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KSCST
Karnataka State Council for Science and Technology
Indian Institute of Science Campus, Bengaluru - 560012

Project Proposal Reference No. : 46S_BE_0143

A Project Report On

“AN INVESTIGATION OF MICROSTRUCTURAL AND INFLUENCE OF BONDING TEMPERATURE ON MECHANICAL PROPERTIES OF DIFFUSION BONDED Al2219-TI-6Al-4V JOINTS”

In partial fulfillment of
BACHELOR OF MECHANICAL ENGINEERING
2022-2023

Submitted by

ROHAN M	**1RN19ME074**
SUNILKUMAR	**1RN19ME091**
SURESHKUMAR	**1RN19ME092**
VARUNKUMAR M J	**1RN19ME100**

Under the guidance of
Dr. Bharath V
Assistant Professor
Department of Mechanical Engineering
RNSIT, Bengaluru

DEPARTMENT OF MECHANICAL ENGINEERING

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DEPARTMENT OF MECHANICAL ENGINEERING

CERTIFICATE

This is to certify that the project work titled "AN INVESTIGATION OF MICROSTRUCTURAL AND INFLUENCE OF BONDING TEMPERATURE ON MECHANICAL PROPERTIES OF DIFFUSION BONDED Al2219-TI-6Al-4V JOINTS" has been successfully carried out by SURESHKUMAR (1RN19ME092), SUNILKUMAR (1RN19ME091), ROHAN M (1RN19ME074), VARUNKUMAR M J (1RN19ME100), bonafide students of RNS Institute of Technology in partial fulfilment for the award of *Bachelor of Engineering in Mechanical Engineering* under Visvesvaraya Technological University, Belagavi during the academic year 2022-2023. It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the report deposited in the departmental library. The project report has been approved as it satisfies the academic requirements in respect of project work for the said degree.

Signature of Guide	Signature of HOD	Signature of Principal
09/05/23	Prof & Head Dept. Of Mechanical Engineering R.N.S. Institute of Technology Channasandra, Bangalore- 560098.	PRINCIPAL R.N.S.I.T., Bengaluru-98
Dr. Bharath V	**Dr. Mukesh Patil**	**Dr. Ramesh Babu H S**

Name of Examiners:	Signature with date
1. Dr. N. Sreenivasulu Reddy	25/5/23
2. Madhusudana H C	25/5/23

Karnataka State Council for Science and Technology
(An autonomous organisation under the Dept. of Science & Technology, Govt. of Karnataka)
Indian Institute of Science Campus, Bengaluru – 560 012
Telephone: 080-23341652, 23348848, 23348849, 23348840
Email: office.kscst@iisc.ac.in, office@kscst.org.in • **Website:** www.kscst.iisc.ernet.in, www.kscst.org.in

Dr. U T Vijay
Executive Secretary

24th April, 2023

Ref: 7.1.01/SPP/33

To,
The Principal,
R.N.S. Institute of Technology,
Channasandra,
Bengaluru – 560 098.

Dear Sir/Madam,

Sub : Sanction of Student Project - 46th Series: Year 2022-2023

Project Proposal Reference No. : **46S_BE_0143**

Ref : Project Proposal entitled **AN INVESTIGATION OF MICROSTRUCTURAL AND INFLUENCE OF BONDING TEMPERATURE ON MECHANICAL PROPERTIES OF DIFFUSION BONDED AL TWO TWO ONE NINE TI-SIX-AL -FOUR V JOINTS**

We are pleased to inform that your student project proposal referred above, has been approved by the Council under "Student Project Programme - 46th Series". The project details are as below:

Student(s)	Mr. VARUN KUMAR M J	**Department**	MECHANICAL ENGINEERING
	Mr. SURESHKUMAR		
	Mr. SUNILKUMAR		
	Mr. ROHAN M	**Sanctioned Amount (in Rs.)**	5,000.00
Guide(s)	Dr. BHARATH V		

Instructions:

a) The project should be performed based on the objectives of the proposal submitted.

b) Any changes in the project title,objectives or students team is liable for rejection of the project and your institution shall return the sanctioned funds to KSCST.

c) Please quote your project reference number printed above in all your future correspondences.

d) After completing the project, 2 to 3 page write-up (synopsis) needs to be uploaded on to the following Google Forms link https://forms.gle/nWTaJjvrwzp3Wmvt6. The synopsis should include following:

1) Project Reference Number
2) Title of the project
3) Name of the College & Department
4) Name of the students & Guide(s)
5) Keywords
6) Introduction / background (with specific reference to the project, work done earlier, etc) - about 20 lines
7) Objectives (about 10 lines)

8) Methodology (about 20 lines on materials, methods, details of work carried out, including drawings, diagrams etc)

9) Results and Conclusions (about 20 lines with specific reference to work carried out)

10) Scope for future work (about 20 lines).

e) In case of incompeted projects, the sanctioned amount shall be returned to KSCST.

f) The sanctioned amount will be transferred by NEFT to the bank account provided by the College/Institute.

g) The sponsored projects evaluation will be held in the Nodal Centre/Online Mode and the details of the same will be intimated shortly by email / Website announcement.

h) After completion of the project, soft copy of the project report duly signed by the Principal, the HoD, Guide(s) and studetn(s) shall be uploaded in the following Google Forms Link https://forms.gle/YWz56TrGg7fnSQgc7. The report should be prepared in the format prescribed by the university.

Please visit our website for further announcements / information and for any clarifications please email to spp@kscst.org.in

Thanking you and with best regards,

Yours sincerely,

(U T Vijay)

Copy to:

1) The HoD
MECHANICAL ENGINEERING
R.N.S. INSTITUTE OF TECHNOLOGY, BENGALURU

2) Dr. BHARATH V
MECHANICAL ENGINEERING
R.N.S. INSTITUTE OF TECHNOLOGY, BENGALURU

3) THE ACCOUNTS OFFICER
KSCST, BENGALURU

DECLARATION

We, **SURESHKUMAR (1RN19ME092), SUNILKUMAR (1RN19ME091), ROHAN M (1RN19ME074), VARUNKUMAR M J (1RN19ME100)** students of *VIII* **Semester B.E, Mechanical Engineering, RNS Institute of Technology, Bengaluru, hereby declare that the project work titled "AN INVESTIGATION OF MICROSTRUCTURAL AND INFLUENCE OF BONDING TEMPERATURE ON MECHANICAL PROPERTIES OF DIFFUSION BONDED Al2219-TI-6Al-4V JOINTS"** has been carried out by us and submitted in partial fulfilment of the requirement for the ***VIII* semester** Degree of ***Bachelor of Engineering*** *in* ***Mechanical Engineering*** of Visvesvaraya Technological University, Belagavi, during academic year 2022-2023.

Date:

Place:

SURESHKUMAR

SUNILKUMAR

ROHAN M

VARUNKUMAR M J

ACKNOWLEDGEMENT

The satisfaction and euphoria that accompany the successful completion of any task would be incomplete without the mention of the people who made it possible, whose constant guidance and encouragement crowned the efforts with success.

We would like to thank the Management of **RNS Institute of Technology** for providing such a healthy environment for the successful completion of project work.

We would like to express our thanks to the Principal **Dr. Ramesh Babu H S** for his encouragement that motivated us to successful carryout the project work.

It gives us immense pleasure to thank **Dr. Mukesh Patil,** Professor and Head of Department, Mechanical Engineering for his constant support and encouragement.

We wish to express our deepest sense of gratitude to our project guide **Dr. Bharath V,** Assistant Professor**,** Department of Mechanical Engineering for his constant support and guidance throughout the project.

Last, but not the least, we would like to hereby acknowledge and thank our parents who have been a source of inspiration and also instrumental in the successful completion of our project.

SURESHKUMAR

SUNILKUMAR

ROHAN M

VARUNKUMAR M J

ABSTRACT

Aluminum alloys have good strength to weight ratio commonly found in structural aircraft parts. Titanium alloys are employed in aerospace applications because they strike a good compromise between having a high specific strength and strong corrosion resistance. So, if these alloys are joined together, they are able to produce parts having significant reduction in weight as well as cost and hence they have greater focus on academic study and commercial applications. The production of oxide layers and brittle intermetallic in the bonded zone is the main challenge when joining titanium and aluminum. Solid state diffusion bonding, however, can be used to join the se alloys without too many difficulties. This investigation outlines the process for determining diffusion bonding parameters including temperature, pressure, and holding time for titanium alloys and aluminum alloys. The current research attempts to solid-state diffuse bond two different aerospace alloys, Ti-6Al-4V and Al2219. The bonding procedure is conducted for varying bonding temperatures, i.e., 480, 500 and 520°C, at constant bonding Time 45min and bonding pressure of 2.5 MPa. The compositional variation across the joint interface is examined using scanning electron microscopy (SEM) and X-ray diffraction (XRD). Using the Vickers Micro-hardness test with a 50g minding load and a15secd well period, the hardness at joint inter faces is assessed. It has been found that the creation of intermetallic compounds causes the hardness at surface stories with temperature. The joint region integrates as bonding time increases and provides a strong bond strength of 143.96MPa after 45 minutes of bonding.

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CHAPTER 1

1. INTRODUCTION

1.1 Diffusion Bonding

Solid-state welding is a diffusion bonding method that can be used to join both different and similar materials. This entire process is based on the solid-state diffusion principle, which states that coalescence of the faying surfaces occurs over time at high temperatures and pressures [1] In order to create a strong link between the base materials. Solid state diffusion bonding is attractive for combining dissimilar materials because, when compared to conventional welding procedures, it has a lower potential for the formation of brittle intermetallic compounds (IMCs), chemical segregation, and residual tension build-up at the bond interface [2]. Diffusion bonding is more expensive than other methods of joining and is mostly employed in the aerospace industry. Diffusion bonding, in addition to joining various materials, can also be used for entire cross-section bonding, which may be especially beneficial for holohedral connections, such as the internal components of plate-type heat exchangers [3].

Transient liquid phase (TLP)bonding differs from solid-stated if fusion bonding in that it uses an interlayer in the center of the materials to be joined that has a lower melting point than the parent materials and can liquefy below the bonding temperature. Isothermal solidification occurs at the bonding temperature as a result of the interlayer material (or component of an alloy interlayer) diffusing into the parent materials. As a result, a bond is formed with a melting point that is greater than the original TLP bonding temperature [4]. In vacuum brazing the filler material (or interlayer) does not completely diffuse into the parent materials when put between them, furthermore isothermal solidification does not take place and the resulting bond still possesses the interlayer (filler) material's melting point. In addition to it, no applicable pressure is applied in vacuum brazing permitting it for much simpler apparatus. For diffusion bonding, exceptional and high-priced equipment is essential as parts have to be warmed up at higher temperatures in a protective gas atmosphere while applying significant amounts of controlled pressure. It is worth considering that interlayers can also be utilized for diffusion bonding in solid state. This could be, for example convenient if a large dissimilarity in coefficient of thermal expansion there must be a solution for different materials. To be classified as a process.

The main advantage of diffusion bonding is its ability to produce connections of excellent quality without porosity or metallurgical discontinuities across the contact. This technique allows for the production of very precise, elaborately formed components without the need for additional machining to ensure that the dimensions of components are within acceptable tolerances. Diffusion bonding makes it possible to combine materials with disparate thermo-physical characteristics, something that is not possible with conventional methods. Combining things comprised of alloys, metals, powder metallurgy, and ceramics has been done using diffusion bonding [7].

There are two basic stages in the solid-state diffusion bonding mechanism. The asperities on each of the fabricating work surfaces will distort plastically in the first phase when pressure is applied. Grinding or polishing marks left over from the surface finishing procedure generate these imperfections. Micro plastic deformation begins when the localized effective stress in the immediate area falls below the material's yield strength at the bonding temperature. In reality, the initial contact takes place between the oxide layers that cover the faying surfaces. Asperities deform as a result of localized disordering of the more brittle oxide coatings, which often shatter quickly, increasing the amount of metal-to-metal contact. At the conclusion of the first phase, there are still a sizable number of voids and oxide between the localized bonded patches and the bonded area is less than 10%. The following bonding stage incorporates thermally driven mechanisms **(**creep and diffusion**),** which result in void contraction and bond area expansion **[**8].

1.2 JOINING PROCESS

One of the manufacturing processes called joining allows two or more materials to be connected or put together, either permanently or temporarily, with or without the use of an external element to create a single unit. These joining techniques come in a wide range of variations today to meet the demands of assembling a wide range of materials in a number of ways for a variety of processing or applications. Welding, brazing, soldering, and adhesive bonding of materials are all examples of joining.

1.3 WELDING

It is a method of connecting metal in which two or more pieces are fused together at their contact surfaces using the proper amounts of pressure and heat. Sometimes pressure is not used during the welding process; only heat is used.

