld ejection on the surface, might occur more quickly because the resistance increases on the surface as a result of oxidation and alloying. Additionally, the electrodes enlarge in diameter when exposed to higher compressive forces at high temperatures. The diameter of the weld nugget should be slightly smaller than the diameter of the electrode contact area in order to produce a solid welding connection and maintain the proper current density. Due to the current density, a tip diameter increases of more than 5% may have an effect on the weld quality. Electrode deposition on workpieces affects electrode life, corrosion resistance, and weld strength in addition to giving them a poor appearance [48].

3.3. HEAT GENERATION

When current flows through a conductor, heat is produced because of the conductor's electrical resistance to current flow. Four variables affect the amount of heat produced [2] [44] [47] [54]:

- What is the current flow rate?
- The resistance of the conductor.
- During periods of current flow.
- The portion of the electrode tip that contacts the work.

It is possible to state the fundamental equation (3.1) for the generation of heat [47]:

$$Q = I\ 2RT \tag{3.1}$$

H equals the heat joules.

I2 is equal to weld current squared ampere.

R = Ohms of Resistance

The components that need to be welded are a part of the circuit's secondary section, which is made up of a number of resistances in a resistance spot welding setup. The circuit's performance is impacted by the electrical resistance's total extra value.

The basic equation (3.1) for the generation of heat can be written as follows [47]:

The following formula is completed when the time component is added (3.2) [2] [44]:

$$H = I\ 2\ R\ T \tag{3.2}$$

Where

H = heat generations	Joules
I = current	Ampere
R = resistance	Ohms
T = time of current Flow	

According to the equation, the amount of heat produced is inversely proportional to the square of the welding current, resistance, and time. The whole heat produced, along with some heat lost to neighboring metal, is used to build the weld. Conduction and radiation are the two main ways that heat is lost from a system.

Radiation loss to the atmosphere is extremely little. Conduction losses affect the electrodes and the nearby base metal. These losses and temperature variations are well related [54].

3.4. HEAT BALANCE

Heat balance refers to the situation in which the components that need to fuse are subjected to equal heat and pressure in the fusion zone. Heat balance is not particularly problematic when the welding materials are of the same type and thickness. The heat is also automatically balanced when the electrode tips are the same width and type. Heat balance could be affected by [47] [54]: Relative geometry of the part *at* the joint.

- The material to be joined relative electrical and thermal conductivities.
- The electrode's thermal and electrical conductivities.
- The electrode's geometry.

Pressure and heat are evenly distributed across the elements of the fusion zone when they are in a condition of thermal equilibrium. Heat balance is not a major issue when the materials to be welded are the same kind and thickness.
When the electrode tips are the same diameter and kind, the heat is also automatically balanced. [47] [54]. Thickness may have an impact on the heat balance. The part's relative geometry at the junction.
When the weldment consists of copper and steel or other materials with different thermal characteristics, a faulty weld may occur for a number of reasons.

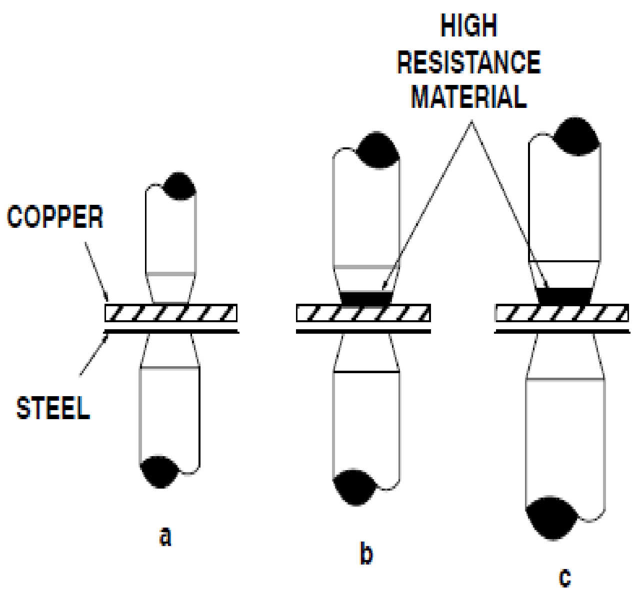


Figure 3.17. Techniques for obtaining heat balance [47].

Figure displays three possible solutions to the problem (3.17). Figure 3.17 (a) shows how to alter the current density in various materials to equalize the fusion properties by utilizing a lower electrode tip area for the junction's copper side. Figure 3.17) (b) shows how to employ an electrode tip with a high electrical resistance material, like tungsten or molybdenum, at the contact point. As a result, a fusion zone similar to that of steel emerges in the copper. A synthesis of the two strategies is shown in Figure 3.17) (c) [47].

3.5. WELD PARAMETERS

Resistance spot welding is the consequence of a wide range of intricate input data that can significantly affect the weld quality. Resistance spot welding is a technique that applies pressure to the sheets that are being welded while using a strong current that is passed briefly through the area where two metals meet [55]. The three most crucial welding parameters in RSW are electrode force, current intensity, and time. Resistance welding procedures are typically automatic, thus all of the process variables are pre-set and kept constant. Only by properly balancing welding current intensity versus welding time with the application of pressure can the fusion zone diameter be determined [56] [17].

3.5.1. Weld Current

Since heat generation is proportional to the square of the applied current, as indicated in equation, the welding current is the most crucial factor in resistance spot welding that determines heat generation (3.1). The single-phase alternating current (AC), which is still the most common type of welding current used in production, the three-phase direct current (DC) systems that can be used by rectifying single-phase or multi-phase alternating current into DC, the condensate discharge (CD), and the recently developed middle frequency inverter DC are some common types of welding current used in resistance welding. Here, an inadequate weld current will result in an incorrectly sized nugget or no bonding at all, while an excessive weld current will result in ejection. The molten substance is ejected in large amounts.

3.5.2. Weld Time

The welding time and heat generation are directly proportional. Time is a crucial factor. Thousands of amps are typically required to create the spot weld. Such amperage values will quickly produce heat when passing through a reasonably high resistance. It is essential to have precise control over the time the current is flowing in order to create high-quality resistance spot welds. The weld time is measured in milliseconds for DC systems while it is measured in 60 cycles for AC systems (60 cycles = 1 second, in a 50 Hz. power system 1 second = 50 cycles) [47]. According to the material, thickness, and coating circumstances, each step's duration should be determined [59].

The heat produced is directly correlated with the welding time. Time is an important factor. Spot welding is typically performed at several thousand amps. Such amperage values will quickly generate heat when they flow through a relatively high resistance. To make high-quality resistance spot welds, the current flow time must be carefully regulated. Weld periods in DC systems are represented in terms of milliseconds, but weld times in AC systems are defined in terms of 60 cycles (60 cycles = 1 second, or 50 cycles in a 50 Hz power system) [47]. The length of each stage should be decided by the material, coating conditions, and thickness [59].

$$MWS = 4 \sqrt{t} \qquad (3.3)$$

Where:

MWS : is minimum weld-nugget size, mm.
t : is the average sheet thickness, mm.

The management of time is crucial. The melting point of the base metal in the joint may be exceeded if the time element is too long. Gas porosity could result in a poor weld as a result. Additionally, the weld may become weaker if molten metal is expelled from the weld pool, which would reduce the joint's cross-section. A shorter weld time reduces the chance of excessive heat transfer in the base metal, minimizes component distortion, and significantly reduces the size of the heat-affected zone surrounding the weld nugget.

The necessary current is abnormally high if the time is very short. The weld zone's heat distribution could be undesirable with this high current/short time combination, leading to significant surface damage.

3.5.3. Spot Welding Cycles

- As indicated below [47], the spot-welding cycle is divided into four key time periods:
- The pause between applying pressure and welding is known as the squeeze time. Or the period of time between the beginning of the application of electrode force and the beginning of the application of current. This setting fixes the workpieces in place up until the supply of the absolute electrode force.
- Heat or Weld Time: Cycles are Weld Time. The factor that has the greatest influence on weld quality. The time that it takes for current to flow from the electrodes through the metal sheets is known as the weld time. The combination of the thickness of the material (necessary nugget size) and the amount of current flowing through determines how the weld time is changed. Hold time: time that pressure is maintained after the weld is made.
- Similar to the squeeze time, the hold time occurs when no current flows through the electrodes as they exert tension on the materials. But once the weld has been made and is in the cooling stage, this characteristic appears. The nugget can be released with the desired diameter by applying force while the metal is still somewhat molten. Off period: Electrodes split apart to allow material to be moved to the next location. Figure displays a schematic of the RSW cycle (3.18).

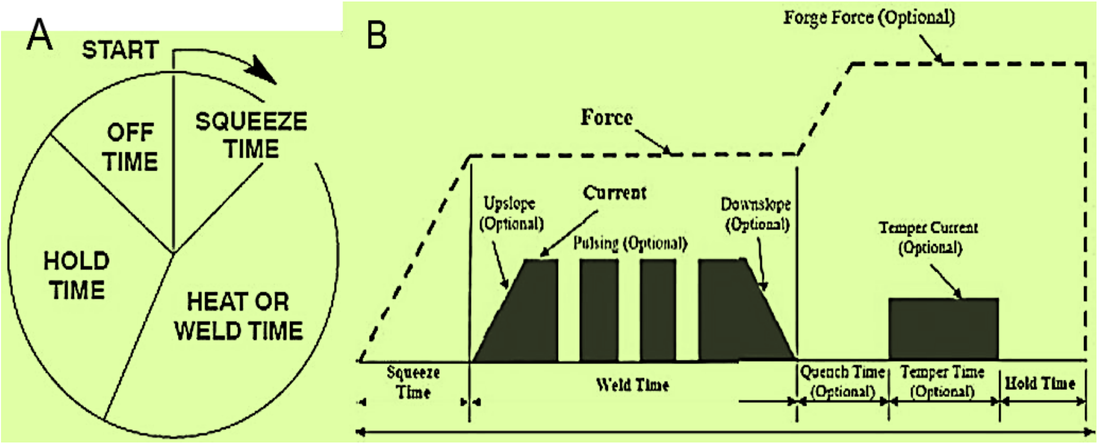


Figure 3.18. RSW weld cycle. A [47] B [63].

3.5.4. Electrode Force

One of the most basic elements that influences the weldability of RSW is wit. It consists of a series of resistances. The total value added to this electrical resistance has an impact on the machine's output current from RSW and heats up the circuit. Even if the current value is consistent throughout the whole electrical circuit, resistance values might differ significantly at different locations. The resistance of the circuit at any point determines how much heat is produced. The weldment requires the most resistance. The remainder of the actual welding circuit is referred to as "relative." The workspace has six main areas of resistance. They're displayed in Figure 3.19. [47]: The point of contact between thetas.

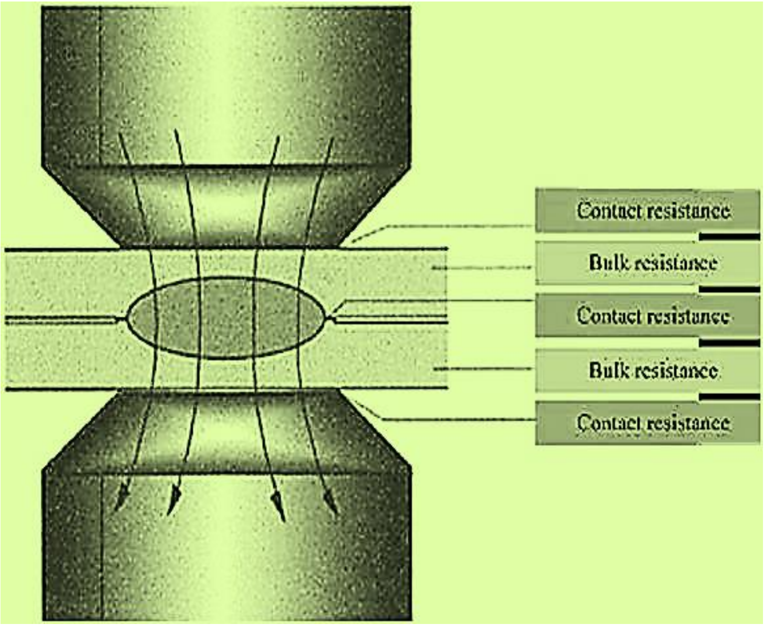


Figure 3.19. Spot welding resistance [58].

Each point of resistance will slow the flow of current since the resistances are connected in series. It depends on the material's capacity for heat transmission, electrical resistance, and thickness at the weld joint to determine how much resistance there is at point 3, the interface between the workpieces. At this circuit component [47], the weld's nugget is created.

3.6. WELD QUALITY

When a weld is evaluated destructively or nondestructively, measurable parameters including its physical qualities and range of strengths are typically used to assess the quality of the weld. Three criteria can be used to describe the quality of a weld: its physical or geometric characteristics, its strength or performance, or its process characteristics during welding and failure mode [66]. An American national standard (Standard Welding Terms and Definitions, ANSI/AWS A3.0:2001 [67]) which defines an acceptable weld as a weld that is primarily at the manufacturing's definition, illustrates the lack of universally accepted weld quality standards. These denote the geometric features that are either immediately apparent following the creation of a weldment or are discovered through destructive tests, like the tensile shear test.

It is one of the more important tests for assessing the quality of the welding.

Additionally employing nondestructive testing such as x-ray and ultrasonic equipment. These are the typical weld characteristics:

- Nugget Size
- Penetration
- Indentation
- Cracks (Surface and Internal)
- Porosity/Voids
- Sheet separation
- Surface appearance

The weldability of a metal is influenced by three variables: resistivity, thermal conductivity, and melting temperature. Metal that has a strong resistance to current flow, a low thermal conductivity, and a low melting temperature is suitable for basic welding. All ferrous metals fall within this category. Metals with low resistance but strong heat conductivity are difficult to weld [2] [44]. Microstructural features typically have a substantial impact on the strength of resistance spot welds. An extensive investigation of the interfacial microstructure and fracture surface of the welds is needed to identify which phases are best to enhance the weld strength. Commercial welds frequently have holes, cracks, and fissures. The geometry and placement of these imperfections affect how they affect the weld's strength. Widespread regard for the nugget [3].

3.7. FAILURE MODES

Resistance spot weld failure mechanisms are a qualitative indicator of mechanical characteristics [62]. RSW can display a multitude of weld failure modes. There are often two distinct failure categories, and they are as follows:

- Interfacial Fractures (IF): As shown in Figure 3.20), the IF mode is defined by the failure of the weld at the intersection of the two sheets, leaving half of the weld nugget in each sheet (3.20). The failure energy of the vehicles is anticipated to suffer as a result of this failure pattern [68]. Cavities, pores, and cracks are frequently seen. The shape of the nugget as a whole and the placement of these faults will have an impact on the weld strength [3].

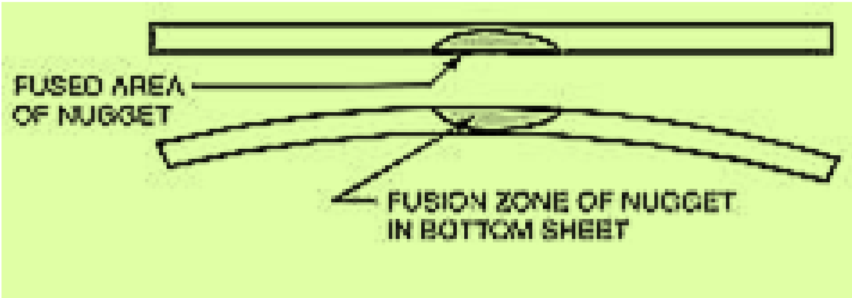


Figure 3.20. Interfacial Fracture [17].

Full Button Pull Out Fractures (PF): this type of fracture happens when a sheet's nuggets escape. Weld nugget has completely removed one of the metal sheets. The base metal (BM) or heat-affected zone (HAZ) at the weld's edge is where fracture occurs in the PF mode. Figure illustrates this failure situation by showing the weld nugget being completely torn from one of the sheets even if the weld is still intact (3.21). It is also possible to combine the two failure scenarios, in which the nugget is torn at the interface from one of the remaining nugget shears. The PF mode has the best mechanical properties. As a result, it's critical to modify welding parameters to ensure the PF mode [68].

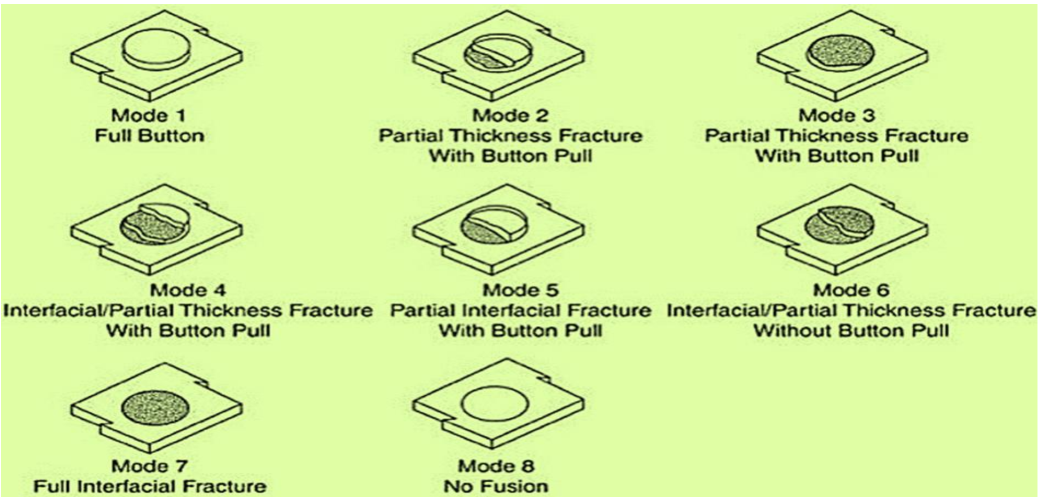


Figure 3.21. Fracture of pullout modes of weld buttons [17].

