Republic Of Iraq
Ministry of Higher Education
& Scientific Research

University of Babylon
College of Engineering/Al-Musayab
Automobile Engineering Department

Gallium-assisted diffusion bonding of steel to aluminum, mechanical properties

A Project

Submitted to the Automobile Engineering Department / University of Babylon College of Engineering/Al-Musayab in partial fulfillment of the requirements for the degree of B. S in Automobile Engineering

By

Mustafa Raad Abd &Sajad Abd alzahra Shahid & Shahd Khadir Ali Hamza

Supervised by

Dr. Dhyai Hassan Jawad Aljashaami

2023-2022 ***1444-1445***

بسم الله الرَّحمن الرَّحِيم

اللَّهُ لَا إِلَٰهَ إِلَّا هُوَ الْحَيُّ الْقَيُّومُ لَا تَأْخُذُهُ سِنَةٌ وَلَا نَوْمٌ لَهُ مَا
فِي السَّمَوَاتِ وَمَا فِي الْأَرْضِ مَنْ ذَا الَّذِي يَشْفَعُ عِنْدَهُ إِلَّا
بِإِذْنِهِ يَعْلَمُ مَا بَيْنَ أَيْدِيهِمْ وَمَا خَلْفَهُمْ وَلَا يُحِيطُونَ بِشَيْءٍ
مِنْ عِلْمِهِ إِلَّا بِمَا شَاءَ وَسِعَ كُرْسِيُّهُ السَّمَاوَاتِ وَالْأَرْضَ
وَلَا يَئُودُهُ حِفْظُهُمَا وَهُوَ الْعَلِيُّ الْعَظِيمُ (٢٥٥) لَا إِكْرَاهَ فِي
الدِّينِ قَدْ تَبَيَّنَ الرُّشْدُ مِنَ الْغَيِّ فَمَنْ يَكْفُرْ بِالطَّاغُوتِ
وَيُؤْمِنْ بِاللَّهِ فَقَدِ اسْتَمْسَكَ بِالْعُرْوَةِ الْوُثْقَى لَا انْفِصَامَ لَهَا
وَاللَّهُ سَمِيعٌ عَلِيمٌ (٢٥٦) اللَّهُ وَلِيُّ الَّذِينَ آمَنُوا يُخْرِجُهُمْ مِنَ
الظُّلُمَاتِ إِلَى النُّورِ وَالَّذِينَ كَفَرُوا أَوْلِيَاؤُهُمُ الطَّاغُوتُ
يُخْرِجُونَهُمْ مِنَ النُّورِ إِلَى الظُّلُمَاتِ أُولَئِكَ أَصْحَابُ النَّارِ
هُمْ فِيهَا خَالِدُونَ (٢٥٧)

سورة البقرة

* إلاهداء *

قال تعالى: {قل اعملوا فسيرى الله عملكم ورسوله والمؤمنون }

إلهي لايطيب الليل إلا بشكرك ولايطيب النهار إلا بطاعتك.......
ولا تطيب اللحظات إلا بذكرك .. ولا تطيب الأخرة إلا بعفوك ....
ولا تطيب الجنة إلا برؤيتك

....

الله جل جلاله

إلى من بلغ الرسالة وأدى الأمانة .. ونصح الأمة .. إلى نبي الرحمة ونور العالمين

....

سيدنا محمد صلى الله عليه وسلم

الى مصدر فخري وأعتزازي الى من استقي منهما عزيمتي ، الى من كانا القدوة في الصبر والعطاء ، الى من دعما مسيرتي في كل الاوقات ، الى من غمراني بسعة صدورهم وزوداني بدفئ قلوبهم وأكرمني الله بفضل دعائهم

....

أبي وأمي الأحباء اطال الله بعمرهما

إلى منارة العلم والعلماء إلى الصرح الشامخ ، إلى الذين حملوا أقدس رسالة في الحياة إلى الذين مهدوا لنا طريق العلم والمعرفة

....

أساتذتنا الأفاضل

أهديكم هذه الثمرة المتواضعة راجيا من الله التوفيق والقبول

Supervisor Certificate

I certify that the preparation of this project entitled Study the " ***Gallium-assisted diffusion bonding of steel to aluminum, mechanical properties*** *" Was made under my supervision in Automotive Engineering Branch in the University of Babylon, as a partial fulfillment of the requirement of the B.Sc Degree in Automobile Engineering*

Signature:

Supervisor: ***Dr. Dhyai Hassan Jawad Aljashaami***

Date:

شكر وتقدير

في البداية ، الشكر والحمد لله ، جل في علاه ، فإليه ينسب الفضل كله

والكمال يبقى له وحده الذي وفقنا واعاننا على انهاء هذا البحث والخروج به بهذه الصوره المتكامله.

و وفاء وتقديرا مني بالجميل فإنني أتوجه بالشكر الجزيل للأستاذ المشرف الدكتور

(م. د ضياء حسن جواد) الذي لن تفيه أي كلمات حقه ، فلولا مثابرته ودعمه المستمر ما تم هذا العمل.

فقد دفعتني ملاحظاته الثاقبة الى صقل تفكيري ورفع عملي الى مستوى اعلى .