In some circumstances, pressure and heat are applied simultaneously; in other circumstances, only pressure is used, with no outside heat. To encourage coalescence, a filler material is sometimes used in welding procedures. Brazing and soldering, which use lower temperatures but do not melt the base metal, are different from welding (parent metal). A filler material is often injected to the joint after the base metal has melted to create a pool of molten metal that cools to form a junction that, depending on the weld configuration, may be stronger than the base metal. To create a weld, pressure can either be applied alone, in combination with heat, or both. In order to prevent contamination or oxidation of the filler metals or molten metals during welding, a shield is also necessary. Two major categories can be used to classify welding processes,

- Fusion Welding (Non-Pressure)
- Solid State welding (Pressure Welding)

❖ FUSION WELDING

Heat is used in fusion welding procedures to melt the base metals. In order to speed up the process and strengthen the welded joint, filler metal is frequently added to the molten pool during fusion welding. The fusion welding process is known as an autogenous weld when no filler metal is employed. A heat-affected zone is produced in the material as a result of the high temperature phase transitions inherent to these operations. Some of the major fusion welding types are explained as below.

1.3.1 ARC WELDING

- **Gas tungsten arc welding**

Due to the high quality of the results, it is a procedure that is frequently used to combine metals that are similar and different from one another. It is an arc welding procedure that creates a weld using tungsten electrode that is not consumable.

An inert shielding gas shields the electrode and the weld region from oxidation. Electrical energy is generated by a constant-current welding power supply and is transferred across the arc by a plasma column, which is a column of highly ionized gas and metal vapours. The most typical application for GTAW is the joining of thin sections of stainless steel and non-ferrous metals like aluminium, copper, and magnesium alloys.

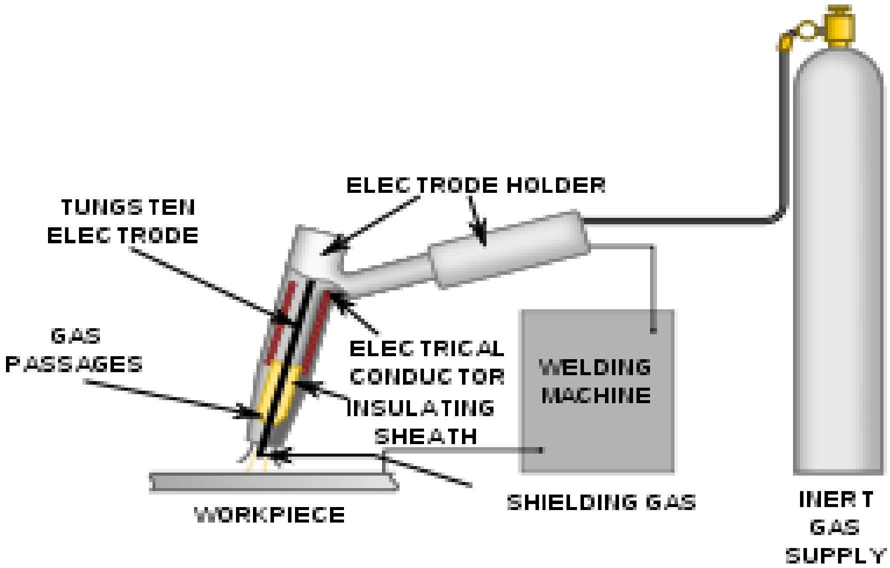

Figure 1.1: Gas Arc Welding

- **Submerged arc welding**

Submerged arc welding is a joining technique that creates an electric arc between the work piece to be joined and a constantly fed electrode. When melted, a layer of powdered lux surrounds and covers the arc, enabling electrical conductivity between the electrode and the metal to be linked. Additionally, this produces a protective gas shield and slag, both of which shield the weld zone. The arc zone and the molten weld are shielded from atmospheric contamination by being covered in granular fusible flux, which is composed of calcium fluoride, lime, silica, manganese oxide, and other substances. The flux creates a current conduit between the work and the electrode when it is molten and becomes conductive. The powerful UV light and fumes that are produced during the submerged metal arc welding process are suppressed by the thick layer of flux that completely covers the molten metal, preventing spatter and sparks.

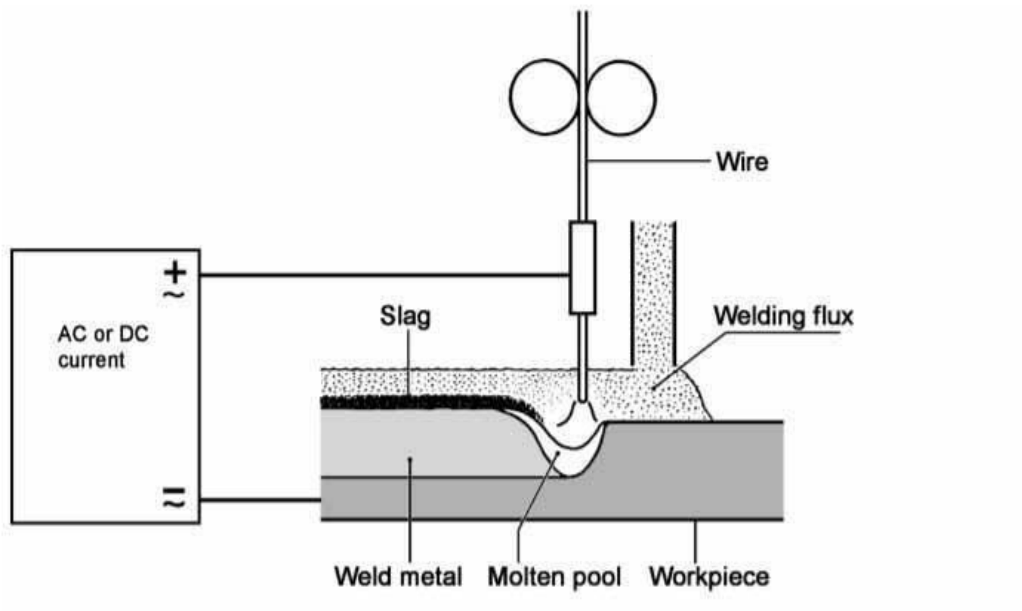

Figure 1.2: Submerged Arc Welding

- **Plasma Arc Welding**

The underlying idea behind this process is that when an inert gas receives enough energy, some of its electrons will break free from their nuclei and move along with the gas. The atoms that are transformed into a heated ionized state after the electrons depart. The fourth state of matter is the one that occurs most frequently. The increased heat produced by these ionized atoms is also employed to connect two plates. The fundamental idea behind plasma arc welding is this. An extended version of TIG welding, this technique of welding creates an arc using a non-consumable tungsten electrode. The inert gases supplied by the inner aperture around the tungsten electrode are heated by this arc. About 30000 degrees Celsius is the heating temperature at which the gas changes into an ionized state. A welding junction is further created by fusion using this hot, ionized plasma. The primary distinction between PAW and TIG is the placement of the electrode within the torch body, which keeps the plasma arc apart from the shielding gas envelope. The arc is then constrained by a fine-bore copper nozzle, forcing the plasma through it. The plasma then exits the orifice at high speeds and temperatures of up to 28,000 °C (50,000°F).

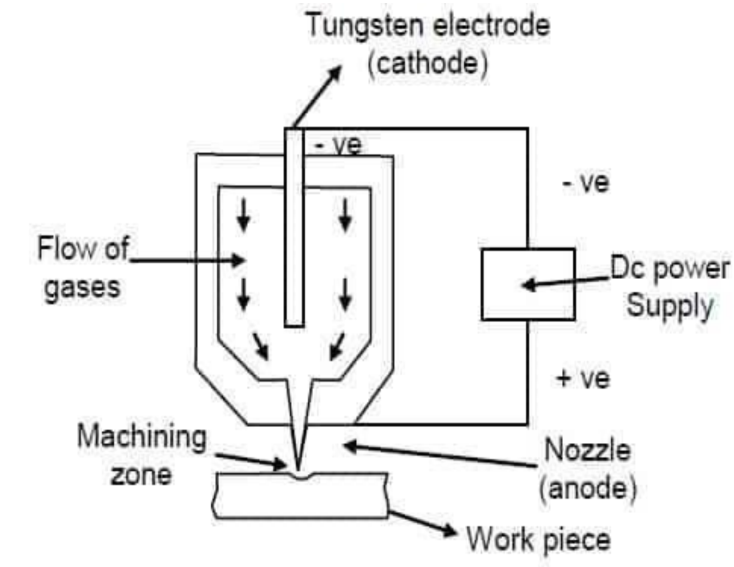

Figure 1.3: Plasma Arc Welding

1.3.2 Resistance Welding

- **Spot Welding**

Spot welding is a sort of electric resistance welding that is used to unite contacting metal surface points on various sheet metal goods. This procedure generates heat through resistance to an electric current. In this method, the sheets are clamped together while the welding current is concentrated into a small area using two shaped copper alloy electrodes. Work pieces are kept together by the electrode pressure. The sheets typically range in thickness from 0.020 to 0.118 inches, or 0.5 to 3 mm. The metal will melt and produce the weld when a strong current is forced through the area. The metal will melt and produce the weld when a strong current is forced through the area. The ability to quickly transfer a significant quantity of energy to the location makes spot welding appealing (approximately 10–100 milliseconds).

This enables the welding to take place without overheating the remaining sheet. Spot welding is a low-cost process because it doesn’t need any fillers or any extra materials unskilled labour can do the spot welding and it’s a faster process compared to the regular welding process.

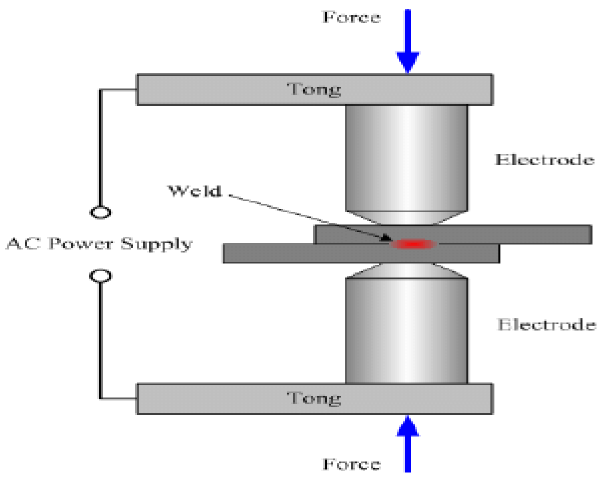

Figure 1.4: Spot Welding

- **Seam Welding**

Seam welding is the technique of applying heat produced by electrical resistance to the seams of two materials, whether they are similar or dissimilar. Resistance welding of this kind uses roller electrodes as opposed to pointed electrodes to create the weld. Most seam welding processes produce a continuous or intermittent seam weld near the edge of two overlapped metals by using two machine driven by the roller electrodes. As in the seam welding process, the roller electrodes move over the work pieces, the work pieces are under pressure and the current passing through them heats the two work pieces of the metal to the melting point. One of the most popular welding techniques for joining metal sheets with a continuous weld is resistance seam welding.

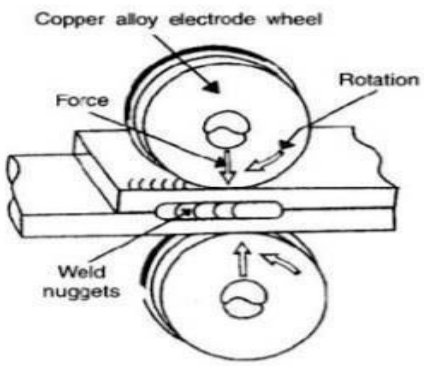

Figure 1.5: Seam Welding

- **Resistance Butt Welding**

By this type welding, the entire cross section in a single operation, this sort of welding is used to combine components with identical cross sections. By encountering resistance as the welding current passes through the pieces, which are held together by a specified force, heat is generated in the weld area. The force forges the soft material to consolidate and finish the join as the material warms. As a result, this process operates in a solid state.

The force acting across the inter face generates the deformation that brings the surfaces close enough together to form a weld, and there is also some material expulsion that removes impurities and the oxide coating from the joint.