3.8. INTERLAYERS USED

In order to link the materials for RSW welding, a metal interlayer is frequently used. Enhance metallic bonding in resistance spot welding between materials that are similar and those that are different, as shown in the picture (3.22). The differences in the employed metals' properties may include differences in their thickness, electrical resistance, or melting temperatures. It can occasionally result in the development of brittle, unstable compounds or an oxide coating between the welded metals. Utilizing the interlayer cause's convergence in the fluctuating temperatures, which lowers the heat produced and lengthens the life of the electrode. The additional interlayer will help the weld to be thicker and more circular, as well as start welding more quickly. However, it will also lower the electrode's surface temperature. When welded without an interlayer, similar metals may be challenging to weld, difficult to overcome minor cracks, or requiring stronger microstructure and greater mechanical qualities for welded metals.

According to data from earlier studies, using an interlayer may be a practical technique to expand the size of the weld nugget and enhance the mechanical properties, which increased the weld joint's tensile and shear resistance and had a substantial impact on metallurgy [22] [28] [31] [40] [17].

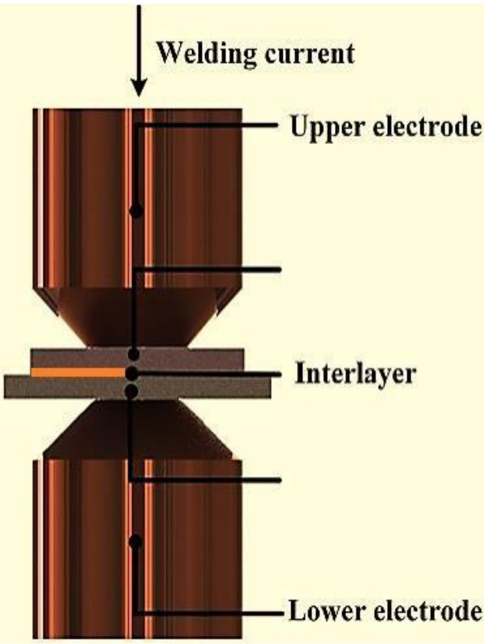


Figure 3.22. Metal interlayer welding.

PART 4

EXPERIMENTAL WORK

4.1. INTRODUCTION

All the experimental work in this research focused on the preparation and bonding of the welding process for dissimilar metals (AA6061, thickness 1.0 mm, and carbon steel, light AISI- SAE 1005, thickness 7.0 mm), the welding process in the presence of pure red copper can be used in several different thicknesses (0.2, 0.3, 0.02, 0.03) and choose the best among them, as an inner layer to improve welding conditions and solve the problem of anisotropy using resistance spot welding. Several variables of time and current are selected with constant pressure to obtain the best joint strength. Depending on the optimal results from the previous operations, in addition to evaluating some mechanical properties and the microstructure of the resulting joints. To determine the effect of process variables and interlayers on joint performance.

4.2. MATERIALS USED

4.2.1. Base Metal (BM)

This study used Red pure Copper metal with a thickness of (0.2, 0.3, 0.02, 0.03 mm). The Energy dispersive spectrometry (EDS) map it was provided to me by the test provider in the laboratory/Al-Khora Company shows the chemical composition of red pure Copper and BM (Aluminum alloy and carbon steel) as in table (4.1), figure 4.1 and mechanical properties in table (4.2), properties of base metal according to the standard ASTM [17].

Table 4.1. The proportions of the elements in the case thickness CU 0.02mm.

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
AL	51.14	39.8	47.97	2.580
CU	38.3	29.8	5.43	1.2
C	17.5	13.6	37.0	5.17
Fe	16.8	13.12	7.63	0.55
co	4.52	3.52	1.94	0.23

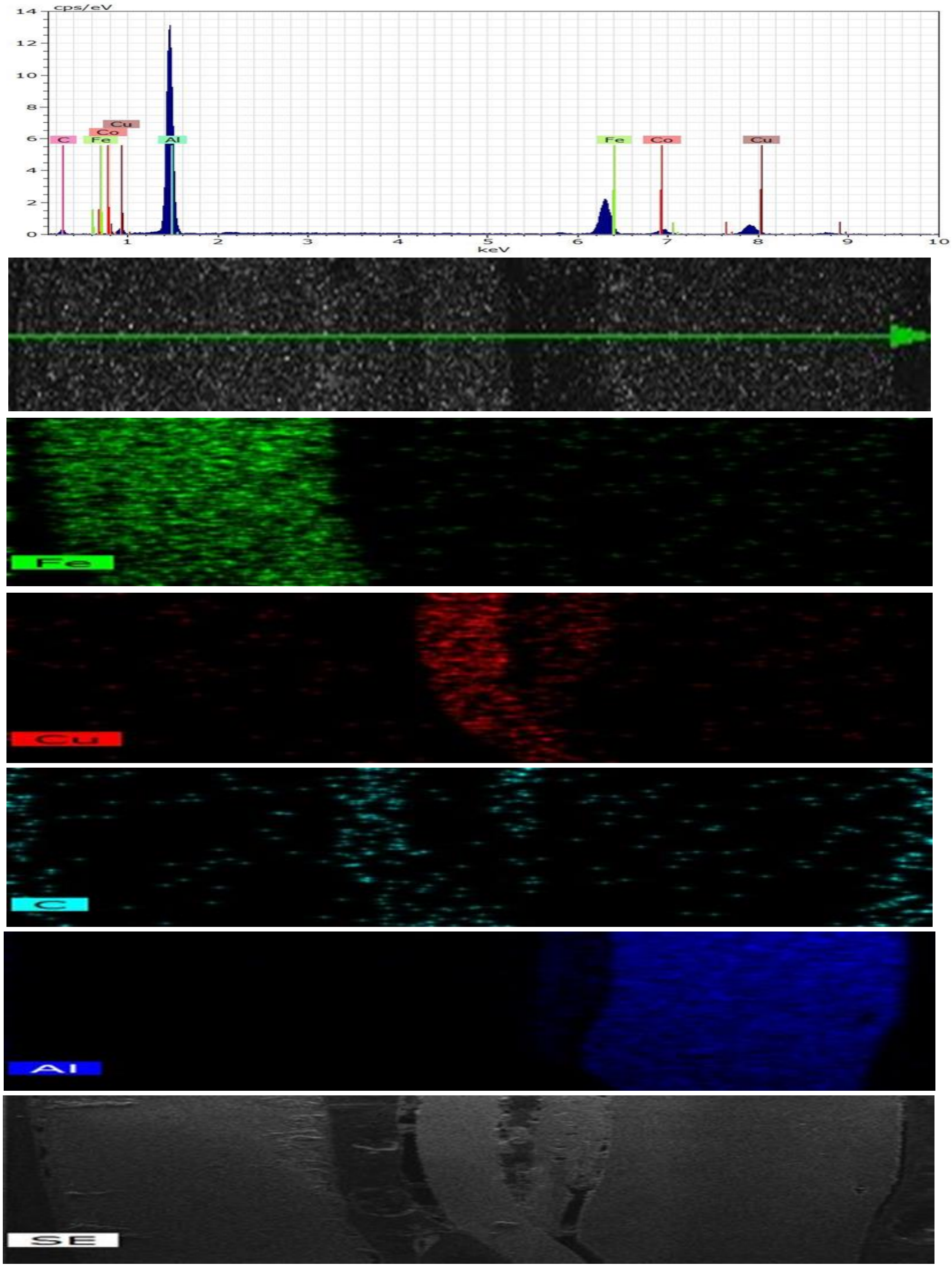


Figure 4.1. Energy dispersive spectrometry (EDS) map.

Table 4.2. Mechanical (Tensile) properties (XHEAD) Metric.

CU	Ultimate Tensile	CU
Foil, sheet and strip case 0.02 mm.	956.97	757.07 (957)

4.2.2. Base and Interlayer Metals

A metal interlayer with a thickness of 0.02 mm was used. The added interlayers are metals: pure copper and aluminum alloy and carbon steel. Table (4.3) A and B shows the chemical composition of the Base and Interlayer metals as shown in Standard ASTM, (Aluminum alloy, pure copper, carbon steel).

Table 4.3. Chemical Composition of AA6061 & Carbon [18].

A

Sample wt%	Si%	Fe%	Cu%	Mn%	Mg%	Zn%	Cr%	Ni%	Pb%	Ti%	AL
Measured values	0. 693	0.29	0.257	0. 128	0.935	0.033	0.181	0.0033	0.015	0.06	Bal
Standard values	0.4-0.8	0. 7	0.15-0	0.15	0.8-1	0.025	0.04-0	0.05	0.05	0.15	Bal
• **ASM Handbook, vol,1,tube12,pp249,2005**											
Composition wt%	C%	Mn%	P%	S%	Si%	Cr%	Mo%	Ni%	Al%	Cu%	Fe%
Measured values	0.05	0.034	0.01	0.016	0.025	0.0247	<0.002	0.0196	0.025	0.054 6	Bal
Standard values	0.06	0.35	0.40	0.05	N/A	N/A	N/A	N/A	N/A	0.02	Bal
• **ASTM B308/B308M-Standard Specifications for Aluminum-Alloy6061- T6**											

B

Material	Cu %	O %
Copper	99.95	0.001
Actual	Rem.	0.0002

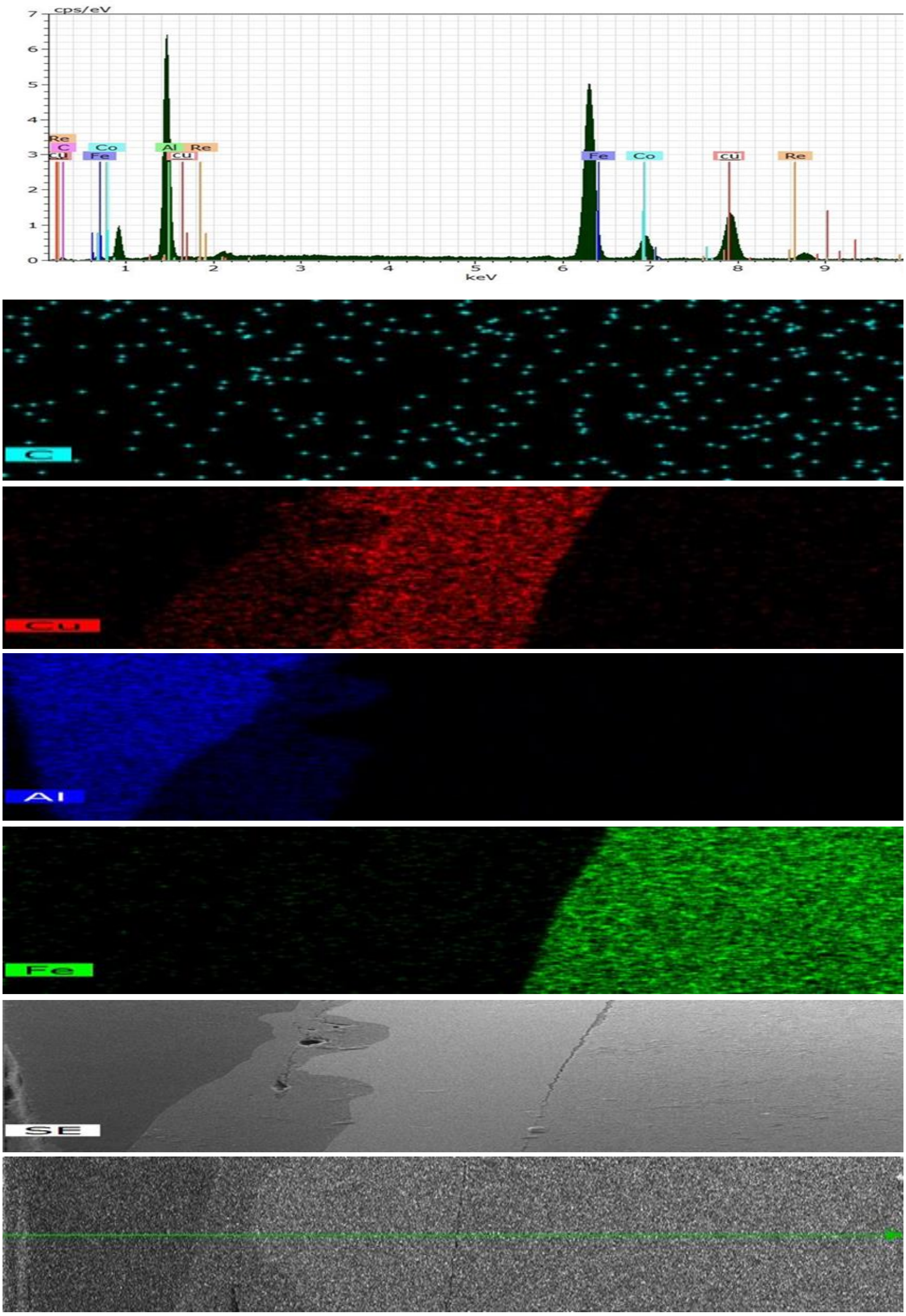


Figure 4.2. Energy dispersive spectrometry (EDS) map, CU 0.02mm.

Table 4.4. Chemical composition of (Cu, Al, C, Fe, Co) Case 0.3mm.

Element	Weight % Error	Weight %	Atomic % Error	Atomic %
Co	0.4	19.6	0.6	34.0
Al	0.1	1.5	0.0	1.1
Fe	0.2	37.3	0.1	13.9
Cu	0.2	2.1	0.1	0.7

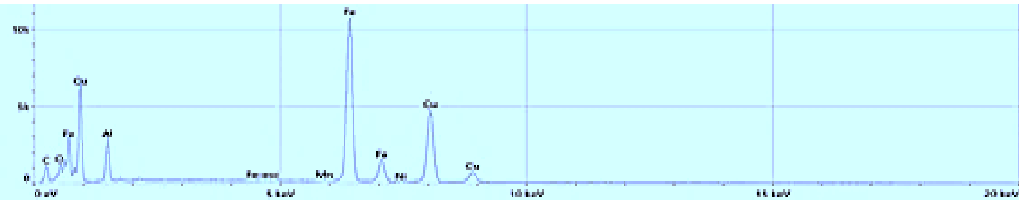


Table 4.5. Chemical composition of (Cu, Al, C, Fe, Co) Case 0. 2mm

Element	Weight%	Weight %	Atomic % Error	Atomic%
Co	0.4	19.6	0.6	34.0
Al	0.1	1.5	0.0	1.1
Fe	0.2	37.3	0.1	13.9
Cu	0.2	2.1	0.1	0.7

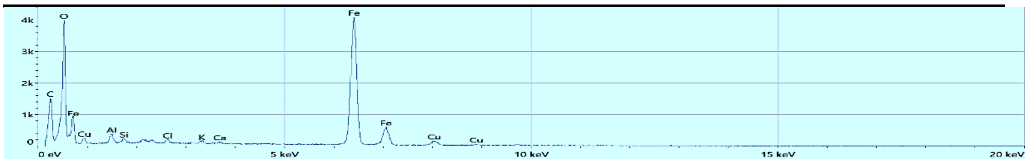


Table 4.6. Chemical composition of (Cu, Al, C, Fe, Co) Case 0.03mm

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
Al	1.1	0.1	0.9	0.1
Si	0.6	0.1	0.5	0.0
Fe	17.1	0.1	30.4	0.1
Cu	20.8	0.1	42.1	0.2

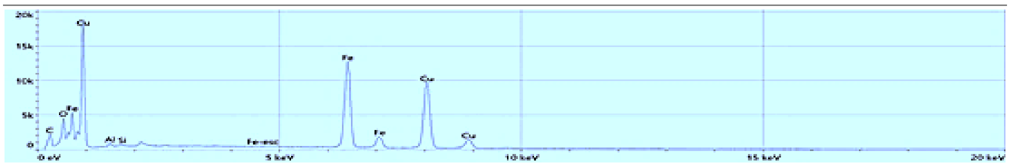
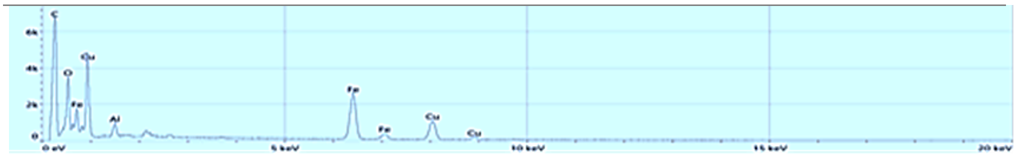


Table 4.7. Chemical composition of (Cu, Al, C, Fe, Co) Case 0.02mm.