وبعدها فالشكر موصول لكل أساتذتي الذين تتلمذت على أيديهم في كل مراحل دراستي

حتى أتشرف بوقوفي أمام حضراتكم اليوم

Abstract

Development of a suitable joining technique for advanced aluminium alloys and composites will enable them to be more widely used. The aim of this project research was to develop new joining methods for these materials for which conventional welding methods have been unsuccessful. Successful joining of heat conducting materials, to high-temperature components is of significant importance for heat management in nuclear power plants and liquid propellant launch vehicles. Solid-state processes are considered for joining such dissimilar materials. In this study, Al/Al composite was triye to processed by Gallium-assisted diffusion bonding technique. A new method for diffusion bonding Al base and Al base superalloys will been developed, which is based on non-chemical oxide removal before the bonding process. Diffusion bonding is a process by which faying surfaces are brought into suffficiently close contact using an applied pressure at elevated temperature to allow bond formation by atomic interdiffusion across the joint interfacevehicles.

In this work, the Experimental part is divided into two stages, first: created the device (heat chamber) which has the heater, load part, and isolator foil. The second stage of this research is to fabricate the composite material by bonding methods and also to an analytical model which may be applicable to all transient liquid phase (TLP) bonding processes. The first stage of this project was completed, but the second part may be done in future work.

CONTENTS

CONTENTS

Chapter One

1-Introduction

1-1 ***General Introduction***

The technology of dissimilar metal joining has a variety of applications, especially when a certain property combination is desired. These joints have received more attention from researchers in recent decades as they create the possibility of achieving a compromise between cost and improved joint efficiency [1]. However, creating such joints poses more challenges due to the differences in the properties of the participating Base Metals (BMs) . Diffusion bonding involves bringing the participating BMs within interatomic distances by applying pressure at elevated temperatures. The quality of joints, therefore, depends on Influence of temperature, bearing pressure, bonding time and design. diffusion-bonded dissimilar joints are less prone to interfacial failure due to the reduction in Intermetallic Compounds formation [2,3]. Among the efforts made by experimenters in improving the quality of dissimilar joints is the incorporation of an interlayer between the BMs. A suitable interlayer has the ability of retarding oxide formation and facilitates the release of residual stresses between the BMs [4]. Despite the existence of several dissimilar metal joints, aluminium/mild steel joints have received more attention from researchers, particularly in the marine industry. This is due to the desire to reduce the overall weight of the deckhouse superstructure, energy consumption and cost of production . Gallium, conversely, is a very ductile metal with a melting point relatively lower than that of mild steel and aluminium [5].

Over time, the advancement has been made in creating dissimilar joints involving aluminium and/or steel with or without interlayers using diffusion bonding. From the foregoing, it is evident that the quality of diffusion-bonded joints is greatly dependent on the bonding parameter. Furthermore, though several studies on aluminium/mild steel dissimilar joints exist, little or no study has been conducted to investigate the properties of the dissimilar joint with a Gallium interlayer despite having the potential to improve the overall joint quality.The dissimilar joints also form part of the marine industry's structural component (deck house superstructure). This study explored the feasibility of creating aluminium/mild steel dissimilar joints with a Gallium interlayer. The effect of the bonding temperature, surface roughness and holding time on the joint's mechanical properties were investigated. The effect of these parameters . [6]

1-2 Influence of bonding temperature

For diffusion welding, the joining temperature is normally set in the range of about 80% of the melting temperature for a pure metal or of the starting melting temperature for alloys. Temperature is calculated in Kelvin. Obviously, similar to the appropriate temperature for recrystallization, the temperature for alloys should exceed this level. For materials with surface passivation layers, temperature should be even higher and the time longer, which changes the whole process in terms of creep rate and appropriate bearing pressure. When comparing diffusion welding of, e.g., pure aluminium (Ts = 660°C) and AlMg3 (Ts = 610–640°C), the whole process has to be optimised. Otherwise, welding will fail due to excessive deformation [7] .

1-3 Influence of bearing pressure

Bearing pressure is responsible for joining the mating surfaces. Influence of the bearing pressure is contrary to that of temperature. When increasing the bonding time from 1 to 4 h,the deformation is not proportional but increased by a factor of about 2.5 [8]. Obviously, a certain minimum bearing pressure is necessary to facilitate the deformation of local contact areas of the sample depending on the temperature applied. Additionally, deformation under the given conditions strongly depends on the aspect ratio of the part and on the frictional cross-section between the part and the die applying the load .

1-4 Influence of bonding time and design

Is required for conducting the diffusion process. After the initial step of approaching mating surfaces, time is needed to fill the pores left in between the local contact areas. Hence, a sufficient long bonding time is required. Bonding time, together with temperature, affects deformation. However, as mentioned above, its influence is non-linear. As soon as creep takes place during diffusion bonding, a long bonding time makes it difficult to control deformation and design changes may have a major impact.difficult to weld prototypes of varying designs or materials without profound experience. It is also hard to give a certain percentage of deformation to obtain a good diffusion bond. In fact, bonding quality depends on the number of layers to be bonded. In any case, the deformation behavior depends not only on the composition of a material but also on its micro-structure .

1-5 Influencing factors

Several additional factors may influence the result or may change the material, e.g. surface roughness and passivation layers, all kinds of lattice defects, polymorphic behavior, and formation of precipitations at grain boundaries, design of the parts to be welded and its aspect ratio as well as mechanical issues of the welding equipment.

1-1-5 Surface effects

For diffusion welding, a very good quality of surfaces is a pre-requisite. Surfaces must be free of single deep scratches preventing vacuum-tight joints and of impurities from machining.Careful cleaning using surfactants and subsequent rinsing with ethanol or acetone are required. Gloves free of powder should be used for handling.The number of stacked layers will also influence deformation at the given diffusion welding parameters, since multiple surfaces are approached and levelled. Hence, it is not possible to give a certain percentage of deformation to achieve highly vacuum-tight joints. Deformation also depends on the composition of the material.

