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A Review on Mechanical Properties and Working of Aluminum and its Alloys

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ABSTRACT

The use of high strength aluminium alloys, especially the alloys of the 7xxx series, in the construction of light armored vehicles, light weight bridging, and other equipment, is of interest to the designers of military equipment. However, in the use of alloys which exhibit the highest mechanical properties and provide superior ballistic protection a major problem has been exposed. Stress corrosion cracking has been found to occur in both the parent plate and the welded joint.

In this review an attempt is made to provide a basis for the understanding of the physical metallurgy and welding behavior of the aluminum alloys. Recent alloys have been improved by a better understanding of the effects of materials processing operations on the microstructure and residual stress state. Advances in welding techniques offer an opportunity to substantially reduce the residual stress level associated with welding thick sections.

Keywords: mechanical, properties, aluminum, alloys.

INTRODUCTION

Aluminium and its alloys have wide range of applications especially in the fabrication industries like aircraft manufacturing, automobile body building and other structural applications due to the good strength to weight ratio, high ductility and corrosive resistance. Pure aluminium and some of its alloys have exceptionally high electrical conductivity second only to copper among common metals used as conductor. Aluminium industry works for the structurally reliable, strong, and fracture-resistant parts for airframes, engines, and ultimately, for missile bodies, fuel cells, and satellite components. The production of semi-fabricated products utilized three different types of aluminum, namely super purity, commercial purity and alloys. Alloys are used for producing castings or fabricating wrought products. The alloys used for casting contain greater amount of alloying addition than those used for wrought products. The addition of alloying elements has the effects of strengthening the wrought alloys and improving the cast ability of the casting alloys.

PROPERTIES OF ALUMINUM ALLOYS

Among the most striking characteristics of aluminum is its versatility of application. The range of physical and mechanical properties that can be developed from refined high purity aluminum to the most complex alloy is remarkable. The properties of aluminium that make this metal and its alloys the most economical and attractive for a wide variety of uses are its appearance, light weight, fabricability, physical properties, mechanical properties, and corrosion resistance. Aluminium has a density of only 2.7 g/cm^2 approximately one-third as much as steel (7.83 g/cm^2), copper (8.93 g/cm^2), or brass (8.53 g/cm^2). It can display excellent corrosion resistance in most environments, including seawater, atmosphere, petrochemicals, and many chemical systems. These alloys are useful, for example, in high-torque electric motors.

Aluminium is often selected for its electrical conductivity, which is nearly twice that of copper on an equivalent weight basis. Aluminium is non-ferromagnetic, a property of importance in the electrical and electronics industries. Aluminium is also nontoxic and is routinely used in containers for foods and beverages. Some aluminium alloys exceed structural steel in strength. However, pure aluminium and certain aluminium alloys are noted for extremely low strength and hardness.

WELDABILITY OF ALUMINUM ALLOYS

Weldability of aluminium alloys like any other metal system must be assessed in light of purpose of application of weld joint considering service conditions, welding procedure being used and welding conditions in which welding need to be performed. Weldability of aluminium may be very poor when joined by shielded metal arc welding or gas welding but the same may be very good when joint is made using tungsten inert gas or gas metal arc welding process. Similarly other aspects of welding procedure such as edge preparation, welding parameters, preheat and post weld heat treatment etc. can significantly dictate the weldability of aluminium owing to their ability to affect the soundness of weld joints and mechanical performance. Thus, all the factors governing the soundness of the aluminium weld, the mechanical and metallurgical features determine the weldability of aluminium alloy system. In general, aluminium is considered to be of comparatively lower weldability than steels due to various reasons a) high affinity of aluminium towards atmospheric gases, b) high thermal expansion coefficient, c) high thermal and electrical conductivity, d) poor rigidity and e) high solidification temperature range. These characteristics of aluminium alloys in general make them sensitive from defect formation point of view during welding. The extent of undesirable effect of above characteristics on performance of the weld joints is generally reduced using two approaches a) effective protection of the weld pool contamination from atmospheric gases using proper shielding method and b) reducing influence of weld thermal cycling using higher energy density welding processes. Former approach mainly deals with using various environments (vacuum, Ar, or their mixtures with hydrogen and oxygen) to shield the weld pool from ambient gases while later one has led to the development of newer welding processes such as laser, pulse variants of TIG and MIG, friction stir welding etc.

WELDING PROBLEMS IN ALUMINUM ALLOYS:

Porosity

Porosity in aluminum weld joints can be of two types.

a) Hydrogen induced porosity
b) Inter dendritic shrinkage porosity

Former one is caused by the presence of hydrogen in the weld owing to unfavorable welding conditions such as improper cleaning, moisture in electrode, shielding gases and oxide layer, presence of hydro-carbons in form of oil, paint, grease etc. In presence of hydrogen porosity in the weld metal mainly occurs due to high difference in solubility of hydrogen in liquid and solid state of aluminum alloy. During solidification of the weld metal, the excess hydrogen is rejected at the advancing solid-liquid interface in the weld which in turn leads to the development of hydrogen induced porosity especially under high solidification rate conditions as high cooling rate experienced by the weld pool increases tendency of entrapment of hydrogen.

