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An Experimental Study on Friction Stir Welded 7075 Aluminum Alloy- Corrosion Properties and Micro Structure

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ABSTRACT:

Friction stir welding is an advanced solid-state joining process and is widely being considered for aluminum alloys. In this work, the corrosion properties and microstructure of friction stir welded 7075 Al alloy were studied. The microstructures of the base metal, bore metal, thermo-mechanically affected zone (TMAZ) and weld region were characterized by transmission electron microscopy and optical microscopy. Micro-hardness profile was obtained across the weld.

The pitting corrosion properties of the weldments were studied in 3.5% NaCl solution. Friction stir welding of this alloy resulted in fine recrystallized grains in weld nugget which has been attributed to frictional heating and plastic flow. The process also produced a softened region in the weld nugget, which may be due to the dissolution and growth of possible precipitates, identified as $Mg_{32}(Al,Zn)_{49}$. Corrosion resistance of weld metal has been found to be better than that of TMAZ and base metal

Keywords:

AA7075, Microstructure, Corrosion resistance, Friction Stir Processing.

1. INTRODUCTION:

High strength precipitation hardening 7XXX series aluminum alloys, such as 7075 are used extensively in aerospace industry. These alloys are difficult to join by conventional fusion welding techniques. Hence realizing a fusion-welded joint in such alloys without impairing the mechanical properties is a difficult task for the welding engineer. Consequently the welding engineer has to rely on rivets and fasteners with substantial increase in fabrication cost and structure weight.

The process of Friction stir welding is described in detail by many authors[1, 2,3 and 4]. Friction stir welding is essentially a hot-working process where a large amount of deformation is induced into the work piece through pin and shoulder and the temperature never exceeds 0.8 Tm[5]. It results in a distinguished microstructure in precipitation hardenable aluminum alloys[,6,7and8]. The first attempt at classifying microstructures was made by P.L.Threadgill[8].

This was further revised and accepted by the friction stir welding licenses association. This system divides the weld zone into unaffected material or parent metal, heat affected zone (HAZ), thermo-mechanically affected zone (TMAZ) and weld Nugget. The microstructure resulted by friction stir process in precipitation hardenable aluminum alloys are different from that of base metal microstructure or cast structure of fusion welds. These changes can bring a difference in corrosion properties of the weldment.Generally a passive oxide film can be readily formed on the surface of aluminum alloys, when exposed to air or water. However the corrosion rate could be very high due to the presence of chloride ions[8]. Further the corrosion behaviour of Al alloys largely depends on heterogeneity of their microstructures. As the friction stir process induces a dramatic change in microstructures, there is every need to understand the microstructure and corrosion behaviour of friction stir welds.The present investigation is aimed at the study of microstructure and corrosion resistance of AA 7075– T6 Al alloy welded by friction stir process.

2. EXPERIMENTAL PROCEDURE:

Friction stir weld was made on a 7075-T6 aluminum alloy plate of 12mm thickness. The nominal composition of the alloy is given in Table 1. The tool rotation speed and work piece travel speed are 350 rpm and 1 mm/sec respectively.The samples made from weld, TMAZ and base metal are polished to mirror finish, etched with Kellers reagent for 20s at room temperature and observed under optical microscope. Transmission electron microscopy was performed using a Philips CM12 Electron Microscope. Foil samples were made by electropolishing in a 20% nitric acid and methanol solution at sub-zero temperature. The Vickers micro-hardness instrument with a 200gf load was used for hardness survey across the weldment.

One square centimeter area of the weld, thermo-mechanically affected zone and base metal are individually exposed to 3.5% NaCl solution with pH adjusted to 10, where transition from passive to active region is very sharp. The potentiodynamic scan was performed with a scan rate of 0.166mV/s by using BES potentiostat supported by 352 SoftCorr III corrosion measurement software. Saturated calomel electrode (SCE) and graphite electrode were used as a reference and auxiliary electrode respectively.

The potential at which current increases rapidly is treated as critical pitting potential (E_{pit}). Specimens exhibiting more positive potential were considered as those with better pitting corrosion resistance. The pitted surfaces were cleaned and observed under optical microscope to assess the number and distribution of pits.

3. RESULTS AND DISCUSSION:

3.1 Base Metal:

The 7075-T6 base plate exhibits elongated matrix grain morphology (pan-cacked type grains) as shown in the Fig. 1a. The optical microstructure shows the Fe-containing and Si-containing particles. The strengthening precipitates observed by transmission electron microscopy given in Fig. 1b and it show basically two populations of precipitates, out of which larger ones are oriented in the rolling direction of the plate. The larger precipitates are indexed as $Mg_{32}(Al,Zn)_{49}$. While the other investigators indexed these precipitates as $Mg_{32}(Al,Zn)_{49}$ and $Mg(Zn_2,AlCu)$ [2]. There is a possibility of the existence of both types of precipitates.

