

# ***Fatigue and Fracture Behaviour of Dissimilar Aluminium and Titanium Alloy Joints by Arc Welding Process***

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*Abstract - Fatigue processes originate at stress concentration points, such as the weld toe in weld elements. Both the fatigue crack initiation and propagation stages are controlled by the magnitude and the distribution of stresses in the potential crack plane. The peak stresses at the weld toe can be calculated using stress concentration factors, available in the literature, and appropriate reference stresses. These stress concentration factors are unique for given geometry and mode of loading. Welded joints are subjected to various forms of cyclic loading in practical applications and fatigue failure is common. Thus, welding is a major factor in the fatigue lifetime reduction of components. Even though the fatigue properties of the weld metal is good, problems can be caused when there is an abrupt change in section caused by excess weld reinforcement, undercut, slag inclusion and lack of penetration and nearly 70% of fatigue cracking occurs in the welded joints. Apart from the mechanical considerations of joint design, the welding process, filler material, heat input, number of weld passes etc., will influence the microstructure of the weld at the joint and in turn will influence the extent of heat affected zone and residual stresses that will build up in the base metal. These factors will invariably affect the fatigue strength by increasing the propensity for crack nucleation and its early growth causing the ultimate failure of the joint. From the literature review, it is understood that enormous research work has been carried out on fatigue and fracture behavior of Aluminum joints, but the reported literatures on dissimilar welding with different grades of Aluminum and other alloys is very limited. Hence, an attempt is being proposed in this work to investigate the fatigue and fracture behavior of dissimilar Aluminum alloys.*

## INTRODUCTION

The procedures mostly described for obtaining quality welds in the literature have been between identical metals or at least of metals of similar composition and properties. There are many applications, however, in which weld elements are made from metals of different compositions. The same is true of a mechanical wear problem, a high-temperature situation, or other conditions in which different properties are required from different parts of the same weld element. This brings about the need for joining dissimilar metals. Welding dissimilar metals is being done more often; therefore, this article is devoted to providing information for successfully joining some of the more common metal combinations. A successful weld between dissimilar metals is one that is as strong as the weaker of the two metals being joined, i.e., possessing sufficient tensile strength and ductility so that the joint will not fail in the weld. Such joints can be accomplished in a variety of different metals and by a number of the welding processes.

The problem of making welds between dissimilar metals relates to the transition zone between the metals and the inter-metallic compounds formed in this transition zone. For the fusion type welding processes it is important to investigate the phase diagram of the two metals involved. If there is mutual solubility of the two metals the dissimilar joints can be made successfully. If there is little or no solubility between the two metals to be joined the weld joint

will not be successful. The inter-metallic compounds that are formed, between the dissimilar metals, must be investigated to determine their crack sensitivity, ductility, susceptibility to corrosion, etc. The microstructure of this inter-metallic compound is extremely important. In some cases, it is necessary to use a third metal that is soluble with each metal in order to produce a successful joint. Another factor involved in predicting a successful service life for a dissimilar metals joint relates to the coefficient of thermal expansion of both materials. If these are widely different, there will be internal stresses set up in the inter-metallic zone during any temperature change of the weld element. If the inter metallic zone is extremely brittle service failure may soon occur.

The difference in melting temperatures of the two metals that are to be joined must also be considered. This is of primary interest when a welding process utilizing heat is involved since one metal will be molten long before the other when subjected to the same heat source. When metals of different melting temperatures and thermal expansion rates are to be joined the welding process with a high heat input that will make the weld quickly has an advantage. The difference of the metals on the electrochemical scale is an indication of their susceptibility to corrosion at the inter metallic zone. If they are far apart on the scale, corrosion can be a serious problem.

In certain situations, the only way to make a successful joint is to use a transition material between the two dissimilar metals. An example of this is the attempt to weld copper to steel. The two metals are not mutually soluble, but nickel is soluble with both of them. Therefore, by using nickel as an intermediary metal the joint can be made.