Element	Weight % Error	Weight %	Atomic % Error	Atom%
Mg	0.0	0.1	0.0	**0.1**
Al	0.0	1.7	0.0	**1.0**
Si	0.0	0.3	0.0	**0.1**
Fe	0.1	11.7	0.0	**3.3**
Cu	0.1	7.8	0.0	**1.9**



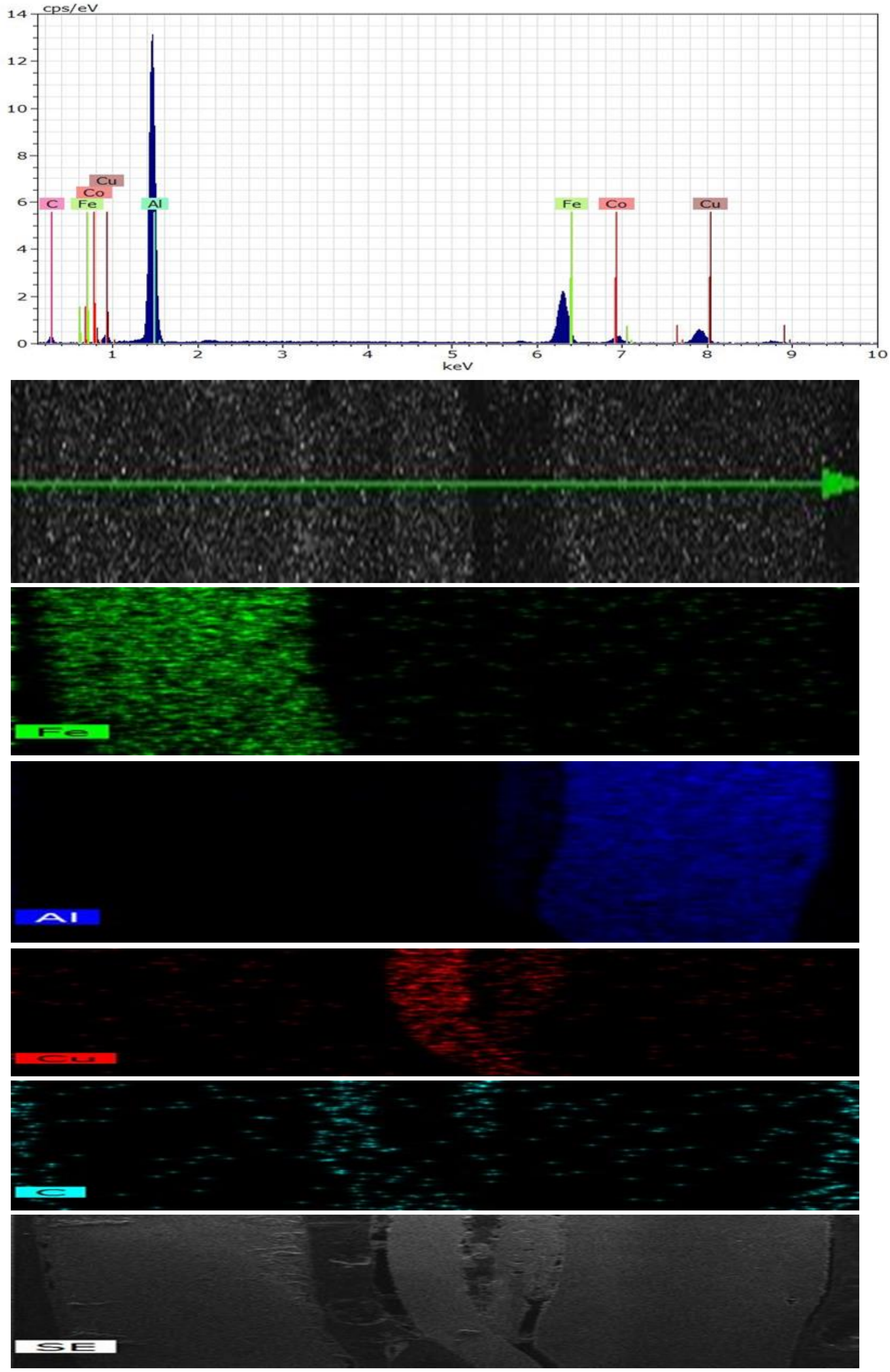


Figure 4.3. (EDS) map case 0.3mm

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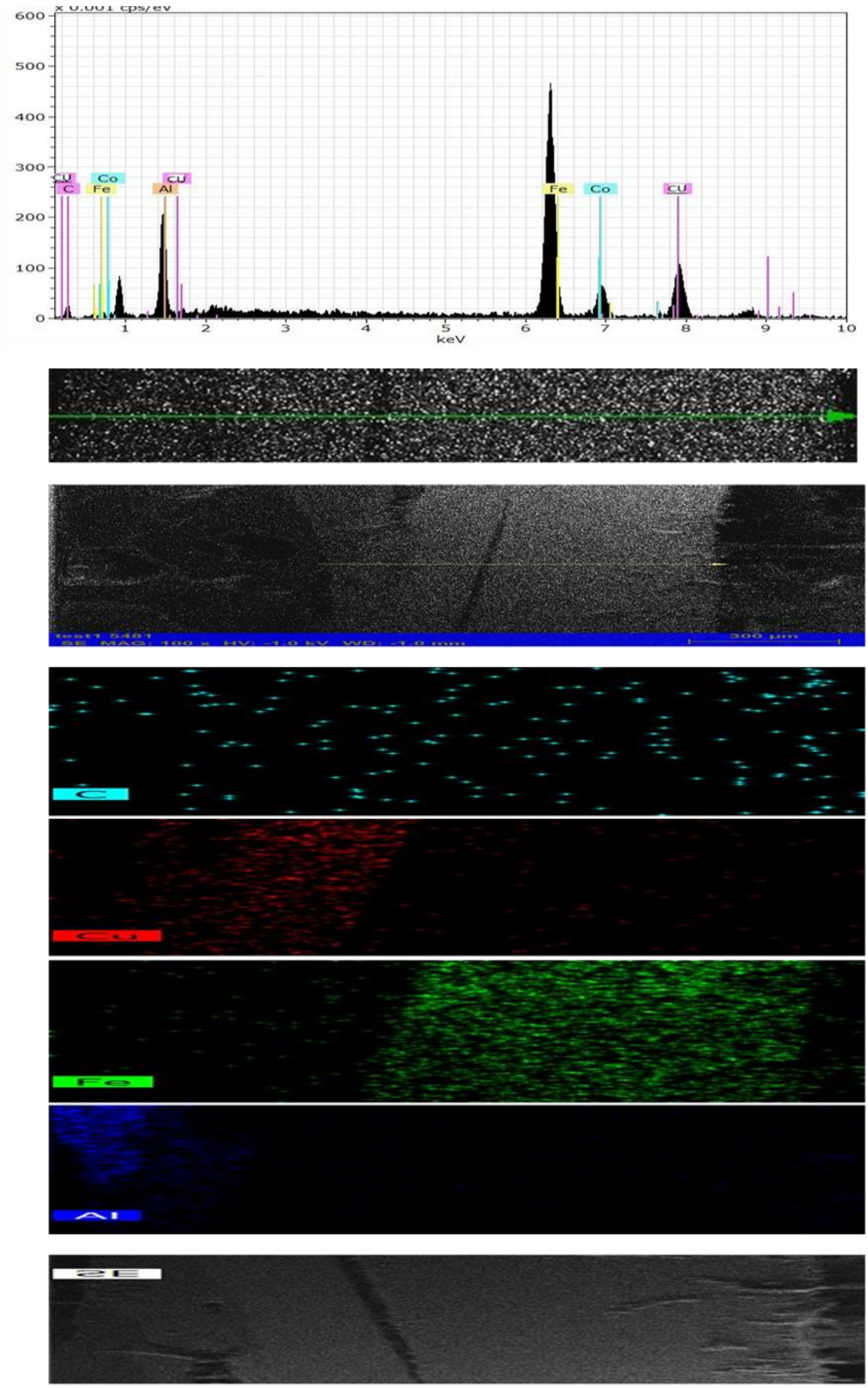

Figure 4.4. Energy dispersive spectrometry (EDS) map case 0.2mm.

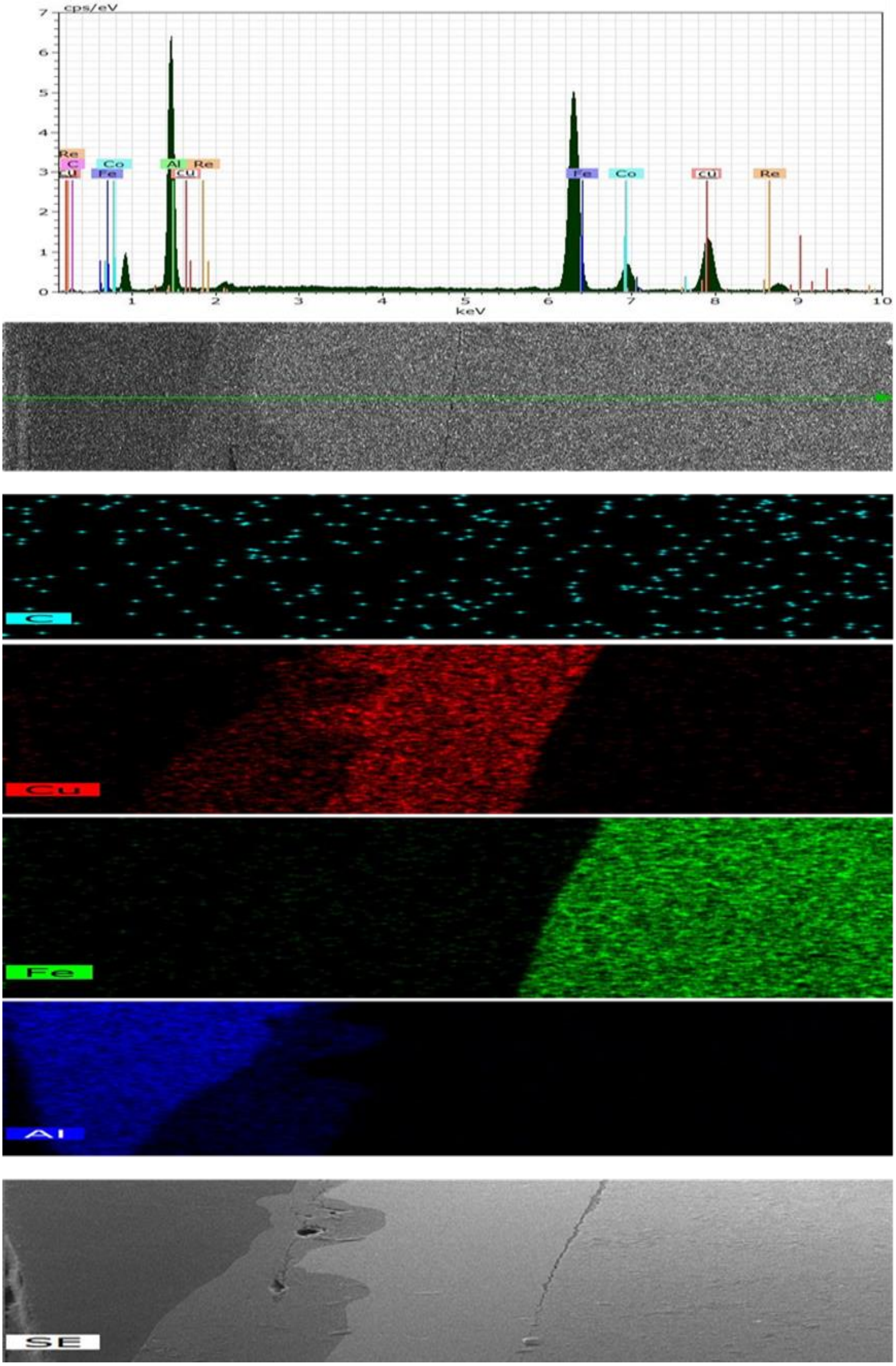

Figure 4.5. (EDS) map case 0.02 mm.

4.2.3. Specimens Preparation

E A6061 aluminum alloy plates that were 1 mm thick and mild steel that was 0.7 mm thick were the materials employed in this study (AISI- SAE 1005). The specimen's dimensions are 100 mm x 25 mm x 1 mm. (0.7mm for Carbon steel) established the samples' dimensions in accordance with the AWS D 17.2 [52] standard (4.3). The metals are cleaned with acetone and wiped with a soft cloth before starting the welding process. Prepare the interlayer metals with dimensions of 20mm x 20mm x (0.2, 0.3, 0.02, 0.03mm).

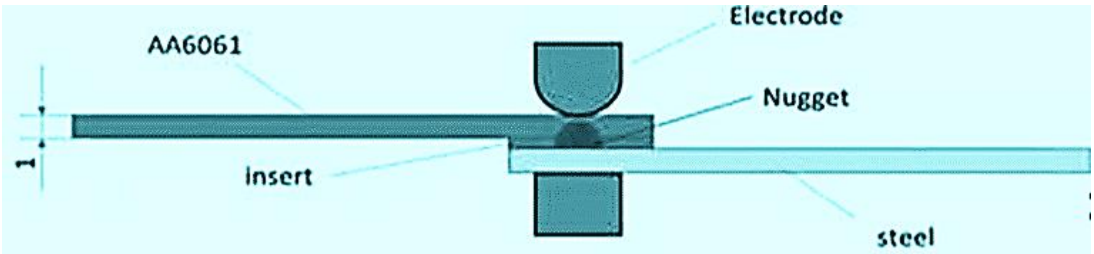

Figure 4.6. Lap shear tensile test sample.

Figure 4.4 shows a schematic diagram of the configuration of the work to be carried out and the heat concentration. The shape and size of joint according to (EN ISO 14273 – 2000), is illustrated in figure 4.4.

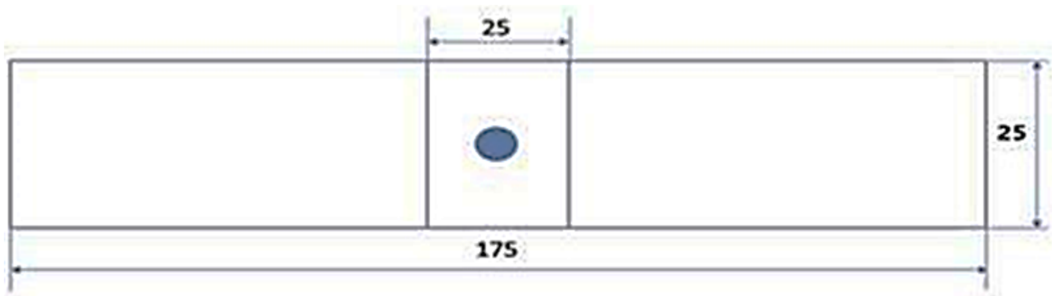

Figure 4.7. Sample dimensions.

The next paragraphs will outline the essential steps for producing and assessing the specimens:

- Preparing the samples is step one (preliminary cleaning, cutting, marking the welding point and trimming the filler strips to the size of the welding zone).
- Deep mechanical cleaning just before to welding

- Using the predefined variables to run the welding method during the two stages of the research (with and without filling materials).
- Calculating the nugget area after the shear test.
- Calculating the welding strength figures.

A qualitative indicator of mechanical characteristics is the reason why resistance spot welds fail [62]. RSW can demonstrate a variety of weld failure modes.

4.3. RSW MACHINES

The samples were welded using a typical rocker arm spot welding machine (SIP 15 KVA Pneumatic Spot Welder Italian) on a 50Hz power source. The welding machine is shown in Figure 4.5), which was made available by the engineering technical college in Baghdad. Single-phase AC machines comprise the majority of RSW equipment. Because it is the easiest and least expensive to install, maintain, and repair, this sort of equipment (SIP) is most frequently utilized.

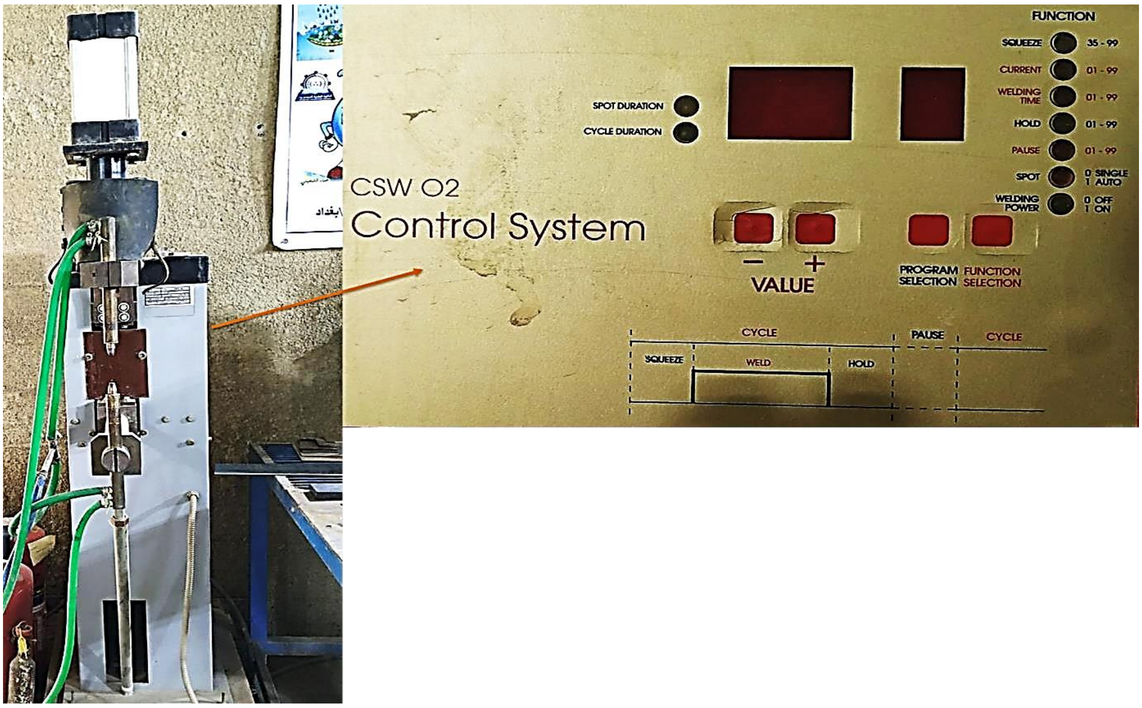

Figure 4.8. Spot welding machine SIP used in this study.