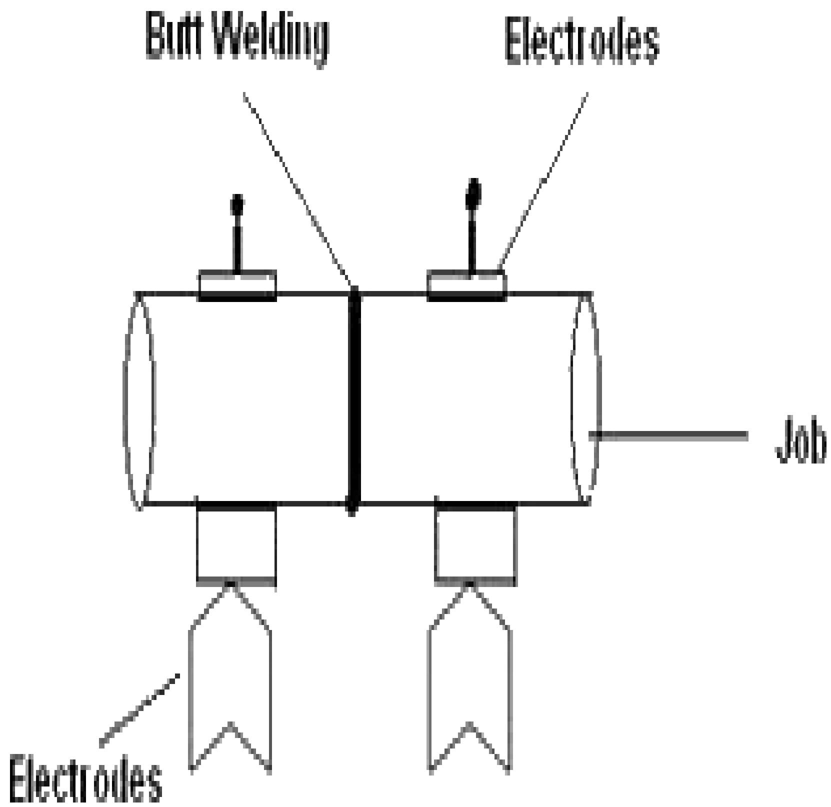

Figure 1.6: Resistance Butt Welding

❖ **SOLID STATE WELDING**

Without the use of brazing filler metal, it is a pressure welding procedure that results in coalescence at temperatures that are practically below the melting point of the base materials being joined. In this process, base metals agglomerate without significantly melting as a result of pressure, time, and temperature acting singly or in combination. Solid state welding comprises the following:

i. Forge welding
ii. Friction welding
iii. Ultrasonic welding
iv. Diffusion welding

1. Forge Welding

It is a solid-state welding process which joins two metal pieces by heating them toa high temperature and pressing the metals together. Forge welding adaptability enables it to join metals that are both similar and dissimilar. Typically, between50%and90%ofthe melting point temperature of the base metal is required for forge welding. This method involves the forging of steels with both high and low carbon contents. Some alloys of aluminium can also be forged

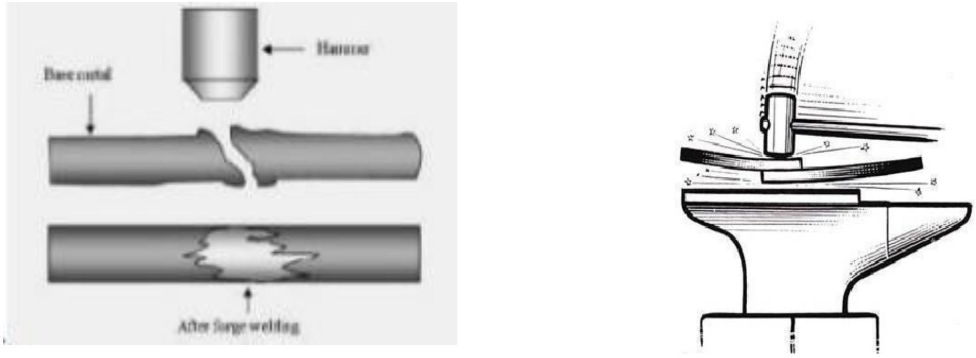

Figure 1.7: Forge Welding

2. Friction Welding

A type of solid-state welding termed friction welding uses mechanical friction between a moving element and a stationary one to produce heat. At the same time, upset, or lateral force, is applied to the parts to plastically displace and merge the material .Metals and thermoplastics are used for friction welding in a number of automotive and aviation applications.

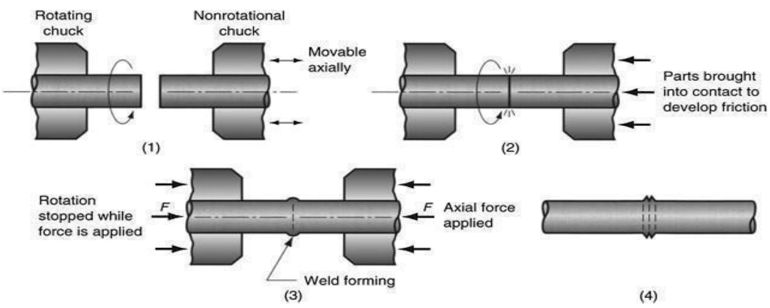

Figure 1.8: Friction Welding

3. Ultrasonic Welding

In order to form a solid-state weld, high frequency ultrasonic acoustic vibrations are imparted to the work piece that is being held together under pressure during the ultrasonic welding process. These methods are frequently employed for connecting different materials, particularly metals and polymers. Nails, bolts, and soldering materials are not used in ultrasonic welding to join the components together. One distinguishing feature of this approach when used on metals is that the temperature will remain below the melting point of the source material, preventing any undesirable qualities that would result from exposing the components to high temperatures.

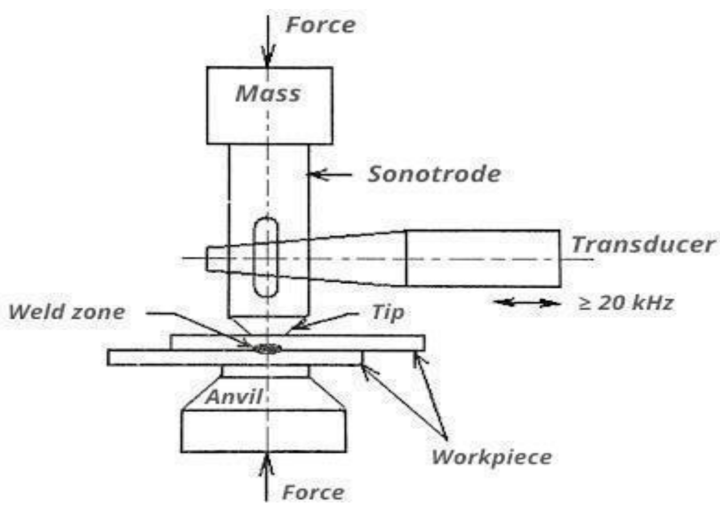

Figure1. 9: Ultrasonic Welding

4. Diffusion Welding

Diffusion welding, also known as diffusion bonding, is a solid state welding technique used in the metal working industry that may fuse metals that are both comp arable and dissimilar. It functions according to the solid-state diffusion principle, in which the atoms of two metallic, solid surfaces scatter one another over time. This entire process is normally carried out at a high temperature, roughly between 50% and 75% of the materials' absolute melting points. The materials to be welded or bonded are typically subjected to high pressure at a temperature that is unavoidably high.

The most typical application of this technology is to join together "sandwiches" made of alternating layers of thin metal foil and metal filaments or wires.

Currently, the aerospace sector as well as the automotive industries both use diffusion bonding extensively to link high strength and refractory metals. There are two main types of diffusion bonding. They are:

1. Solid state diffusion bonding
2. Transient liquid phase bonding

- **Solid State Diffusion Bonding**

With the help of applied pressure for a period of time ranging from a few minutes to a few hours, two flat interfaces can be bonded utilizing the solid-state diffusion bonding method at a temperature between 50% and 90% of the parent material's absolute melting point. Diffusion bonding makes it possible to combine materials with disparate thermos physical characteristics, something that is not possible with conventional methods. Diffusion bonding has been utilized to bind ceramics, powder metallurgy products, alloys, and metals. This entire procedure has the capacity to yield high-quality joints with no metallurgical discontinuities or porosity present across the interface.

- **Transient Liquid Phase Bonding**

The bonding procedure known as transient liquid phase (TLP) bonding uses an interlayer to link the components. When heated, the interlayer melts, releasing an element (or an alloy interlayer component) that diffuses into the substrate materials and leads isothermal solidification.

When choosing an appropriate interlayer for this bonding process, it is important to take into account factors like wettability, flow characteristics, high stability to prevent reactions with the base materials.

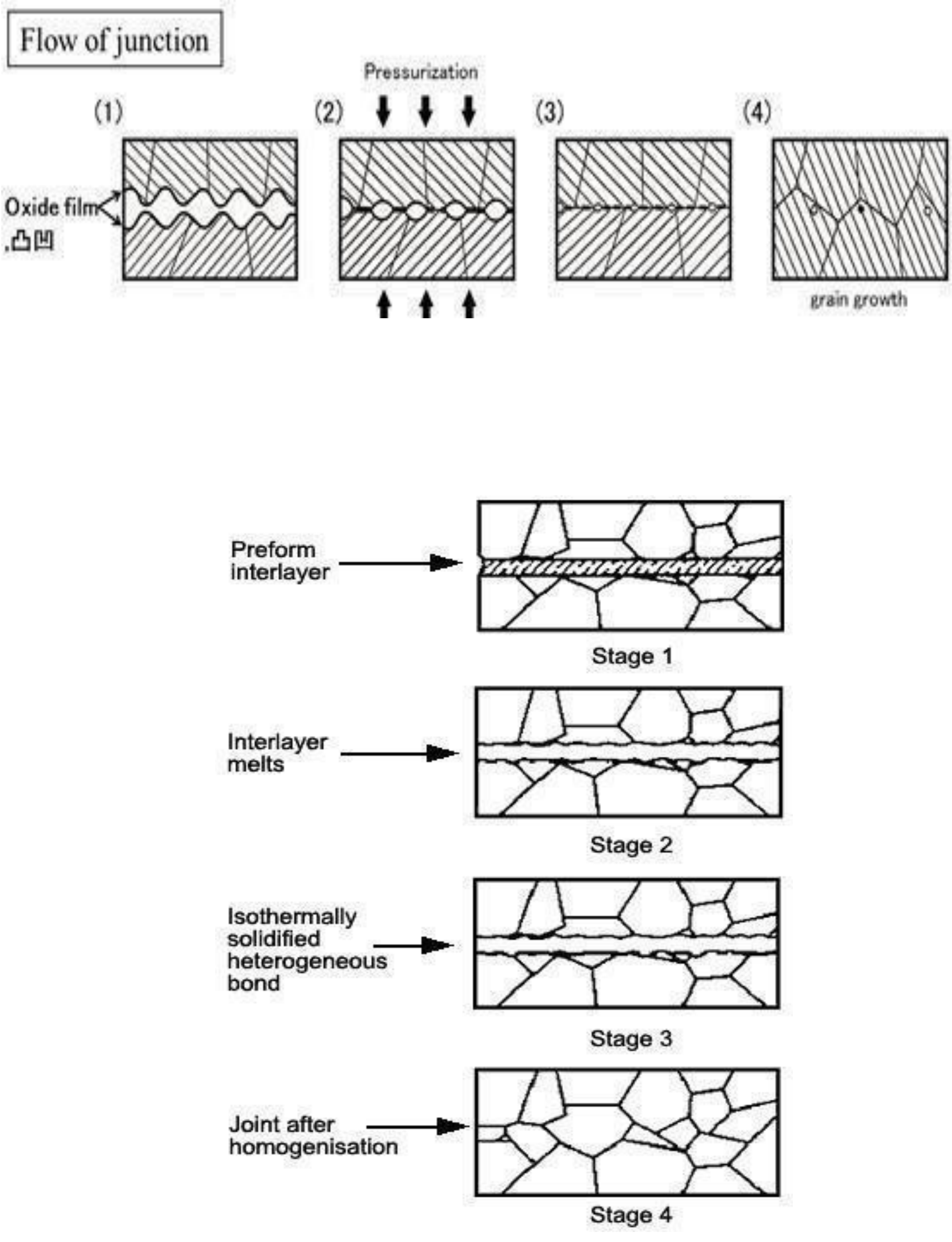

Figure 1.1.1: Transient liquid phase bonding

CHAPTER 2

2. LITERATURE REVIEW

Yongkang Liu et al (2022) utilized a Cu nano -coating interlayer, the Al-Mg Li alloy was air atmospheric diffusion bonded; the interlayer prevented the formation of an oxide film and improved atomic diffusion. According to the findings, the joint' side a shear strength is 187.9 MPa, which is 90.6 percent higher than the shear strength of base metals. The interlayer has a significant number of Nano twins with good thermal stability because it was ultrasonically deposited. Since there are more grain boundaries in nano structured coatings than in their course- grained equivalents, atomic diffusivity is greatly increased. Additionally, Cu coatings exhibit exceptional plastic deformation capability at higher temperatures. More Cu components mix with Al and Mg in the matrix to generate many IMCs as the coating thickness rises. The ideal shear strength for a 1 μ m thick diffusing contact was187.9MPa, or90.6 percent of the base metal, and the diffusion temperature was 530 °C [9].

Aravindan T et al (2021) investigated solid state diffusion bonding with similar metal sheets of Al2024 sheets with and without hematite ore particulates in between the sheets, the complete process is carried out under compression testing machine. In this bonding process customized dies are used where the dies are heated directly through the temperature control unit so when the dies get heated automatically the specimens also get heated. When the process is run with and without an interlayer, a thin diffused zone is seen at the Al/Al joint, and samples with interlayers also show this. It is observed that the diffusivity at the interface region increases as the load and holding duration increases, and that the thickness of the interface region decreases with good bonding at the interface. Due to the entrapment of atmospheric air, void sand other interface defects are visible with an oxide layer at the interface for a bonding period of 20 minutes. This indicates insufficient bonding at the interface. In order to achieve the highest tensile strength in the investigated specimens, it is therefore concluded that the diffusion bonding parameters directly affect the joint interface region and the temperature of 400 °C with a bonding load of 120kn and holding duration of 30 minutes. Tensile test results indicate that Department of Mechanical Engineering, SIT, Tumakuru.

