Studies Of Corrosion On Aa6061 And Az61 Friction Stir Welded Plates

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Abstract— Friction Stir Welding (FSW) is remarkably new joining process with solidus state. This joining technique is environment friendly, energy efficient, and versatile. In particular, FSW can be utilized to join the high strength aluminium alloys and other dissimilar alloys that are difficult to weld by conventional fusion welding. The process parameters have a key role in determining the characteristics of the joint. In this work, three parameters of the weld namely, axial load (kN), rotational speed (rpm) and weld speed (mm/min) are considered. Three pairs of AA6061 and AZ61 plates were welded with three different sets of these parameters. After six months, the welded zone was immersed in corrosive solution of NaOH for different time periods. The corrosion was studied with the help of SEM and EDAX.

KEYWORDS: Friction Stir Welding, Corrosion behavior, AA6061, AZ61, Tool geometry.

1.INTRODUCTION

The chemical and/or electro chemical reaction of metals with environment causes the corrosion. Due to the conservation and safety requirements of alloys the need of investigation on corrosion arises. To reduce the impact of corrosion, corrosion engineers and scientists made a major investigations on the corrosion of piping, bridges, marine structures,ships, metal components of machines and so on to reduce material losses and to utilize the conservation metal usage. Corrosion study is vast important in the safety point of operating equipment, for example, metallic containers for toxic chemicals, pressure vessels, turbine blades and rotors. Loss of metal by corrosion is not only the poor conservation of physical strength but also of the wastage of energy used to produce and fabricate the metal structures. In addition, rebuilding of the corroded components involves further investment of all the men, materials and machines resources.

Aluminium is the most abundant metal in nature. It is ductile and can be readily cast and machined. Several properties set aluminium apart from other metals. First, it is lighter than all other engineering metals except magnesium and beryllium. It has a density of about 0.1lb/in^3 (2990 kg/m^3). A second important property of aluminium is its thermal and electrical conductivity. The third property that is responsible for the wide use of aluminium alloys is their corrosion resistance. Aluminium is not widely used for chemical resistance, but for applications involving atmospheric corrosion resistance it is probably the most widely used metallic material. There are hundreds of commercially available aluminium alloys. It can be seen that aluminium alloys can be cast by all the common casting techniques. Resistance welding can be preferred on some aluminium alloys but the surface preparation is expensive and the formation of surface oxide being a major problem.

The Magnesium series alloys are often used in automobile applications, marine and aviation due to their high strength to density ratio. The challenge on making fatigue and fracture resistant welds in aluminium alloys have been found wider use for joining aerospace structures. In the case of Magnesium alloy, if the Aluminium content is a dominant alloying element then it is characterized as Magnesium alloy AZ61.

Aluminium andMagnesium are lightweight metals having good corrosion resistance to the atmosphere and many aqueous media, combined with good electrical and thermal conductivity. The observed corrosion behaviour of aluminium is sensitive to small amounts of impurities in the metal; all these impurities, with the exception of magnesium, tend to be cathodic to aluminium. In general, the high-purity metal is much more corrosion-resistant than commercially pure aluminium, which, in turn, is usually more resistant than aluminium alloys.

The distinct applications of aluminum alloys in aerospace and automobile industries directs the choice on welding behavior and selection of most appropriate welding method. Aluminum alloys of 2xxx, 6xxx and 7xxx series have been adopted for remarkable usage in these industries [1]. This transpires the desirable strength to weight ratio, good form ability, appropriate weld ability and acceptable corrosion resistance [2]. Depending on the particular application, corrosion behavior is a significant factor of the welded joint [3].

Magnesium (Mg) alloys are considered to be a light weight metallic alloys because of its high mechanical stiffness and low density which is around 1.74 g/cm^3 [4]. The benefits of Magnesium are contrasted by high corrosion rate as compared to aluminium or steel, due to the electro-chemical potential of Magnesium in the presence of seawater [5]. The areas unexposed to the atmosphere such as electronic boxes and car seats have been regulated its usage of alloy by high corrosion resistance of magnesium [6,7].

Earlier investigations on the tool geometry design were aimed on optimization of the tool pin with respect to mechanical properties and micro structure [8-11]. However the studies focused to the effect of tool pin profile on the corrosion behavior and micro structure of welds are scarce [12]. The current investigation is with corrosion behaviour of FSW joints with different weld parameter threaded pin profile (Figure 2).