3.2 Weld Nugget:

The weld nugget has a recrystalized, fine equiaxed grain structure of the order of 4-5 Om as shown in the Fig.2a and electron diffraction studies reveals that these grain boundaries are high angle, thus in weld nugget eliminating the possibility of being subgrains. Randomly oriented precipitates observed in transmission electron microscopy are shown in the Fig . 2b.

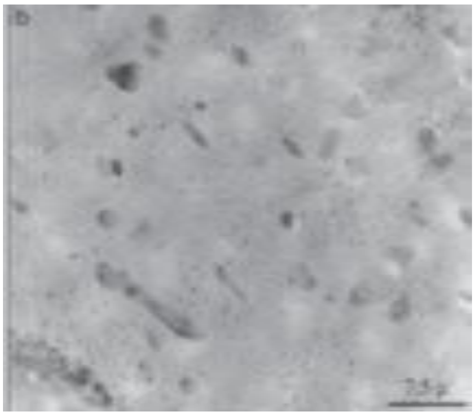

Fig. 1 Microstructure of base metal (a) Optical (b) TEM showing strengthening precipitates

As in base metal, these precipitates are indexed to $Mg_{32}(Al,Zn)_{49}$. This indicates that, during the process of FSW, the precipitates have dissolved into the solution and reprecipitated on subsequent cooling. The finer precipitates as in basemetal are absent in weld nugget. The recrystalization of the weld nugget and the redistribution of the precipitates indicate that the temperature obtained during the process is above the solutionizing temperature but below the melting temperature of the alloy. The finer precipitates are absent in weld nugget because the cooling rates are such that larger precipitates could nucleate and grow but not the finer ones.

3.3 Thermo-mechanically affected Zone:

This is the transition zone between the base metal and the weld nugget, characterized by a highly deformed structure as shown in fig. 3a. The optical microscopy does not reveal the grains properly. It shows a banded structure. There is no recrystalization in this region. TEM reveals the strengthening precipitates and are shown in Fig. 3b. There is no significant change in the size and morphology of coarser precipitates, but their orientation along rolling direction like in parent metal is absent in TMAZ. The precipitates are quite random. The finer precipitates observed in parent metal are coarsened during welding.

