MECHANICAL AND MICROSTUCTURAL ANALYSIS OF DISSIMILAR METAL WELDS

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ABSTRACT
Welding process can be performed on similar or dissimilar metals. Welding of dissimilar metals involves different types of metals with distinct chemical composition. The two dissimilar metals involve in welding process have different mechanical properties and microstructures which in turn may affect welding parameters like weld current, hold time, weld force etc. When a structure or component of a machine is build or undergo any repair procedure this change in chemical composition of metals get prominent. The difference in chemical composition of metals may be due to several factors such as age hardening, oxidation etc.The study of mechanical properties of welding is important because welded structure may be installed at highly sensitive and risky place. Problem of formation of inter-mettalic compound may arise which affect the weld quality. In this paper a brief review has been given on the work done on mechanical characterization, microstructure properties of welded joints.

Keywords: *Dissimilar metals, Microstructure, Mechanical properties, Inter-metallic, Welding*

1. INTRODUCTION
The modern age demands fast production of structures. Welding is an efficient process where two materials whether of same or different composition are join togetherpermanently[1].Many industrial/commercial structures are made of materials having different composition or in the same welding technique different properties are essential for different parts. These situations give rise to dissimilar metal welds. An excellent weld is that which have adequate tensile strength and ductility so that the joint which is formed to the welding of materials will not fail [2]. The major problem that arises when joining dissimilar metal welds is formation of inter-metallic compound in the welded region. These inter-metallic compounds should be checked in order to find problems related to crack sensitivity, ductility, corrosion, etc which make the study of microstructure significant. Study of inter-mettalic compound formation showed that residual stresses are developed in this region [3]. Due to decrease intemperature, ductile to brittle transition may occurand later this brittle nature result in weld's failure. In order to avoid the formation of inter-mettalic compounds intermediate layers of nickel or vanadium are used[4].In a welding process two metals are joined together often by melting the work piece or by filler, when the molten metal cool down it takes the shape of solid joint.There are different methods of joining dissimilar metal; one of those methods is composite insert[5]. As the name indicates, another material is inserted between two metals at the interface to complete the procedure.

A. Welding Methods
There are different methods of welding that are used to join dissimilar metals such as explosive welding, cold welding, ultrasonic welding, diffusion welding, friction welding, electron beam welding, arc welding and resistance spot welding.

Explosive welding is carried out by the relative movement of metal over one another. One of the metal pieces is accelerated at very high velocity by using some kind of explosive. Figure 1 show the explosive welding process.Some of the advantages of explosive welding are that it is a simple process, can join large surfaces, it will not affect the real and actual properties of metal. There are some limitations also such as it can only weld simple geometries, produced so much noise and large vibrations due to explosive[6].

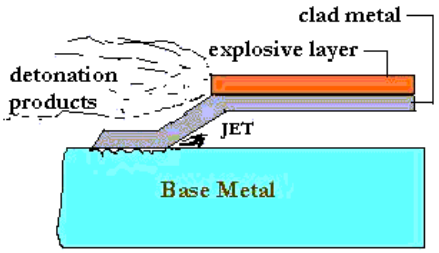

Figure 1. Explosive welding [6]

In cold welding, there is no heat used during welding process so, inter-mettalic compound and heat affected zone formation is avoided. There are some limitations of cold welding like if the weld is exposed to oxygen rich environment, the oxygen will react with the weld and failure occurs[7].In ultrasonic welding, vibrations are used to weld dissimilar metals under pressure. This type of welding is mostly used for thin sheet of metals. Figure 2 show ultrasonic welding technique [8].