Inclusion

In general, presence of any foreign constituent (one which is not desired) in the weld can be considered as inclusion and these may be in the form of gases, thin films and solid particles. High affinity of aluminium with atmospheric gases increases the tendency of formation of oxides and nitrides (having density similar to that of aluminium) especially when a) protection of weld pool is not enough b) proper cleaning of filler and base metal has not been done c) shielding gases are not pure enough and therefore making oxygen and hydrogen available to molten weld pool during welding d) gases are present in dissolved state in aluminium itself and tungsten inclusion while using GTA welding. Mostly inclusion or oxides and nitrides of aluminium are found in weld joints in case of unfavorable welding conditions. Presence of these inclusions disrupts the metallic continuity in the weld therefore these provide site for stress concentration and become a source of weakness leading to the deterioration in mechanical and corrosion performance of the weld joints.

Solidification cracking

This is an inter-dendritic type of cracking mostly observed along the weld centerline in very last stage of solidification primarily due to two factors a) development of tensile residual stresses and b) presence of low melting point phases in inter-dendritic regions of solidifying weld is called solidification cracking. The solidification cracking mainly occurs when residual tensile stress developed in weld (owing to contraction of base metal and weld metal) goes beyond the strength of solidifying weld metal. Moreover, the contribution of solidification shrinkage of weld metal in development of the tensile residual stress is generally marginal. All the factors namely thermal expansion coefficient of weld and base metal, melting point, weld bead profile, type of weld, degree of constraint, thickness of work piece etc. affecting the contraction of the weld will govern the residual stresses and so solidification cracking tendency. The presence of tensile or shear stress is mandatory for cracking means no residual tensile stress no cracking. Residual stresses in weld joint cannot he eliminated but can he minimized by developing proper welding procedure.

LITERATURE REVIEW

N Karunakaran et al., (2010) studied the effect of pulsed current on temperature distribution and weld bead profile of gas tungsten arc welded aluminium alloy joints. The effects of pulsed current welding on tensile properties, hardness profiles, microstructural features and residual stress distribution of aluminium alloy joints were reported. It was found that the pulsed current welding technique records lower peak temperature, lower magnitude of residual stresses and superior tensile strength as compared to constant current welding due to formation of finer grain structure.

A Hussain et al., (2010) investigated the effect of welding speed on tensile strength of the welded joint by TIG welding process of AA6351 aluminium alloy of 4 mm thickness. Welding was done on specimens of single v butt joint with welding speed of 180 -720 mm/min. From the experimental results it was revealed that strength of the weld zone is less than base metal and tensile strength increases with reduction of welding speed.

A Kumar et al., (2008) welded 5456 aluminium alloys sheets using Pulse TIG welding using ER 5356 filler wire for optimization of the process parameters to improve the mechanical properties. The process parameters were varied between as pulse current 70-80 A, base current 40-50 A, welding speed 210- 230 mm/min and pulse frequency 42-45 Hz. Taguchi method was used to optimize the process parameters and a regression model was developed. The optimum process parameters improve the mechanical properties by 10-15% due to grain structure refinement at weld center.

T Senthil Kumar et al., (2007) welded AA6061 alloy sheets using pulsed current tungsten inert gas welding to observe the influence of welding parameters on the tensile properties of welded joints. Taguchi method was used to find out the effect of various parameters and their response was measured. It was reported that peak current and pulse frequency have direct relationship with tensile strength while base current and pulse on time have indirect relationship with tensile strength.

V Balasubarmanian et al., (2006) welded AA 7075 single V groove butt joints using continuous current GTAW (CCGTAW), pulsed current GTAW (PCGTAW), continuous current GMAW (CCGMAW) and pulsed current GMAW (PCGMAW) with AA 5356 filler wire. The effect of four welding processes on fatigue properties and microhardness properties was reported. Transverse tensile properties of the welded joints were evaluated. It is increasing by increasing peak current and pulse frequency and decreasing with increasing base current and pulse on time was found that current pulsing leads to relatively finer and more equi-axed grain structure in gas tungsten arc (GTA) and gas metal arc (GMA) welds. Fatigue performance of pulse current welded joints was found to be superior as compared to continuous current welded joints. Pulsed current GTAW process endured large number of cycles as compared to other welded joints.

Urena et al., (2000) investigated the influence of the interfacial reaction between the Al alloys matrix and SiC particle reinforcement on the fracture behavior in TIG welded Al matrix composites. TIG welding was carried out on 4 mm thick AA2014/SiC/Xp sheets using current setting in the range of 37-155 A and voltage of 14-16.7 V. From study, it was found that, the failure occurred in the weld metal with a tensile strength lower than 50% of the parent material. Fracture of the welded joint was controlled by interface debonding through the interface reaction layer. Probability of interfacial failure increases in the weld zone due to formation of aluminium-carbide which lowers the matrix/reinforcement interface strength.