1-2-5 Influence of roughness

A pre-requisite for solid-state diffusion is a very good contact of the mating surfaces on theatomic level. Often, a “low surface roughness” that is not specified otherwise is required in the literature [9] .

1-3-5 Passivation layers

Some metals and alloys like aluminium, stainless steel, nickel-based alloys or titanium spontaneously form surface passivation layers. They consist mainly of oxides of the base metal, some alloying elements may be enriched. Often, oxygen is blocked to prevent further oxidation and the passivation layers are responsible for the good corrosion resistance in aqueous media or hot gases. Especially for aluminium, formation of passivation layers cannot be avoided completely. The thickness of these passivation layers is in the range of 2–20 nm depending on the type of metal and the content of alloying elements [10,11]

1-6 Literature survey

SB Dunkerton-Diffusion bonding 2, 1-12, 1991 Diffusion bonding is a micro deformation solid phase process finding application in niche areas. The mechanisms of bonding are generally understood, and data on modelling is available although limited to simple metal systems. Application areas range from electronics and sensors to the aerospace and nuclear industries, and these applications are expected to continue and develop. An extension of these applications will result from developments in HIP bonding where the unit costs can be reduced for bulk production, and more complex geometries can be bonded. Another driving force to extend the use of diffusion bonding, is the increasing development of new and advanced materials [12] .

D Joyson - BARC Newsl 331 (3-4), 19-25, 2013 Competitive advanced technique in joining similar and dissimilar materials which are difficult to join using the conventional methods. The technique is elaborated with emphasis on the key variables, the mechanisms involved and optimization of the process parameters[13] .

Nils Haneklaus - Metals 11 (2), 323, 2021 Diffusion bonding is a solid-state welding technique used to join similar and dissimilar materials. Relatively long processing times, usually in the order of several hours as well as fine polished surfaces make it challenging to integrate diffusion bonding in other production processes and mitigate widespread use of the technology. Several studies indicate that varying pressure during diffusion bonding in contrast to the traditionally applied constant load may reduce overall processing- and bonding times [14].

1-7 Aim of this project

The focus of research in this frontier is primarily on the improving the joint strength by optimizing the bonding parameters and nature of interlayers. However, the main objective of the present work was to carry out an in-depth investigation on the evolution of the mechanical prosperities at the SS-Al interface during gallium-assisted diffusion bonding.

Chapter Two

Theoretical Part

2-1 Diffusion bonding

Is a solid-state welding technique used in metalworking, capable of joining similar and dissimilar metals. It operates on the principle of solid-state diffusion, wherein the atoms of two solid, metallic surfaces intersperse themselves over time. This is typically accomplished at an elevated temperature, approximately 50-75% of the absolute melting temperature of the materials [15] . Diffusion bonding is usually implemented by applying high pressure, in conjunction with necessarily high temperature, to the materials to be welded; the technique is most commonly used to weld "sandwiches" of alternating layers of thin metal foil, and metal wires or filaments. Currently, the diffusion bonding method is widely used in the joining of high-strength and refractory metals within the aerospace and nuclear industries.

2-1-1 Mechanism of Diffusion Bonding

In diffusion bonding, the nature of the joining process is essentially the coalescence of two atomically clean solid surfaces. Complete coalescence comes about through a three-stage metallurgical sequence of events. Each stage, as shown in Fig. 1, is associated with a particular metallurgical mechanism that makes the dominant contribution to the bonding process. Consequently, the stages are not discretely defined, but begin and end gradually, because the metallurgical mechanisms overlap in time. During the first stage, the contact area grows to a large fraction of the joint area by localized deformation of the contacting surface asperities. Factors such as surface roughness, yield strength, work hardening, temperature, and pressure are of primary importance during this stage of bonding. At the completion of this stage, the interface boundary is no longer a planar interface, but consists of voids separated by areas of intimate contact. In these areas of contact, the joint becomes equivalent to a grain boundary between the grains on each surface. The first stage is usually of short duration for the common case of relatively high-pressure diffusion bonding.

