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Research Article

Tensile Properties and Microstructural Characteristics of Friction Welded Similar Joints of Aluminium Alloys

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Abstract

Friction Welding (FW) is a process of solid state joining which is used extensively in recent years due to its advantages such as low heat input, production efficiency, ease of manufacture and environment friendliness. Friction welding can be used to join different types of ferrous metals and non-ferrous metals, which are not easy to be welded by traditional fusion welding processes. The process parameters such as friction pressure, friction time, forging pressure, forging time, and rotating speed play the major roles in determining the strength of the joints. The main objective of this investigation was to apply friction welding for joining of 12mm dia aluminium alloy similar joints 2024 & 2024. In the present study an experimental friction welding setup, in which continuous drive friction welding used. At first optimum parameters were obtained to join parts having equal diameter and length through trail experiments. Trial experiments were conducted to determine the working range. The parameters were chosen in such a way that the friction welded joints should be free from any visible external defects. In the second part of the study, the effect of welding parameters on welding strengths was investigated. Later the mechanical properties of joints were examined by using tensile test, SEM fractograph analysis, macro & micro structure analysis and Vickers micro hardness test.

Keywords: *Friction welding, Aluminium alloy 2024, Tensile strength, SEM Fractograph, Microstructure, Macrostructure and Vickers microhardness.*

1. Introduction

Friction welding is a solid state welding process. It makes use of frictional heat generated at the rubbing surfaces to raise the temperature at the interface high enough to cause the two surfaces to be forged together under high pressure. In the process, heat is generated by conversion of mechanical energy into thermal energy at the interfaces of the components during rotation under pressure without any energy from environment. Friction pressure, friction time, forging pressure, forging time and rotating speed are the most important parameters in friction welding. The parameters have to be selected properly in the experiments since these directly affect welded quality (Vill, 1962). Aluminium alloy strength must be adequate to resist denting at a thickness which offers cost effective weight savings over steel. Body structural components must be made from materials which absorb energy and fail gracefully during a crash. Designers of aircraft desire materials which will allow them to design lightweight, cost effective structures which have the performance characteristics of durability and damage tolerance. Increase in fuel economy because of lighter weight structure (Staley *et al*. 1993). Sathiya *et al*. (2008) reported the friction welded joints exhibited comparable strength with the base material and joint strength decreased with an increase in the friction time. The material shear flow and dimples at the fractured surface confirms the ductile mode of failure of joints during tensile testing. Sammaiah *et al*. (2009) reported that there is considerable improvement in tensile strength, impact strength and joint efficiency with increase in upset pressure at low friction pressure. The hardness is high at the interface with high upset pressure and low friction pressure. The microstructure shows fine grains at central region and coarse grains at the periphery. Khalid Rafi *et al*. (2010) revealed that sound joints in AA7075-T6 can be achieved using friction welding. Friction pressure, spindle speed and burn off length are the three most significant parameters

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affecting the joint strength. Eder *et al*. (2010) reported the friction welding process was very efficient in the welding of dissimilar materials such as AA1050 aluminum and AISI 304 stainless steel. Vickers micro hardness values measured near the bonding interface, central region, were higher than in the metal bases. Emel Taban *et al*. (2010) reported that fracture surfaces from the mechanical test specimens indicate failure through the highly plasticized aluminium over steel. Hazman seli *et al*. (2010) investigated friction welding of two dissimilar materials are welded together by holding one of them still while rotating the other under the influence of an axial load which creates frictional heat in the interface and they are found bonds of aluminium and mild steel were achieved in the friction welding process. The welded materials have lower hardness compared to their parent materials due to thermal effects of the friction welding. Mumin sahin (2010) reported that though tensile strength for copper and aluminium joints were generally acceptable when compared with those of the base metals, some of the welds showed poor strength as a result of the accumulation of alloying elements at the interface. Hardness variations on the aluminium side were lower than those on the copper side as expected. Ahmad fauzi *et al*. (2010) reported the Heat Affected Zone (HAZ) is very narrow in the case of low spindle speed. But when the speed was increased, the HAZ is more visible on the aluminum alloy part. The effect of rotation speed and degree of deformation appears to be high on the 6061 Al alloy than on the alumina part. Paventhan *et al*. (2011) developed an empirical relationship to predict the tensile strength of friction welded aluminium alloy 6082 and AISI 304 austenitic stainless steels joints. As a result, friction pressure was found to have greater influence on tensile strength of the joints, followed by friction time, forging time, and forging pressure incorporating process parameters. Sandeep kumar *et al*. (2012) investigated the friction welded joint of dissimilar metals to evaluate the mechanical properties of mild steel and aluminium alloy joint. As a result the friction welding has been successfully employed to weld dissimilar metal. And found that tensile strength and micro hardness of both of the material were good and fusion joint of the material were also in good condition and the ductility was reasonable.