2. FRICTION STIR WELDING

2.1. Process

It is a solid-state joining technique, and it was initially investigated with aluminium alloys. The basic principle of FSW is concerned with a metal flow of metal/alloy to be welded by a combination of axial load and rotational as well as transverse feed by a non-consumable rotating tool which is having a specifically designed pin and shoulder profiles. The tool preserves two primary functions such as heat input to the metal to be welded and metal flow to produce the joint. The heat input is generated by friction between the tool and the metal/alloy to be welded. The localized heat generation softens the metal/alloy which is welded around the pin and combination of tool rotation and translation plays major role in the metal flow. As a result of this combined actions a joint is produced in almost solidus state. Because of different geometrical features of the tool profiles and the metal flow intense plastic deformation set up. Due to the efficient utilization of energy, environment friendly feature and versatility the FSW is considered to be the most significant metal joining method in a decade and is a ‘‘green’’ technology .

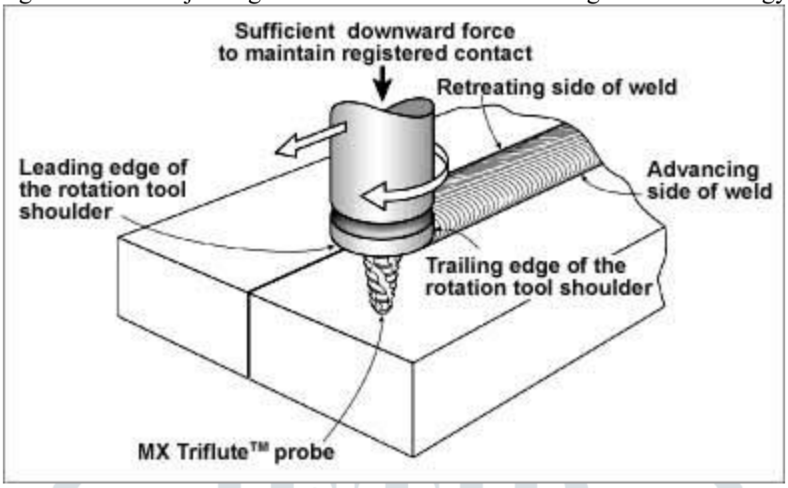


Fig 1: Schematic diagram of friction stir welding

2.2. Tool Geometry

The design/selection of tool geometry is the influential aspect of heat input in FSW process. Since tool geometry have a critical role in material flow and in turn it governs the heat generation rate at which FSW is processes. An FSW tool consists of a shoulder and a pin as shown schematically in Figure 1. As mentioned earlier, the tool has two primary functions one is a localized heating, and the other one is material flow. In the initial stage of tool plunging, the heat generation is primarily from the friction between tool and base metal/alloy. Later additional heat results from plastic deformation of material. From the heating aspect, the relative size of tool pin and shoulder is most important. The uniformity of micro structure and physical properties are governed by the tool design. Generally a threaded cylindrical pins and concave shoulder are used. Complex features have been added to improve material flow and reduction of process loads.

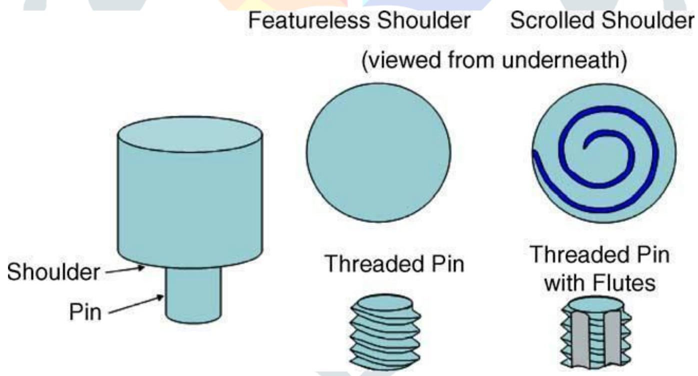


Fig 2: Schematic diagram of the FSW tool

2.4. Welding Parameters

As per the trend on weld parameters of FSW for investigation tool rotation rate (v, rpm) and tool traverse speed (n, mm/min) are the most involved along the line of joint. The rotation of tool with some axial load results in stirring and mixing of base metal/alloy to be welded and the translation of tool pushes the stirred material from the advancing side to the retreating side. Higher tool rotation rates set up a higher temperature because of higher friction and results in more influences on stirring and mixing of material. However the friction of tool with weld metal is responsible for the heating.