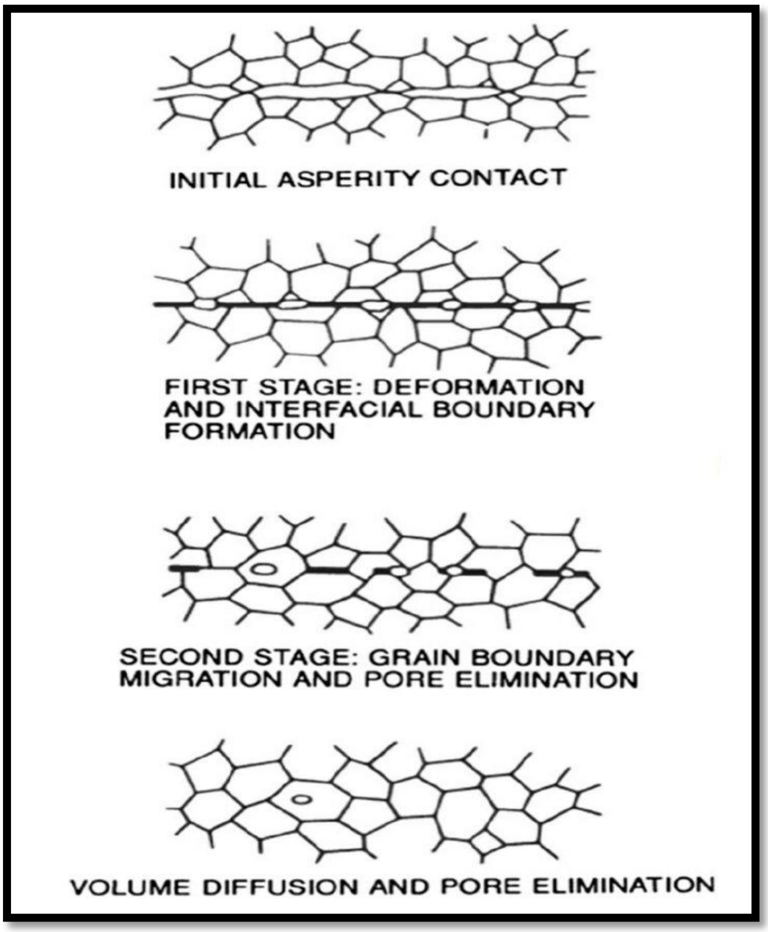

Figure (2- 1) shows the mechanism of diffusion bonding

During the second stage of joint formation, two changes occur simultaneously. All of the voids in the joints shrink, and most are eliminated. In addition, the interfacial grain boundary migrates out of the plane of the joint to lower-energy equilibrium. Creep and diffusion mechanisms are important during the second stage of bonding and for most, if not all, practical applications, bonding would be considered essentially complete following this stage. As the boundary moves, any remaining voids are engulfed within grains where they are no longer in contact with a grain boundary. During this third stage of bonding, the voids are very small and very likely have no impact on interface strength. Again, diffusional processes cause the shrinkage and elimination of voids, but the only possible diffusion path is now through the volume of the grains themselves.

2-1-2 Characteristics

Diffusion bonding involves no liquid fusion, and often no filler metal. No weight is added to the total, and the join tends to exhibit both the strength and temperature resistance of the base metal(s). The materials endure no, or very little, plastic deformation. Very little residual stress is introduced, and there is no contamination from the bonding process. It may theoretically be performed on a join surface of any size with no increase in processing time, however, practically speaking, the surface tends to be limited by the pressure required and physical limitations. Diffusion bonding may be performed with similar and dissimilar metals, reactive and refractory metals, or pieces of varying thicknesses. Due to its relatively high cost, diffusion bonding is most often used for jobs either difficult or impossible to weld by other means. Examples include welding materials normally impossible to join via liquid fusion, such as zirconium and beryllium; materials with very high melting points such as tungsten; alternating layers of different metals which must retain strength at high temperatures; and very thin, honeycombed metal foil structures[16] [17] [18].

2-1-3 Advantages

1-The bonded surface has the same physical and mechanical properties as the base material. Once bonding is complete, the joint may be tested using tensile testing for example.

2-The diffusion bonding process is able to produce high quality joints where no discontinuity or porosity exists in the interface.[19] In other words, we are able to sand, manufacturing and heat the material.

3-Diffusion bonding enables the manufacture of high precision components with complex shapes. Also, diffusion is flexible.

4-The diffusion bonding method can be used widely, joining either similar or dissimilar materials, and is also important in processing composite materials.

5-The process is not extremely hard to approach and the cost to perform the diffusion bonding is not high [20].

2-1-4 <u>Gallium</u>

Gallium is a metallic element represented by the symbol Ga and belongs to group 13 in the periodic table. It was discovered by French chemist Paul-Émile Lecoq de Boisbaudran in 1875. Chemically it is similar to aluminum. However, both metals end up showing properties that make them different from each other.
For example, aluminum alloys can be worked to give them all kinds of shapes; While those in gallium have very low melting points, they practically consist of silver liquids. Also, the melting point of gallium is lower than that of aluminum; The former can melt from the heat of the hand, while the latter does not [21] .

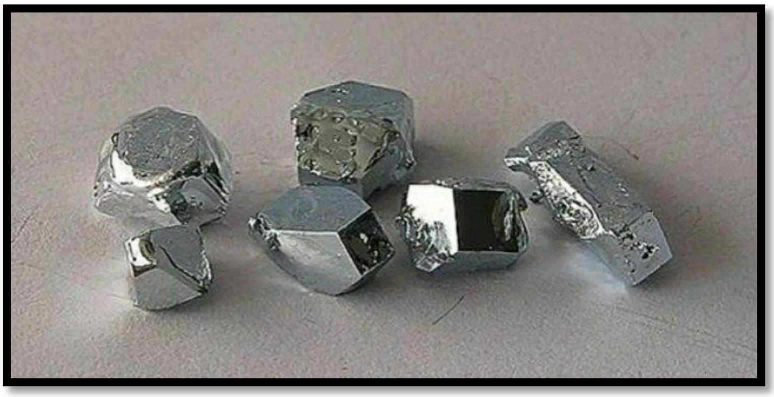

Figure (2 –2) The Gallium

Also, the chemical similarity between gallium and aluminum brings them together geochemically; That is, minerals or rocks rich in aluminum, such as bauxite, contain estimated concentrations of gallium. Apart from this mineral source, there are other sources of zinc, lead and carbon, which are widely scattered throughout the earth's crust.Gallium is not a popular metal and Although gallium is not toxic, like mercury, it is a destructive agent to metals, because it makes them brittle and useless (in the first place). On the other hand, it interferes pharmacologically with the processes in which biological matrices use iron.

2-1-5 <u>Physical properties</u>

Gallium is a silvery metal with a glassy surface, odorless, with an astringent taste. a soft and brittle solid, which when broken becomes conchoidal; That is, the pieces formed are curved, similar to sea shells.When melting, depending on the angle at which it is viewed, it can exhibit a bluish glow. This silvery liquid is not toxic on contact; However, it "sticks" too much to surfaces, especially if they are ceramic or glass [22] .

