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Friction Stir Welding as New Emerging Trend in Joining Technology for Aluminum Alloys

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Abstract

Today, aluminum alloys are used in a diverse range of markets and applications, each one exploiting the unique physical and mechanical properties of those alloys. Recent development on joining technology showed a good potentiality on the application of Friction Stir Welding (FSW) for aluminum alloys. Some information about the application of friction stir welding technology for aluminum alloys are reviewed, including mechanical properties, micro hardness and micro structure of the welded aluminum alloys, and also a few information of the study on friction stir welding in University of Lampung, Inodnesia.

Keywords: aluminum alloys, friction stir welding, mechanical properties, and microstructure

INTRODUCTION

The demands made of new materials are increasing rapidly. Consequently there is now, a new kind of inter-metallic alloy based on heat treatable aluminum alloys and non-heat treatable aluminum alloys. The industry is striving to lighter product and at present this is achieved through the use of aluminum alloys for some body parts and structure.

Typical aluminum alloys are that it has a protective film at the surface with form of aluminum oxide (Al_2O_3), where it is an advantage in the application because in practice it will protect the metal from corrosion process. But, on the other hand, it can nevertheless be welded because of some problems such as: the oxide can be dispersed by the action of a welding arc, some aluminum alloys are susceptible to hot cracking and grain coarsening, and the melting temperature of oxide film is higher than the main alloy.[1,2]

Due to the affinity of aluminum for oxygen, it cannot successfully be arc welded in an air environment. If fusion welded in a normal atmosphere oxidization readily occurs and this results in both slag inclusion and porosity in the weld, greatly reducing its strength. To overcome these problems one of the most common ways of welding aluminum has been to use the electric arc process whilst shielding the weld pool with an inert gas, so called metal inert gas welding. This method produces good welds, but more recently solid-state methods for welding the material have been developed, one of these being friction stir welding. [3, 4]

Stir Welding Technology

Friction stir welding is a solid state joining technique that has made it possible to weld a number of materials that were previously extremely difficult to reliably weld without voids, cracking or distortion. Friction stir welding, a derivative of conventional friction welding, was invented at The Welding Institute (TWI, U. K.) in 1991. [1, 2, 3]

The following are manufacturing applications for friction stir welding: Aircraft, Aerospace, Marine (shipbuilding and decks for car ferries), Trucking, Railroading, assembling large tank structures (fuel tanks, and radioactive waste canisters). [5]

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Friction stir welding is a relatively simple process (see Figure 1) using a specially shaped cylindrical tool with a profiled probe (see Figure 2), made from a hard and wear resistant material relative to the material being welded, is rotated and plunged into the abutting edges of the parts to be joined. After entry of the profiled probe to almost the thickness of the material and to allow the tool shoulder to just penetrate into the plate, the rotating tool is transitioned along the joint line. The rotating tool develops frictional heating of the material, causing it to plasticized and flow from the front of the tool to the back where it cools and consolidates to produce a high integrity weld, in the solid phase.

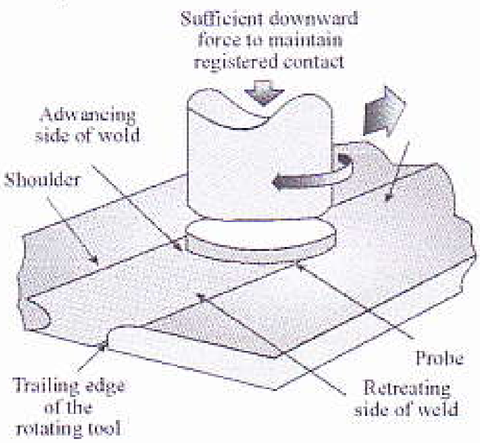
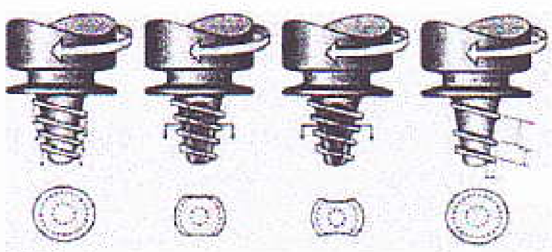


Figure 1. Friction stir welding process [1, 2, 3]



a) Oval antape

Figure 2. Fsw PIN [4]

Although the FSW process is more reliable and maintains higher material properties than conventional welding methods, two major drawbacks with the initial design impacted the efficacy of the process: the requirement for different-length pin tools when welding materials of varying thickness and the reliance on a pin tool that left a keyhole at the end of the weld. The latter was a reliability concern particularly when welding cylindrical items such as drums, pipes, and storage tanks.