3. EXPERIMENTAL WORK

3.1. Welding

Two alloys were chosen for the current corrosion investigation of FSW butt joint. One is from the AA6XXX series– AA6061. The other one is from the Magnesium alloy series– AZ61. Three plates each of 5mm thickness of these alloys were taken. The dimensions of the plates are 100mm x100mm. The Friction Stir Welding of these plates was carried on these plates using three different weld parameters listed below. Thus, three different samples were prepared.

These samples were left as such for six months. During this period the defects in the welded region, if present, would have been attacked by atmospheric corrosive agents. The aged plate is then taken for further analysis.

TABLE 1: Weld Parameters of the three samples

SAMPLE	A	B	C
LOAD (kN)	10	12	16
ROTATIONAL SPEED (rpm)	400	600	1200
WELD SPEED (mm/min)	30	40	50

Fig 3: Welded sample A cut into pieces

3.2. Corrosion test

To examine the effect of corrosion on the weld it was decided to immerse the welded region in strong alkaline solution for specific time periods. Then NaOH solution of pH 8 was prepared. The welded portion of each sample was cut into five pieces of 10 mm width (Figure.3). These were separately immersed in 100 ml of the NaOH solution prepared. They were immersed for different time periods. They were removed after one hour, two hours, three hours, four hours and five hours. After removing the samples from the solution, they were washed in distilled water. Then they were washed with acetone to prevent further corrosion of the samples. These samples were concealed in airtight covers and labelled. A few photographs of the samples tested are shown in the Figure 4.

a) Sample A b) Sample B c) Sample C

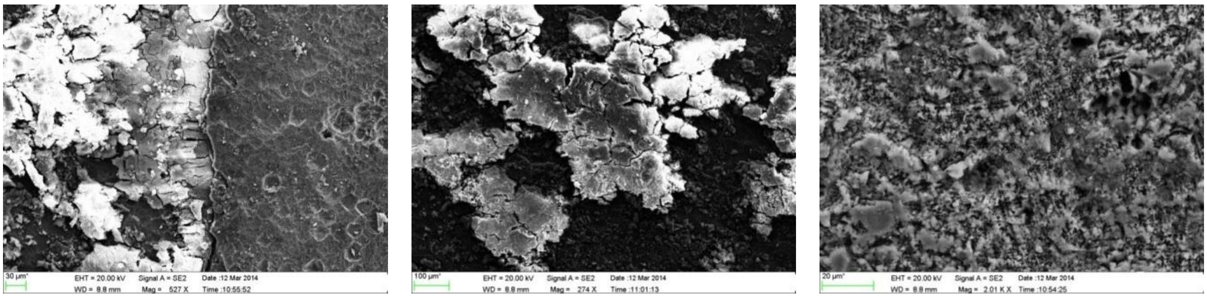
Fig 4: Samples dipped in NaOH (a) sample A (FSW joint with parameters axial load 10 KN, rotational speed 400 rpm and transverse speed 30 mm/min.) (b) sample B (FSW joint with parameters axial load 12 KN, rotational speed 600 rpm and transverse speed 40 mm/min.) (c) sample B (FSW joint with parameters axial load 16 KN, rotational speed 1200 rpm and transverse speed 50 mm/min.)

3.3 Microscopic Examination

Each specimen was examined under metallurgical microscope. The effects of corrosion were hard to find under it. So the samples were examined with a Scanning Electron Microscope (SEM). The images were taken at the portion where the welded region met with the parent metal and at the centre of the welded region. The Energy Dispersive X-Ray Analysis (EDAX) was also carried out for the welded and corroded region. The SEM images are shown below.