2-1-6 chemical properties

1-Atomic number (Z): (31 Ga)
2-Molar mass: 69.723 g/mol
3-Melting point:29.7646 degrees Celsius.
4-Boiling point: 2400 degrees Celsius.
5-Density: At room temperature: 5.91 g/ cm3 , At the melting point: 6.095 g / cm3
6-Interactive:The metal gallium is relatively inert at room temperature. It does not react with air as a thin layer of Ga 2 or 3 oxide protects it from oxygen and sulfur.
7-isotopes:Gallium occurs mainly in nature in the form of two isotopes: the 69 Ga, with an abundance of 60.11%; and the 71- ga, with an abundance of 39.89%. For this reason, the atomic weight of gallium is 69.723 St.

2-1-7 Risks

A - environmental and physical

From an environmental point of view, metallic gallium is not highly reactive and soluble in water, so spills from it theoretically do not present severe contamination risks. In addition, it is not known what biological role it may play in living organisms, as most of its atoms are excreted in the urine, with no signs of accumulation in any of its tissues. Unlike mercury, gallium can be handled with bare hands. In fact, the experience of trying to melt it with the heat of the hands is so common. Anyone can touch the resulting silvery liquid without fear of harming or cutting the skin; Although it does leave a silver stain on it. However, ingesting it could be toxic, because in theory it would dissolve in the stomach to generate GaCl 3 ; Gallium salt whose effects on the body are independent of the metal [23].

B - Metal damage

Gallium is characterized by highly staining or sticking to surfaces; And if it is metallic, it passes through it and instantly forms ingots. This property of being able to mix with almost all metals makes it inappropriate to spill liquid gallium on any metal object. Therefore, metallic objects run the risk of breaking into pieces in the presence of gallium. Its action can be so slow and unnoticed that it brings unwanted surprises; Especially if it spills on a metal chair, which can collapse when someone sits on it.This is why those who wish to handle gallium should not come into contact with other metals.

2-1-8 Applications

1-thermometers
Gallium replaced mercury as the liquid for reading temperatures marked by a thermometer. However, its melting point of 29.7 °C is still high for this application, which is why in its metallic state it would not be possible to use it in thermometers; Instead, an alloy called Galinstan (Ga-In-Sn) is used. Galinstan alloy has a melting point around -18°C

2-Mirror manufacturing
Again, the wettability of gallium and its alloys is mentioned. When touching a porcelain or glass surface, it spreads over the entire surface until it is completely covered with a silver mirror. In addition to mirrors, gallium alloys have been used to create objects of all shapes, because once cooled they harden.

3-Computers
The thermal paste used in computer processors is made from gallium alloys.

4-drugs
Ga3 + ions bear some resemblance to Fe3 + in the way they are involved in metabolic processes. Therefore, if there is a function, parasite or bacteria that requires the performance of iron, it can be stopped by confusing it with gallium; This is the case for pseudomonas bacteria.

5-technological
Gallium arsenide and nitride are semiconductors that have replaced silicon in some optoelectronic applications. With them, transistors, laser diodes, light-emitting diodes (blue and violet), chips, solar cells, etc. were made.

6- stimuli
Gallium oxides have been used to study their catalysis in various organic reactions of great industrial interest. One of the newer gallium catalysts consists of its own liquid, in which atoms of other metals acting as active centers or sites are dispersed [24].

2-1-9 Aluminium

Is a chemical element with the symbol Al and atomic number 13. Aluminium has a density lower than those of other common metals, at approximately one third that of steel. It has a great affinity towards oxygen, and forms a protective layer of oxide on the surface when exposed to air. Aluminium visually resembles silver, both in its color and in its great ability to reflect light. It is soft, non-magnetic and ductile. It has one stable isotope, 27Al; this isotope is very common, making aluminium the twelfth most common element in the Universe. The radioactivity of 26Al is used in radiodating [25].

Figure (2 –3) The Aluminium

Chemically, aluminium is a post-transition metal in the boron group; as is common for the group, aluminium forms compounds primarily in the +3 oxidation state. The aluminium cation Al^{3+} is small and highly charged; as such, it is polarizing, and bonds aluminium forms tend towards covalency. The strong affinity towards oxygen leads to aluminum's common association with oxygen in nature in the form of oxides; for this reason, aluminium is found on Earth primarily in rocks in the crust, where it is the third most abundant element after oxygen and silicon, rather than in the mantle, and virtually never as the free metal [26] .

2-1-10 Aluminum alloy

Cast and wrought alloy nomenclatures have been developed. The Aluminum Association system is most widely recognized in the United States. Their alloy identification system employs different nomenclatures for wrought and cast alloys, but divides alloys into families for simplifi-cation.

A- For wrought alloys a four-digit system is used to produce a list of wrought composition families as follows :

1xxx: Controlled unalloyed (pure) composition, used primarily in the electrical and chemical industries

2xxx: Alloys in which copper is the principal alloying element,although other elements, notably magnesium, may be specified. 2xxx-series alloys are widely used in aircraft where their high strength (yield strengths as high as 455 MPa, or 66 ksi) is valued.