In exploring methods to improve the use of FSW on the manufacturing floor, NASA Marshall, a licensee of TWI's FSW process, created new pin tool technology, including an automatic retractable pin tool. The automatic retractable pin tool uses a computer-controlled motor to automatically retract the pin into the shoulder of the tool at the end of the weld, preventing keyholes. NASA Marshall's innovative retractable pin tool has contributed to customize the FSW that has been proven to provide routinely reliable welds. [5]

In another practical experimental, Friction Stir Welding process can also perform using ***Universal Milling Machine***, such as Universal Milling Machine, MILKO 12 that has been intensively used at Mechanical Engineering Dept. University of Lampung. The picture of the main handle and welding tool of

Figure 3. FSW Process using Universal Milling Machine MIKLO 12 [6]

The process temperature of friction stir welding is below the melting temperature of materials. The maximum temperatures were estimated from the microstructures in some studies. Rhodes and co workers [7] have shown that larger precipitates might have gone into solution and re-precipitation in the weld center, and they concluded that process temperatures are between about 400°C and 480°C in friction-stir-welded 7075 Al. In general, researcher has stated that the maximum temperature reached is about 0.8 of the alloys melting temperature.

There are some benefits of friction stir welding process, such as: [4,5]

- Diverse materials: Welds a wide range of alloys (carbon steel, stainless steel, aluminum, and magnesium), including previously unweldable and composite materials
- Excellent welding result: no porosity, lack of fusion, low distortion and low shrinkage
- Retained material properties: no change in material composition and post treatment or

straightening of panels not necessary
- Safe operation: does not create hazards such as welding fumes, radiation, high voltage, liquid metals, or arcing.

Mechanical Properties

Because of the variation of the properties, the evaluation of mechanical properties of welded aluminum alloys using FSW process can be divided into pure aluminum (Seri of Al 1xxx), heat treatable alloys (Series of Al 2xxx, 6xxx, and 7xxx) and non heat treatable aluminum alloys (Series of Al 3xxx and 5xxx). [3]

The micro-hardness investigation of friction stir welded pure aluminum Al 1100-H8 has been published by Sustiono and Agung as shown on Figure 4. It is explain a good result in welding process, which the hardness numbers of welding regions: heat affected zone (HAZ), thermomechanically affected zone (TMAZ), and stir zone (SZ) are higher than based metal (BM).

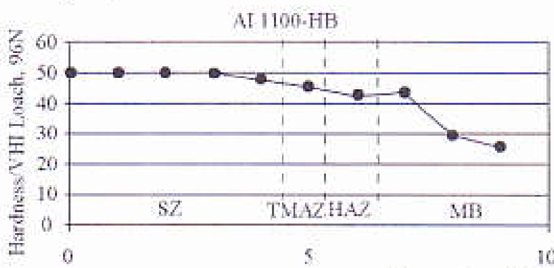


Figure 4. Micro hardness profile of Friction Stir Welded Al 1 100-H8 [6, 8]

Sato and co-worker also reported the hardness profile of Al 1080-O, the cross section of perpendicular to the welding direction and hardness across the stir zone as shown on Figure 5. The stir zone had an average hardness of about 20 *Hv*, which is slightly higher than that of the base material (about 16 *Hv*). The maximum hardness (about 24 *Hv*) is located in thermomechanically affected zone (TMAZ). [9]