Abas Ali Saleh (2019) carried out the characterization of diffusion bonding of aluminium alloy AA2014 with and without applying copper powder (used as an interlayer). The specimens were made into cylindrical form with the copper interlayer of thickness equal to 100µm. Mechanical properties of the bonded materials were carried out by uniaxial testes. This test establishes that the base metal was where the fracture occurred. This indicates that the strength at the bonded area is stronger in the bonded zone because of the high vacuum environment and good surface roughness of the samples with favorable conditions, which drove to Cu powder diffusion in the direction of base metal. In light of this, it can be said that Al2014's bonded joint with the Cu powder interlayer is stronger than it would be without it. The ideal bonding conditions are 475 °C, 4 MPa, and one hour, which results in a strong bond with a tensile strength of 187.83 MPa. Because copper is harder than aluminium alloy AA2014, the micro hardness in the diffusion bonding zone is higher than that of the base metal [11].

Yanni Wei et al (2018) Al-11Si-4Cu-2Mg and Al-4.5Si- 2Cu-1Mg foil was used to study transient liquid phase bonding of aluminium and copper without the need of an interlayer. The process was carried out in vacuum under various temperature circumstances. Cu and Al were joined together in this technique using two different types of Al-based alloy foils (Al-11Si-4Cu-2Mg and Al-4.5Si-2Cu-1Mg). In sandwich -like coupon assemblies, three different types of Cu/Al transient liquid phase joints (without inter layer, Al-11Si-4Cu2Mg, and Al-4.5Si-2Cu-1Mg foil) were transient liquid phase bonded at varied temperatures in vacuum. Three different types of joints formed two layers of composites.

The joint without the interlayer has a much lower shear strength than the junction with the interlayer. At 575°C, theAl-11Si-4Cu-2Mg foil joints' shear strength reached 77 MPa. Al-11Si-4Cu-2Mg foil was used to create the Cu/Al blend structures, and as the resistivity was nearly equivalent to the theoretical resistivity, the structures have good potential [12]. The existence of intermetallic phases like Al3Mg2and Al12Mg17on the surface of Al and Mg is confirmed by the XRD results of fracture surfaces [13].

Majid Samavatian et al (2014) performed Al2024 and Ti-6Al-4V were transiently bonded in the liquid phase using a Cu-22 percent Zn interlayer at 510 °C and 0.01 Pa of vacuum. The development of the metallurgical bond is caused by the formation of the eutectic as a result of the

Diffusion of Cu and Zn within Al 2024 and solid-state diffusion bonding at the Ti alloy sides.

Based on the X-ray diffraction results, it is evident that there is an interlayer between the alloys, which causes brittle intermetallic like TiAl3 to be diluted at the bonded region. The bonded zone becomes homogenized as the bonding duration goes up, and the joint width decreases to roughly 10 μ m. Additionally, at the bonded junction, a number of intermetallic compounds such as Al2Cu, TiCu3, Ti2Cu, TiZn16, and Al4.2Cu3.2Zn0.7 develop. The bond formed at 60 minutes has maximum shear strength of 37 MPa [14].

Seyyed Afghani (2016) Al7075 and Mg AZ31 alloys were diffusion-bonded in a vacuum environment. The bonding procedure was tested, with pressure taken between 10 and 35MPa and temperature held between 430 and 450°C for 60 minutes. Following Department of Mechanical Engineering, SIT, Tumakuru 16 experimental trials using process parameters, it was discovered that a pressure of 25 MPa is the ideal pressure at which the bonded joint has the least amount of plastic deformation.

In the interfacial transition zone, several reaction layers comprising inter metallic compounds, such as Al12Mg17, Al3Mg2, and (Al) solid solution, were observed (ITZ). The layer thickness has increased as the temperature increased. As a result, there was more aluminium atom diffusion bonding into the magnesium alloy, and there was affiliate migration toward the aluminium alloy. A maximum bond strength of 38MPa was achieved at 440 °C and 25 MPa of pressure. According to fractography studies, the brittle fracture came from the Al3Mg2 phase.

Mg17Al12in the area closest to the substrate (AZ31), and Mg2Al3in the area nearest the cover material (Al). Due to the alloying components in alloyAZ31, the amount of diffusion for the flow material couple (AZ31/Al) is comparable to that of the couple (Mg/Al) with negligible deflection. The process settings under investigation include a temperature of 300 °C and a hot press cladding to 10 MPa for a holding period of 6 hours [15].

M Harhash et al (2014) investigated joints made up of AZ31/Al that have been hot press clad with diffusion bonds. A pure aluminium sheet was clad over a magnesium alloy AZ31 sheet using hot pressing. Thermal press was used to complete the bonding procedure. The hot press cladding was created at 10 MPa with a holding period of 4 hours at a temperature of 300°C.According to the findings, bonded formed at 6 hours demonstrates uniform bonding.

This is due to the three steps of diffusion mechanisms. Surface roughness is deformed by ductile flow and creep in the first stage, followed by grain boundary diffusion of atoms to the voids and grain boundary relocation in the second stage, and volume diffusion of atoms to the voids in the third stage. Two Department of Mechanical Engineering, SIT, Tumakuru 17 distinct diffusion zones with differing chemical compositions make up the bonded region:

Naci Kurgan (2014) carried out diffusion bonding of aluminium alloy (AA7075) sheet materials, utilized mostly in the aerospace and automotive industries, was done for 180 minutes in an argon environment at temperatures of 425 and 450°C and pressures of 2 and3MPa.With various welding specifications, such as bonding pressure and temperature, the mechanical and microstructural characteristics of bonding have been described. Tensile shear tests and micro hardness tests were used to determine the mechanical properties while scanning electron microscopy, light optical microscope, and energy dispersive spectroscopy were used to determine the microstructure. Both the mechanical and microstructural points of view on the results are discussed. The intersecting oxide layer was shown to be lowered with increasing bonding pressure and temperature during the microstructural analysis.

Kavain O Cooke etal (2011) performed transient liquid phase bonding of Al6061, which is done at various bonding temperatures and contains 15% alumina particles. A nano-sized alumina layer with an electrodeposited nickel covering that is 5 m thick is employed as the interlayer during the bonding process. A temperature range of 570 °C to640°C was used for the diffusion bonding technique, but samples bonded above 620°C Department of Mechanical Engineering, SIT, Tumakuru 19 Underwent significant macroscopic deformation. According to the study, Al6061/15%Al2O3 aluminium metal-matrix composites can be successfully bonded via transient liquid phase diffusion bonding with the aid of Ni-coatings that have a nano dispersion of Al2O3.Allocation of joint formation to a eutectic phase between Al-Ni-Si. The connections formed at 620 °C had the greatest joint strength. The issue of reinforcement particles across the bond interface is the key factor impacting the joint properties during transient liquid phase diffusion bonding ofAl-6061/15 percentAl2O3aluminium metal matrix composite. As a result, failure was seen to occur along regions that were particle rich. The solid-state diffusion of Ni into the Al-6061alloy, followed by isothermal solidification and Using wavelength dispersive of the

Scanning electron microscopy, and X-ray diffraction, the joint area was examined, and it was found that intermetallic phases such Al3Ni, Al9FeNi, and Ni3Si had formed there. The results show that joint hardness can be increased by adding nano size Al2O3 dispersions to the interlayer [17].

D.Dietrich et al (2010) examined how the diffusion-welded joints of magnesium and aluminium alloys create intermetallic phases. Below the eutectic temperature of 430 °C, the bonding temperature was maintained, and the bonding duration varied between 15and 120 minutes. In order to prevent the plastic deformation of the parent materials during the bonding process, the bonding pressure, which is typically started at 11 MPa, was lowered to 3 MPa. XRD phase identification and EBSD phase plotting have revealed the phase emergence. Al12Mg17/Al3Mg2 bi existence layers has been confirmed.

The placement of the precipitates forming from the alloys as well as the microstructure and distribution of the inter metallics discovered have been identified. The intermetallic phases ductility is noticeably lower than that of the parent materials, as would be predicted.

It is surprising that the aluminium alloy HAZ shows a maximum increase in hardness while also experiencing a further decrease in ductility. As a result, the Al3Mg2phase and the nearby aluminium HAZ are where brittle fractures occur most frequently. Precipitations also function as notches when they are under load. To give a changed interface design for Al/Mg composites, more research must be done on the kinetics of quenching, annealing, and ageing of the diffusion-welded joints [18].

A. AlHazaa et. al. (2010) employed Ti-6Al-4V and Al7075 alloys to transiently bond them at 500 °Cover a variety of bonding times using 22 μ m thick Cu inter layers. The specimens were joined in the ethanol container, and then they were moved to the diffusion bonding chamber. Once a vacuum of 3104 Torr was achieved in the chamber, induction coils were used to warm the bonding surface at a rate of 100°C/min. To enhance inter facial diffusion, a 0.2MPa pressure was applied to the bonding surfaces. The shear strength of the diffusion bonds was established by the one lap shear test. The bond strength showed that after a bonding time of 30 minutes, the shear strength values levelled off. According to this, bond strengths of about 19 MPa needed a minimum bonding time of 30 minutes. All examined samples showed failure at the bonded contact close to the Cu/Ti alloy interface, demonstrating that the solid-state bond at the Cu/Ti alloy interface joint.

Although no hard inter metallic were produced in the joint region in this work, the bond strengths were still lower than those seen when an interlayer made of Al-10Si-1Mg was used. Al7075 forms a eutectic at 500 °C, resulting in the emergence of multiple phase orders, including (Al2Cu), T(Al2Mg3Zn3), and Al13Fe. When the bonding time is increased to 30 minutes, iso thermal solidification produces a metallurgical bond. Cu3Ti2 intermetallic is produced as a result of Cu's diffusion into titanium alloys, which is a result of titanium alloys. The hardness values for the bonded contact show a gradual transition, and hard intermetallic development at the interface was prevented [19].

A.N. Alhazaaet.al. (2009) Ti-6Al-4V and Al7075 were bonded utilizing a combination of Cu coatings and Sn-3.6Ag-1Cu interlayers and were formed at 500 °C, 1MPa at various bonding durations. Diffusion bonding of these two dissimilar aerospace alloys has also been studied. Given that the microstructure of the diffusion zone on the Ti-6Al-4V side is different from the microstructure of the Ti-6Al-4V alloy, it may be an inter metallic phase.

T in was dispersed into the Al7075 alloy at grain boundaries. The micro hardness outline for bonds created using 100 m Sn-3.6Ag-1Cu interlayers with copper coatings at 500 °C and 1 MPa for 10, 20, 30, 40, 50, and 60 min. The general trend of the micro hardness profiles demonstrates that as bonding time increases, the hardness of the bonded region will also increase. Cu coatings were employed to improve the wettability on both alloy surfaces and to prevent oxide development at the Al7075alloy surface. The production of inter metallic was facilitated by the eutectic phases produced by the diffusion of silver and copper into the alloy Al7075.At theAl7075Department of Mechanical Engineering, SIT, Tumakuru 21 interface, these intermetallic kinds create a metallurgical link. XRD analysis was used to identify the inter metallic with copper, titanium, and magnesium that were discovered as a result of the diffusion of Sn into the alloys Al7075 and Ti-6Al-4V. Solder bonding was used to achieve intermetallic production at the bond contact as a result of Sn diffusion inTi-6Al-4V. Cu coatings were effective in halting surface oxidation during the bonding process, according to the X-ray study, which revealed no evidence of the production of oxides. According to joint fractography, intermetallic phases had an influence on the fracture initiation and propagation that occurred there [20]. The tensile strength of the bonded joints thus exhibits a continuous temperature dependence. The joints' tensile strength is quite low when the temperature is 350°C.(only122MPa). The situation can be described as follows: at this temperature, stainless steel has a relatively high yield strength, making contact between the bonded surfaces very low.

P. Heet.al. (2007) have performed hot pressing diffusion bonding of titanium alloy and stainless steel with an interlayer made of an aluminium alloy. Ti alloy TC4 (Ti-6Al4V), stainless steel (1Cr18Ni9Ti), and the inter layer metal Al alloy LF6 with a thickness of 500 m were all usedin the process. The dominating alloy's yield strength and atomic diffusion are both influenced by the bonding temperature T. Therefore, it is the presiding parameter during the bonding process it regulates the inter face microstructure and homogeneity of composition of the bonded joints. The tensile strength of the bonded joints thus exhibits a continuous temperature dependence.

The joints' tensile strength is quite low when the temperature is 350°C. (only122MPa). The situation can be described as follows: at this temperature, stainless steel has a relatively high yield strength, making contact between the bonded surfaces very low.