3xxx: Alloys in which manganese is the principal alloying element,used as general-purpose alloys for architectural applications and various products

4xxx: Alloys in which silicon is the principal alloying element, used in welding rods and brazing sheet

5xxx: Alloys in which magnesium is the principal alloying element,used in boat hulls, gangplanks, and other products exposed to marine
environments

6xxx: Alloys in which magnesium and silicon are the principal alloying elements, commonly used for architectural extrusions and automotive components

7xxx: Alloys in which zinc is the principal alloying element (although other elements, such as copper, magnesium, chromium, and zirconium,may be specified), used in aircraft structural components and other high-strength applications. The 7xxx series are the strongest aluminum alloys, with yield strengths ≥500 MPa (≥73 ksi) possible.

8xxx: Alloys characterizing miscellaneous compositions. The 8xxx series alloys may contain appreciable amounts of tin, lithium, and/or iron .

B- Casting compositions are described by a three-digit system followed by a decimal value. The decimal .0 in all cases pertains to casting alloy limits.Decimals .1, and .2 concern ingot compositions, which after melting and processing should result in chemistries conforming to casting specification requirements. Alloy families for casting compositions include the following:

1xx.x: Controlled unalloyed (pure) compositions, especially for rotor manufacture

2xx.x: Alloys in which copper is the principal alloying element. Other alloying elements may be specified. 3xx.x: Alloys in which silicon is the principal alloying element. The other alloying elements such as copper and magnesium are specified.The

3xx.x series comprises nearly 90% of all shaped castings produced.

4xx.x: Alloys in which silicon is the principal alloying element.

5xx.x: Alloys in which magnesium is the principal alloying element.

6xx.x: Unused

7xx.x: Alloys in which zinc is the principal alloying element. Other alloying elements such as copper and magnesium may be specified.

8xx.x: Alloys in which tin is the principal alloying element [27].

2-1-11 <u>Properties of aluminium</u>

The three main properties on which the application of aluminium is based are its low density of approximately 2.7, the high mechanical strength achieved by suitable alloying and heat treatments, and the relatively higb corrosion resistance of the pure metal. Other valuable properties include its high thermal and electrical conductance, its reflectivity, its high ductility and resultant low working cost, its magnetic neutrality, high scrap-value, and the non-poisonous and colourless nature of its corrosion products which facilitates its use in the chemical and food-processing industries . In its pure state, aluminium is, however, a relatively soft metal with a yield strength of only 34.5 $N/rrnn^2$ and a tensile strength of 90 N/mm^2. Through the development of a wide range of alloys, however, very varied strengths and ductility can be achieved, and this has led to the many applications of today.

2-1-12 <u>Applications</u>

The properties of the various aluminium alloys has resulted in aluminium being used in industries as diverse as transport, food preparation, energy generation, packaging, architecture, and electrical transmission applications.Depending upon the application, aluminium can be used to replace other materials like copper, steel, zinc, tinplate, stainless steel, titanium, wood, paper, concrete and composites. Some examples of the areas where aluminium is used are given below.

- Packaging

Corrosion resistance and protection against UV light combined with moisture and odour containment plus the fact that aluminium is non-toxic and will not leach or taint the products has resulted in the widespread use of aluminium foils and sheet in food packaging and protection.

-Transport

After the very earliest days of manned flight, the excellent strength to weight ratio of aluminium have made it the prime material for the construction of aircraft. These same properties of aluminium mean various alloys are now also used in passenger and freight rail cars, commercial vehicles, military vehicles, ships & boats, buses & coaches, bicycles and increasingly in motor cars.

-Marine Applications

Aluminium plate and extrusions are used extensively for the superstructures of ships. The use of these materials allows designers to increase the above waterline size of the vessel without creating stability problems.

-Building and Architecture

Aluminium use in buildings covers a wide range of applications. The applications include roofing, foil insulation, windows, cladding, doors, shopfronts, balustrading, architectural hardware and guttering. Aluminium is also commonly used as the in the form of tread plate and industrial flooring.

-Other Applications

Laminates- Ladders , High pressure gas cylinders , Sporting goods , Machined components , Road barriers and signs , Furniture , Lithographic printing plates.

2-1-13 <u>Steel</u>

Is an alloy of iron and carbon with improved strength and fracture resistance compared to other forms of iron. Many other elements may be present or added. Stainless steels that are corrosion- and oxidation-resistant typically need an additional 11% chromium. Because of its high tensile strength and low cost, steel is used in buildings, infrastructure, tools, ships, trains, cars, machines, electrical appliances, and weapons [28].

Figure (2 –4) The Steel

Iron is the base metal of steel. Depending on the temperature, it can take two crystalline forms : body-centred cubic and face-centred cubic. The interaction of the allotropes of iron with the alloying elements, primarily carbon, gives steel and cast iron their range of unique properties. In steel, small amounts of carbon, other elements, and inclusions within the iron act as hardening agents that prevent the movement of dislocations.

The carbon in typical steel alloys may contribute up to 2.14% of its weight. Varying the amount of carbon and many other alloying elements, as well as controlling their chemical and physical makeup in the final steel (either as solute elements, or as precipitated phases), impedes the movement of the dislocations that make pure iron ductile, and thus controls and enhances its qualities.

Steel was produced in bloomer furnaces for thousands of years, but its large-scale, industrial use began only after more efficient production methods were devised in the 17th century [29] .

2-1-14 Different Types of Steels

-Steel can be classified depending on various factors or characteristics .

1.Based on Carbon Content:

-Low Carbon Steels

-medium Carbon Steels

-high Carbon Steels

2.Based on the Method of manufacture of Steels:

-Bessemer steel Method

-Electric Arc Furnace Method

3. Based on properties of some other types of Steels:

-Shock-resisting Steels

-High strength Steels

-Tool Steels

-Spring Steels

-Heat Resistant Steels

4. Based on Effect of Alloying elements on Steel:

Silicon, Sulphur, Phosporous, Aluminium, Vanadium, Chromium, Cobalt/Molybdenum

2-1-15 Properties of Steel

Steel has a number of properties, including: hardness, toughness, tensile strength, Ductility, Malleability, Durability, Conductivity, Luster, Rust Resistance .