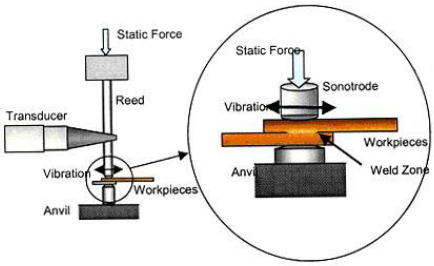

Figure 2. Ultrasonic welding [8]

Friction welding is performed by keeping one metal piece stationary while other metal piece is moved over the stationary piece to produced friction that welds the two metals together. A little amount of heat is generated through the process of friction welding. Figure 3 show friction welding technique[9].In diffusion welding, the atoms of one metal get diffused into the other metal. There is apparently no visible line of weld joint[7].Arc welding process is carried out by using electrode which melts the base metal and join them. This welding is further divided into several other types. Figure 4 show the process of tungsten gas arc welding[7].Beam welding is performed by using high electron beam and the welded region is very small. Figure 5 show process equipment for electron beam welding[7].Resistance spot welding is performed by using heat which is produced from resistance to current. This heat is used to join two metal surfaces. The advantages of resistance spot welding are that it is a cheap process, it provide dimensional accuracy and high speed process. There are also limitation of the process such as the tensile strength and fatigue strength is low, increase he weight and hard to repair [7].

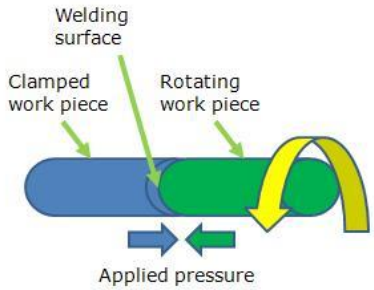

Figure 3. Friction welding [9]

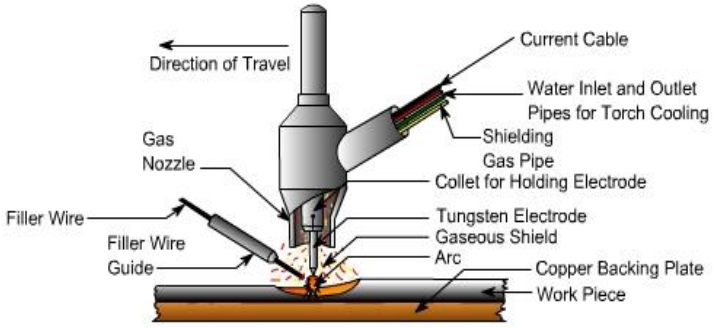

Figure 4. Gas Tungsten Arc welding [7]

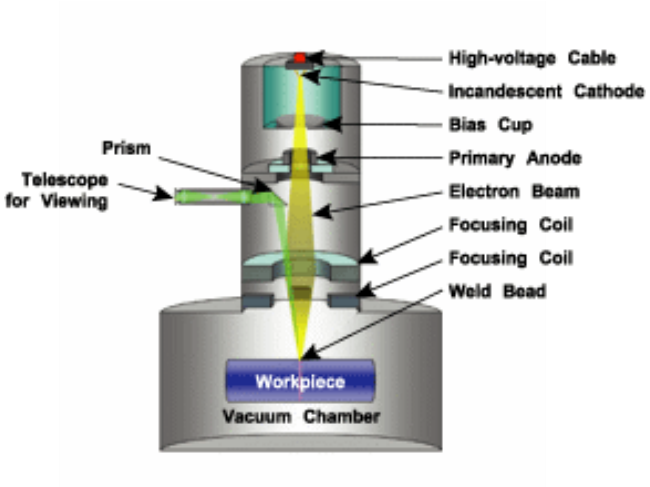

Figure 5. Electron beam welding [7]

B. Advantages and Disadvantages

The welding processes are mainly divided into four categories such as arc welding, solid state welding which consists of cold welding, explosion welding, diffusion welding, friction welding and ultrasonic welding, resistance welding and other welding processes which include processes like electron beam welding [10].

The advantages of solid state welding includes defect free weld surface, mechanical properties same as that of original metal, used for dissimilar metal welds. There are some limitations also such as there is a need of surface preparation before welding like removing any oxides or grease and this process need expensive equipment.The advantages of resistance welding include less deformation of weld, no need of filler and a cost effective process. The limitations are that this process is used for thin sheets and similar to solid state welding it also requires expensive equipment.The advantages of arc welding include low cost process equipment, excellent process for small and narrow spacing and a suitable process for metal alloy. The limitations are that the process requires replacement of electrodes repeatedly and after welding process the slag has to be removed from welded surface.The advantages of electron beam welding include continuous weld, there is no need of filler and suitable for small and narrow spaces so there will be a narrow heat affected zone. The limitations include expensive equipment and expensive production[10].