Norman et al., (1999) investigated the microstructures of autogenous TIG welded Al-Mg-Cu-Mn alloy for a wide range of welding conditions. Welding was done with current in the range 100-190 A and welding speed 150-420 mm/min. The fine microstructure was observed at the centre of the weld which was form due to higher cooling rate at the weld centre compared to the fusion boundary. It was observed that as the welding speed increases, the cooling rate at the centre of the weld also increases, producing smaller size dendrite structure.

APPLICATIONS OF ALUMINIUM ALLOYS

Aerospace alloys (Aluminium–Scandium)

It has been suggested that this section be split out into another article titled Aluminium–scandium alloy.

The addition of scandium to aluminium creates nanoscale Al3Sc precipitates which limit the excessive grain growth that occurs in the heat-affected zone of welded aluminium components. This has two beneficial effects: the precipitated Al3Sc forms smaller crystals than are formed in other aluminium alloys and the width of precipitate-free zones that normally exist at the grain boundaries of age-hardenable aluminium alloys is reduced. Scandium is also a potent grain refiner in cast aluminium alloys, and atom for atom, the most potent strengthener in aluminium, both as a result of grain refinement and precipitation strengthening.

An added benefit of scandium additions to aluminium is that the nanoscale Al3Sc precipitates that give the alloy its strength are coarsening resistant at relatively high temperatures (~350 °C). This is in contrast to typical commercial 2xxx and 6xxx alloys, which quickly lose their strength at temperatures above 250 °C due to rapid coarsening of their strengthening precipitates.

The effect of Al3Sc precipitates also increase the alloy yield strength by 50–70 MPa (7.3–10.2 ksi).

In principle, aluminium alloys strengthened with additions of scandium are very similar to traditional nickel-base superalloys, in that both are strengthened by coherent, coarsening resistant precipitates with an ordered L12 structure. However, Al-Sc alloys contain a much lower volume fraction of precipitates and the inter-precipitate distance is much smaller than in their nickel-base counterparts. In both cases however, the coarsening resistant precipitates allow the alloys to retain their strength at high temperatures.

The increased operating temperature of Al-Sc alloys has significant implications for energy efficient applications, particularly in the automotive industry. These alloys can provide a replacement for denser materials such as steel and titanium that are used in 250-350 °C environments, such as in or near engines. Replacement of these materials with lighter aluminium alloys leads to weight reductions which in turn leads to increased fuel efficiencies.

Additions of erbium and zirconium have been shown to increase the coarsening resistance of Al-Sc alloys to ~400 °C. This is achieved by the formation of a slow-diffusing zirconium-rich shell around scandium and erbium-rich precipitate cores, forming strengthening precipitates with composition Al3(Sc,Zr,Er). Additional improvements in the coarsening resistance will allow these alloys to be used at increasingly higher temperatures.

Titanium alloys, which are stronger but heavier than Al-Sc alloys, are still much more widely used.

The main application of metallic scandium by weight is in aluminium–scandium alloys for minor aerospace industry components. These alloys contain between 0.1% and 0.5% (by weight) of scandium. They were used in the Russian military aircraft Mig 21 and Mig 29.

Some items of sports equipment, which rely on high performance materials, have been made with scandium–aluminium alloys, including baseball bats, lacrosse sticks, as well as bicycle frames and components, and tent poles. U.S. gunmaker Smith & Wesson produces revolvers with frames composed of scandium alloy and cylinders of titanium.

Potential use as Space Materials

Due to its light-weight and high strength, aluminium alloys are desired materials to be applied in spacecraft, satellites and other components to be deployed in space. However, this application is limited by the energetic particle irradiation emitted by the Sun. The impact and deposition of solar energetic particles within the microstructure of conventional aluminium alloys can induce the dissolution of most common hardening phases, leading to softening. The recently introduced crossover aluminium alloys are being tested as a surrogate to 6xxx and 7xxx series in environments where energetic particle irradiation is a major concern. Such crossover aluminium alloys can be hardened via precipitation of a chemical complex phase known as T-phase in which the radiation resistance has been proved to be superior than other hardening phases of conventional aluminium alloys alloys.

CONCLUSION

Welding and structural design is an area in which further advances are likely. It would be desirable to obtain an understanding of the nature of residual stress in a structure as a function of joint design and welding process. Welding processes such as synergic pulsed MIG with synchronized transverse oscillation offer the possibility of very high quality, high productivity, welding at markedly reduced heat inputs, and therefore with lower accompanying residual stresses. These processes may also lead to improved 'out of position' mechanised welding procedures which, in the future, may be capitalised on by robotic work stations to allow design freedom from straight down hand runs.

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