The machine is supplied with a programmable controller and a wandering Foot pedal. Welding was conducted using the electrode of Resistance Welding Manufacture Association (RWMA) Group a Class 2 [17]. The welding machine details are shown in Table 4.8.

Table 4.8. Welding Machine Details

Manufacturer	**SIP 15KVA (Italian)**
Type	Rocker arm
Controller	CSW-02, 7 Functions
Type of Current	AC
Phases	1
Max Welding Power	90KVA
Duty cycle 50%	15KVA
Short Circuit current	13.8 KA
Electrode Force (max)	4.5 KN
Arm's length	340 to 480mm
Electrode Throat Size	100mm
Electrode Holder	25mm
Electrode Size	20mm
Arms	45mm
Air Pressure	70 psi
water flow	4 Liters/min
Weight	178Kg
Cooling Water Temp.	15 – 25 °c
Frequency	50 Hz
Capacity for Welding (Sheet Metal)	4+4 mm
Capacity for Welding current(max)	14800(A)
Squeeze Time maximum	99 (c)
Welding Time maximum	99 (c)
Hold Time maximum	99 (c)

4.3.1. Aluminum Alloy and Carbon Steel without Interlayer

Due to the fact that the welding settings are crucial in defining the quality of the weld joint. In order to achieve optimal welding and enhance performance, a number of criteria were used during the welding process. The spot-welding parameters that were applied in this study are.

- The weld current.
- Welding period
- Consistent pressure

Before starting the welding process, should initialize the machine by running the electrical feeders, and the compressed air passes into the welding machine. The aluminum alloy and carbon steel metals dissimilar was welded using a lap joint by the resistance spot welding method by changing the parameters of time and current. For parameter a time, used four variables (0.8, 1.2, 1.6, seconds) and three variables of current (8500, 9100, 12300 amperes) with steady pressure. Then the foot pedal is pressed to begin the process of welding. The experiments of the welding were repeated several times in each process parameters setting. Four samples were welded for each parameter used, one for metallographic investigations and the three others for the tensile shear tests. 12 samples were obtained for the microscopic examination and 18 for the tensile stress test. The following table (4.9) shows the variables used. The welded strips were grouped and coded according to the input process parameters. Figure 4.9 shows the sheets cut before welding according to the dimensions mentioned.

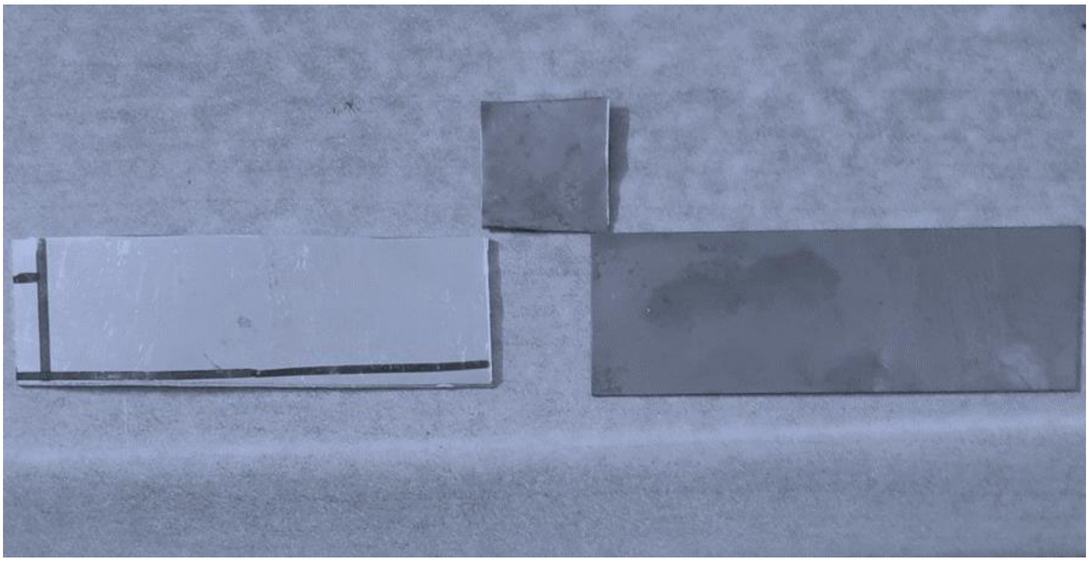

Figure 4.9. Specimen before welding.

Table 4.9. Process parameters.

Material	No of samples	Current (A)	Time (s)
Al–C.ST–CU	6	8500	0.8
Al–C.ST–CU	3	9100	0.8
Al–C.ST–CU	4	12300	0.8
Al–C.ST–CU	10	8500	1.2
Al–C.ST–CU	1	9100	1.2
Al–C.ST–CU	11	12300	1.2
Al–C.ST–CU	5	8500	1.6
Al–C.ST–CU	2	9100	1.6
Al–C.ST–CU	12	12300	1.6

4.3.2. B M with Metal Interlayer

To improve the mechanical properties and bonding strength of pure copper. A metallic interlayer plating was used in the RSW method, where three pure metals were used.

- Aluminums
- Copper
- Carbon steel

After creating the metal interlayer, the mild steel, pure copper, and aluminum alloy utilized in food cellophane were sandwiched between the sheet surfaces of the lap joint, as illustrated in Figure 4.10.

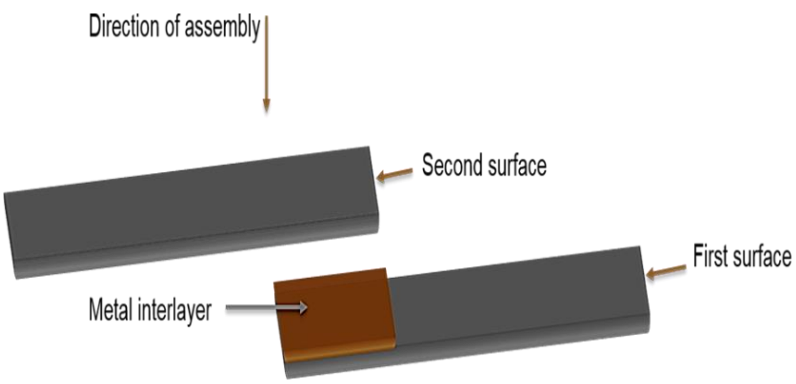

Figure 4.10. Application of metal interlayer.

The interlayers used in welding are four different layers: aluminum, copper and mild steel. The last fourth layer used is two layers of aluminum interspersed with a layer of mild steel. While the other resistance welding variables were constant, namely current, time and pressure, where the welding current was (9100 amperes) and time Welding (0.8 seconds).

According to the optimum experimental results obtained from the previous welding processes of metals without the interlayer. Based on the results of the tensile shear test tests these parameters have the highest value of the tensile test. Four samples were spot welded for each interlayer plating used, one for metallographic investigations and the other three for the tensile shear tests. 4 samples were obtained for the microstructure examination and 12 for the tensile stress test. The following table (4.10) shows the variables used. The welded specimen was grouped and coded according to the input process parameters.

Table 4.10. Welding metal interlayer.

Material	**Metal interlayer**	**No of samples**	**Current (A)**	**Time (s)**
Al–C.ST	Copper	4	12300	0.8
Al–C.ST	Copper	7	12300	0.8
Al–C.ST	Copper	5	12300	0.8
Al–C.ST	Copper	9	12300	0.8

4.3.3. Microstructure Examination

Mild steel, pure copper, and the aluminum alloy used in food cellophane were sandwiched between the sheet surfaces of the lap joint after the metal interlayer had been created, the welded specimens were cut perpendicularly near the edge of the nugget zone using wire cutting machine. Because they had small dimensions, making cold mounting was used manually with acrylic resin (pink and transparent). As shown in Figure 4.11.

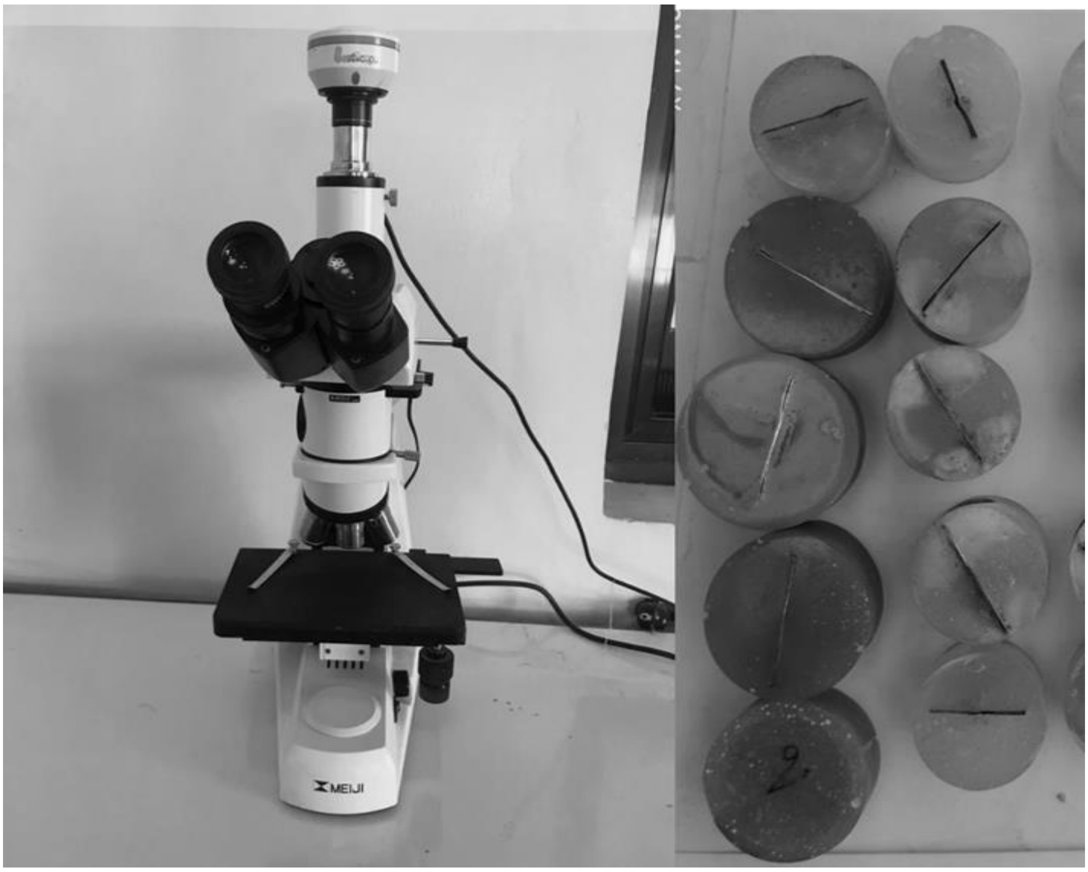

Figure 4.10. Optical microscope device and specimens in mounting.

Using a global polishing and grinding machine for metallographic specimen preparation, grind the mounted specimens with silicon carbide grinding papers that have (800, 1000, 1200, 1500, and 2000, 2500, 3000, 4000) grains per square inch, respectively, while spinning at a speed of 600 rpm. Each time the grinding paper was changed, the specimen was rotated 90 degrees. Water was used during the grinding process as a cooling liquid.

The polishing stage began just after the grinding stage was finished. It involved polishing the disc using an exclusive cloth, a 5 to 1 μm alumina solution (Al2O3), mass solution, and rotational speed before being rinsed with water.
Started the etching stage immediately following the polishing stage, and it involved submerging the specimen in the etching solution as shown in the table 4.10.

Table 4.11. Used etching solution [76].

Material	Solutions
Aluminum	1- 1 mL HF,200ml water
Copper	26- 5g FeCl3,10ml HCl,50ml glycerol,30ml water
Carbon steel	172- H2O2 3%, 25ml glycerol, 10ml HCl,100ml water,
Copper- Aluminum	35- 20g $FeCl_3$,5ml HCl,1g CrO_3,100mL water

In accordance with ASTM E 407-99 [68], after applying the upper solutions for a brief period of time, the specimens were immediately rinsed with water and dried using hot forced air to prevent surface oxidization. Using a digital camera and a microscope. In Baghdad's Postgraduate Laboratory/Technical College of Engineering, a microstructure analysis was done.

Using a global polishing and grinding machine for metallographic specimen preparation, grind the mounted specimens with silicon carbide grinding papers that have (800, 1000, 1200, 1500, and 2000, 2500, 3000, 4000) grains per square inch, respectively, while spinning at a speed of 600 rpm. Each time the grinding paper was changed, the specimen was rotated 90 degrees. Water was used during the grinding process as a cooling liquid.

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Started the etching stage immediately following the polishing stage, and it involved submerging the specimen in the etching solution as shown in the table 4.10.

In accordance with ASTM E 407-99 [19], after applying the upper solutions for a brief period of time, the specimens were immediately rinsed with water and dried using hot forced air to prevent surface oxidization. Using a digital camera and a microscope. In Baghdad's Postgraduate Laboratory/Technical College of Engineering, a microstructure analysis was done.

4.3.4. Tensile Shear Test

AWS standard AWS D 17.2 [52] was used to construct the rectangular specimen for the shear strength test, which had dimensions of 100mm in length and 25mm in width (4.12A, B). With a 100 KN maximum capacity, the (United Test) machine was used to conduct the tensile shear test. The Engineering Technical College-Baghdad/Mechanic Department has this machine available. As shown in Figure 4.12 A&B.

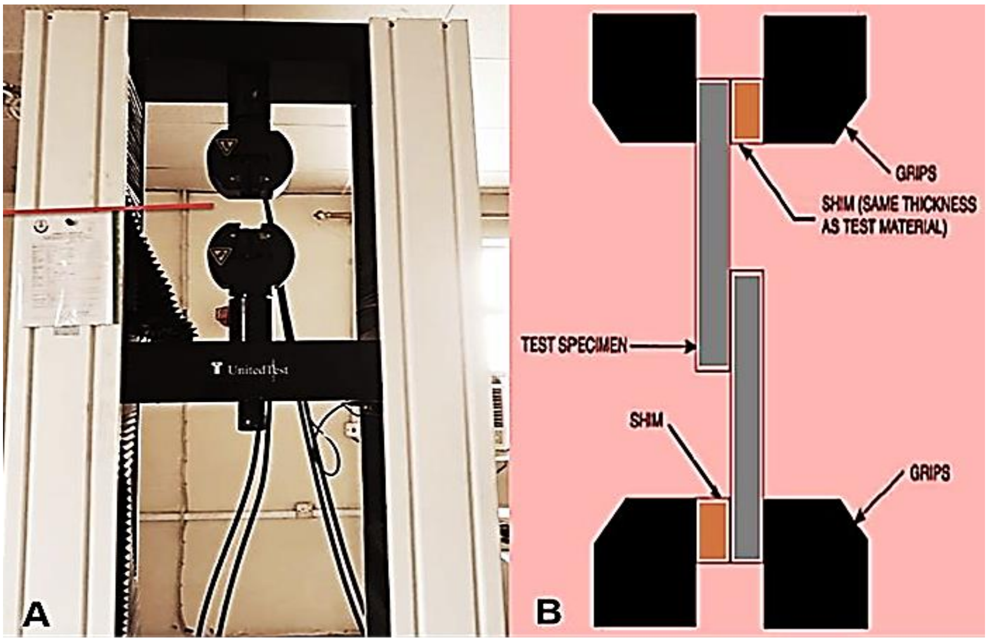


Figure 4.11. A, Tensile strength test machine and (4.12) B Tensile shear strength test.

The tensile shear strength test was carried out at first on 18 samples to obtain the optimum joining parameter. Then carried out the test on 12 samples welded with the interlayers listed in table (4.12) using the optimum joining parameter. The tension-shear tests were performed at a crosshead speed of 0.5 mm/sec. shows the variables used. The welded specimen was grouped and coded according to the input process parameters.

Table 4.12. Welding metal interlayer.

Material	Metal interlayer	No of samples	Current (A)	Time (s)
Al–C.ST	Copper	4	12300	0.8
Al–C.ST	Copper	7	12300	0.8
Al–C.ST	Copper	2	12300	0.8
Al–C.ST	Copper	9	12300	0.8

4.3.5. Scanning Electron Microscopy SEM

SEM is used to see surface features its texture (Topography) and particle morphology (shape and size). The test was carried out using SEM (Thermos Fisher Scientific) device in the laboratory/Al-Khora Company as show in figure 4.10. With the same device, a test was performed (EDS), as shows in figure 4.13. The SEM analysis was used to examine the joint microstructure and joining behavior between the two materials.

The microstructure is observed and study joint structures at the interface line are. Before examining SEM specimens, the surface of the samples was coated with a coating film of gold containing an argon gas to obtain consistent results in the SEM. The examination can identify the thickness of the intermetallic compound during the bonding process after adding the metal interlayer.

Figure 4.12. SEM device tests.

4.3.6. Energy Dispersive X-rays Spectroscopy EDS

EDS is an analytical method used to characterize a sample's chemical makeup or determine its elemental composition. EDS allows users to determine the type of elements present as well as the proportion of elements concentration within the sample and distribution through qualitative and quantitative analysis. The test was conducted in the physics department of the Al- Nahrain University's College of Science utilizing an EDS (Bruker Company/Germany) instrument. When the material is attacked with electrons in an electron beam system, as is done in SEM, the function (X-rays) are produced.

The elemental mapping test was carried out using EDS equipment. The test provides a spectrum that gives information on what components are present, distribution and quantities. -ray diffraction test XRD the X-ray diffraction test is one of the most important non-destructive tests used to detect the phases present in the joining region between the 3 sheets.