HARDNESS

Is the material's ability to withstand friction and abrasion. It is worth noting that, while it may mean the same as strength and toughness in colloquial language.

-TOUGHNESS

Is difficult to define but generally is the ability to absorb energy without fracturing or rupturing. It is also defined as a material's resistance to fracture when stressed.

- Tensile Strength

Is the amount of stress that a substance can take before becoming structurally deformed. The tensile strength of steel is comparatively high, making it highly resistant to fracture .

-Ductility

One of the useful mechanical properties of steel, is its ability to change shape on the application of force to it, without resulting in a fracture. This property is known as ductility, which enables it to be used in the making of different shapes and structures ranging from thin wires or large automotive parts and panels.

- Malleability

Malleability is closely linked with ductility, and allows steel to be deformed under compression. It allows this alloy to be compressed into sheets of variable thicknesses, often created by hammering or rolling.

-Durability

The hardness of this alloy is high, reflecting its ability to resist strain. It is long-lasting and greatly resistant to external wear and tear.

- Conductivity

Steel is a good conductor of heat and electricity. These properties make it good choice for making domestic cookware, as well as electrical wiring.

-Luster

One of the physical properties of steel is its attractive outer appearance. It is silvery in color with a shiny, lustrous outer surface.

-Rust Resistance

The addition of certain elements, makes some types of steel resistant to rust. Stainless steel for instance contains nickel, molybdenum and chromium which improve its ability to resist rust.

2-1-16 Applications of Steel

As Steel has high tensile strength, it was used in:

1-Construction of buildings.
2-Infrastructure.
3-Tools.
4-Ships.
5-Automobiles.
6-Machines & appliances.
7-Weapons.
8- Machine steel.
9-Spring steel.
10-Boiler steel.
11-Structural steel .

Chapter Three

Experimental part

3-1 project strategy

This chapter focuses on the materials prepared in this project, which includes an iron bar with a diameter of (8in) inside two samples of aluminum clamped tightly and the use of gallium as a coating material through the diffusion process for different scientific applications. The descriptions of the procedures and test tools were used in this project.

3-2 Materials and preparation process

3-1-2 Materials used

An iron cylinder with thickness of 2 mm, inside diameter of 16 mm and length 25mm , iron supports, brick, heating heater, electrical wires that withstand high temperatures, an electronic scale for mass measurement, a pressure gauge, and a column related to the sample. Measure the pressure on it, sound the alarm.

3-2-2 preparation process

In the first step, the iron bar is cleaned with cleaning and polishing equipment, then painted with white paint and prepared for work.

Figure (3-1) The iron rod before the cleaning process

After that, a rectangular iron base is made in order to fix the rod on it by welding, as well as it is painted and cleaned.

Figure (3-2) The iron rod and the base after the cleaning process

Putting a cover from the top of the cylinder on which an iron column is fixed, used to install the first sample inside and calculate the pressure through it, and then put a gauge to calculate the pressure applied to it set an alarm whistle for the purpose of warning ,protection from the interactions ,influencing factors that occur inside the rod as a result of exposure to heat, pressure and other chemical reactions.

As for the bottom, the rod is tightly closed and a small hole is made in it for the purpose of inserting the column associated with the first sample to calculate the pressure applied to it.

The second sample is installed inside through a column fixed on the lower base of the penis.

Figure (3-3) outer cover before cleaning

Iron supports are placed inside on both sides of the rod for the purpose of fixing the brick on it, A heater was placed around the rods to heat them for the best welding process.

Make a small hole on the side of the penis for the purpose of inserting electrical wires.

Figure (3-4) The final shape of the penis

3-3 <u>procedure methods</u>

After completing the preparation processes ,preparing the samples and the rod for work, the tests are conducted by connecting the wires to electricity for the purpose of operating the thermal heater (which converts electrical energy into thermal energy) placed inside the brick at a temperature of about (80%).

After that, the gallium material was placed on the top of the surface of the second aluminum rod , which is attached from the bottom to the base of the rod, the first rod is pressed from the top over the second rod to , applied the necessary pressure.
After completing these steps, we record the appropriate readings at different temperatures and pressures .

Chapter Four

Results and discussion

Some experimental tests were carried out, and some measurements were taken using heat and pressure. In the first test, the temperature was used at a rate of (400°C), a time of (30 min), and a pressure of approximately (200pa). We noticed that the result failed. We conducted the second test with different measurements, where the temperature was (450°C), time (1h) and pressure (250pa). We also noticed that the test failed. In the third test, the temperature was (500°C), time (an hour and a half) and pressure (300pa). The test also failed. In the last test, the temperature (550°C), time (2h) and pressure (350pa) were taken. We also noticed that the test failed.Therefore, through these tests, the required results were not obtained, i.e. the welding process was not completed.

Chapter Five

Conclusions & Recommendations

5-1Conclusions

In short, an iron rod with a diameter of (8in) was prepared, inside two samples of aluminum, fixed tightly, and using gallium as a coating material through the diffusion process, and some tests were carried out using heat and pressure and with different measurements, and we noticed that in all of them the test failed and the required results were not obtained, i.e. the welding was not done.

5-2 Recommendations for future work:

Several recommendations for future work have been proposed in order to improve and complete the experimental work:

1- Using other types of samples such as steel.