## WELDING PROCESSES FOR COMPOSITE INSERTS

The following is a brief description of some of the welding processes that can be used for composite inserts that include transition joints and that do not employ filler metals. Explosion welding is used to join many so-called incompatible metals. In explosion welding the joint properties will be equal to those of the weaker of the two base materials. Since minimum heat is introduced there is no melting, no heat-affected zone, and no thermal compounds are formed.

The characteristic sine wave pattern of the interface greatly increases the interface area. This process is used for cladding, but is also used to make composite transition inserts used for the fusion welding of dissimilar metals. Composites containing a transition joint are commercially available between aluminium and steel, aluminium and stainless steel, aluminium and copper, and other materials. Cold welding is used for making dissimilar metal transition joints. This process does not use heat, thus avoids the heat-affected zone and the inter metallic fusion alloy. Little or no mixing of the base metals takes place. It is commonly used to join aluminium to copper.

It can be used for joining copper to steel at very high speeds. Diffusion welding is widely used for aerospace applications of dissimilar metals welding. Percussion welding is also used but this process is restricted to wires or small parts. The laser beam welding process has also been used but it is restricted, at this time, to very thin materials. The electron beam welding process has had wide application for joining dissimilar metals. Electron beam uses high-density energy and fast welding speed. It seems to overcome the difference of thermal conductivity when welding metals together having wide variation of thermal conductivity. In addition, the weld zone is extremely small and filler metal is not introduced. Since there is such a small amount of inter metallic compound formed electron beam does offer an advantage for many dissimilar combinations.

The flash butt welding process will make high-quality welds between copper and aluminium. With proper controls all or most of the molten metal is forced out of the joint and the weld is complete as a solid state process.

Flash butt welds are made in rods, wires, bars, and tubes. There are many welding requirements to join dissimilar metals in which the above processes cannot be used. In these cases, the three popular arc welding processes are most often utilized. These are the shielded metal arc welding process, the gas tungsten arc welding process, and the gas metal arc welding process.

#### WELDING NICKEL-BASE ALLOYS TO STEELS

Nickel-base alloys such as Monel and Inconel can be successfully welded to low-alloy steel by using the Monel analysis of filler material when using any of the arc welding processes. In the case of Inconel to mild or low-alloy steel the Inconel base electrode would be used. The same situation applies also to the welding of Inconel or Monel to stainless steels. Here the Inconel or Monel type electrode is used.

#### LITERATURE REVIEW

T.S. Balasubramanian , V. Balasubramanian-The present investigation is aimed to evaluate fatigue crack growth parameters of gas tungsten arc, electron beam and laser beam welded Ti-6Al-4V titanium alloy for assessing the remaining service lives of existing structure by fracture mechanics approach. Centre cracked tensile specimens were tested using a 100 kN servo hydraulic controlled fatigue testing machine under constant amplitude uni axial tensile load. Crack growth curves were plotted and crack growth parameters (exponent and intercept) were evaluated. Fatigue crack growth behaviour of welds was correlated with mechanical properties and micro structural characteristics of welds. Of the three joints, the joint fabricated by laser beam welding exhibited higher fatigue crack growth resistance due to the presence of fine lamellar microstructure in the weld metal.<sup>[1]</sup>

Claudia Fleck, Dietmar Eifler -In recent years, implants have gained growing importance in all areas of medicine. Of these, orthopaedic and dental implants are routinely exposed to high mechanical loads such as friction

and wear together with multi axial, multistep fatigue. Sustaining these loads is one prime challenge of these implants which is complicated by the need to survive in body electrolytes (proteins, enzymes, salts) that are very corrosive. Even though titanium and its alloys form a very stable oxide layer in physiological environments bestowing them exceptional biocompatibility as compared to other metal implant materials, surface reactions do take place. Such reactions, for example ion exchange or adsorption of proteins, determine the quality and stability of the bone-implant-interface, and consequently mechanical activation of the surface plays an important role. The present paper reviews the current knowledge on the corrosion, fatigue ,and corrosion fatigue behaviour of titanium and its alloys, with a special emphasis on the influence of simulated in vivo conditions. Masoud Anahid , MahendraK. The fatigue crack nucleation model is developed for dual-phase titanium alloys admitting room temperature creep phenomenon. The crystal plasticity finite element (CPFE) model uses rate and size-dependent anisotropic elasto-crystal plasticity constitutive model to account for these effects. Stress rise in the hard grain is a consequence of time-dependent load shedding in adjacent soft grains, and is the main cause of crack nucleation in the polycrystalline titanium microstructure. CPFE simulation results are post-processed to provide inputs to the crack nucleation model. The nucleation model is calibrated and satisfactorily validated using data available from acoustic microscopy experiments for monitoring crack evolution in dwell fatigue experiments.<sup>[2]</sup>