The test was performed at Al-Nahrain University-College of Science-Department of Physics. The sample is prepared for testing, where the welded metal is separated from the other, or the tensile shear test samples are used after a fracture. The size of the nugget zone of the spot is obtained in one face with dimensions of 1cm x1cm. This investigation was used to analyses the Welding area interface line, classify the intermetallic compounds that formed after added metal interlayer, and define potentially new developed phases. Figure 4.14) shows a device XRD.

Figure 4.13. X-ray diffractometer device.

PART 5

RESULTS AND DISCUSSION

5.1. INTRODUCTION

Resistance spot welding plays a significant role in the manufacturing industry. Due to its strength and general dependability as a means of attaching two pieces of metal, as well as the complete lack of panel deformation caused by the welding process, it is widely utilized in the industry. The quality of the weld is greatly influenced by controlling the welding parameters. To achieve the best weld strength, it is crucial to choose the welding process parameters. The mechanical properties of RSW joining the two weld metals were discussed in relation to the bonding parameters, welding current, and welding time. Second, the effects of adding a metal interlayer with the suitable thickness on improving mechanical properties and weld quality. The joint microstructures were examined using optical microscopy (OM) and scanning electron microscopy (SEM). These tests were carried out to validate the interface in the bonded region between the base metal and the metal interlayer. Also see the pictures of the weld blocks. In this project, a tensile shear test is employed to ascertain the strength and caliber of the weld. Tensile shear tests on the overlay welded panels were used to determine the strength of the joints. The interlayer thickness was used to categorize samples into various categories. Examples of resistance points that have been welded using various welding settings [4]. All samples were put through a tensile test, and the results were compared with the tensile shear value of the weld joint using the formula provided in the AWS standard (AWS D8.1 2003) [17] (5.1).

$$ST = \frac{(-6.36 \times 10^{-7} \times S^2 + 6.58 \times 10^{-4} \times S + 14.674) \times S \times 4 \times t^{1.5}}{1000} \quad (5.1)$$

ST: Shear Tension Strength KN

S: Ultimate Tensile Strength MPa

t: thickness mm

The thickness is 0.3 mm of copper, and the tensile strength is 280 MPa. Equation (5.1) above states that the limit for welded specimens should be greater than the minimum of 0.132 kN. Also three thickness of copper samples of each of two base metals underwent a tensile test, as depicted in Figure 5.1. The evaluations showed: (0.330 KN, 0.757KN, 0.289 KN).

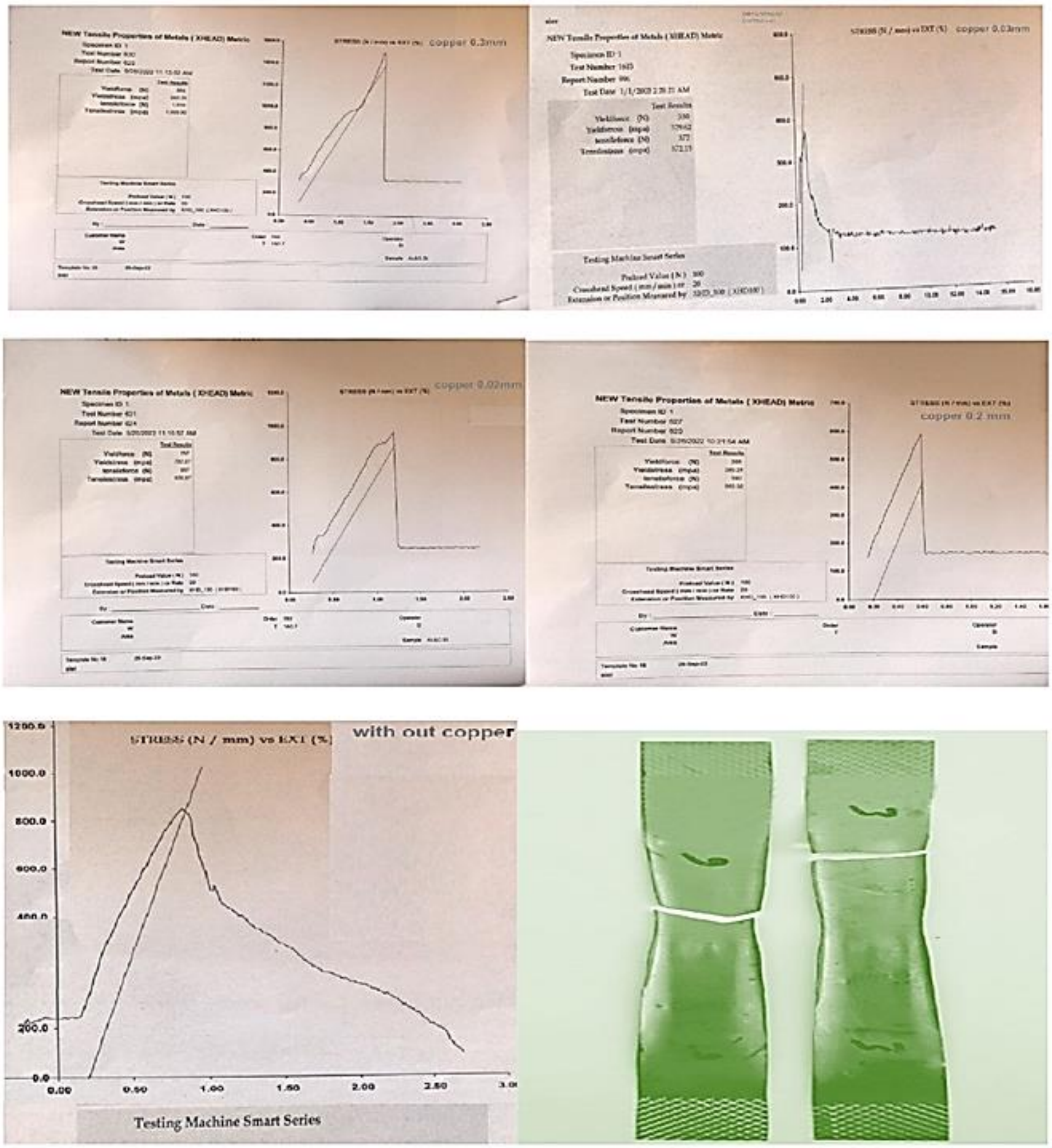


Figure 5.1. Specimens after shear test without welding and diagram values of shear test with several thicknesses of copper and without.

5.1.1. Base Metals with Interlayer

As mentioned earlier, there are 36 weld samples with different tensile test variables. The results of the samples were divided into four groups, each group containing nine samples of fixed welding time (welding time 0.8 seconds, welding time 1.2 seconds, welding time for the group 1.6 seconds) with different welding currents. Tensile and shear strength effects of welding time and current are demonstrated. With more time spent welding, the tensile strength of spot-welded connections increases, which also causes the nugget size to grow. The reason is because, in accordance with Joule's rule, an increase in welding time exactly corresponds to an increase in the heat created during the resistive spot-welding process. The weld sample's strength does, however, increase, two failure types are pull-out and pull-out with shredder mode.

Table (5.1A, B, C, D) show the shear force for specimens of spot welding formed with welding time (0.8,1.2,1.6) and different currents (8500,9100,12300 A).

Table 5.1. Shear force for specimens of spot welding for group A (CU 0.03).

Specimen No	Welding time (s)	Welding current (A)	Shear force (N)
1	0.8	8500	327
2	1.2	8500	321
3	1.6	8500	301
4	0.8	9100	297
5	1.2	9100	285
6	1.6	9100	367
7	0.8	12300	330
8	1.2	12300	341
9	1.6	12300	235

Table 5.2. Shear force for specimens of spot welding for group B (CU 0.2).

Specimen No	Welding time (s)	Welding current (A)	Shear force (N)
1	0.8	8500	**311**
2	1.2	8500	**318**
3	1.6	8500	**389**
4	0.8	9100	**379**
5	1.2	9100	**287**
6	1.6	9100	**357**
7	0.8	12300	**289**
8	1.2	12300	**200**
9	**1.6**	**12300**	**176**

Table 5.3. Shear force for specimens of spot welding for group C (CU 0.02).

Specimen No	Welding time (s)	Welding current (A)	Shear force (N)
1	0.8	8500	245
2	1.2	8500	265
3	1.6	8500	245
4	0.8	9100	215
5	1.2	9100	207
6	1.6	9100	157
7	0.8	12300	955
8	1.2	12300	203
9	1.6	12300	256

Specimen No	Welding time (s)	Welding current (A)	Shear force (N)
1	0.8	8500	332
2	1.2	8500	398
3	1.6	8500	301
4	0.8	9100	297
5	1.2	9100	314
6	1.6	9100	363
7	0.8	12300	757
8	1.2	12300	657
9	1.6	12300	154

Table 5.4. Shear force for specimens of spot welding for group CU 0.3).

The majority of the tensile test outcomes were excellent. The welding period is just about 0.8 seconds, which results in less heat being generated and greater penetration. However, caution should be used while welding at high currents since ejection can occur in the rock mass region, which can result in a weak joint. An interfacial mode with high currents of 12300A and a lengthy welding duration is the failure mode. A fracture's interfacial route of propagation through the FZ fusion area. The shear strength of spot-welded samples with the metal interlayer is shown in Figure 5.2. It demonstrates that a weld block is separating from a single sheet and that the sheet is also being pulled and torn. As demonstrated by EDS LINE, it is also obvious to us that copper and aluminum overlap one another plainly.

Figure 5.2. Failure specimens after shear test.

5.1.2. Aluminum & Carbon Steel with Interlayer

36 samples were tested, 9 samples for each interlayer, all welded with a welding current of (8500, 9100, 12300 A) and a welding time of (0.8, 1.2, 1.6 sec) Tensile test results for the welded 36 interlayer samples gave higher values than the tensile stress value for base metals welded without interlayer. The twelve specimens have a good estimate of joint strength.

It was better than the results of the tensile test for dissimilar metals without interlayers, as it was shown through the tensile tests the best thickness used from the copper interlayer. The fracture behaviors indicate that the fracture spreads along the circumference of the localized area outside the weld block during the roll tensile test. When the specimen is welded with an inner layer of copper.as shown Figure 5.3 and Figure 5.4.

Figure 5.3. Specimens before shear test of metal interlayer.

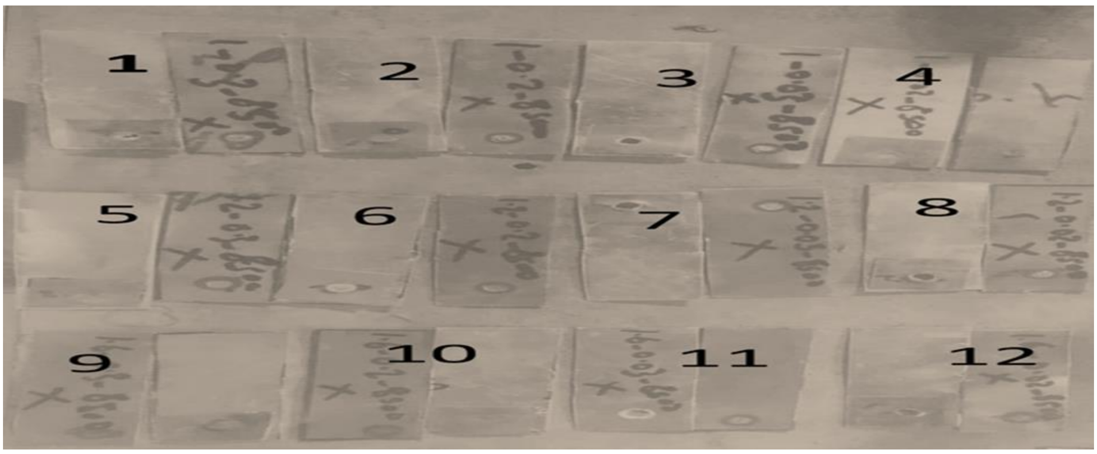
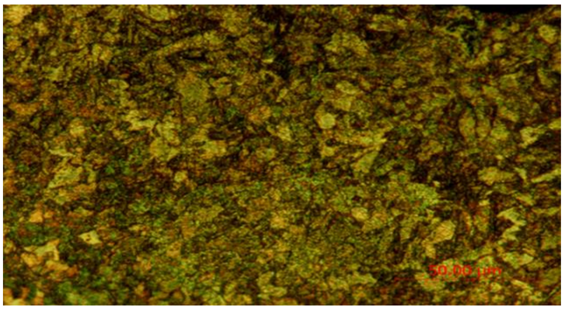


Figure 5.4. Specimens after shear test of metal interlayer.

The metallic interlayers significantly improved metal bonding at the interface and produced high strength welds. An additional bonding mechanism increases the total weld area. The thickness and diameter of the weld block increases the tensile strength of the tensile shear due to the use of an interlayer [39] [28]. The increase in tensile shear test results was 32% compared to the welded tantalum test results obtained by spot welding with a classical resistance without an interlayer. Through the previous figure, failure modes are shown, which are withdrawal and withdrawal with tearing of the paper mode. Pull-out mode in which failure is induced by pulling the weld block off one sheet. Fracture may begin in the base metal (BM) in this position. The solid mass is completely removed from the leaf, which is severely petiolate. However, the solid block is still attached to the other sheet. The withdrawal process with rupture of the plate position is accompanied by higher plastic deformation and energy absorption with respect to the withdrawal[20].

5.2. MICROSTRUCTURE OF WELDS

The microstructure of BM, HAZ, and WZ was similar to the investigation of the microstructure of resistive spot welding, according to microscopic analysis of alloying aluminum with carbon steel in the presence of the interlayer. However, the HAZ and WZ area is where grain refining is attained. Within the cell granules, the dendritic structure's development can be seen. Dendrites can be seen across the whole weld bead, and the fusion line interface exhibits a pattern of hardening. At the same time, we comprehend the dendritic structure as a columnar structure that was sufficiently developed to drive grain progression in branching directions under the inducing force of solidification. Considering that the base material is in close proximity to the (weld mass). Grain refinement is achieved in this fusion line as a result of thermal shock brought on by the welding temperature. Throughout both microstructures [43]. Like Figure 5.5. Produced a good weld (exhibiting no fractures or pores), as demonstrated by microscopic analysis and ocular inspection.



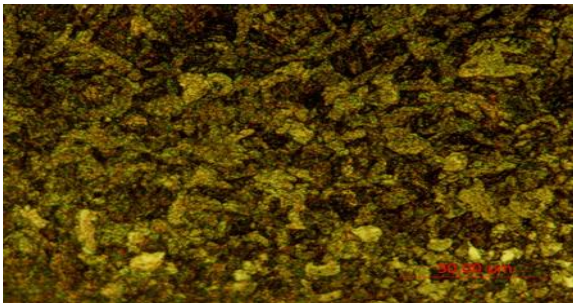


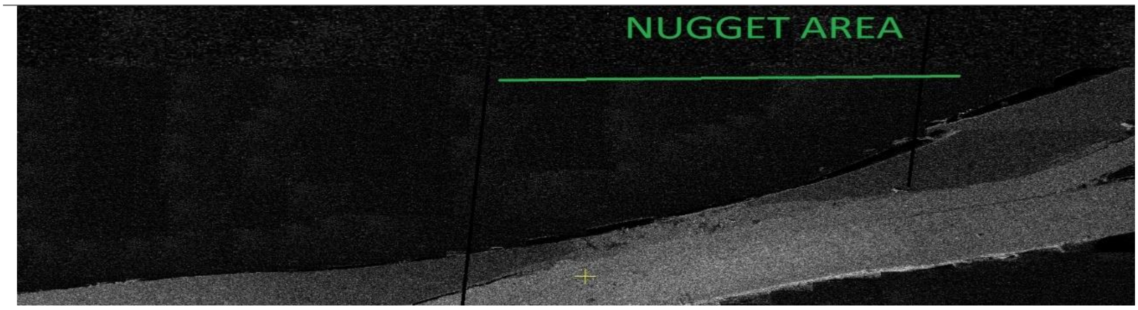
Figure 5.5. Microstructure of joint carbon steel& Al.

5.2.1. Microstructure to AL-Alloy

Microscopic testing of AA6061 aluminum alloy to carbon steel group shows that the spot welding parameters are the reason for the difference in microstructure. For resistive spot welding, welding current and time are typically the most crucial variables in regulating heat input. In all circumstances, if ejection does not take place because of high current or excessive electrode strength, an increase in welding current may result in an increase in the nugget size. Depending on the amount of heat produced, the weld block's diameter either rises or decreases. The solid mass begins with a dot in the center and grows outward in all directions. Therefore, the parameter functions accurately and stably control the weld block proportionality. After measuring the size of the weld block for each welding sample was found that there is a difference in the size of the weld block depending on the process variables, as the smallest diameter of the weld block was found for sample No. [1]. 3.4 mm welded with a current of 12300A and welding time 0.8 s. The diameter increases gradually with the increase in heat generated due to the increase in welding time and current. Table (5.5) and Table (5.6) Shows the joints welded of the welded BM samples. The weld nugget consists of a dendritic structure for all samples, and the HAZ was difficult to distinguish between the WN in the micrograph. Welding occurred without clear defects.

Table 5.5. Diameter of the nugget area with cu (0.3, 0.03) mm.