2- Using other coating materials such as sodium alginate.

3- Using other measuring devices.

[1] Wu, W.; Hu, S.; Shen, J. Microstructure, mechanical properties and corrosion behavior of laser welded dissimilar joints between ferritic stainless steel and carbon steel. Mater. Des. 2015, 65, 855–861. [CrossRef]

[2] Lagdani, O.; Tarfaoui, M.; Rouway, M.; Laaouidi, H.; Sbai, S.J.; Dabachi, M.A.; Aamir, A.; Nachtane, M. Influence of Moisture Diffusion on the Dynamic Compressive Behavior of Glass/Polyester Composite Joints for Marine Engineering Applications. J. Compos. Sci. 2022, 6, 94. [CrossRef]

[3] Ismail, A.; Bahanan, W.; Hussain, P.B.; Saat, A.M.; Shaik, N.B. Diffusion Bonding of Al–Fe Enhanced by Gallium. Processes 2020, 8, 824. [CrossRef]

[4] Nasir, T.; Kalaf, O.; Asmael, M.; Zeeshan, Q.; Safaei, B.; Hussain, G.; Motallebzadeh, A. The experimental study of CFRP interlayer of dissimilar joint AA7075-T651/Ti-6Al-4V alloys by friction stir spot welding on mechanical and microstructural properties. Nanotechnol. Rev. 2021, 10, 401–413. [CrossRef]

[5] Nicholas, M.G.; Crispin, R.M. Diffusion bonding stainless steel to alumina using aluminium interlayers. J. Mater. Sci. 1982, 17, 3347–3360. [CrossRef]

[6] Telegdi, J.; Shaban, A.; Vastag, G. Biocorrosion—Steel. In Encyclopedia of Interfacial Chemistry; Wandelt, K., Ed.; Elsevier: Amsterdam, The Netherlands, 2018; pp. 28–42.

[7] W. Behr et al.: "Diffusion bonding of aluminium materials for the manufacturing of cooling structures to be used in ultra-high vacuum", DVS-Media, vol. 263, 2010, ISBN: 978–3–87155–589–3, pp. 127–133.

[8] D. R. Askeland: "The science and engineering of materials", Boston, Cengage Learning,

7th ed. ISBN 978-1-305-07676-1, 1989, 153 pages.

[9] S. Jahn: "Technologieentwicklung zur Herstellung variantenreicher innenstrukturiert- er Bauteile und Werkzeuge", PhD thesis, TU Ilmenau, 2007, ISBN 3–86130993–9, Verlagshaus Mainz GmbH Aachen.

[10] P. Gümpel (ed.): "Rostfreie Stähle", expert-Verlag, 4th ed., 2008, ISBN 978–3–8169–2669–4, pp. 51–52.

[11] Beizen von Edelstahl, Merkblatt 826, Informationsstelle Edelstahl Rostfrei (ed.), 2016, Available from:http://www.edelstahl-rostfrei.de/downloads/iser/MB_826.pdf [Ac- cessed: 2016–06–23].

[12] Dunkerton, S. B. "Diffusion bonding—An overview." Diffusion bonding 2 (1991): 1-12.

[13] Bhanumurthy, K., et al. "Diffusion bonding of nuclear materials." BARC Newsletter (2013).

[14] AlHazaa, Abdulaziz, Nils Haneklaus, and Zeyad Almutairi. "Impulse pressure-assisted diffusion bonding (IPADB): Review and outlook." Metals 11.2 (2021): 323.

[15] "Diffusion Bonding". Welding Fundamentals and Processes. Vol. 06A. Materials Park, Ohio: ASM International. Handbook Committee. 2011. pp. 682–689. ISBN 978-0-87170-377-4. OCLC 21034891.

[16] Schrader, George F.; Elshennway, Ahmad K. (2000). Manufacturing Processes and Materials (4th illustrated ed.). pp. 319–320. ISBN 0872635171.

[17] Chawla, Krishan K. Composite Materials: Science and Engineering. Materials research and engineering (2nd illustrated ed.). p. 174. ISBN 0387984097.

[18] Jacobson, David M. (2005). Principles of Brazing (illustrated ed.). pp. 11–14. ISBN 0871708124.

[19] Diffusion Bonding". www.msm.cam.ac.uk. Retrieved 2016-02-17.

[20] "Solid State Welding". www.totalmateria.com. Retrieved 2016-02-17.

[21] Cilla Andrea. (23 September 2009). Gallium. Chemistry world. Retrieved from: chemistryworld.com

[22] Wikipedia. (2019). Gallium. Retrieved from: en.wikipedia.org

[23] Encyclopaedia Britannica editors. (5 April 2018). Gallium. Encyclopedia Britannica. Retrieved from: britannica.com

[24] Dr. Doug Stewart. (2019). Gallium element facts. chemicalol. Retrieved from: chemicool.com

[25] aluminum". Oxford English Dictionary (Online ed.). Oxford University Press. (Subscription or participating institution membership required.)

[26] Standard Atomic Weights: Aluminium". CIAAW. 2017

[27] Aluminum and Aluminum Alloys, in Metals Handbook Desk Edition, 2nd ed., J.R. Davis, Ed., ASM International, 1998, p 417–505

[28] R., Allen. "(1979). International Competition in Iron and Steel, 1850-1913". JSTOR. Cambridge university. JSTOR 2120336. Retrieved November 13, 2020.

[28] "Decarbonization in steel | McKinsey". www.mckinsey.com. Retrieved 2022-05-20.