C. Casavola , C. Pappalettere , G. Pluvinage - This paper presents a detailed study on fatigue strength of welded joints made of two titanium alloys, grade 2 and grade 5, and welded by laser or hybrid process. Fatigue strength curves obtained for each alloy and each welding technique are compared in terms of safety factors with fatigue design curves of welded joints provided by standards. Material and welding process effects on fatigue strength are discussed; the influence of the weld seam geometry is assessed by evaluating the fatigue strength reduction factor. This parameter is computed by using the Volumetric Method of the Notch Fracture Mechanics and defined as the ratio of the effective stress and the gross stress. Effective stress is defined on the weld toe stress distribution by the minimum of relative stress gradient method. Distribution of opening stress at weld toe is analyzed also with the finite element analysis.<sup>[3]</sup>

M.D. Halliday, P. Bowen-Small fatigue cracks in the aluminium alloys 2024-T351 and 8090-T8771 have been observed to grow by a heterogeneous process of three-dimensional slip band decohesion. Local, finely-divided crack path excursions at slip bands, the pull-out of small sections of decohered slip band and the formation of fatigue extrusions at slip bands produced micro-roughness on the crack surfaces. The hybrid form of plastic deformation induced surface roughness provides a potential source of crack closure. This may be effective in reducing the nominal crack growth driving force at small cracks and near

threshold for long cracks when the crack tip opening displacement is small. Fatigue extrusions imply a dynamic form of crack closure that could develop immediately at the crack tip even for fatigue at high mean load. Complex influences of crack size, grain orientation and crack path on crack closure and crack growth rate indicate that a stochastic approach to determining fatigue life is appropriate for the critical small crack regime in these and similarly behaving materials.<sup>[4]</sup>

J.Y. Huang , R.F. Liu -Corrosion fatigue behaviour of the dissimilar metal weld metal, Alloy 52-A508, under a simulated BWR coolant condition was studied. Corrosion fatigue crack growth rates of the dissimilar metal weld elements were observed to increase with crack extension under the nominal constant DK loading mode. It could be accounted for by a decrease in the Cr and Ni contents and the crack closure effect with the weld depth. Finite element analysis on the welding residual stress was performed. The trend of analytical results agreed well with that of the residual stress measurements obtained by a hole-drilling strain gauge method.<sup>[5]</sup>

T. Majewski, J. Bobinski, J. Tejchman-Paper presents results of FE modelling of failure behaviour of reinforced concrete columns under eccentric compression. Concrete was described with an elasto-plastic model using isotropic hardening and softening. A Drucker-Prager criterion with a non associated flow rule was defined in a compressive regime and a Rankine criterion with an associated flow rule adopted in a tensile regime. To ensure the mesh-independence and to capture strain localization in concrete, both criteria were extended by a characteristic length of microstructure in a softening regime with the aid of a non-local theory. The FE-calculations were carried out with a different characteristic length of micro-structure, reinforcement ratio, column slenderness, load eccentricity, distribution of the tensile strength, bond-slip between concrete and reinforcement and fracture energy. The FE results were quantitatively compared with those from laboratory experiments performed by Kim and Yang A satisfactory agreement was achieved.<sup>[6]</sup>

Prashant Kumar, Ritesh Kumar Singh-FRP-joints were made between two components by winding a tow made of strong and stiff glass fibers. The tow was wetted with a suitable resin before it was wound. In a few hours the winding cures to give a strong and stiff joint. A T-joint between two pipes was selected as a specimen. Three kinds of appropriate windings, diagonal, straight and circular were used. The strength of the T-joint was determined under four loading conditions: (i) tensile, (ii) in-plane bending, (iii) bending under a transverse load, and (iv) torsion-cum bending. The strength of FRP-joint between mild steel pipes was found to be comparable to the strength of a welded joint. Also the strength of a joint between pipes of dissimilar materials, mild steel and aluminium, was found to be marginally higher than the strength of the FRP-joint between mild steel pipes.<sup>[7]</sup>