Specimen	Welding Current (A)	Welding Time (s)	Dia. of the Nugget
1	12300A	0.8 s	3.4mm



2	12300A	0.8 s	3.6mm

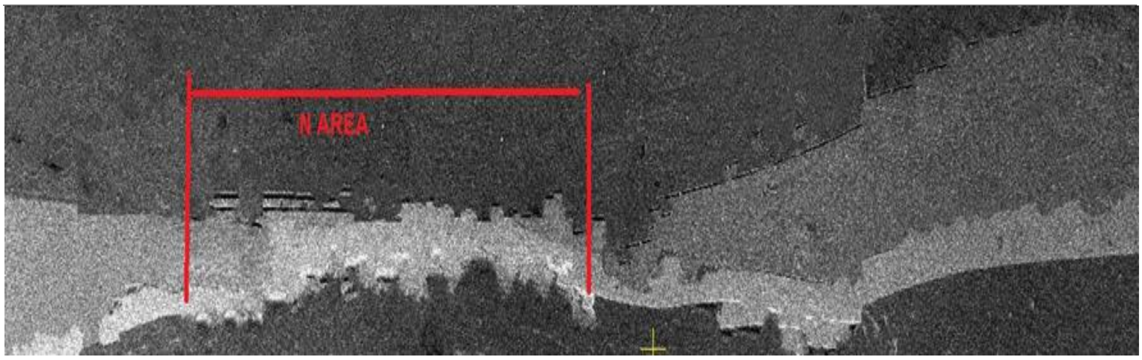
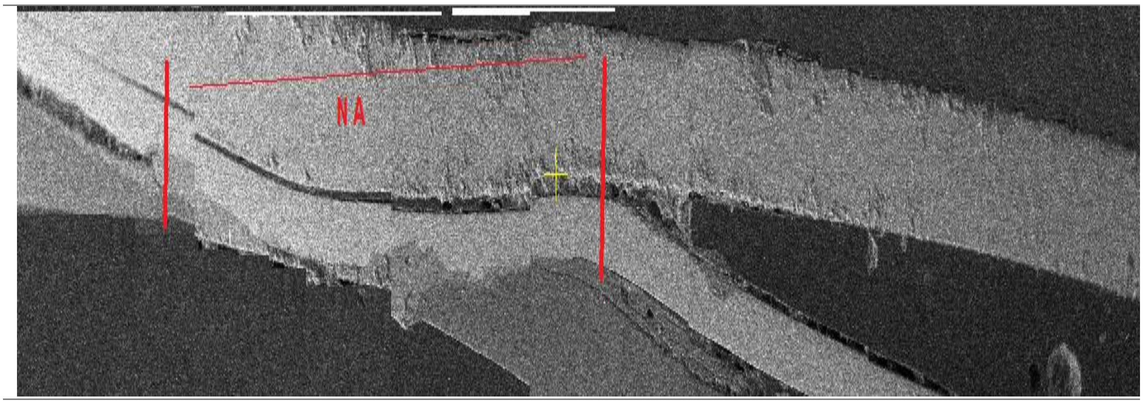
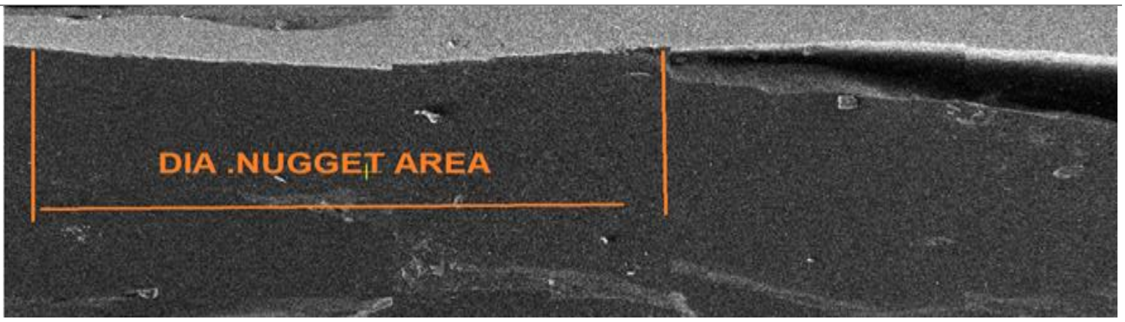


Table 5.6. Diameter of the nugget area with cu (0.2, 0.02) mm.

3	**12300A**	**0.8 s**	**3.8mm**



	12300A	0.8 s	3.4mm



5.2.2. Microstructure for BM with Interlayer of CU (0.3, 0.03, 0.2, 0.02) mm

A welding current of 12300 A and a welding time of 0.8 s were used to examine the interfacial microstructure of four welded metal contact samples. The junction between the metallic copper layer technique and the standard RSW shows a sizable difference. The following figures illustrate the conventional RSW, which is welded with additions of metallic copper.

The solid mass is concentrated rather than conglomerated on one side of the plate, and the additional bonds between the plates cause an improvement in weld strength which has been confirmed in shear tensile tests. Additionally, despite the interfacial metal on the aluminum side melting, there was no change in composition. The presence and thickness of the metallic interlayer have a significant impact on the chemistry, microstructure, and mechanical characteristics of a resistance spot-welded weld joint. In order to decrease the amount of heat generated at the electrode surface and lengthen electrode life, the interlayer has frequently been employed in narrow gauge welding. The metal interlayer will contribute to faster welding initiation, increased thickness and diameter of the weld block, and reduced electrode surface temperature [39]. Figures (5.6, 5.7, 5.8, 5.9) show the typical interfacial microstructure of the solder joint and the interlayer of copper. The interlayer of copper spreads in a clearer direction from the aluminum side Additional bonding increases the diameter of the weld block and the total area of the weld.

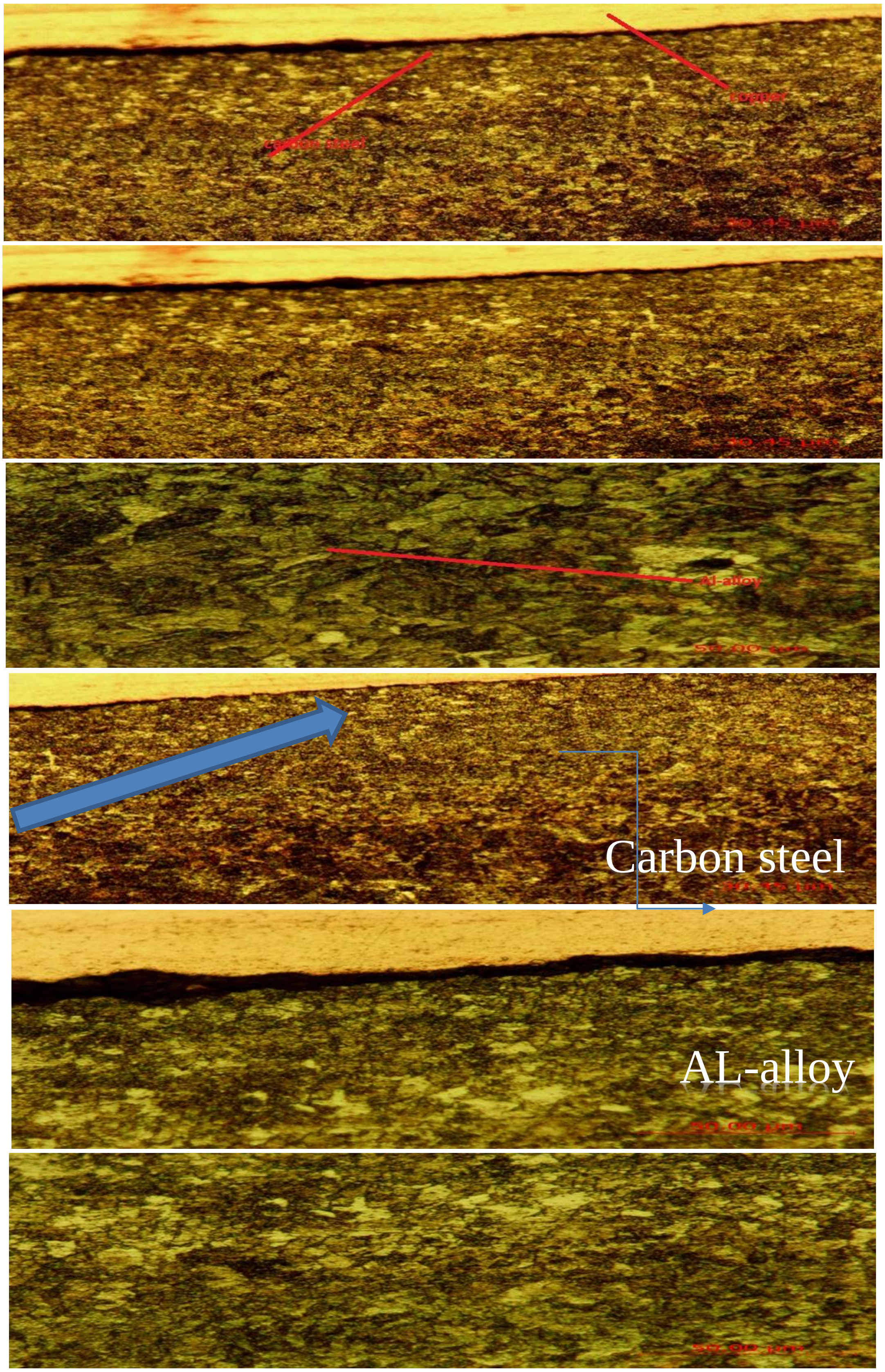


Figure 5.6. Microstructure of BM with interlayer of copper 0.02mm.

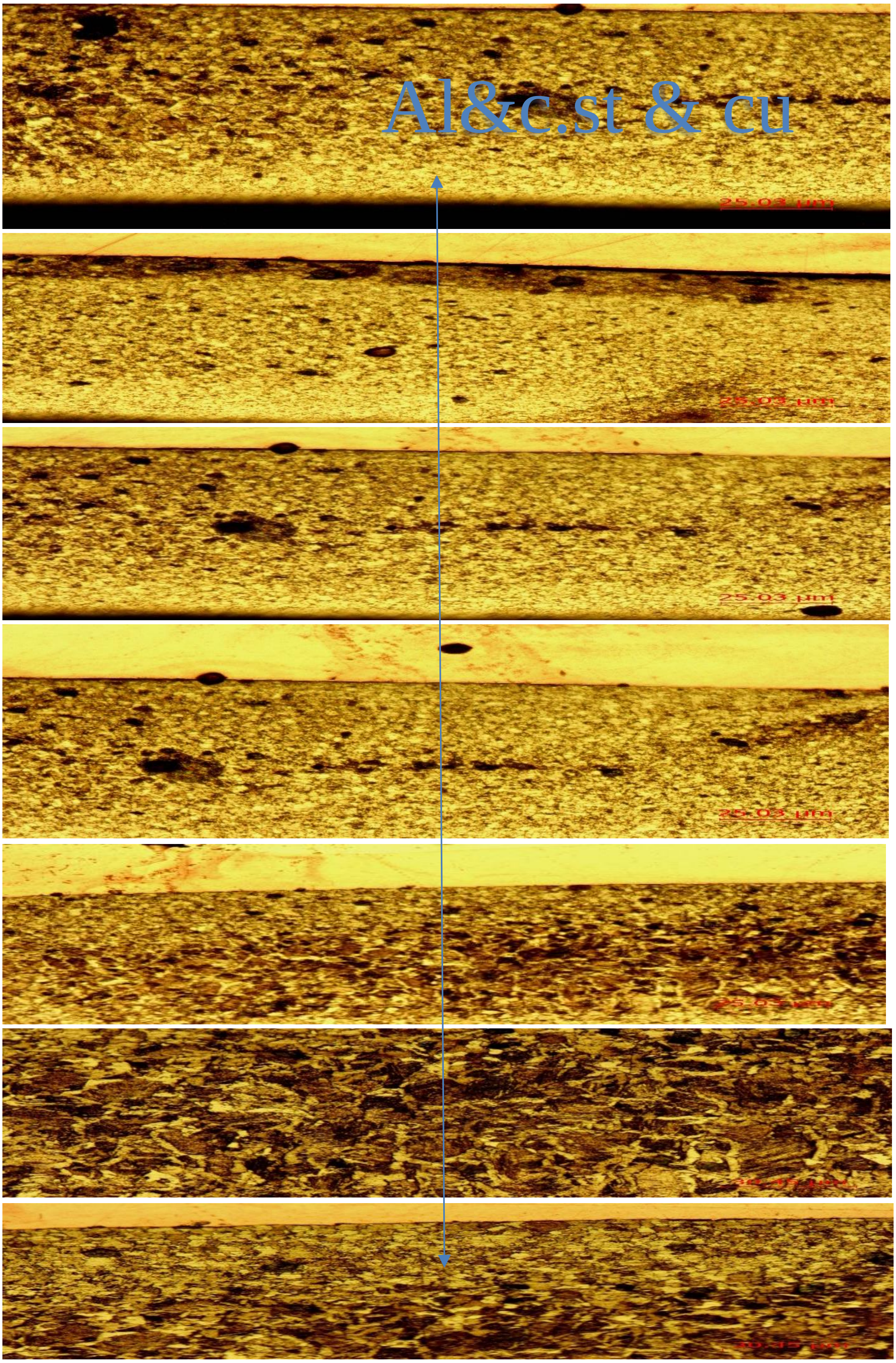


Figure 5.7. Microstructure of BM with interlayer of copper 0.03mm.

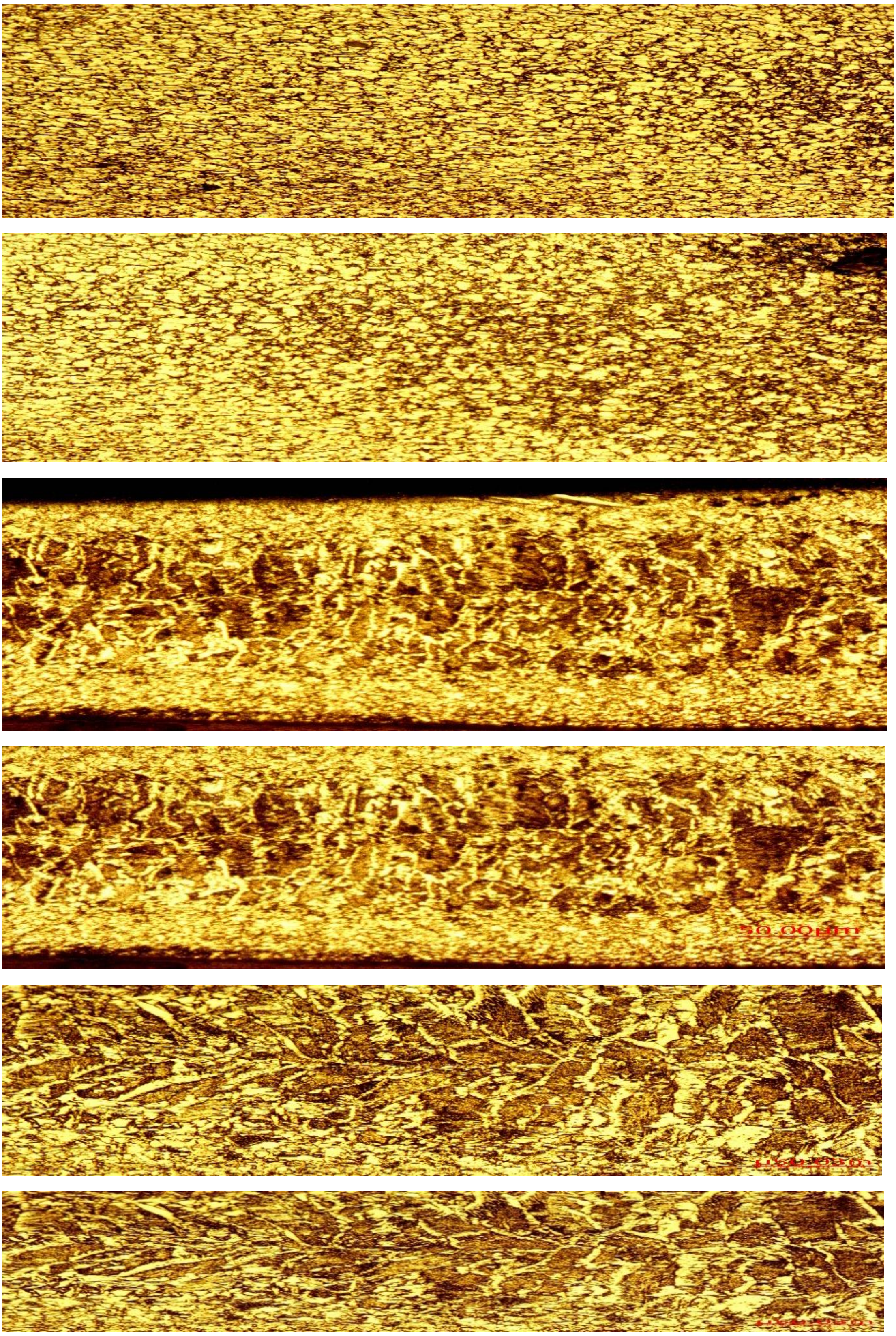


Figure 5.8. Microstructure of BM with interlayer of copper 0.2mm.