The most commonly used industrial welding process is arc welding especially flux cored welding, gas tungsten arcwelding (TIG), metal arc welding (MIG) and shielded metal arc welding because it require less expensive process equipment and most suitable process for metal alloys than other welding processes[11].

The cost of welding process plays an important role during manufacturing phase. The cost of welding process includes equipment, labor and material cost. When welding is done manually the labor cost increases but in modern era welding process are making automatic in order to save labor cost and save time. Industrial welding especially in automotive industry the welding processes are getting automatic with the help of robots. Researcher are working on new area like dissimilar metal welds by using processes like friction stir welding and laser beam

welding. A lot of work has being going on in making laser beam welding technique practical for many applications in which cost is not an important factor like in aerospace.

2. MECHANICAL CHARACTERIZATION

SHUBHAVARDHAN et al. worked on joints of dissimilar metal welds by taking AA6082 aluminum alloy and AISI 304 stainless steel using friction welding. Different tests including impact test, tensile test, hardness test and fatigue test were conducted to find out different and optimized welding parameters. The test results showed that strength of joint varies with increasing pressure and time. When tensile test was conducted the results showed that in the start, strength of the joint increases but after reaching maximum value it decreases with increasing pressure and time. When temperature increases with time alloying element get deposited on the interface which make the weld strength decreased. Authors obtained better interface weld strength and improved fatigue strength by optimizing pressure and time[12].

TABAN et al. worked on the microstructure of interface which was done by the friction welding [13]. CHEN worked on the process parameters of friction stir welding and found the pieces of steel in weld zone [14]. OZDEMIR studied friction welding of dissimilar metal weld. The main combination used was AISI 304 L and AISI 4340 steel. These combinations were used in applications where certain special properties required and it also saves cost [15]. WATANABE et al. studied friction stir welding and showed a possible way to join the metal combination of aluminum and steel [16]. WATANABE et al. obtain the tensile strength of the joint of about 86% of aluminum base metal [17] after combining Aluminum to steel and SATHIYA et al studied about the friction time when the weld zone is fully plastically deformed [18].

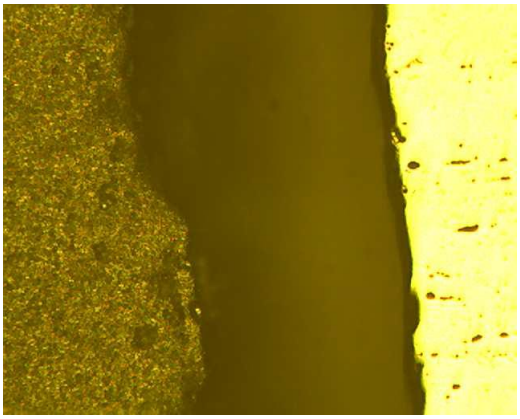

Figure 6. Interface region of dissimilar metal weld joint [12]

SADAT ALI et al. studied the mechanical properties of the welded joints in dissimilar metal welds and how these mechanical properties affect the welding parameters using arc welding. In dissimilar metal welds two different metals are welded together having different chemical composition. This difference in chemical composition further affects the weldability and mechanical properties of the joints. Some of the major elements in an alloy are carbon, sulphur, manganese etc. All these elements are added to increases the strength, toughness and impact properties of the alloy but their increased amounts may affect the weld quality. If carbon content increases in the metal it reduces its weldability. If sulphur content is increased it may combine with the manganese and form manganese sulfide (MnS) which cause through thickness weld shrinkage strains. Phosphorous start separate when it is added in steel and may get deposited on grain boundaries and weaken the grain boundaries. Sulphur reduces the ductility. An experimental setup is created from which a comparison is done on the parent and welded material. When two different material having different mechanical properties are welded by arc welding their properties depends on type of filler material, pre and post heating conditions [19].YLBAS et al.worked on the dissimilar metal welds by taking combination of steel-aluminum and aluminum-copper and studied their mechanicalproperties [20].CHEN et al. joined the technique of fusion