3.3.1. Sample A

The SEM images of five hour specimen of sample A are shown in the figure below.



a) Left side b) Centre c) Right side

Fig 5: SEM images of sample A with FSW joint with parameters axial load 10 KN, rotational speed 400 rpm and transverse speed 30 mm/min. (a) left side of nugget zone (b) nugget zone (C) right side of nugget zone

Figure 5.shows the scanning electron microscopic images of sample A. It has three parts:

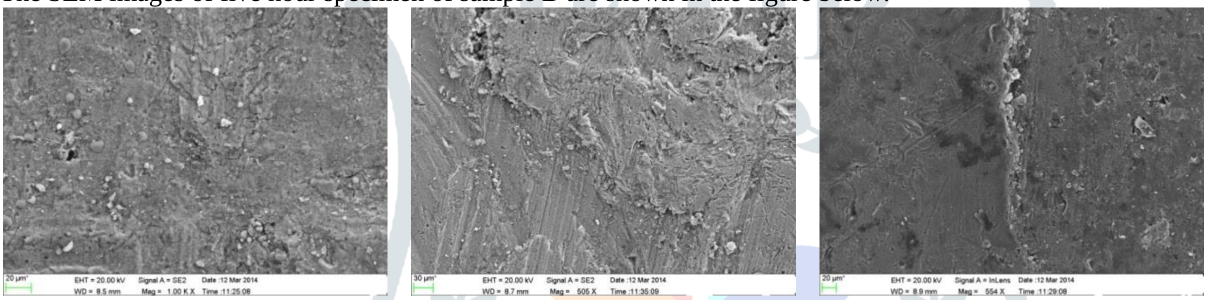
(a) showing the left side of the weld zone, (b) showing the right side of the weld zone and (c) showing the centre of the weld zone. The sample A shows severe attack of the alkaline solution on the surface of the welded plate. The corrosion of the metal is found to have occurred in the welded zone. The oxides of metal are formed on the surface. Pitting corrosion is found to take place in the welded zone.

3.3.2. Sample B

Figure 6.shows the scanning electron microscopic images of sample B. It has three parts:

(a) showing the left side of the weld zone, (b) showing the right side of the weld zone and (c) showing the centre of the weld zone. The alkaline solution, in which the welded plate was immersed, is found to have caused some effect on the surface. There are no severe traces of corrosion in sample B. The sample B shows considerable corrosion resistance.

The SEM images of five hour specimen of sample B are shown in the figure below.

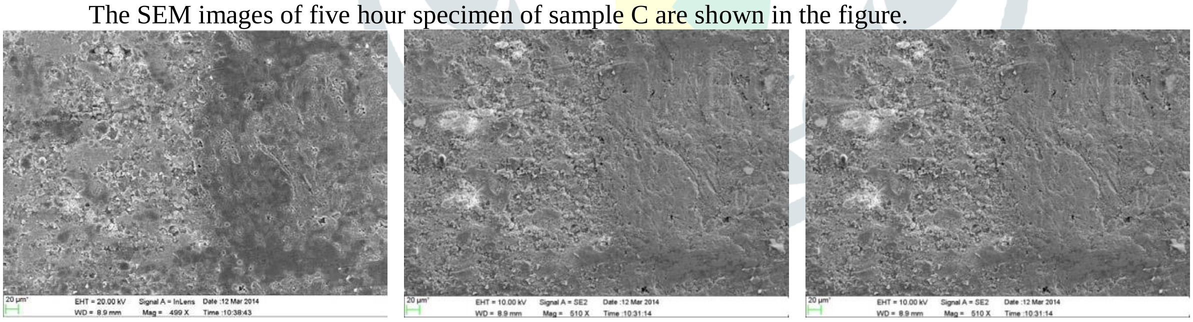


a) Left side b) Centre c) Right side

Fig 6: SEM images of sample A with FSW joint with parameters axial load 12 KN, rotational speed 600 rpm and transverse speed 40 mm/min. (a) left side of nugget zone (b) nugget zone (C) right side of nugget zone

3.3.3 Sample C

The SEM images of five hour specimen of sample C are shown in the figure.



a) Left side

b) Centre c) Right side

Fig 7: SEM images of sample A with FSW joint with parameters axial load 16 KN, rotational speed 1200 rpm and transverse speed 50 mm/min. (a) left side of nugget zone (b) nugget zone (C) right side of nugget zone

Figure 7.shows the scanning electron microscopic images of sample C. It has three parts:

(a) showing the left side of the weld zone, (b) showing the right side of the weld zone and (c) showing the centre of the weld zone. The welded surface is found to be least attacked by the alkaline solution in sample C. There are traces of oxides present on the surface. It is not as severe in sample A.

4. RESULTS AND DISCUSSION

The Energy Dispersive X-ray Analyses of the three samples are:

4.1 Sample A

The EDAX images of sample A are shown in the Figure 8. This shows the presence of oxides of aluminium alone. The spectrum shows that 23.56% of O and remaining Al are present. Thus, the welded zone is severely corroded. The pitting corrosion has occurred on the surface due to the effect of the alkaline solution.