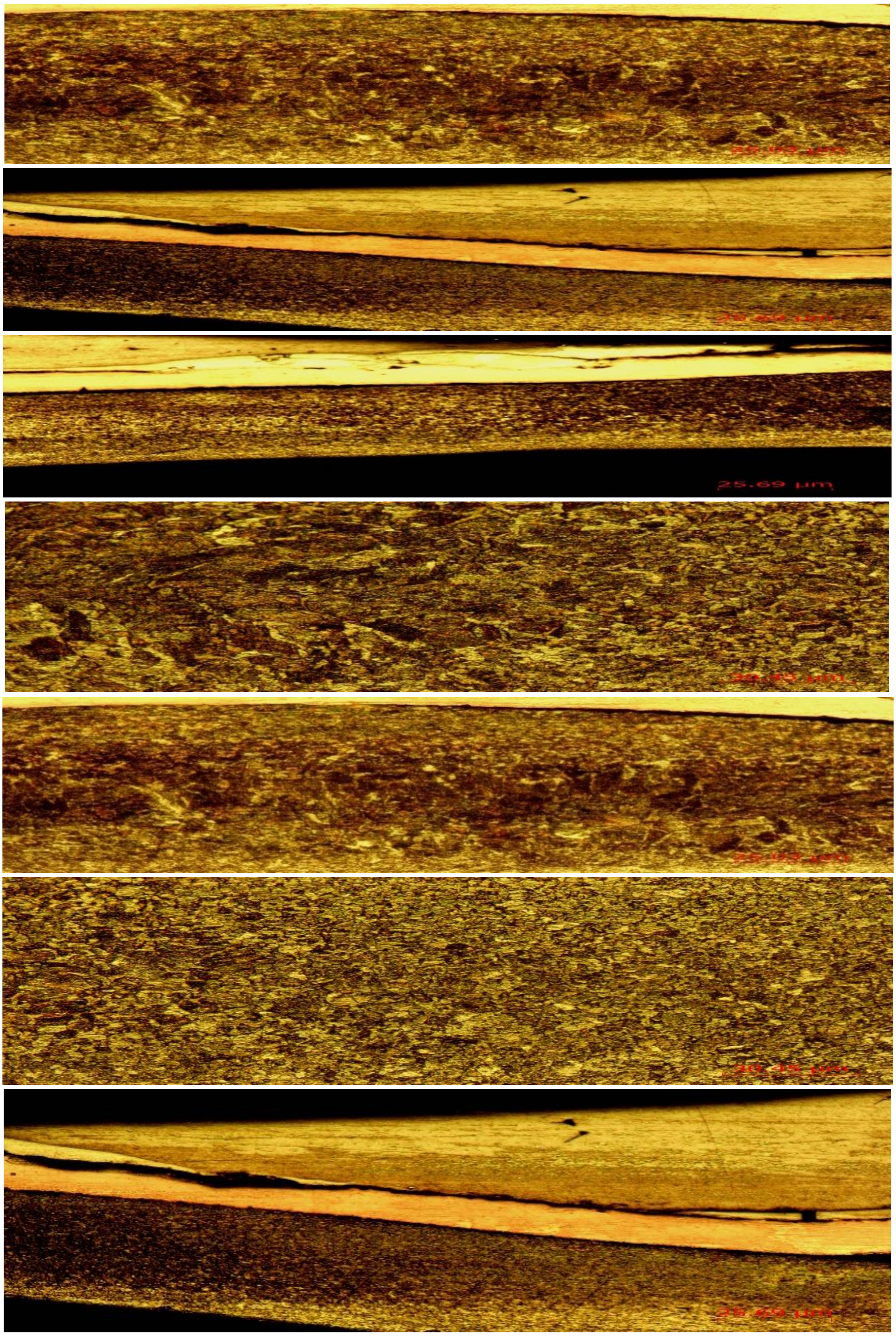


Figure 5.7. Microstructure of BM with interlayer of copper 0.3mm.

5.3. SCANNING ELECTRON MICROSCOPE SEM

Figure 5.8, 5.9 Depicts the SEM pictures of the welding areas with a pure red copper interlayer that is several layers thick (0.02, 0.2, 0.03 , 0.3) mm.

All weld joints exhibit the branching structure. SEM images of the weld block interface in RSW, displaying the entire interlayer area, the post-weld SEM examination discovered that the appearance of uniform microstructure, and the spot area is in wavy shape, indicating the overlap between the interlayer and the aluminum alloy metal and carbon steel giving the impression of welding successfully. The interlayer was homogenized or melted with aluminum metal to produce these waves and their propagation. The interlayer's thickness is a good indicator of it. The final layer of aluminum and copper has a lesser surface area than the other metal layers, but it is 26 microns thick. According to SEM pictures, the copper interlayer obviously leans more toward the alloyed aluminum than the carbon steel.

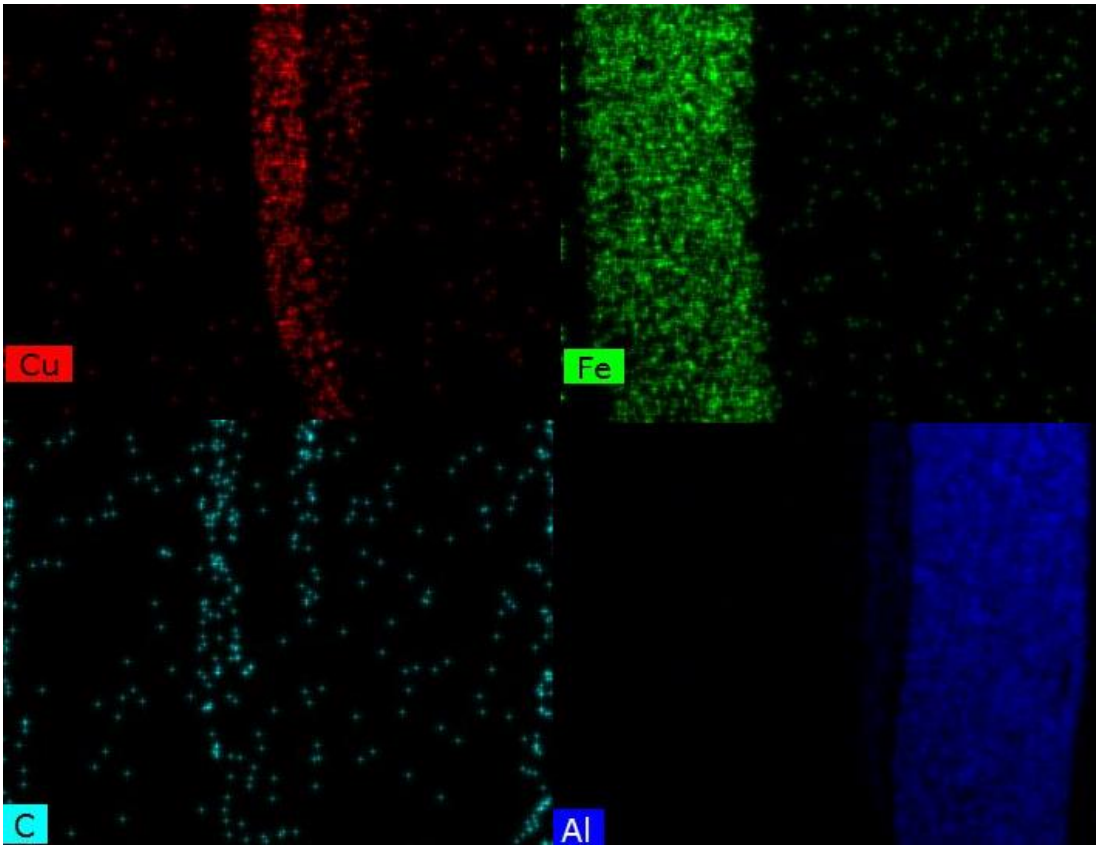


Figure 5.10. SEM for BM with copper 0.02.

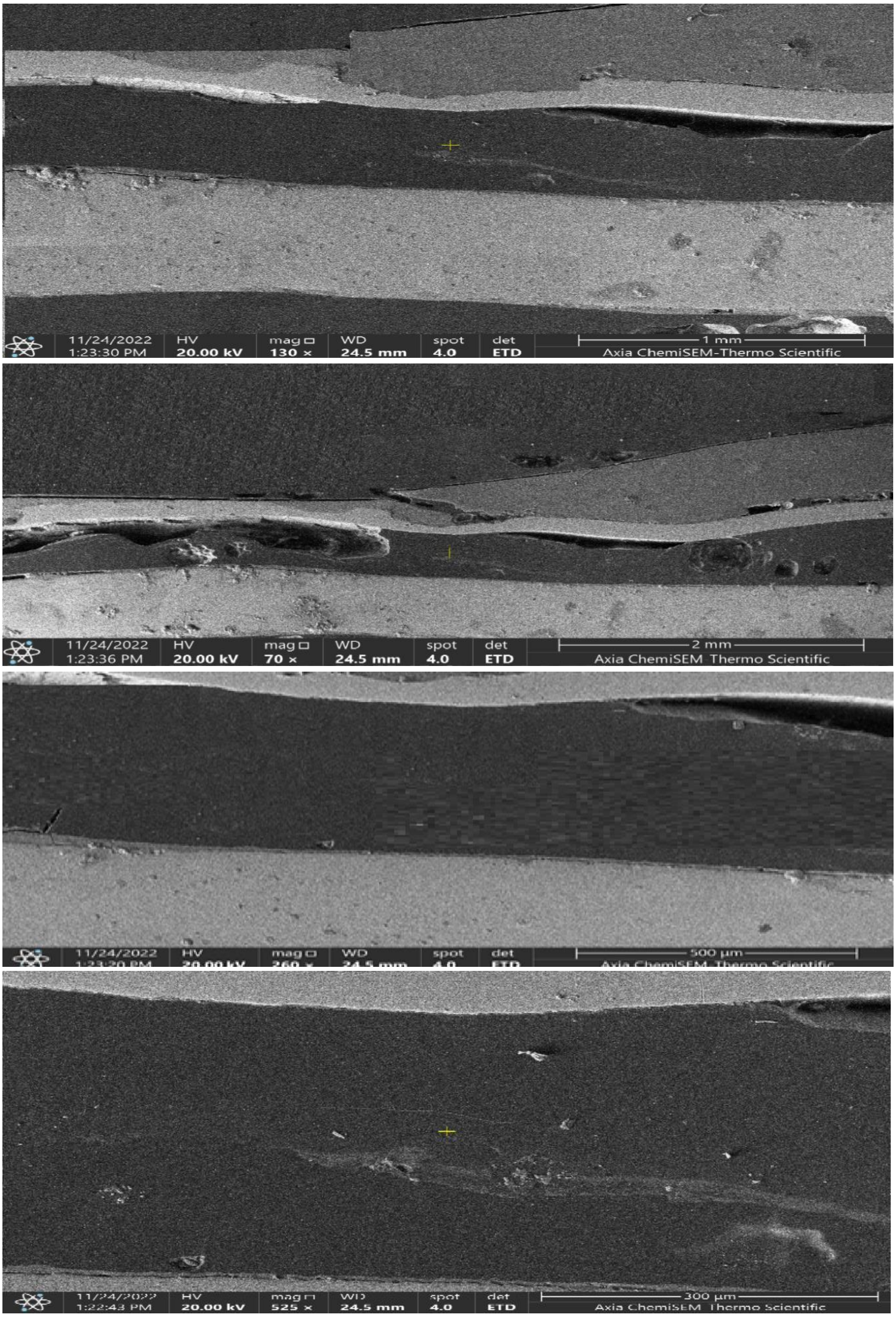


Figure 5.11. SEM for BM with interlayer copper 0.02 mm.

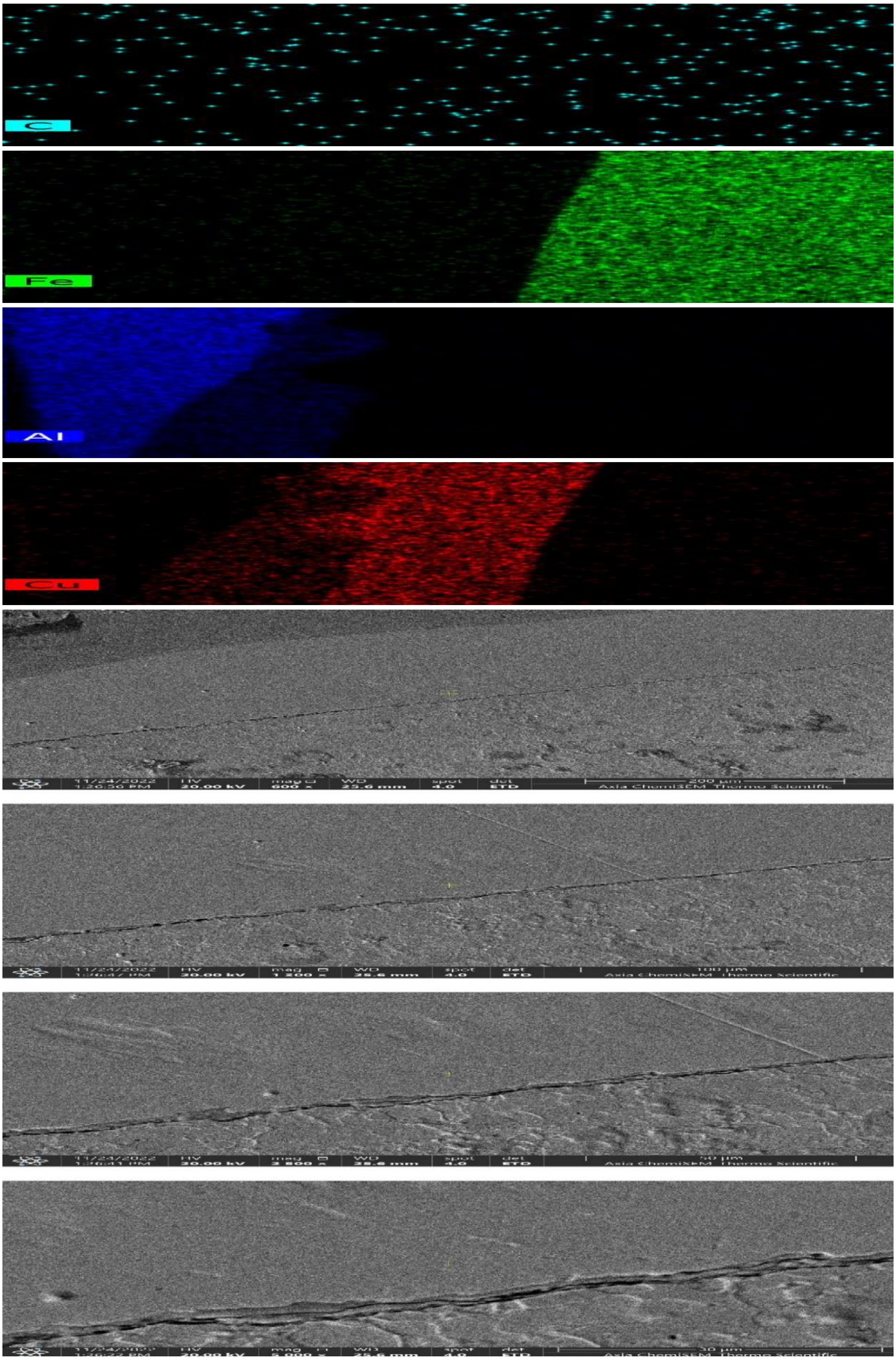


Figure 5.12. SEM for BM with interlayer copper 0.03 mm.

5.4. X-RAY DIFFRACTION XRD

In the XRD test, tensile stress test samples were used after fracture, as they were cut with dimensions of 1cmx1cm, as in Figure 5.8.

Figure 5.13. Specimen of XRD test.

To investigate the phase formation during the joining process, the interface line XRD test was carried out. The XRD spectra, for instance in Fig. 1, showed the initial BM peaks at the interface line in the joint zone (5.15) When spot welding using a metallic interlayer, phase formation screening interface line spectroscopy was used to examine the elements that made up the weld mass. Metal components have been demonstrated to contain chemicals related to the type of interlayer applied. The experiment revealed that the associated region's interface line had fresh X-ray diffraction spectra. The interfacial weld area's XRD patterns. That of copper is around 120 s bond by comparing the intensities of the diffraction peaks and the phases created in welds with various interlayers. Spot welding AA6061 aluminum alloy and carbon steel with an inner copper layer produced a bond that shows indicates that molten copper interferes with aluminum more than steel because aluminum melts at a lower temperature (660 °C) than copper (1084 °C) and carbon steel (1536 Co), and because copper and aluminum alloys have better electrical and thermal properties than carbon steel, which could lead to bonding on the side of aluminum alloys to create this bond[9].

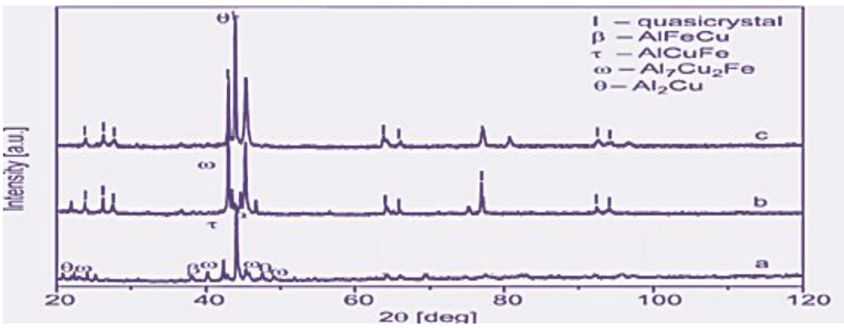


Figure 5.14. XRD of BM with metal interlayer.

5.5. ELEMENTS MOVEMENT THROUGH SPOT WELDING ZONE

- (EDS) line analysis was performed to determine the chemical element distribution across the joint area between the weld metals and the interfacial copper metals. For the analysis of weld mass components in the case of SW with the addition of interlayer. It is proved that the metal pieces contain materials related to the type of interlayer added by the interference, as shown in the figures.
- Demonstrates testing of different welding areas with several interlayer thicknesses.
- The width of the welding area ranges from 280 to 150 micrometers, and the width of the copper is about 120.
- The bond created by spot welding for aluminum alloy AA6061 and carbon steel by using a copper interlayer pointing out that the melted copper interfering through aluminum more than steel because of that aluminum melting (660 c^o) low than copper (1084 c^o) and carbon steel (1536 c^o) and the copper , aluminum alloy electrical and thermal characteristic are higher than carbon steel characteristic, so the bonding may create at the aluminum alloy side to stablish this bond as showing in figural below Figure 5.16 , 5.17 , 5.18 , 5.19.