## PROBLEM IDENTIFICATION

Mainly the method of laser beam welding is done to weld two dissimilar materials. By using laser beam welding, due to emission of more heat, the properties of the materials are changed and we cannot able to use that material for our particular usage. So the methods of revited joints are used now days to join two dissimilar materials. It leads to increase the weight.

To avoid those difficulties, arc welding process is done between two dissimilar materials at different voltage and different current level. By welding two different materials by using this method, the various material properties like fatigue and fracture are noted at different voltage and current level.

## METHODOLOGY

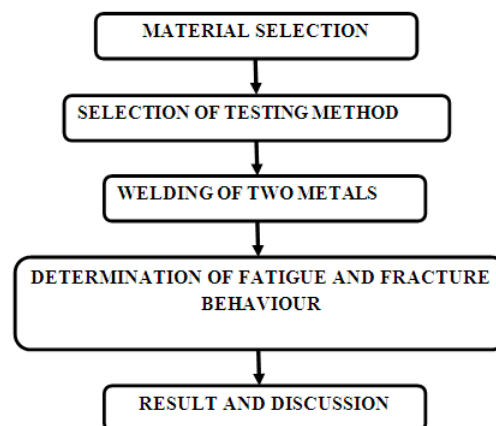


Fig.1 Methodology Flow Chart

## MATERIAL SELECTION

The main pre-process part of the fabrication process is the selection of the materials for welding process. The material selected includes the filler material, torch and core material.

## CHARACTERISTICS OF ALUMINIUM

Aluminium (or aluminum) is a chemical element in the boron group with symbol Al and atomic number 13. It is a silvery white, soft, ductile metal. Aluminium is the third most abundant element (after oxygen and silicon), and the most abundant metal, in the Earth's crust. It makes up about 8% by weight of the Earth's solid surface. Aluminium metal is so chemically reactive that native specimens are rare and limited to extreme reducing environments. Instead, it is found combined in over 270 different minerals. The chief ore of aluminium is bauxite.

## PHYSICAL

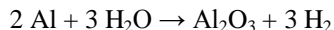
Aluminium is a relatively soft, durable, lightweight, ductile and malleable metal with appearance ranging from silvery to dull gray, depending on the surface roughness. It is nonmagnetic and does not easily ignite. A fresh film of aluminium serves as a good reflector (approximately 92%) of visible light and an excellent reflector (as much as 98%) of medium and far infrared

radiation. The yield strength of pure aluminium is 7–11 MPa, while aluminium alloys have yield strengths ranging from 200 MPa to 600 MPa. Aluminium has about one-third the density and stiffness of steel. It is easily machined, cast, drawn and extruded. Aluminium atoms are arranged in a face-centered cubic (fcc) structure. Aluminium has a stacking-fault energy of approximately 200 mJ/m<sup>2</sup>. Aluminium is a good thermal and electrical conductor, having 59% the conductivity of copper, both thermal and electrical, while having only 30% of copper's density. Aluminium is capable of being a superconductor, with a superconducting critical temperature of 1.2 Kelvin and a critical magnetic field of about 100 gauss (10 milliteslas).

#### CHEMICAL

Corrosion resistance can be excellent due to a thin surface layer of aluminium oxide that forms when the metal is exposed to air, effectively preventing further oxidation. The strongest aluminium alloys are less corrosion resistant due to galvanic reactions with alloyed copper. This corrosion resistance is also often greatly reduced by aqueous salts, particularly in the presence of dissimilar metals. Owing to its resistance to corrosion, aluminium is one of the few metals that retain silvery reflectance in finely powdered form, making it an important component of silver-coloured paints. Aluminium mirror finish has the highest reflectance of any metal in the 200–400 nm (UV) and the 3,000–10,000 nm (far IR) regions; in the 400–700 nm visible range it is slightly outperformed by tin and silver and in the 700–3000 nm (near IR) by silver, gold, and copper.