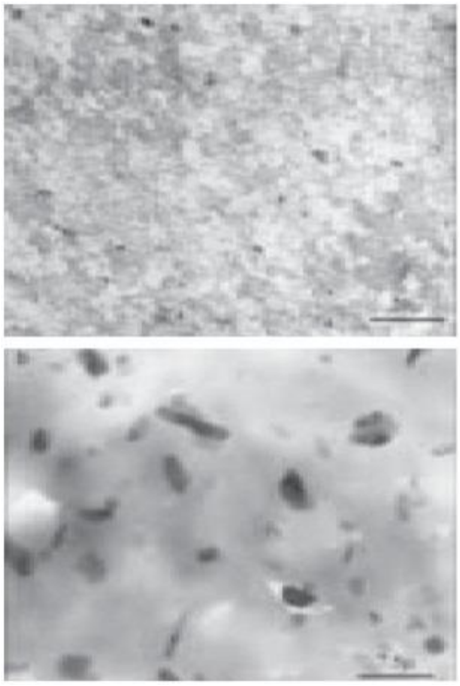

Fig. 2: (a) Equiaxed grains in weld nugget (b) Precipitates in weld nugget

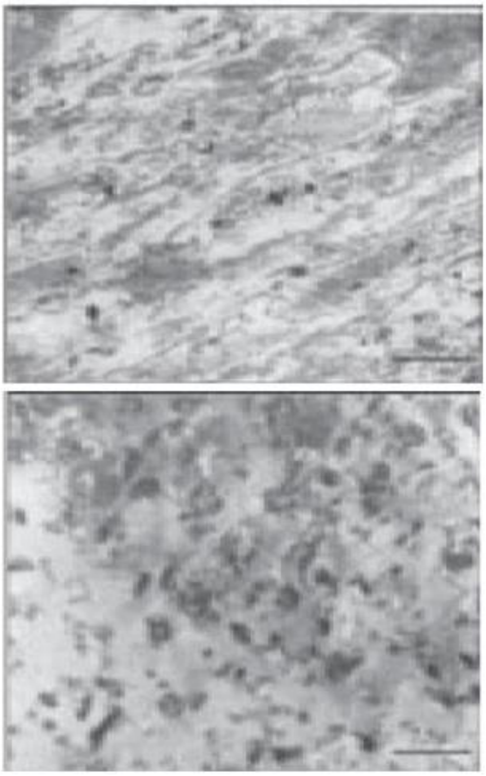

Fig. 3: (a) Microstructure in TMAZ (b) Distribution of precipitates in TMAZ

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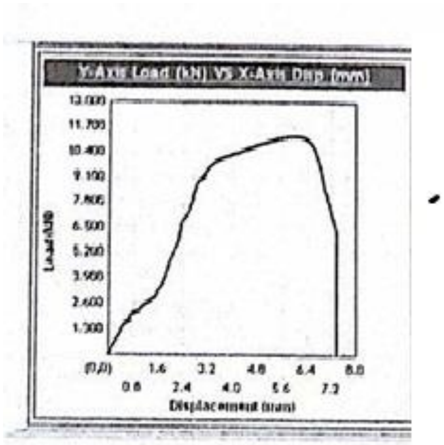
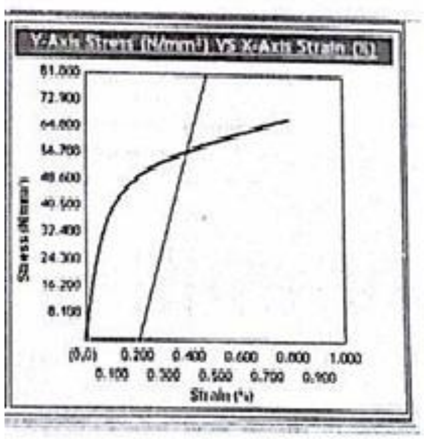
3.4 Hardness Profile:

The hardness profile indicates a decrease in the weld hardness as shown in the Fig 4 and this has been attributed to the dissolution of precipitates into solution and subsequently the weld cooling rates do not favor nucleation and growth of all the precipitates. The transition region indicates a reduction in hardness because of coarsening of precipitates. The hardness on one side of weld centre is higher than the other side. This difference could be explained as follows. In the leading side for the rotating tool where the rotational velocity vector and the forward motion vector are in the same direction and due to this there is higher heating on one side of weld center and hence higher the hardness. Even though there is reduction in hardness of weld, it still meets classification societies requirements





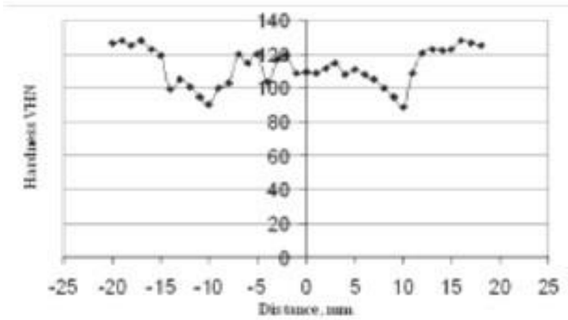


Fig. 4 : Hardness profile of friction stir welded sample

3.5 Corrosion:

The potentiostatic polarization curves for base metal TMAZ and weld in 3.5% NaCl solution are given in Fig. 5. The critical pitting potentials of test specimens (table 2), clearly indicates a greater pitting corrosion resistance of weld metal than base metal. This is because the precipitates present in the alloy promote matrix dissolution through selective dissolution of aluminum from the particle.

Table 2

PITTING POTENTIALS OF 7075-T6 AL ALLOY IN 3.5%

NACL SOLUTION

Specimen	Critical Pitting potential (E_{Pitt}) mV
Base Metal	-789
TMAZ	-799
Weld	-764

These precipitate deposits are highly cathodic compared to the metallic matrix, which initiates pitting at the surrounding matrix and also enhances pit growth. As discussed earlier, during FSW only the coarser precipitates could nucleate and grow but not the finer ones. This aids in formation of passive film, which remained more intact on surface of the sample.