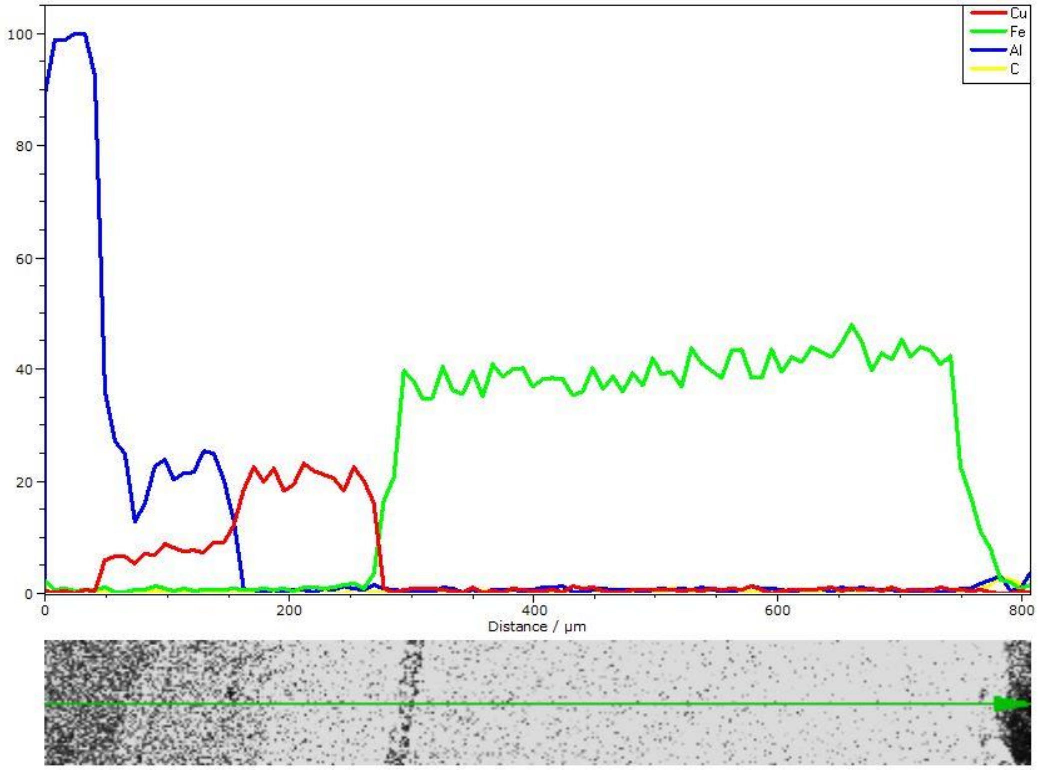


Figure 5.15. EDS line for BM with interlayer of copper 0.3 mm.

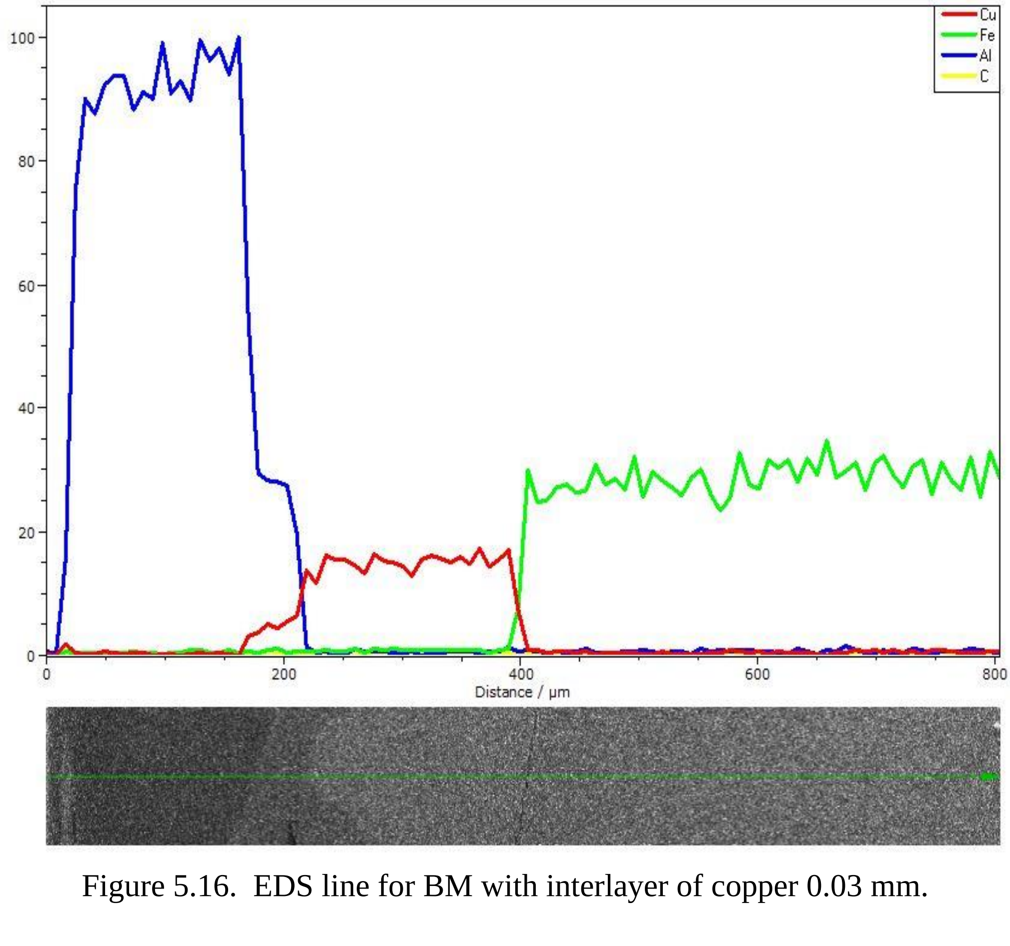


Figure 5.16. EDS line for BM with interlayer of copper 0.03 mm.

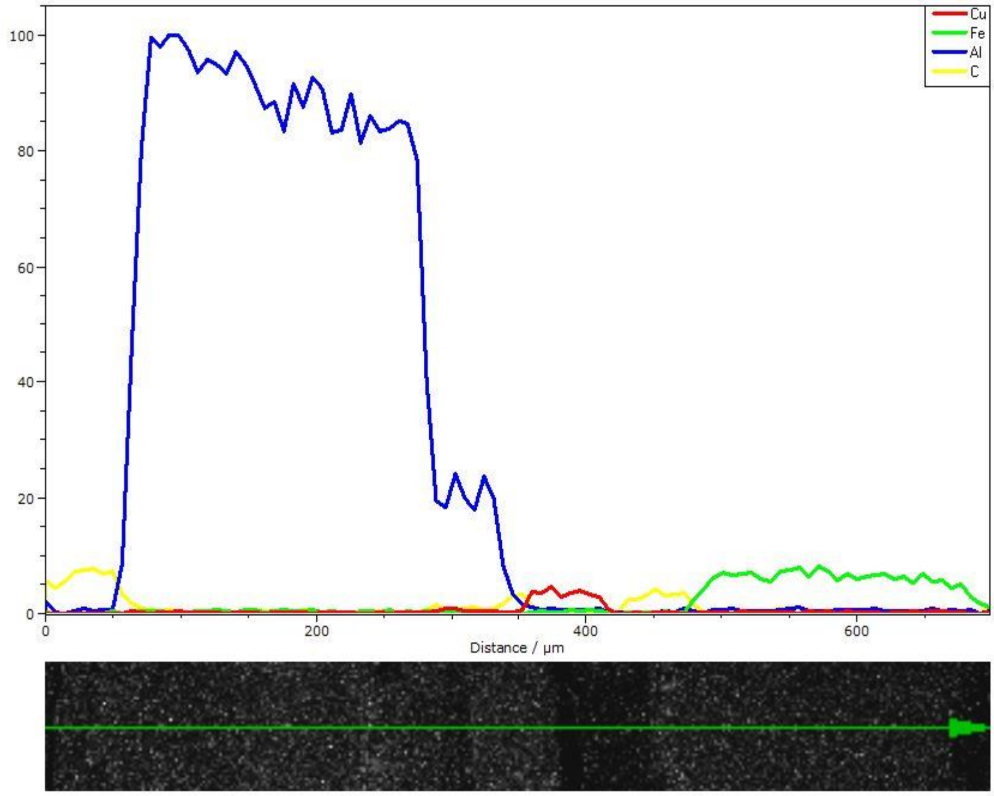


Figure 5.17. EDS line for BM with interlayer of copper 0.02 mm.

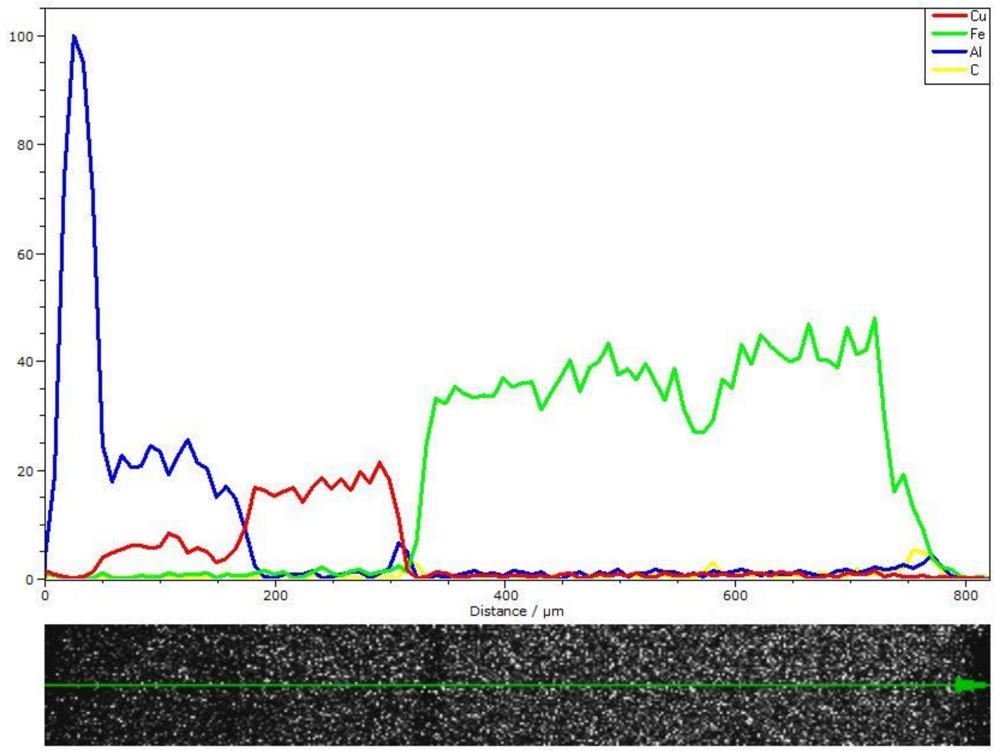


Figure 5.18. EDS line for B.M with interlayer of copper 0.2 mm

PART 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. CONCLUSIONS

Using pure red copper interlayer and resistance spot welding, aluminum alloys and carbon steels are joined together. Weld quality was investigated in the resistance spot welding method with respect to welding parameters (time, current). The present work demonstrated the feasibility of enhancing the weld resistance of resistive spot welding by using an interlayer, the optimum thickness of the pure copper layer. The conclusions that can be made are as follows: During resistance spot welding, the welding current and time usually have the greatest effects on heat input regulation. To obtain spot welds with a good fusion area size but without electrode indentation and extrusion, the welding parameters must be altered. Any increase in welding current and associated welding time causes an increase in the diameter and width of the weld block, which increases the shear resistance. Because the size of the fusion region increased the total bond area. Copper (0.3 mm), carbon steel, and aluminum, which were welded for 0.8 seconds at a current of 12,300 amperes, had a maximum tensile strength (595 N). The lowest tensile strength value was (286 N), which was welded at a current of 12300 amperes and a time of 0.8 seconds, with a thickness of (0.03) mm for the interfacial copper layer.

- The microstructure of the BM joints consists of a wooded structure and the shape is different for all specimens. Common assembly areas are fine (no obvious defects are visible).
- The new method uses the best thickness of the metallic interlayer to greatly increase the welding strength of the pure copper RSW. The increased contact resistance results in increased heat generation, and thus the volume of the solid block. The addition of the metallic interlayer significantly improved the

metallic bonding at the interface and produced high strength welds. Different bonding mechanism increases the total weld area.

- The use of the best thickness of the copper interlayer improves and increases the mechanical properties by comparing the tensile test results of metals welded by spot resistance welding with several thicknesses of the copper interlayer. The increase in the results of the shear tensile test was 33% compared to the results of the other thickness test.
- The interface structure of welded joints was changed due to the introduction of the metal interlayer, and a uniform microstructure appeared.
- It was discovered that the thickness and existence of the metallic interlayer had a considerable impact on the chemical makeup, microstructure, and mechanical characteristics of the base metal joints and the interlayer. The results of the tensile test show that all samples are broken outside the weld area. Withdrawal and withdrawal with ripping of the sheet locations are the two observed failure types.
- Tensile stress, not shear stress, causes the deformation that takes place.
- In any situation, 0.8 s is the ideal joining time.
- Microscopy and SEM images show that the metallic interlayer-added components are what make up the nugget in the alternate method.
- The electrodes' deterioration owing to melting and diffusion, which may result in pitting and rapid electrode corrosion due to pitting on the electrodes' surface, is indicated by the presence of copper (the electrode material) in the welded aluminum strips on the outer surface. Because aluminum melts at a lower temperature than copper (1084 °C) and carbon steel. (1536 °C), and because copper and aluminum alloys have higher electrical and thermal properties than carbon steel, bonding may occur on the side, as shown by the bond formed by spot welding AA6061 aluminum alloy and carbon steel using an inner copper layer. Using aluminum alloys to create this connection. Due to its benefits over other welding techniques, such as its short welding cycle and capacity to join workpieces without the use of consumables, resistance spot welding (RSW) is widely utilized in a range of industries. Suitable for joining materials that are related and unrelated. Of total control over the process variables, this method yields joints with higher quality. Numerous studies are being conducted to

enhance and develop spot resistance welding so that it would be suitable for additional applications. This study aims to investigate the bonding characteristics. Between mild steel and an aluminum alloy, a pure copper metal interlayer is RSW welded for resistance. Pure red interlayer copper sheets in various thicknesses were welded together as filler metal using a resistance spot welding process, with overlay joints measuring 0.2, 0.3, 0.02, and 0.03 mm. There are two sections to the project plan.

- The impact of welding variables (welding current, welding time) on the mechanical characteristics and microstructure of B.M. with a metallic inner layer to be revealed is the topic of the first half of the essay. The tensile shear test and microstructure determine the best welding parameters.
- Three welding currents (8500, 9100, and 12300 A) and three welding times (0.8, 1.2, and 1.6 seconds) were employed.
- The second part was performed to improve the strength and mechanical properties of the BM joint which was welded using metal layers with the best welding parameters of the results of the first part. Pure copper metals with thicknesses of 0.2, 0.3, 0.02, 0.03 mm were used. Use a light microscope to study the solder joint formation technique. Electron microscopy (SEM) and X-ray diffraction (XRD) were also used to evaluate the feasibility of using interlayers. While the patterns of joint strength and failure were tested using the tensile test, the results indicated that the best time to join was 0.8 seconds in all cases. Tensile strength value. The interlayers significantly increased the metallic bonding at the interface. When the total weld area increases, this increase leads to more bonding and stronger welds. When using interlayers, the tensile strength was increased due to the increase in the thickness and diameter of the weld block. It was found that there is a difference in the size of the weld according to the variables.

6.2. RECOMMENDATIONS

Based on the insights gleaned from this research, the following recommendations are given for further research:

- Rerun the tests with different metallic interlayer thicknesses. The pole strength also alters.
- Repeat the tests with a different metallic coating, like gold or nickel.
- Use the cross-section test and peel test to immediately assess the tensile strength of welded specimens.
- Researching several mechanical qualities, such as the micro-hardness of welds in RSW, as well as some dynamic properties, such as stress.
- Improving the resistance spot welding technique such that the DOE approach may be used to analyze how parameters affect the solid mass area of welded metals.
- Examine the impact of resistance spot welding parameters on the temperature distribution using finite element analysis (FEM). On identical tantalum's temperature distribution.
- Monitoring welding temperature with a thermal camera.

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RESUME

Hamzah Younus is a highly skilled mechanical engineer who graduated from the Department of Mechanical Engineering at Central Technical University-Technical College of Engineering in Baghdad in 2005. He has worked as a mechanical engineer for the past fifteen years in Baghdad, gaining extensive experience and expertise in the field.

Throughout his career, Hamzah has held several positions in government jobs, showcasing his ability to thrive in challenging environments. He is currently employed by the Department of Municipalities of Baghdad Governorate, where he continues to apply his mechanical engineering skills to improve the city's infrastructure and facilities.

Hamzah is a dedicated professional who takes pride in his work, and his commitment to excellence has made him a highly valued member of the engineering community in Baghdad. He is known for his strong work ethic, attention to detail, and ability to tackle complex engineering challenges.

In addition to his impressive career achievements, Hamzah is happily married and has been since 1996. He is an excellent role model both in his professional and personal life and has earned the respect and admiration of those who have worked with him over the years.