4.2 Sample B

The EDAX image of the sample B (Figure 9) shows the presence of 28.34% of O, 18.75% of C, 5.20% of Cu, 1.29% of Mg, 1.21% of Si, 1.12% of Na, 0.86% of Fe, 0.71% of Mn, 0.50% of Cl, 0.42% of Ca and remaining Al by weight. This shows that the percentage composition by weight of sample B shows small deviation from that before corrosion.

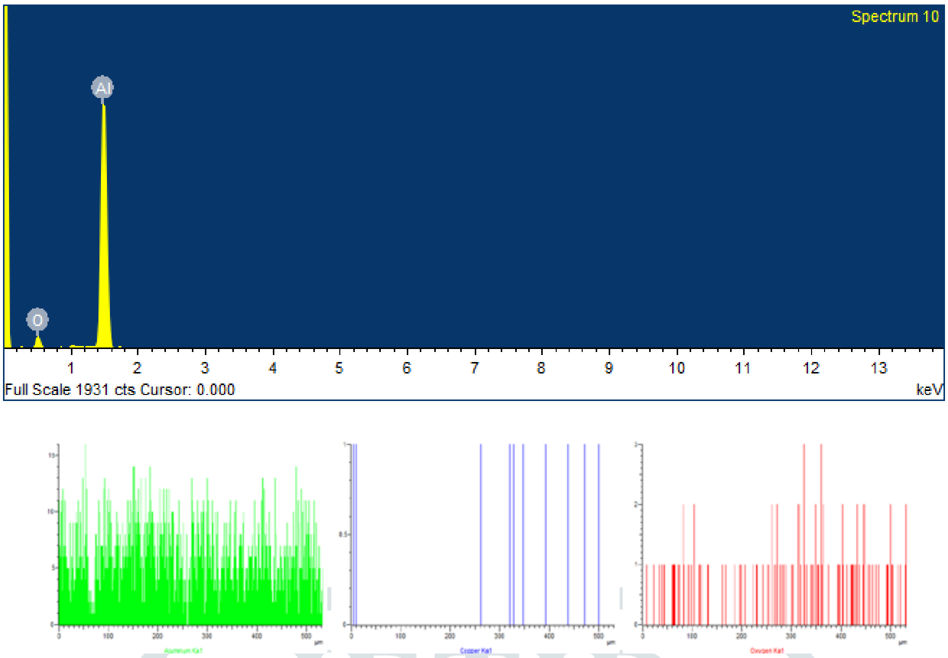


Fig 8: EDAX images of sample A (FSW joint with parameters axial load 10 KN, rotational speed 400 rpm and transverse speed 30 mm/min.)

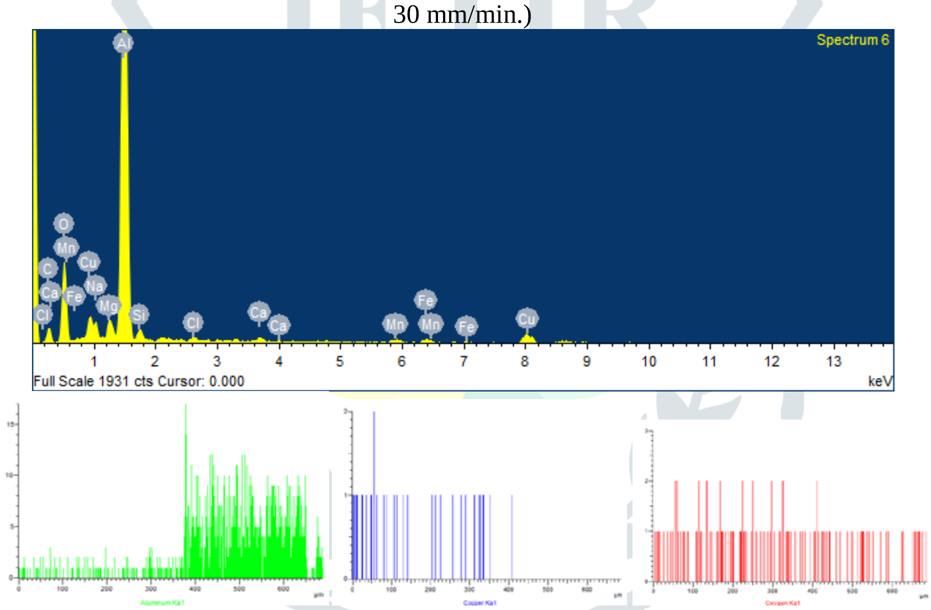


Fig 9: EDAX images of sample B (FSW joint with parameters axial load 12 KN, rotational speed 600 rpm and transverse speed 40 mm/min.)