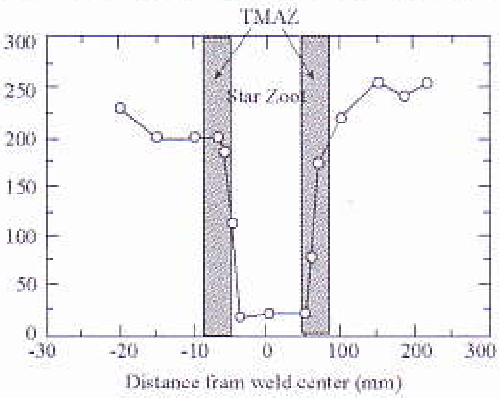
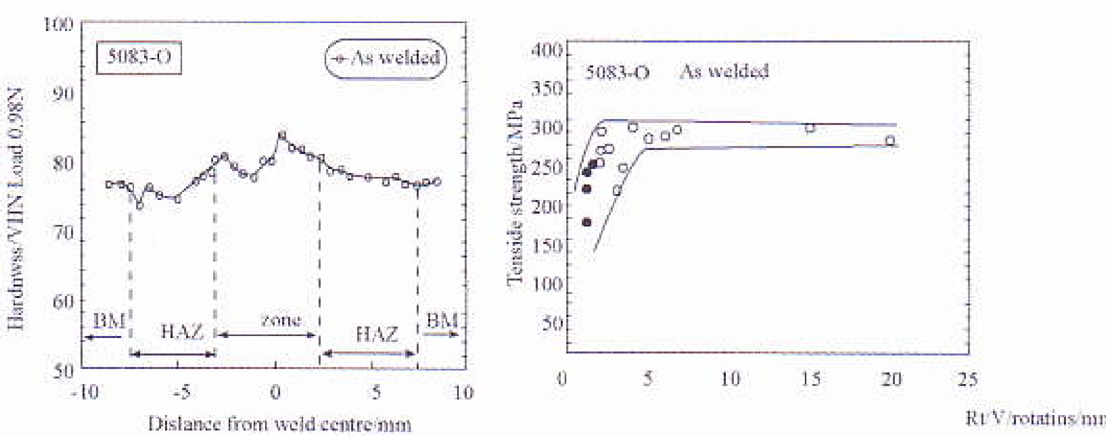


Figure 5. Hardness profile of Al 1080-O

The hardness profile of Al 5083 series indicated a good result while no large drop in welded region (HAZ, TMAZ and SZ), as reported by Nakata *et al.*[10] and Sato *et al.*[9] The traverse of FSW measured hardness profile and the tensile strength of Al 5083-O as shown on Figure 6.[10] Nakata *et al.* also reported that welding parameters will give a significant effect on tensile strength of welded aluminum alloys. Evaluation in mechanical properties of friction stir welded of heat treatable aluminum alloys has been done by some researcher [8-14]. Nakata *et al.* reported that hardness profile and the tensile strength heat treatable aluminum alloys, Al 7075-T6, depend on its aging condition. Aging process will increasing both



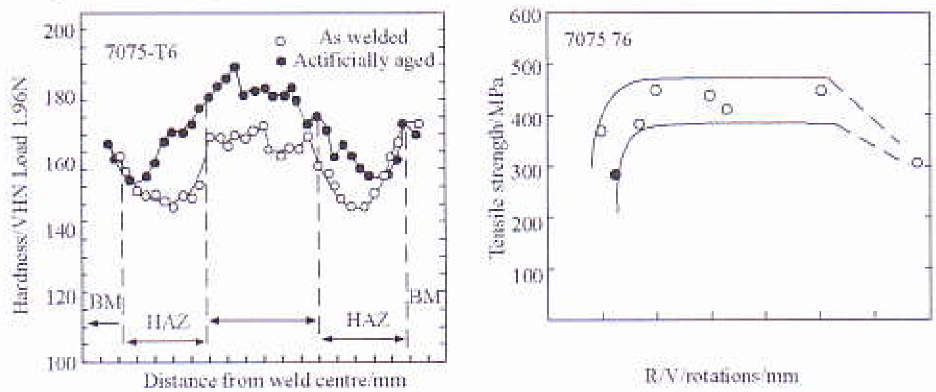
(a) Hardness Profile

(b) Tensile Strength

Figure 6. Hardness profile and Tensile strength of Al

hardness and tensile strength of welded alloys, as shown on Figure 7.