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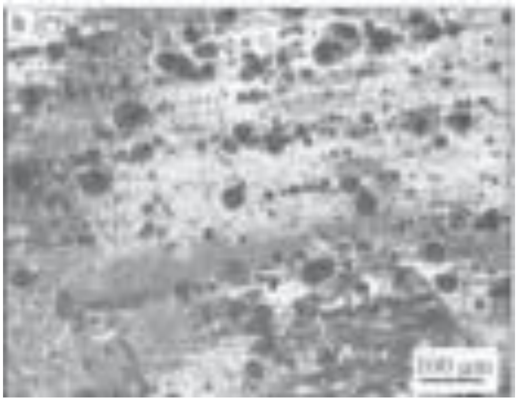
Aging produces a microstructure of uniform distribution of precipitates in aluminum matrix. This condition creates inhomogeneity on a microscopic scale. The precipitates are noble and promote anodic dissolution of the matrix. The higher pitting corrosion resistance of the weld region can be attributed to partial elimination of inhomogeneity of microstructure in this region. The TMAZ shows a poor pitting corrosion resistance as compared to base metal.



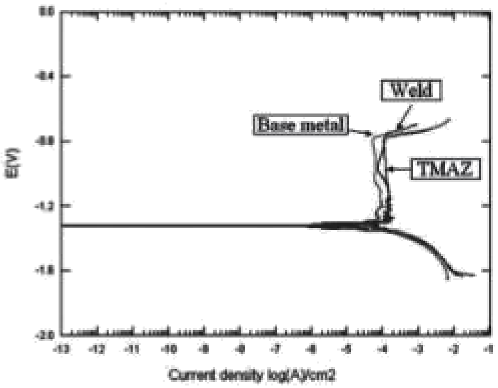
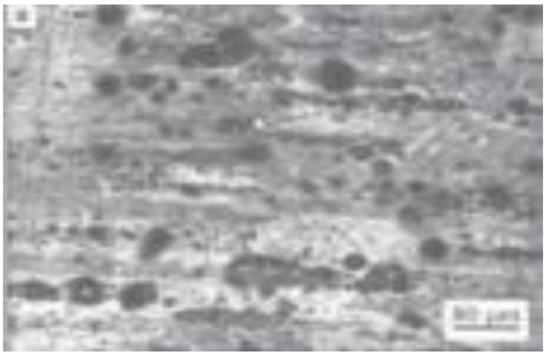
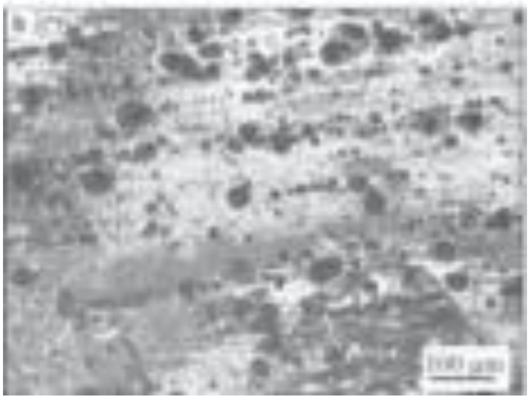


Fig. 5 : Polarization curves of base metal, TMAZ and weld regions in 3.5% NaCl solution

During FSW process this region heats up to a temperature just below the solutionizing temperature of the alloy. This results in coarsening of precipitates, as evident by the decrease in the hardness. The slightly more negative critical pitting potential of TMAZ than base metal can be attributed to the residual stresses induced during the process of FSW.





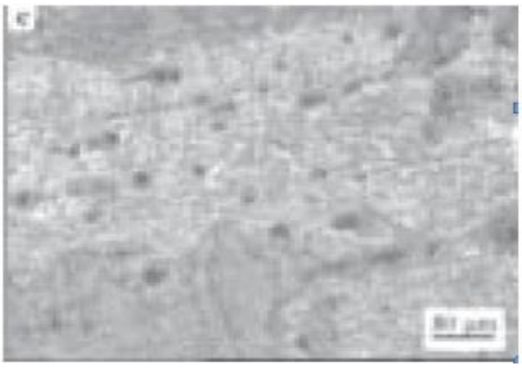


Fig.6 : Microstructures showing pits after potentiodynamic polarization in 3.5% NaCl aqueous solution (a) base metal, (b) TMAZ and (c) weld.

The microstructures of pitted surfaces shown in Fig 6a-c and it reveals clearly that pit density of weld region is much less than that of base metal and TMAZ. Hence it can be concluded that pitting resistance of weld region is better than that of base metal and TMAZ. However there exists a problem of galvanic kind of corrosion because of difference in pitting potentials across the friction welded joint, especially in

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aggressive environments containing halide ions. Therefore corrosion protection of these welds with conversion layer coatings is highly desirable.

4. CONCLUSIONS:

1. Considerable grain refinement in weld metal has been achieved and it may be due to frictional heating and plastic flow.
2. Pitting corrosion resistance of weld metal is better than that of thermo-mechanical affected zone and the base metal.

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