At the same time, atomic diffusivity decreases and thermal excitation is insufficient, so only specimen fracture occurs, and it primarily affects the SS/LF6 interface. As a result, the yield stress of the primary alloys lowers and atomic diffusivity rises when the bonding temperature is raised from 350 °C to 450 °C, causing significant interfacial deformation and making chemical bonding simpler. As a result, the tensile strength of the joints increases. As a result, as the bonding temperature increased, more brittle intermetallic compounds likeFeAl6, Fe3Al, and FeAl2 appeared at the interface between the aluminium alloys inter layer and stainless steel. As a result, the quality of the joints significantly decreased, and the joints fractured by brittle fracture [21].

Ren Jiangwei et. al. (2002) has examined microstructural characterization in the Ti/Al diffusion bonding interface zone. The bonding procedure made use of the Workhorse-II vacuum diffusion bonding device. The equipment used in the bonding process has the following main specifications: 45 kVA of heating power, 1350 °C for the peak temperature, 30 tons of maximum pressure, and hydraulic pressure applied. A Department of Mechanical Engineering, SIT, Tumakuru 22 mechanical pump and a diffusion pump are used in the vacuum system. Atom diffusion leads to the formation of new phases in the transition zone. Chemical reactions occur and new compounds are created when Ti and Al atoms spread to a specific location close to the Ti/Al contact surface.

Different Ti/Al inter metallic (Ti3Al, Ti Al, and TiAl3) are created depending on the ratio of Ti and Al. Ti/Al was successfully bonded at 640 °C, 90 min of holding time,24MPa of pressure, and1.12-2.66x 103Paofvacuum.Thetransition zone and aluminized coating on the Al substrate are both parts of the bonded zone in a Ti/Al diffusion Bonding.

There were inter metallics like TiAl3and Ti Al in the transition zone of the titanium substrate and aluminized coating, but none were created in the transition zone of the aluminium substrate. The production of inter metallics at the bonded surface between Al and has a delay time, t D. Therefore, Ti/Al inter metallics will occur when the holding time of the diffusion bonding process exceeds the delay time t D. The breadth of inter metallics close to the diffusion inter face can be reduced by adjusting technological parameters [22].

C.S. Lee et. al. (1999) has joined metal and aluminium composites using vacuum free diffusion bonding. Due to the metallurgical makeup of these materials, typical fusion welding techniques like arc welding cannot be used to combine them. Diffusion bonding is one technique that enables the combining of these materials without impairing their characteristics. The base metal used in this bonding method was an aluminium alloy 6061that had a T6 thermal treatment and contained 20% aluminium oxide as the matrix. The first bonding temperature range was 193–380°C because Al has a melting point of 660 °C. The bonding period ranged between 6 and 20 minutes, according to the trial-and error experiments. For the bulk of the specimens, pressure greater than the yield stress value was used because it was thought improper to use pressure equal to the yield stress. The standard of the bonded zone was evaluated utilizing metallographic investigations, percentages, and joint effectiveness of the bonded area. Matrix and reinforcement particles that cross the bonded line can be used to identify the bonded zone. Reinforcement particles have uneven shapes despite the fact that air spaces frequently have wide and planar shapes.

The unbonded zone can be seen as long voids that are parallel to the bond line. The achievement of mean joint efficiencies of 90.5 percent and a percentage bonded area of 77.7 percent during an examination into the viability of vacuum-free diffusion bonding of an aluminium matrix composite proved that it was achievable. Additionally, tensile testing confirmed ductile fracture, and metallographic Department of Mechanical Engineering, SIT, Tumakuru 23 analysis proved that bonding had taken place across the bond line. Furthermore, it was found that even in the presence of a hard oxide layer, the in-situ surface treatment process can still produce an acceptable joining surface [23].

Y.Huanget.al. (1998) has explored diffusion bonding of hot-rolled7075 aluminium alloy while carrying out the experiment in vacuum on a Gleeble 1500 test machine. In the current study, Bonding temperatures between 450°Cand 530°C, pressures between 1.0 MPa and 12 MPa, and durations between 30 and 360 min were all used.

The surfaces to be joined were immediately coated with an organic solution after the elimination of surface oxides in a novel surface investigation method. For hot rolled 7075 aluminium alloy, diffusion bonds with origin metal tensile strength and microstructure have been created utilizing a technique including the application of thoroughly cleaned surfaces with an organic solution.

The organic solution's key features were it seas of application to clean surfaces that were to be bonded, which totally protected them from oxidation, and its complete volatilization upon heating in vacuum to bonding temperatures. Recrystallization was induced at the interface during the bonding process, according to metallographic inspection. There crystallized grains eventually diffused into the adjacent hot worked parent form and increased across the interface, leaving no traces on the bond line [24]

A.S. Zuruziet.al. (1998) has utilized an interface treatment technique to do diffusion bonding on aluminium alloy 6061 in the air. An In strong universal testing machine was connected to an Instron temperature chamber, where the bonding process was conducted in the air.

A perfection of 93 °C was used to fix the temperature at 450 °C. By stacking two specimens, one with a side of 15.8 mm and the other with a side of 25.2mm, the ground surfaces of the two specimen were brought into touch. Localized yielding begins to take place in this bonding process at a pressure of 12.1 MPa. The interfacial oxide layer is distorted by localized yielding, which leads to bonding. Therefore, bonding may not be successful if the interface treatment is not utilized when the applied pressure is less than 12.1 MPa. The specimen won't bond when 8.1 MPa of pressure is applied since the interface wasn't treated. The optimal bonding pressure forAl6061 at 450 °C is slightly lower than the material's bulk compressive yield strength at this temperature [25].

H. Kato et. al. (1986) carried out phase transition in air diffusion welding of Ti/Ti and Ti/stainless steel rods. The test specimens were cleaned with acetone after the basic bonding process, supported by electrodes, and subjected to compressive force. An electric current was used to warm the test specimen to a maximum temperature (T max) over titanium's transition temperature (Tt), And it was subsequently cooled to a minimum temperature below one, two, or three iterationsof this process (thermal cycling) were carried out in air. The joint interface is 10 m wide. At the specimen's center, the interface zone vanishes, and the interfacial grain boundaries cross the joint inter face. At the inter face, there is also no noticeable void. Nevertheless, tiny spaces less than 10 m in diameter were found.

The interface zone was also visible in the specimens with weak bonding. The bonds between titanium rods were of a high standard; the yield stress was280 MN m2, which was more than 90%of the parent metal's yield stress; the ultimate tensile strength was 380 MN m2, which was more than 80% of the parent metal's ultimate tensile strength; and the elongation for joints was 40%. Thermal cycling has a maximum bonding temperature between1200and1300K, a pressure of 13.9 MPa, and a temperature variation of 300K. One, two, or three thermal cycles; a cooling or heating rate of roughly 50 Ks-1. Rods made of titanium and stainless steel were also joined. However, the welds' quality was still inferior to that of Ti/Ti welds. Joints had a yield stress greater than 90% greater than that of stainless steel, an ultimate tensile strength greater than 60% greater than that of titanium, and an elongation less than 2%. The conditions for thermal cycling are the same as for Ti/Ti welding, with the highest temperature between 1150 and 1200 K, pressure of 158 MPa, a heating or cooling rate of roughly 30Ks1, and other conditions.

Summary

When traditional welding techniques have failed to successfully fuse the materials, diffusion bonding is a good option. Experiments on the diffusion bonding of aluminium-based materials over more than three decades have led to a thorough understanding of the bond development mechanisms and the challenges posed by the stable aluminium oxide, which prevents the creation of a flawless joint at the bonding line. If plastic deformation is sufficient to provide metal-to-metal contact as a result of oxide rupture on the Faying surfaces, solid- Department of Mechanical Engineering, SIT, Tumakuru 25 state diffusion bonding may produce joints with high strength. Investigations have been done into the effects of alloying components other than the parent material or an inner layer. Due to the presence of a liquid phase between two bonding surfaces, transient liquid phase (TLP) diffusion would be an alternate method for bonding materials with stable oxide layers

Objectives

The main objectives defined for the present study are,

- To prepare the base metals according to the required dimensions using Wire EDM.
- To chemically clean the faying surfaces ofAl2219 andTi-6Al-4V.
- Vacuum solid state diffusion bonding at Al2219 with constant pressure of 2.5MPa, bonding duration of 45 min with bonding temperature of 480°C , 500°C, 520 °C .
- Microstructural evaluation – SEM, EDS and XRD study of diffusion bonded sections to know the presence of major elements and oxide behaviour.
- Micro hardness properties evaluation and comparison on bondedjoints, base metal of the bonded section.

CHAPTER 3

3. EXPERIMENTAL PROCEDURE

The main aim of the present study is to produce an excellent grade and high strength joints of non-ferrous dissimilar materials Al2219/Ti-6Al-4V by diffusion bonding process. The bonding process was organized in the following sequence

- Preparing the customized diffusion bonding setup.
- Producing Diffusion bonded joints.
- Assessment of bonding strength and shear strength.
- Micro structural study using Scanning electron microscopy (SEM), optical microscope (OM), and mechanical properties assessed viz. micro hardness and shear strength
- Analyzing the effect of bonding duration or holding time on the bonding strength