whereas the TMAZ has larger and elongate grain size



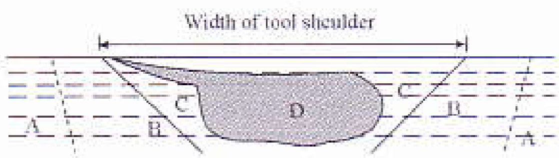
(a) Hardness Profile

(b) Tensile Strength

Figure 7. Hardness profile and Tensile strength of Al 7075-T6

Microstructure

The microstructure of a friction stir weld depends in detail on the tool design, the rotation and translation speeds, the applied pressure and the characteristics of the material being joined. However, it can be summarized that unlike fusion welding, in friction stir welding, the process not only generates a heat-affected zone (HAZ) and weld nugget, but also thermomechanically-affected zone (TMAZ) as shown in Figure 8. The TMAZ is a result of both plastic deformation and thermal exposure.



A. Parent metal unaffected by weld
B. Heet affected zone (HAZ)
C. Unrecrystallised arrea found in aluminium alloys
D. Recrystallised nugget found in aluminium alloys
C+D Thermomechanically affected zone (TMAZ)

Figure 8. Cross section of Friction Stir Welded Microstructure [3-7]

Figure 9 show the micro structure of friction stir welded Al 1100-H8 that has been investigated by Agung [8]. Figure 9(a) shows the original microstructure of based metal with biggest grain size and same with a conventional welding, HAZ region characterized by more equiaxed grains when compared to the parent plate, but no plastic deformation is evident, as shown in Figure 9(b). Grains within the HAZ were typically their length being 50 to 100 % greater than width. Figure 9(d) is a microstructure of a nugget with smallest grain size; relatively equiaxed grains that illustrated in the deformation map, as shown on Figure 9(c).

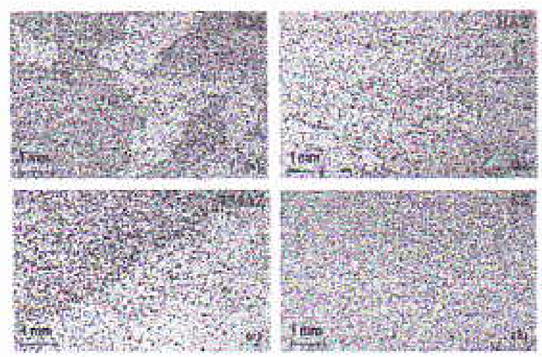


Figure 9. Frictrion Stir Welded Microstructure of Al 1100-H8

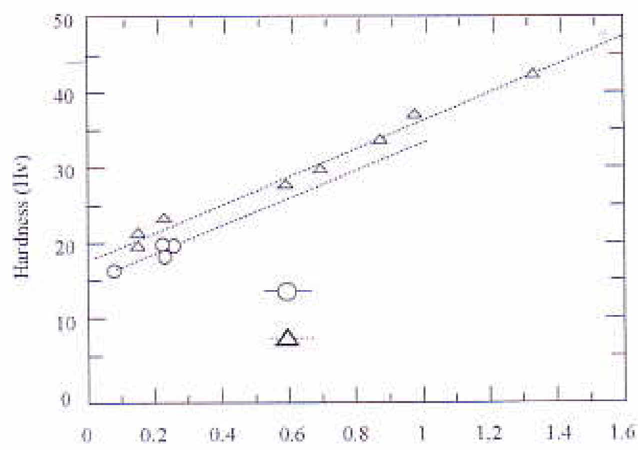
Many researchers has investigated the relation of hardness (Hv) and grain size (d) of non-heat treatable Aluminum alloys based on the Hall-Petch equation as the following:

$$Hv = H_0 + k_H\, d^{1/2} \quad \text{.... ....(1}$$

Where H_0 and k_H are appropriate constants.