Aluminium is oxidized by water to produce hydrogen and heat:



This conversion is of interest for the production of hydrogen. Challenges include circumventing the formed oxide layer which inhibits the reaction and the expenses associated with the storage of energy by regeneration of the Al metal.

#### ISOTOPES

Aluminium has many known isotopes, whose mass numbers range from 21 to 42; however, only Al (stable isotope) and Al (radioactive isotope,  $t_{1/2} = 7.2 \times 10^5$  y) occur naturally. Al has a natural abundance above 99.9%. Al is produced from argon in the atmosphere by spallation caused by cosmic-ray protons. Aluminium isotopes have found practical application in dating marine sediments, manganese nodules, glacial ice, quartz in rock exposures, and meteorites. The ratio of Al to Be has been used to study the role of transport, deposition, sediment storage, burial times, and erosion on  $10^5$  to  $10^6$  year time scales. Cosmogenic Al was first applied in studies of the Moon and meteorites. Meteoroid fragments, after departure from their parent bodies, are exposed to intense cosmic-ray bombardment during their travel through space, causing substantial Al production. After falling to Earth, atmospheric shielding drastically reduces Al production, and its decay can then be used to determine the meteorite's terrestrial age.

Meteorite research has also shown that Al was relatively abundant at the time of formation of our planetary system. Most meteorite scientists believe that the energy released by the decay of Al was responsible for the melting and differentiation of some asteroids after their formation 4.55 billion years ago.

#### NATURAL OCCURRENCE

In the Earth's crust, aluminium is the most abundant (8.3% by weight) metallic element and the third most abundant of all elements (after oxygen and silicon). Because of its strong affinity to oxygen, it is almost never found in the elemental state; instead it is found in oxides or silicates. Feldspars, the most common group of minerals in the Earth's crust, are aluminosilicates. Native aluminium metal can only be found as a minor phase in low oxygen fugacity environments, such as the interiors of certain volcanoes. Native aluminium has been reported in cold seeps in the north eastern continental slope of the South China Sea and Chen *et al.* (2011) have proposed a theory of its origin as resulting by reduction from tetra hydroxoaluminate  $\text{Al}(\text{OH})_4^-$  to metallic aluminium by bacteria. It also occurs in the minerals beryl, cryolite, garnet, spinel and turquoise. Impurities in  $\text{Al}_2\text{O}_3$ , such as chromium or iron yield the gemstones ruby and sapphire, respectively. Although aluminium is an extremely common and widespread element, the common aluminium minerals are not economic sources of the metal. Almost all metallic aluminium is produced from the ore bauxite ( $\text{AlO}_x(\text{OH})_{3-2x}$ ). Bauxite occurs as a weathering product of low iron and silica bedrock in tropical climatic conditions. Large deposits of bauxite occur in Australia, Brazil, Guinea and Jamaica and the primary mining areas for the ore are in Australia, Brazil, China, India, Guinea, Indonesia, Jamaica, Russia and Suriname.

**Table 1 Analysis of Fatigue at 140v**

S.NO	VOLTAGE IN VOLTS	CURRENT IN AMPS	TENSILE STRENGTH IN MPA	NO.OF CYCLES	FATIGUE LIFE IN % OF ALUMINIUM
01	140	16	530	10000	60
02	140	16.5	534	13000	62
03	140	17	537	20000	65
04	140	17.5	542	24500	68
05	140	18	544	29700	70
06	140	18.5	550	34800	71
07	140	19	556	44500	74

The above table shows that fatigue life of welded joint lies between 60 to 74 percentage of aluminium life.

**Table 2 Analysis of Fatigue at 150v**

S.NO	VOLTAGE IN VOLTS	CURRENT IN AMPS	TENSILE STRENGTH IN MPA	NO.OF CYCLES	FATIGUE LIFE IN % OF ALUMINIUM
01	150	16	534	10100	61
02	150	16.5	538	13200	62
03	150	17	540	20500	66
04	150	17.5	546	25000	68
05	150	18	548	30000	71
06	150	18.5	555	35200	73
07	150	19	560	41500	74

The above table shows that fatigue life of welded joint lies between 61 to 74 percentage of aluminium life.