welding with solid state welding and studied the joining of Al6061 and mild steel [21]. JIANG et al. studied the joining of 6061-T6 aluminum alloy with AISI 1018 steel and showed that the strength and hardness is higher than the base aluminum [22]. TANAKA et al. showed that the mechanical properties of the joints are greatly influenced by the formation of inter-metallic compounds [23]. SPRINGER et al. worked on the inter-metallic compound influence on the mechanical properties of welds joint by taking steel and aluminum alloys [24]. AKINLABI did tensile test by taking various welding parameters and he produced a weld joint which has the efficiency between 73 and 86% [25]. GALVAO et al studied about the welding condition especially rotational speed and was able to obtain good surface finish weld but was not successful in dissimilar metal welds [26]. ESMAEILI et al. studied that the rotational speed greatly affects the mechanical behavior of welded joint. Due to the inter-metallic layer at the interface there was increase in the tensile strength but later due to the formation of cavities the tensile strength decreases. The thickness of inter-metallic compound at the interface increases with the rotational speed which in turn reduces the tensile strength [27].

AKINLABI et al.observed an increase in the micro hardness value at the interface due to the strain hardening at the interface of the welded joint [28]. XUE et al. studied that tensile strength of the weld decreases with low rotational speed and high tool offset. The strength of the weld increases by increases the rotational speed and proper tool offsets [29]. SAEID et al. achieved maximum tensile and shear strength of the joint while working on the friction stir welding process by taking aluminum and copper. When the rotational speed increases, micro cavities get developed this in turn decreases the tensile sear strength [30].

3. MICROSTRUCTURAL EVOLUTION

MUKUNA et al. worked on the dissimilar metal weld by taking aluminum and copper. The process of welding used is friction stir welding (FSW) technique. They focused on the study of microstructure, mechanical testing and tools which are used during welding process. Friction stir welding technique is used because this type of welding reduces solidification or liquefaction cracking. This is a type of solid state welding which provide more efficiency [31].

Previously,Friction Stir welding of copper and aluminumhas not been studied widely except the study of material flow, welding parameters and their optimization. There is a room of improvement while developing their application in industries. According to the study of microstructure if on the advancing side we place copper plate it will provide god results. Some inter-metallic compound developed while this welding which need to be properly understands in order to have a clear view of their impact on the weldments. The optimization of the welding parameters will reduce the amount of inter-metallic compound formed. The friction stir welding will be the most used welding technique in the future but more understanding should be developed to enhance the mechanical properties of welds. If the tools used for friction stir welding improved then high quality welds can be produced [31].

LIU et al. worked on welding between copper and aluminum. It was showed that the boundary between copper and aluminum was apparent and there was plastic combination of materials at the boundary. There was a circular ring seen between the copper and aluminum boundary which was an indication of good material flow [32]. XUE at el. worked on the welding between AA1060 aluminum and copper. They did X-Ray diffraction analysis and find out that aluminum reacted with copper forming some compounds around large copper particles and at small copper particles, copper get converted into intermetallic. When microstructural study of the welded region was done they found that at the bottom of weld there was a region where bulk of particles was present [33]. BISADI et al. showed that when welding was done at low temperature some defects were formed. When welding was done at very high temperature some cavities were formed at the interface. They also find out that if the temperature of the process was keep on increasing more copper particles will get diffuse into aluminum matrix which will lead to intermetallic compounds and micro cavities [34]. AKINLABI et al. studied about the microstructure of the interface when welding of copper and aluminum was done and observed fine metallurgical bonding at the interface [35]. RAJ SINGH et al. showed that at the different region of the weld different microstructure was seen. At the centre of the weld mix matrix of copper and aluminum was observed. At the opposite side small particles of copper and aluminum was observed. The heat affected zone is not apparent in either copper or aluminum. The Thermo Mechanically Affected Zone was apparent in copper but not in aluminum [36]. XUE et al. worked on the joining of copper and aluminum through friction stir welding process. They showed that in the interface good metallurgical bonding was observed [37].