Sato and co-worker examining relation of grain size and hardness profile of Al 1080-O and Al 1050 and concluded that the relation of hardness profile and grain size of Al 1080-O and Al 1050 as shown on Figure 10. [9]

Based on Figure 10, that relation can be generalized with the following equations:



- For Al 1080-O : $Hv = 15.4 + 18.7d^{1/2}$ ....(2)
- For Al 1050 : $Hv = 18.2 + 18.9\,d^{-1/2}$ ....(3)

Microstructure and mechanical properties of friction stir welded of heat treatable aluminum alloys are depend on the aging or post heat treatment process. Paola, M.Di. *et al.* have published the friction stir welded of Al alloys Al 6065-T6.[12] Figure 11 shows the microstructure of the region of transition between weld nugget and non re-crystallized stirred material, Figure 11(a) and the typical microstructure of the weld nugget interior. A dramatic difference in dislocation density between re-crystallized and non re-crystallized grains is apparent.

The grain interior is heavily decorated with inter granular Mg_2Si precipitates, which are extremely effective in reducing dislocation mobility, as clearly indicated by the high fraction of dislocations pinned on these precipitates. The low dislocation density in the re-crystallized grains is well documented in Figure 11(b). The fine grain size in the weld nugget can easily be appreciated; in particular, TEM analysis demonstrates that the average grain size obtained with light microscopy (LM) measurements is overestimated.

The size and distribution of inter granular precipitates do not change appreciably in the re-crystallized region. Aging curves at 160°C and 175°C are shown in Figure 12. Analysis of this figure allowed to identify the conditions for T6 treatment (solution treatment at 530°C for 4 h and artificial aging at 175°C for 24 h).[12]

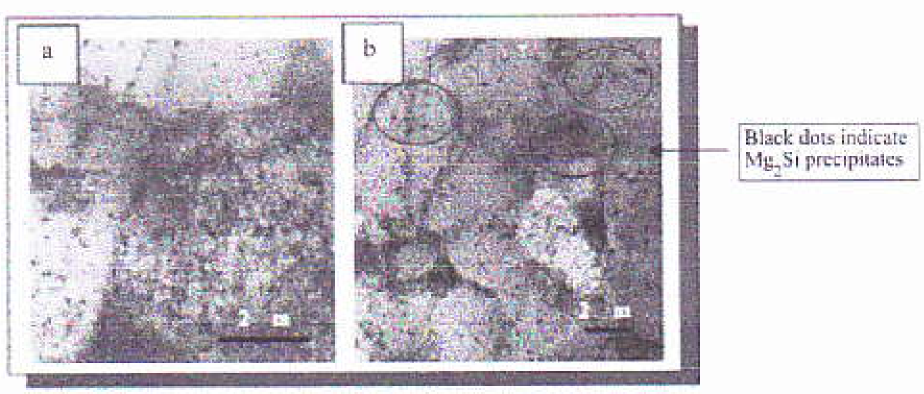


Figure 11. Microstructure of FS welded Al 6065-T6, (a) the effect of precipitates is apparent; (b) finer grain size with high fraction of precipitates

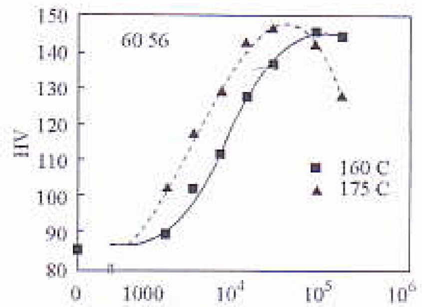


Figure 12. Aging curves of Al 6065-T6 at 160°C and 175°C

Based on Figure 12, the aging temperature at 160°C will give a higher *Hv* of welded alloys than 175°C. It can be seen that longer aging time can increased the hardness of friction stir welded alloys, but after an optimum time, the hardness will decreased, it caused by an over aging phenomenon. Sato *et al.* [11] also concluded that postweld aging of a heat treatable aluminum alloys produces an increase in the forms, volume fraction and distribution of fine strengthening precipitates, which leads to the improvement of strength and loss of ductility. The same conclusion also given by other researchers. [7, 9, 10]

Summary

Friction Stir Welding Technology promises many opportunities on the application of Aluminum alloys, which are often difficult to fusion weld, without weld defect. FSW leads to a number of new product designs, previously not possible. Mechanical properties and mictrostructural evaluation of welded alloys show good result due hardness and tensile test. FSW no need postweld heat treatment for non heat treatable Al alloys but some additional postweld aging processes are needed for heat treatable Al alloys.

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