**Table 3 Analysis of Fatigue at 160v**

S.NO	VOLTAGE IN VOLTS	CURRENT IN AMPS	TENSILE STRENGTH IN MPA	NO.OF CYCLES	FATIGUE LIFE IN % OF ALUMINIUM
01	160	16	538	12000	63
02	160	16.5	542	15000	66
03	160	17	545	23500	69
04	160	17.5	550	28000	72
05	160	18	552	34500	75
06	160	18.5	559	40000	77
07	160	19	565	45200	79

The above table shows that fatigue life of welded joint lies between 63 to 79 percentage of aluminium life.

**Table 4 Analysis of Fatigue at 170v**

S.NO	VOLTAGE IN VOLTS	CURRENT IN AMPS	TENSILE STRENGTH IN MPA	NO.OF CYCLES	FATIGUE LIFE IN % OF ALUMINIUM
01	170	16	542	10200	61
02	170	16.5	546	13300	63
03	170	17	550	20000	65
04	170	17.5	555	24000	69
05	170	18	557	29500	70
06	170	18.5	563	36500	72
07	170	19	569	43800	75

The above table shows that fatigue life of welded joint lies between 61 to 75 percentage of aluminium life.

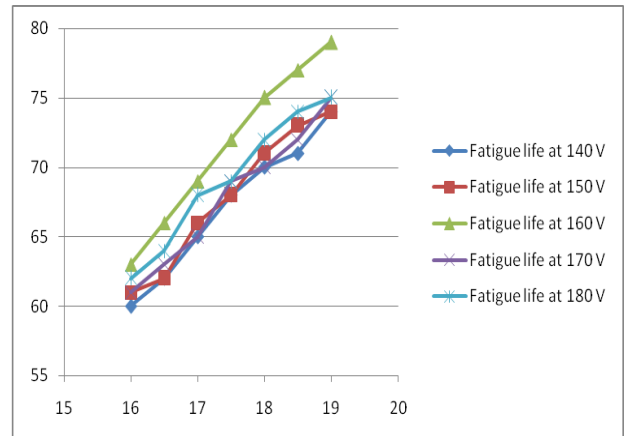
**Table 5 Analysis of Fatigue at 180v**

SL.NO	VOLTAGE IN VOLTS	CURRENT IN AMPS	TENSILE STRENGTH IN MPA	NO.OF CYCLES	FATIGUE LIFE IN % OF ALUMINIUM
01	180	16	546	11000	62
02	180	16.5	550	14000	64
03	180	17	555	15500	68
04	180	17.5	559	23500	69
05	180	18	562	28000	72
06	180	18.5	567	35000	74
07	180	19	570	44500	75

The above table shows that fatigue life of welded joint lies between 62 to 75 percentage of aluminium life.

**Table 6 Analysis of Fatigue at Different Voltage Level.**

Current in Amps	Fatigue life at 140 V	Fatigue life at 150 V	Fatigue life at 160 V	Fatigue life at 170 V	Fatigue life at 180 V
16	60	61	63	61	62
16.5	62	62	66	63	64
17	65	66	69	65	68
17.5	68	68	72	69	69
18	70	71	75	70	72
18.5	71	73	77	72	74
19	74	74	79	75	75



**Fig.2 Analysis chart for Various Fatigue Life.**

From this analysis flow chart the fatigue life of the welded joint between aluminium and titanium is better at 160 v level.

## CONCLUSION

The conclusion of my project deals with fatigue and fracture behaviour of dissimilar welding of Aluminium and titanium work piece. The fatigue life of the weld joint will be increased in arc welding process. In this process also reduce the weight of the structure.

At different voltage level the two dissimilar materials are welded together. From this the fatigue strength is absorbed and the level of hardness is noted. From the different cycles of welding at various temperature level is used. The fatigue level is notified from 63 to 75 percentage life of aluminium at the voltage level of 160V.

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