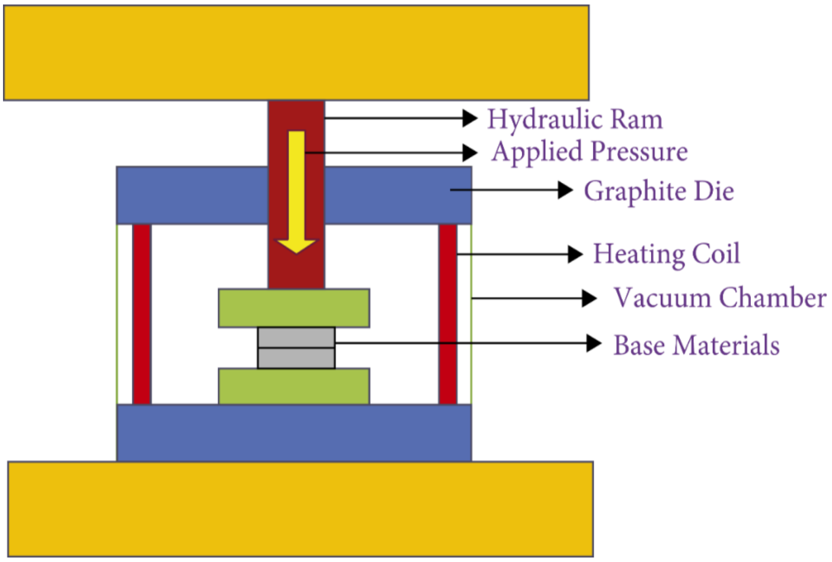

Figure 3.1: Schematic representation of diffusion bonding process On a UTM

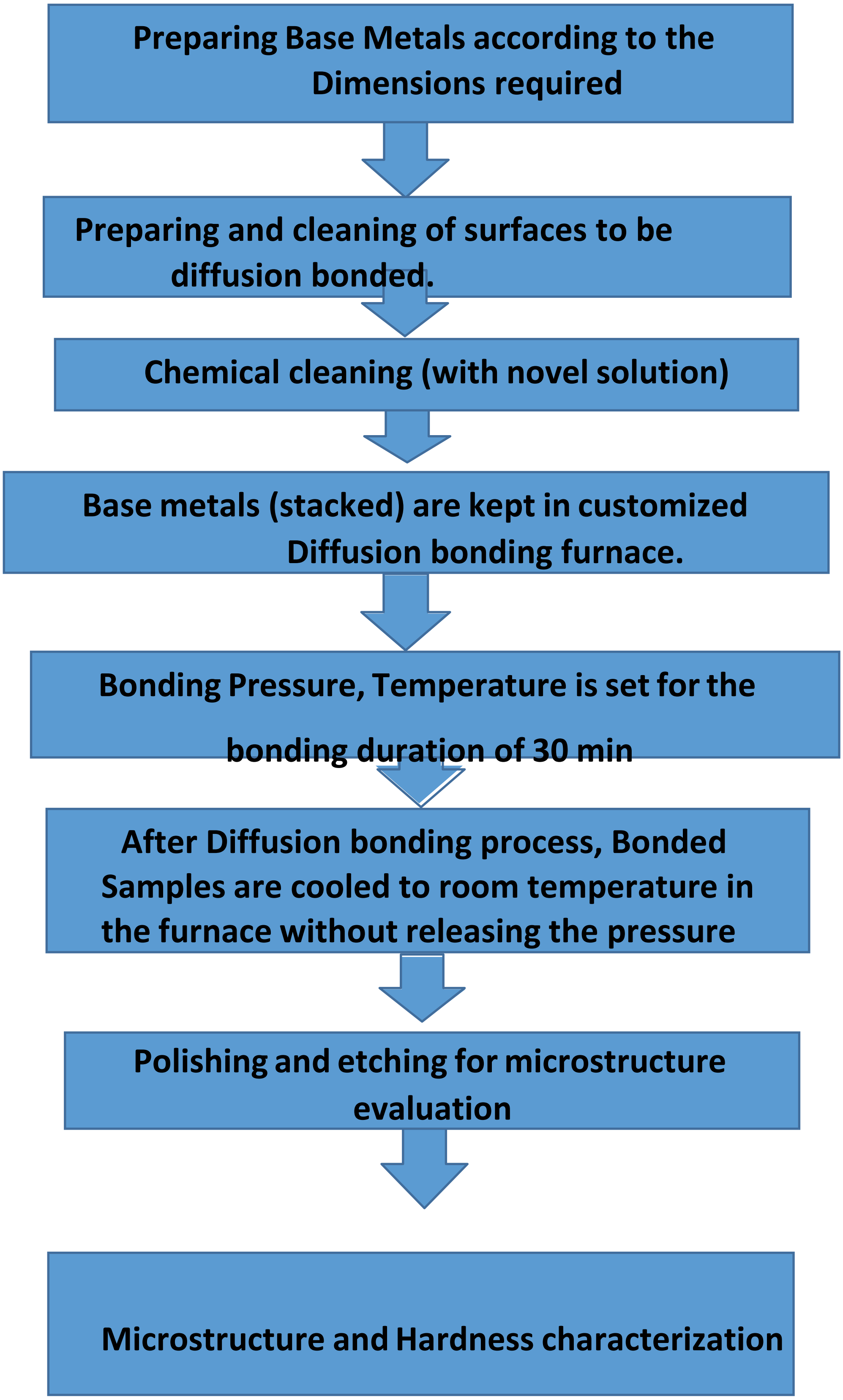

Figure 3.2: Diffusion Bonding Methodology

3.1 BASE METALS

- **Aluminum Alloy**

Al2219 aluminum alloy is utilized in this work. It is typically employed in a variety of engineering applications, as well as in construction and transportation, where superior mechanical qualities, like hardness and tensile strength, are unavoidably necessary. Table 2 shows the chemical composition of Al2219. Due to its exceptional resistance to corrosion, it is a suitable material form a time structural application. Metal matrix composites (MMCs) of various types are now needed to meet the demand for low-cost, high-performance, and lightweight performance materials for use in structural and non-structural applications [27].

- **Titanium Alloy**

The main application for Ti-6Al-4Visasanalloy is a high strength, low density, high strength, and outstanding biocompatibility titanium alloy with high fracture toughness. Ti-6Al-4V, which is regarded as the most used titanium alloy, accounts for over half of all current titanium goods used worldwide. In the 1950s, the Ti-6Al-4V alloy was first developed for structural uses in aircraft. Due to its light weight and strength, this alloy is particularly well suited for gas turbines, jet engines, and various airframe components. While the aerospace sector continues to have an impact on the demand forTi-6Al-4V, other application areas like the automotive, marine, energy, chemical, and biomedical sectors have also achieved widespread acceptance over the past 50 years [28]. TheTable3 shows chemical composition of Ti-6Al-4V.

Table 3.1 Chemical composition of Al2219 aluminium alloy

Elements	**Mg**	**Sn**	**Ti**	**Cu**	**Fe**	**Si**	**Mn**	**Fe**	**Cr**	**Al**
Wt. (%)	0.02	0.	0.02-0.1	5.8-6.8	0.3	0.2	0.2-0.4	0.3	0.25	91.5-93.8

Table 3.2 Chemical Composition of Ti-6Al-4V titanium alloy

Elements	**Sn**	**Al**	**Zr**	**Cu**	**Fe**	**Si**	**V**	**Ni**	**Cr**	**Ti**
Wt. (%)	0.062	5.48	0.028	<0.02	0.11	0.022	4.22	<0.001	0.009	90

Table 3.3 Mechanical Properties of the base materials

Base Metal	Crystal Structure	Melting Point ˚C	Density g/m^3	Ultimate Tensile strength (MPa)	Elongation %	Shear strength (MPa)
Ti-6Al-4V	HCP	1660	4500	1170	10	760
Al2219	FCC	510	2800	414	3- 14	207

3.2 Fabrication of Joints

The presiding sections cover every aspect of the entire diffusion bonding experiment in deathfic

3.2.1 Wire EDM

The importance of the Wire Electron Discharge Machine (WEDM) in the manufacturing and tooling industries is illustrated by the fact that WEDM automation is required to suit a variety of industrial needs, particularly in the precision mold and die business. WEDM has a CNC, allowing for increased productivity and accuracy. The material is removed from the work piece in this thermoelectric process by a succession of discrete sparks that are split by a thin layer of demineralized water, a dielectric fluid, which is continually fed to the machining area to wash off the eroded bits [29]. The underlying materials were machined to a dimension of 30X30X10. The machining was done on a CNC DK7720 high precision 4 axis CNC WEDM (Wire Cut Electro Discharge Machine) produced by the Chinese firm STEER Corporation. The WEDM machine is made up of the wire, worktable, servo control system, power supply, and dielectric supply system. Based on the specifications of the material and height of the work piece and tool material, the CNCDK7720 enables the machine is to choose the variables from a handbook provided by the WEDM maker. The machine has reusable automation for molybdenum wire. This machine is capable of cutting tasks using reused molybdenum wire. A wire drum that can rotate at a speed of 1500 rpm contains the wire that has been looped around it [30].

3.2.2 Polishing

After the base materials are machined through the WEDM, the materials will be further finished by polishing machine. This operation the importance of the Wire Electron Discharge Machine (WEDM) in the manufacturing and tooling industries.

3.2.3 BISS Static and Dynamic Mechanical Testing

The servo-hydraulic trial systems in the BISS Nano Plug-n'-Play sequence are particularly intriguing to academic groups. The Nano's singularity can be seen in its completely integrated, single-track architecture, which is portable, quiet, and small in size. The hydraulic pump and the thermostatic cooling fans are both controlled by 3- phase varying frequency drives that are fed by traditional single-phase mains power. With 0.1 m stroke precision, 2N load resolution, and stroke-load-strain-COD feedback, the developed digital control system tracks actuator position. The strength of the bonded joints in the current bonding method was assessed using Biss equipment using a shear test. A unique die was created for this test using the specimens' dimensions.

Illustrated by the fact that WEDM automation is required to suit a variety of industrial needs, particularly in the precision mold and die business. WEDM has a CNC, allowing for increased productivity and accuracy. The material is removed from the work piece in this thermoelectric process by a succession of discrete sparks that are split by a thin layer of demineralized water, a dielectric fluid, which is continually fed to the machining area to wash off the eroded bits [29]. The underlying materials were machined to a dimension of 30*30*10. Is performed because it increases material durability, reduce corrosion chemical and electrical resistance further it enhances the material regards to color and brightness. This process is done by placing the Sic grit papers in the polishing machine, the grit papers used in these experiments are from no.120 to1200 grit.

3.2.4 Diffusion Bonding

Using chemically cleaning the materials with 6% NaOH and 40% HNO3, oxide coatings on the faying surfaces are removed after they have been polished by SiC sheets. Prior to the diffusion bonding procedure, the bonding specimens are ultrasonically cleaned in acetone for 10 min. In a specialized furnace connected to a universal testing machine (UTM), solid-state diffusion bonding is carried out at a temperature of 480 °C, 500 °C and 520 °C a heating rate of 6 °C/min. 2.5 MPa bonding pressure for holding times of 45 minutes. The solid-state bonding procedure performed on a UTM with a unique heating chamber. To prevent thermal shocks, the specimens that are being bonded are cooled to room temperature in the furnace.

3.3 Microstructural, Compositional and Mechanical characterization

All of these characterization procedures are used to identify the mechanical properties of the material, which are independent of geometry, and to learn more about how the material was created. The samples are cut into sections perpendicular to the joint, polished, ground, and treated with Keller's reagent (3mlHCl, 5mlHNO_3, 2mlHFand 90 ml distilled water). Through the characterization tools listed below, the microstructure at the interface and base metal surface is inspected.

3.3.1 Optical Microscope

For the current experiment, a CARLZEISS optical microscope that Nomarski created in1952 is being employed. The accessories for the Zeiss equipment are as follows: (i) a single beam splitting slide mounted in a screw-driven carriage, oriented at 45 degrees to an attached analyzer (ii) a strain-free achromatized condenser out fitted with three auxiliary modified Wollaston prisms and two annular stops for phase-contrast microscopy. Up to 1000x in maximum magnification [31]. This apparatus analyses the sectioned specimens for various bonded specimens.

3.3.2 Scanning Electron Microscope

SEM analysis, commonly known as scanning electron microscopy (SEM), has been applied internationally in a variety of fields. On a Nano scale to micrometer (nm–m) scale, it can be regarded as a successful method for examining both biological and in organic materials. The scanning electron microscope produces extremely accurate pictures of a wide variety of materials while operating at a high magnification of up to 300,000x and even 1000x (in some newer models). As seen in Figure 13, Energy Dispersive X-ray Spectroscopy (EDS) and SEM work together to produce qualitative and semi-quantitative results. Both methods, jointly, have the capability to initiate fundamental details on material composition of examined specimens, which the common laboratory tests are incapable to provide these kinds of outcomes [32].

In the present examination Scanning Electron MicroscopeTESCAN-VEGA3LMU equipment is used, its specification are as follows; resolution of 3nm at 30kv, magnification of 4.5x to 1000000x with tungsten heated cathode, scanning speed of 20 ns to 10ms per pixel adjustable in steps or continuously, image size up to 8, 192 pixels in 32-bit quality. The bonded samples were tested for the following specifications. The SEM images results are discussed in the upcoming chapters.

3.3.3 X-Ray Diffraction Analyzer

An invaluable insight into the lattice structure of a crystalline substance, such as unit chemical compositions, bond angles, cell dimensions, and crystallographic structure of artificial and natural materials, can be gained through X-ray diffraction (XRD), a non-destructive type of systematic method. The XRD process is based on the idea that x-rays can be used positively and that the material being studied should be crystallized [33]. Present investigation is carried out in X-ray diffraction analyzer with the following specifications; scanning range 2θ is -40°to + 220°, resolution of 0.029°2θwith PIXcel@21.4° (low angle) 2θ, X-ray generator capacity of 4kW. The bonded samples XRD results are discussed in further chapters.

CHAPTER 4

4. RESULTS AND DISCUSSION

4.1 Temperature effect on the microstructure

Initially, an SSDB instigates between the aluminum and copper surfaces as the melting point of the copper interlayer is higher than that of the Al2219 [24]. Then, at an adequate temperature, and well within the melting temperature of aluminum, a eutectic reaction between Al2219 and copper occurs, in which Cu-rich atoms diffuse into Aluminum [25]. Fig.4.1 shows BSE images of the bonded specimens at 480, 500 and 520 °C. A diffusion zone of a thickness of 60.01 µm is observed at the bonding temperature of 480 °C, with a wider Cu-rich zone of a thickness of 37.62 µm (Fig.4.1 (a)). When the bonding temperature increased to 500 °C, the diffusion zone increased to a thickness of 60.28 µm, whereas the Cu-rich zone reduced to a thickness of 26.94 µm (Fig.4.1 (b)). However, when the bonding temperature is further increased to 520 °C, a thicker diffusion zone of 71.88 µm is formed, with wider IMC layers towards Al 2219, and the Cu-rich zone reduced to a thickness of 15.47 µm (Fig.4.1 (c)). The thickness of the bonded zone on all specimens is measured in 20 different areas and then averaged.

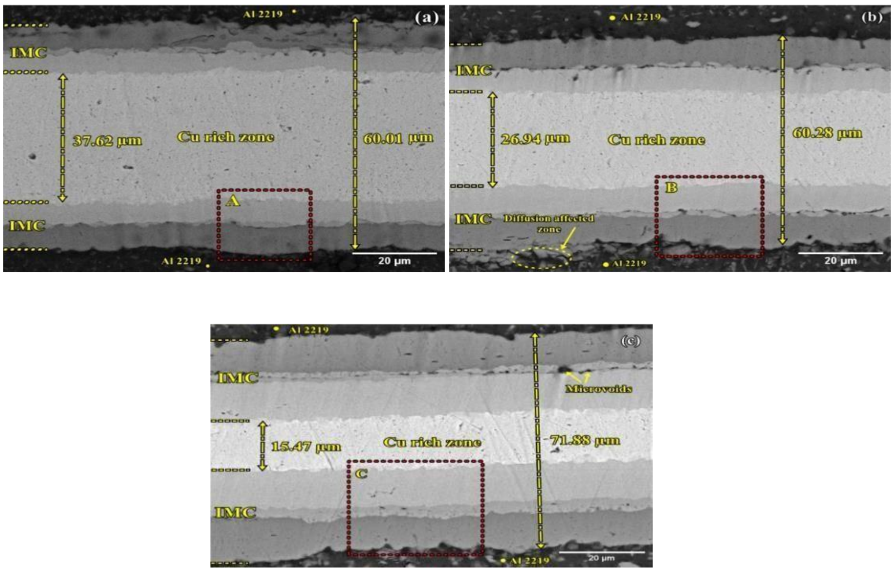

Fig.4.1 BSE images of diffusion bonded specimens at (a) 480 °C (b) 500 °C (c) 520 °C

The increase in the thickness of the diffusion zone is mainly attributed to theimproved inter diffusion with the increase in bonding temperature, and meanwhile, the thicknessof the copper interlayer is effectively reduced.