4.3 Sample C

The EDAX of sample C (Figure 10) shows the presence of 28.92% of O, 16.52% of C, 3.51% of C, 0.96% of Fe, 0.82% of Si, 0.74% of Mg, 0.42% of Ca and remaining Al by weight. This shows that the composition percentage by weight of the corroded region shows slight variation from parent metal composition.

Thus upon experimental analysis, followed by imaging of the specimen with Scanning Electron Microscope, to study the microstructure, and the Energy Dispersive X-ray Analysis of the specimen, to study the composition, showed that two out of three specimen were much resistant to corrosion than the third specimen.

The specimen B with weld parameters 12 kN, 600 rpm and 40 mm/min and the specimen C with weld parameters 16 kN, 1200 rpm and 40 mm/min are suitable for application. The specimen A with weld parameters 10 kN, 400 rpm and 30 mm/min is susceptible to corrosion. So it is not suitable for application in highly corrosive environments such as seawater.

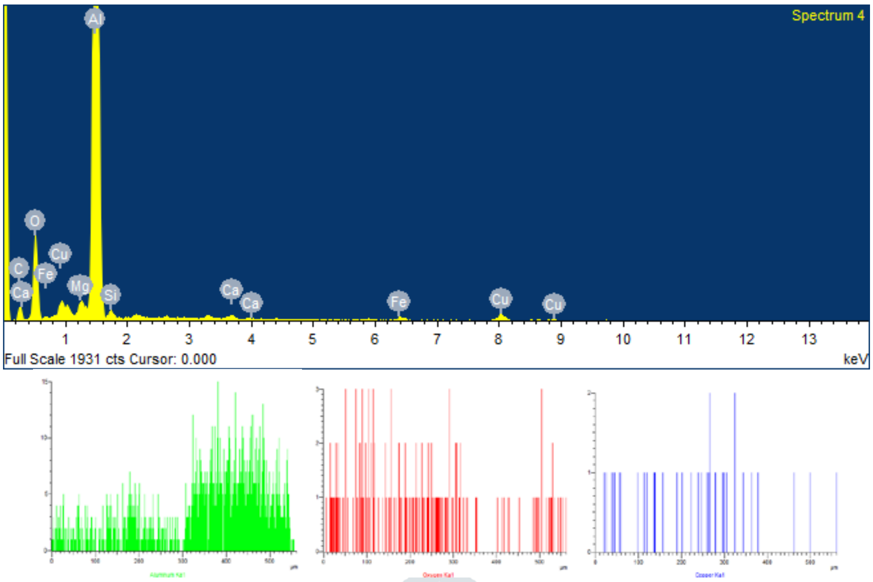


Fig 10: EDAX images of sample A (FSW joint with parameters axial load 16 KN, rotational speed 1200 rpm and transverse speed 50 mm/min.)

5. CONCLUSION

The Aluminium and Magnesium alloys have a wide range of application such household utensils, construction equipment, packaging, vessels used in industries, pipes, aircrafts, ships, marine equipments, weapons, etc. They are mainly used for their corrosion resistance property. High strength alloys of Aluminium and Magnesium alloys are used in aircrafts and ships. They can be welded easily only by using Friction Stir Welding technique. So care has to be taken that there is no probability of corrosion in the welded region. This work reveals that the so called non-corrosive alloys of Aluminium and Magnesium are also affected by the universal process of corrosion. But it can be reduced by using the optimum parameters of the weld. Welding can take place at any set of parameters, but a safe set of parameters to weld, which will prevent the welded zone from corrosion should be chosen.

Through this investigation, it is concluded that welded region is susceptible for corrosion when the axial load and the rotational speed are kept low. As the value of these parameters increased the welding is done more and more perfectly. Out of the three sets of parameters the welded sample C shows more corrosion resistance than the other two sets of parameters. So we conclude that welding the alloy plates of AA6061 and AZ61 at 16 kN axial load, 1600 rpm rotational speed and 50 mm/min weld speed is most suitable.

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