4. FORMATION OF INTERMETTALIC COMPOUNDS

YOON et al. studied that usually fusion welding is used for dissimilar meal welds. This welding technique fails when intermetallic compounds are formed or where temperatures of two materials don't match or where the two materials involved have wide different melting points. In order to overcome all these problems friction welding technique is used [38]. A. AMBROZIAK worked on the friction welding by taking liquid and studied that by using liquid the joint area can be protected by atmospheric gases [39]. A. AMBROZIAK et al. worked on friction welding by taking tungsten- titanium joints [40].
AMBROZIAK et al. studied that friction welding was used to join dissimilar metals like aluminum-steel, steel-copper etc. The metals that are present in group IV, V and VI like titanium, vanadium, Zirconium etc can also be welded by friction welding process. The major that someone might have come across in friction welding is the development of intermetallic phases between two different metals. In order to overcome this problem intermediates layers of different elements are used. To study the effect of intermediate layers by using friction welding in dissimilar metals three combinations of materials is taken into account niobium-D18 pseudo-alloy of tungsten, titanium-D18 pseudo-alloy of tungsten, and steel-titanium. Pseudo-alloy are those alloy which are produced by powder-metallurgy technique, in which base is 95% and other bonding elements are mixed together to form the remaining 5% composition. Results shows when direct friction welding is used in the above three combinations intermetallic phases are formed and it is very hard and difficult to remove them. When the metallic intermediate layers are used no intermetallic phases are formed between the two different metals but when there is no micro crack developed in that area. For niobium-D18 pseudo-alloy of tungsten, copper as an intermediate layer can be used. For titanium joints vanadium intermediate layers have to be used [41].

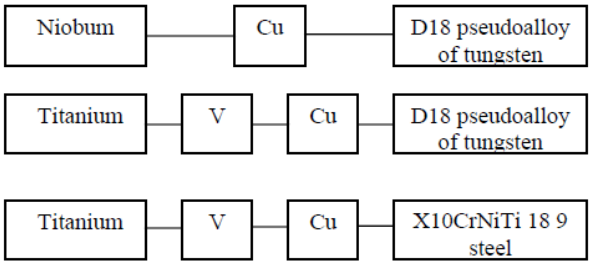

Figure 7. Inter layering system in niobium and titanium joints [41]

WALLURA et al. investigated the problems that rise due to the diffusion welding in different combinations. The combinations are titanium to steel or titanium to Armco iron [42]. A. NENTWIG and J. RUGE worked on the welding in solid state. The welding method is applied to joints in niobium and titanium [43, 44]. Other materials can be taken, e.g. to join niobium and austenitic steel, inter layer of titanium is used. OUYANG et al. studied on the dissimilar metal weld by taking copper and aluminum. He showed that the direct application of friction stir welding process is difficult because of the intermetallic compounds formed and these compounds are brittle in nature [45]. ZADEH et al studied the friction welding method in dissimilar metal welds. During the tensile test they find out that some intermetallic compounds like Al4Cu9, AlCu etc were formed and from these intermetallic compounds crack can be initiated and then propagation occurred. They also showed that rotational speed while the test was an important parameter as at high speed increase in the intermetallic compounds occurred and at low speed imperfect joint may result [46]. ESMAEILI et al. worked on the friction stir welding by taking brass and aluminum. When the rotational speed was low, intermetallic compounds were not found because input of the heat is very less. As the rotational speed increased intermetallic compounds was gradually start developing [47].

5. CONCLUSION

The conclusions which can be made from the review paper are, different types of welding processes can be used in order to weld dissimilar metals. Study of the mechanical properties of the weld is very important because the main purpose of the welding is to strongly join the two metals together as the application of the welded structure may be at sensitive place. It is important to check the tensile strength of the weld and the factors affecting the strength of the weld. The major problem occurs with dissimilar metal welds is formation of inter-metallic compounds at the interface which affect the properties and efficiency of the weld. In order to improve the strength of the dissimilar metals weld intermediate layers at the interface can be used.

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