4.2 IMC formed at Diffusion zone

The binary phase diagram [26] of Al-Cu shown in Fig.4.2, predicts the formation of $CuAl_2$(θ), Cu Al (η), Cu_4Al_3 (ζ), Cu_3Al_2 (δ), and Cu_9Al_4 (γ). Lee et al. reported the difficulty in finding Cu_3Al_2 (ζ) and Cu_3Al_2 (δ) phases, anticipating that the short bonding time generates thin, unclear reaction layers that may have intermixed with different IMC [27]. Initially, the $CuAl_2$ phase is observed at the interface between the aluminum and copper, as the maximum solubility of Cu in Al is 2.48 at%, whereas that of Al in Cu is 19.7 at%. Hence, Al the IMC reaction layers formed on the bonded sections are depicted as R1, R2, and R3. The R3 layer (Fig. 4.3(a)) appears dark grey, with 55.08 wt.% of aluminum and 44.92 wt% of copper, indicating the presence of the α-Al+$CuAl_2$ phase, and the R1 layer (Fig. 4.3(a)) appears light grey, with 80.84% wt.% of copper and 19.16 wt.% of aluminum, which predominate the presence of Cu_9Al_4. However, in the specimen bonded at 500 °C, the R2 layer (Fig.4.3 (b)) is observed as a continuous band compared to that of the section bonded at 480 °C and it has 63.05 wt% of copper and 36.95% of aluminum, whereas the R1 layer (Fig.4.3 (b)) has 74.99 wt% of copper and 25.01% of aluminum, speculating the phase CuAl+Cu_4Al_3. When the bonding temperature is further increased to 520 °C, a continuous and thick R2 layer (Fig.4.2) of width 3.57 μm is formed. It has 64.82 wt % of copper and 35.18 wt% of aluminum, predicting the $CuAl_2$+CuAl phase in it. Fig. 5 shows the XRD patterns of the TLP bonded specimens, for further confirmation of IMC, which are formed at the interface of Al/Cu, and it is evident that only three phases, $CuAl_2$ (θ), Cu Al (η), and Cu_9Al_4 (γ) are observed, whereas Cu_4Al_3 (ζ), Cu_3Al_2 (δ) are not found for the current TLP bonding conditions. Atoms diffuse into the copper readily, leaving vacancies on the aluminum side, and the copper-rich atoms, which have lower diffusivity, occupy these vacancies created on the Al side [28-30].

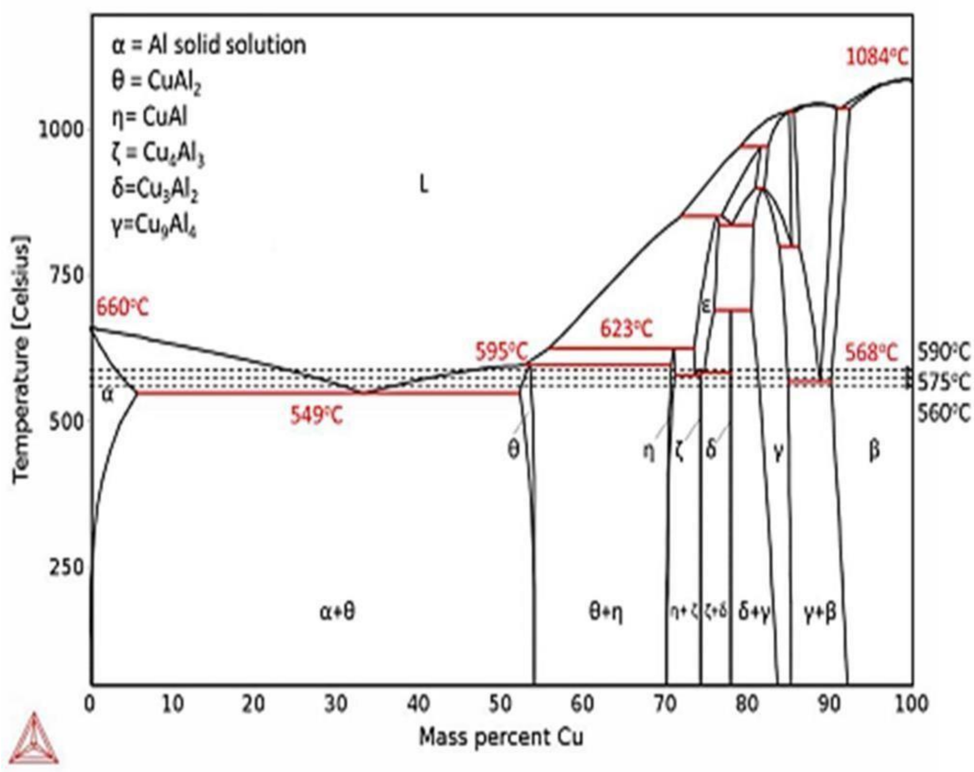

Fig. 4.2 Calculated Al-Cu binary phase diagram [27]

All the bonded specimens exhibit three IMC reaction layers and are depicted as R_1, R_2, and R_3. Having different concentrations of Al and Cu elements. The EDS analysis is carried out to investigate the composition variation of each element at different IMC reaction layers. The magnified view of sections A, B and C in Fig. 4.1 on the specimens bonded at 480°C, 500°Cand 520 °C is shown in Fig.4.3 (a), (b) and (c) respectively.

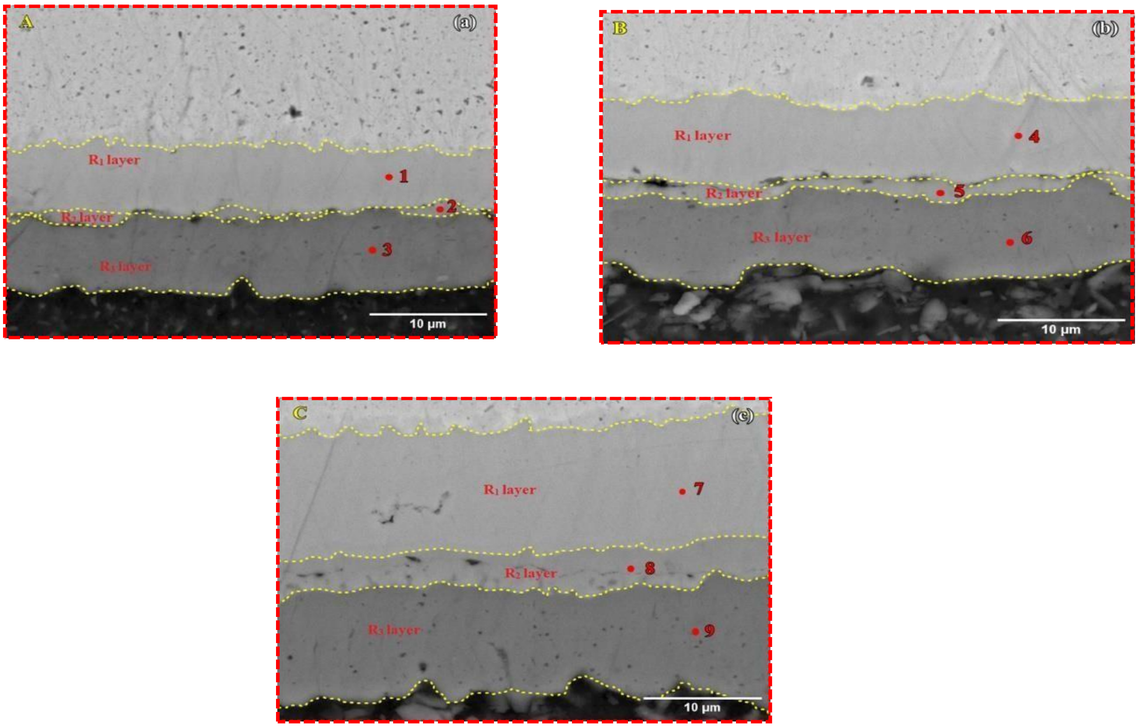

Fig. 4.3 The magnified view of the area A B and C marked in Fig. 4.2 (a), (b) and (c)

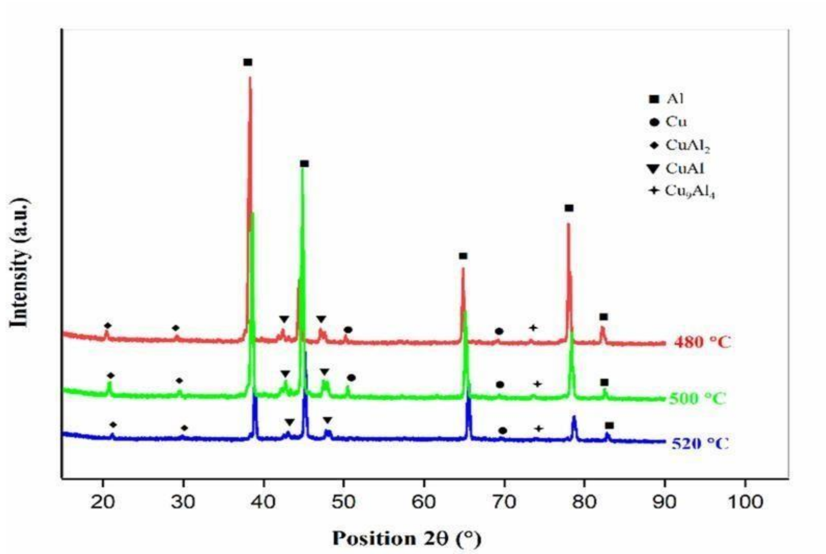

Fig.4.4 XRD pattern for the specimens bonded at 480, 500 and 520 °C

Delamination and micro voids are seen between the R1 and R2 layers of all the bonded specimens, which may be owing to insufficient pressure applied for complete plastic deformation of the IMC layers or inadequate bonding time provided for maximum nucleation of the CuAl2 phase. However, the surface interaction between aluminum and copper may also be affected by the inter diffusion of atoms and kinetics in addition to the thermodynamic force [31]. Table 4.1 shows the summarized point EDS results for different reaction layers, and the respectiveEDS spectrographs are shown in Fig. 4.5.

Table 4.1 Composition variation of elements confirmed by EDS

EDS Points	**Al**		**Cu**		**Probable**
Fig 4.3	**wt%**	**at%**	**wt%**	**at%**	**Phase**
1	**19.16**	**35.82**	**80.84**	**64.18**	**Cu9Al4**
2	**28.62**	**48.56**	**71.38**	**51.44**	**CuAl+Cu4Al3**
3	**55.08**	**74.28**	**44.92**	**25.72**	**α-Al+CuAl2**
4	**25.01**	**43.99**	**74.99**	**56.01**	**Cu4Al3+Cu3Al2**
5	**36.95**	**57.98**	**63.05**	**42.02**	**CuAl2+CuAl**
6	**51.95**	**71.80**	**48.05**	**28.20**	**α-Al+CuAl2**
7	**26.11**	**45.42**	**73.89**	**54.58**	**CuAl+Cu4Al3**
8	**35.18**	**56.11**	**64.82**	**43.89**	**CuAl2+CuAl**
9	**52.62**	**72.34**	**47.38**	**27.66**	**α-Al+CuAl2**

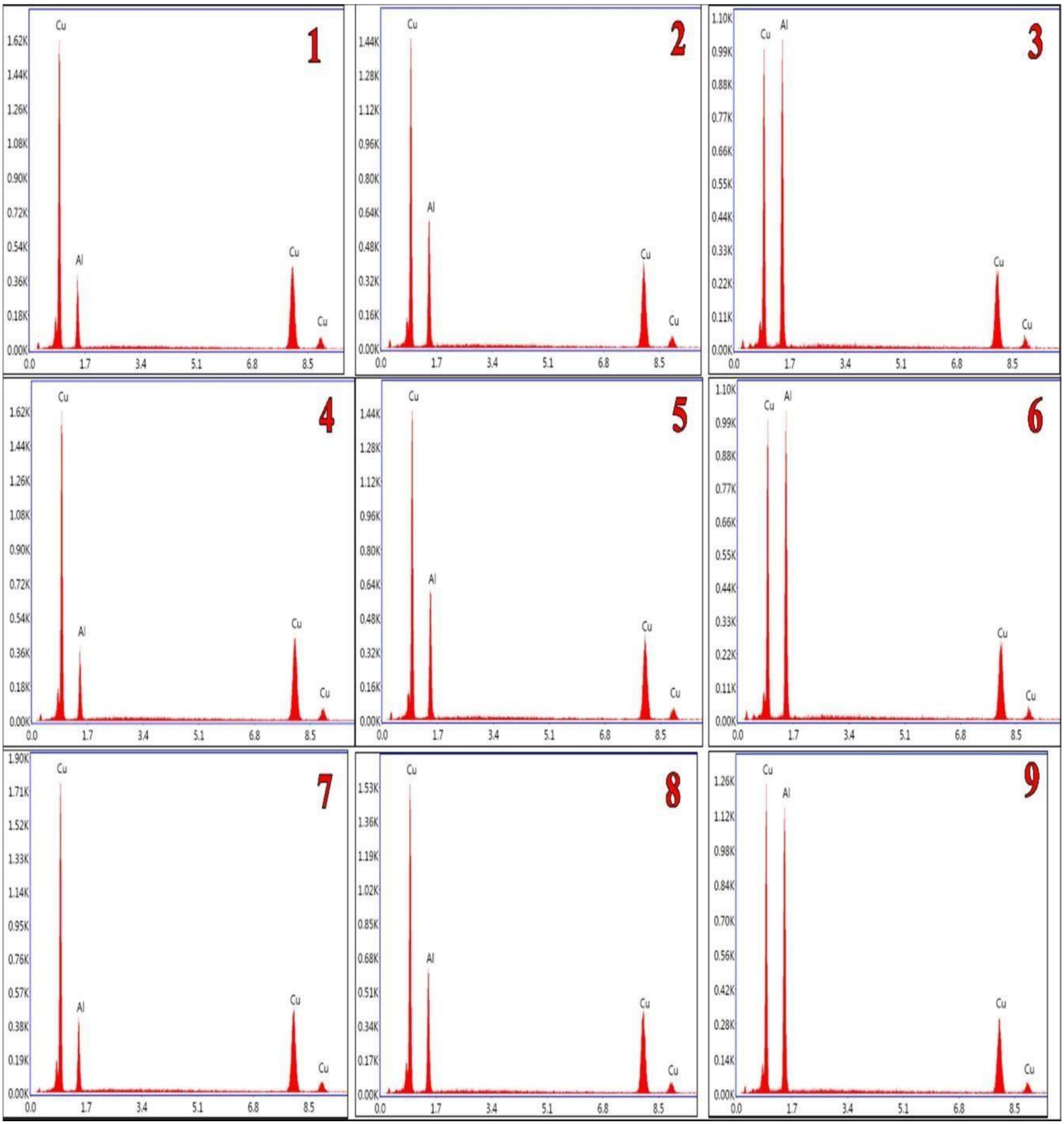

Fig.4.5 EDS spectrographs of the points marked in Fig. 4.3 (a), (b), and (c)

4.3 Temperature Effect on Hardness

The micro hardness behaviors of the TLP bonded joints obtained at 480, 500, and 520 °C is shown in Fig.4.6. The hardness values on the base metal, diffusion zone, and copper interlayer are obtained by averaging ten readings taken at different indent locations. A maximum hardness of 66 Hv is observed on the Al2219 base metal, whereas on the copper interlayer, it is 125 Hv. Further analysis observed an increase in hardness values at the diffusion zone where the IMC reaction layers are formed, which stipulates the presence of hard intermetallic beside the copper interlayer. The specimen bonded at 480 °C shows a hardness of 397 Hv at its diffusion zone, and it is increased to 466 Hv on the diffusion interface produced at 500 °C. However, the diffusion zone of the specimen bonded at 520 °C exhibits a maximum hardness of 723 Hv, which elucidates that the hardness value of the diffusion zone of the TLP joints increases with an increase in the bonding temperature.

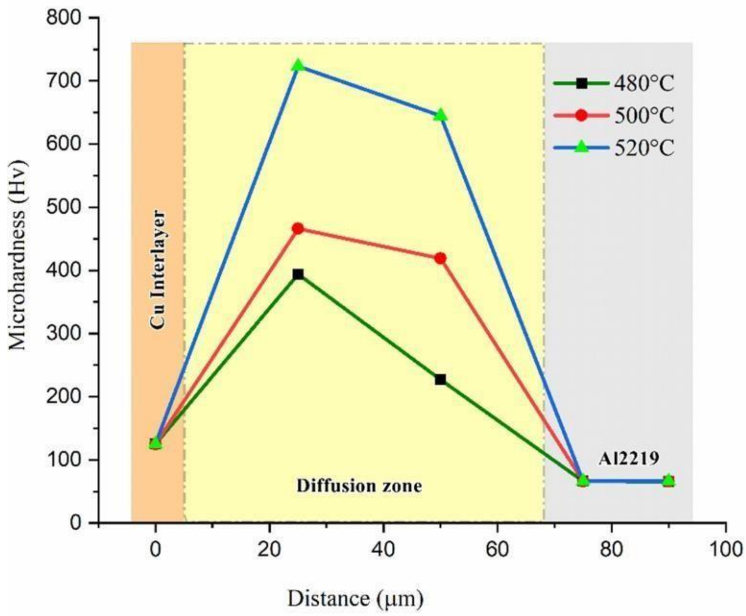

Fig.4.6 Micro hardness profile across the TLP bonded joints

CHAPTER 5

CONCLUSIONS

TLP diffusion bonded joints of Al2219 with a copper interlayer are successfully produced, and the intermetallic compounds formed across the diffusion joints are investigated over the temperature range of 480-520 °C. All the bonded specimens exhibit three reaction layers at the bond interface of Al/Cu, and in addition, it is observed that the interface thickness of the bonding zone has increased with an increase in the bonding temperature. The diffusion thickness of 60.01, 60.28 and 71.88 μm are obtained for the boding temperatures of 480, 500, and 520 °C, respectively. In the present study, only three intermetallic phases, CuAl2 (θ), CuAl (η), and Cu9Al4 (γ) are found among the five major phases, which is confirmed by the XRD patterns. The hardness at the interface of the bonded sections has increased with an increase in the bonding temperature, and a maximum hardness of 723 Hv is found on the diffusion zone of the specimen, bonded at 520 °C.

CHAPTER 6

SCOPE OF FUTURE WORK

TLP diffusion bonded joints of Al2219 without a copper interlayer can be produced. TLP diffusion bonded joints of Al2219 with copper interlayer can be produced at different Pressure and time and Mathematical Modeling can be developed for the optimized process parameter of the obtained results

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ANNEXURE-1

Experimental Details

Fig.1 (a). Surface Preparation of the Sample

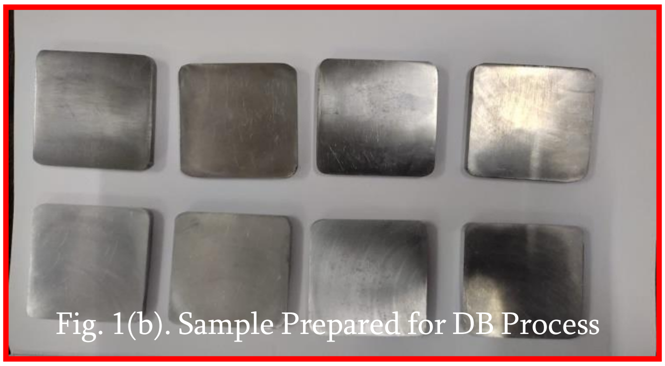

Fig. 1(b). Sample Prepared for DB Process

Fig. 1(c). Al2219-Ti-6Al-4V for DB Process

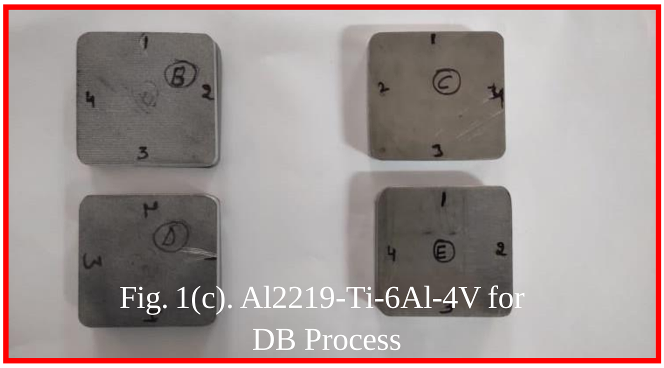

Fig. 1(c). Al2219-Ti-6Al-4V for DB Process

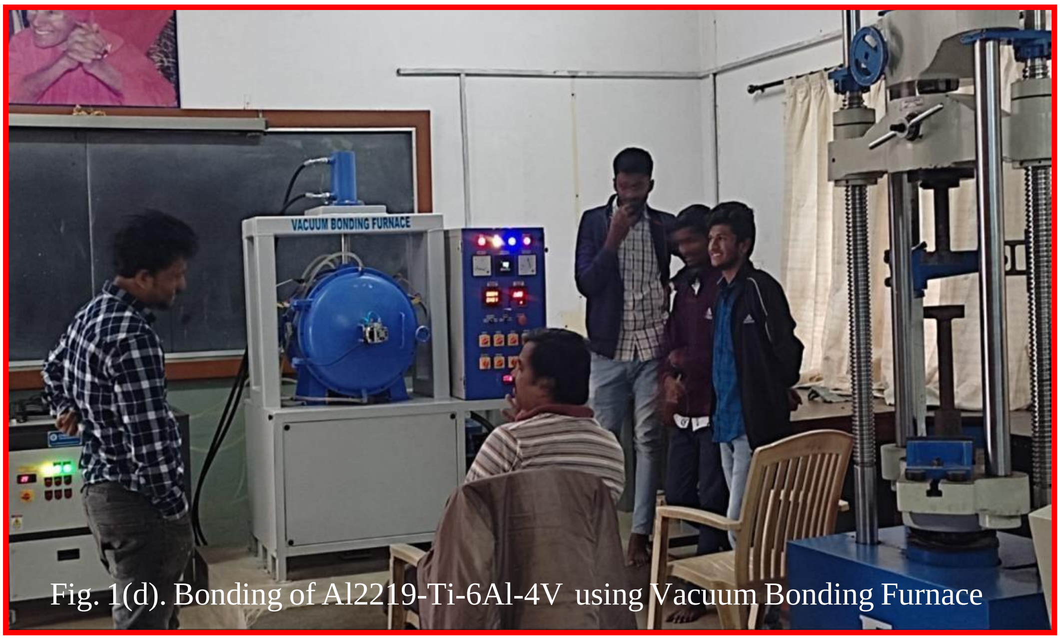

Fig. 1(d). Bonding of Al2219-Ti-6Al-4V using Vacuum Bonding Furnace

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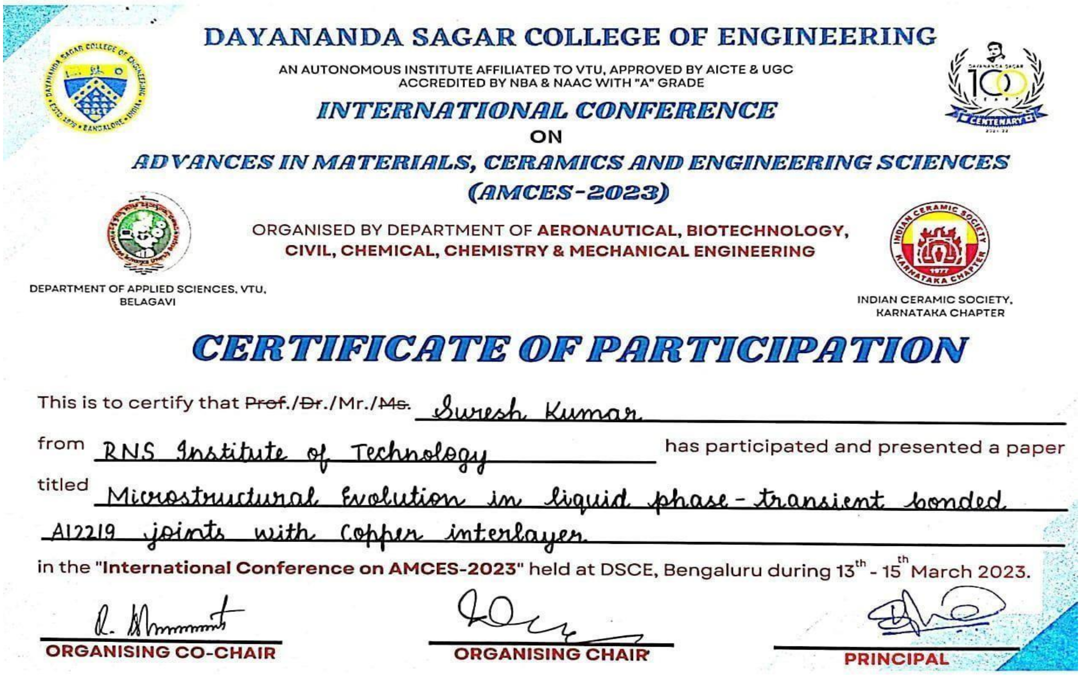

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Bharath V <bharathv88@gmail.com>

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