From the literature reviews, it is understood that limited published information are available on friction welding of aluminium alloys on similar joints. Further, most of the investigations were carried out on aluminium alloys with copper, stainless steel and mild steel. Hence, in this investigation an attempt has been made to study the tensile properties and micro structural characteristics of friction welded similar joints of aluminium alloys.

2. Experimental Work

The base matel aluminium alloy 2024 used in this investigation, were cylindrical rods with 12 mm in diameter and 75 mm in length. The chemical composition and mechanical properties of the base materials are presented in Table 1 and Table 2. A hydraulic controlled continuous drive friction welding machine (20 kN capacity) was used to weld the joints are shown in Fig. 1. From the literature the predominant factors having greater influence on the tensile strength of friction welded joints were identified as: 1) friction pressure; 2) friction time 3) forging pressure 4) forging time and 5) rotating speed. Trial experiments were conducted to determine the working range. The parameters were chosen in such a way that the friction welded joints should be free from any visible external defects. The important parameters influencing the tensile properties of friction welded joints and their working range of similar joints of AA 2024 details are presented in Table 3. Tensile specimens were prepared as per the ASTM E-8M standards. Tensile test was carried out in 100 kN, electro-mechanical controlled Universal Testing Machine (Make: FIEBLUE STAR, India; Model: UNITEK-94100). The specimen was loaded at the rate of 1.5 KN/min as per the ASTM E8M specifications, so that tensile specimen undergoes uniform deformation. For supporting the visual inspection of tensile test failure, the fracture analysis was done. For that Scanning Electron Microscope (SEM) of make JEOL model no. JSM-6610LV was used. Micro structural examination was carried out using a light optical microscope (Make:MEIJI, Japan, Model: ML7100) incorporated with an image analyzing software (Clemex-Vision). The specimen prepared for microstructural analysis by following ASTM E3 and E340 standards. A Vicker's microhardness testing machine (Make: Shimadzu, Japan; Model HMV-2T) was employed for measuring the hardness of the materials with 50gf load.

Fig. 1 Friction welding machine

Table 1 Chemical composition of base material

Material	Si	Fe	Cu	Mn	Mg
AA 2024	0.09	0.25	4.16	0.66	1.67
	Ni	**Zn**	**Ti**	**Ca**	**Al**
	0.01	0.01	0.06	0.01	Bal.

Table 2 Mechanical properties of base material

Materials	Yield Strength (Mpa)	Ultimate Tensile Strength (Mpa)	Notch Tensile Strength (Mpa)	% of Elongation	Vickers micro hardness (VHN)
AA 2024	501.5	573.0	553.5	12	126

Table 3 Friction welding parameters

Parameters	AA 2024
Rotational speed (rpm)	1200
Friction Pressure (ton)	1.24
Forging Pressure (ton)	1.24
Friction Time (sec.)	5
Forging Time (sec.)	5

3. Results and Discussion

3.1 Tensile test

Tensile test was performed with Universal Testing Machine (Make: FIEBLUE STAR, India; Model: UNITEK-94100) having the capacity 100 kN. ASTM E-8M standards were followed to make the standard specimens. The gauge lengths of the specimens were maintained according to the ASTM standards keeping the weld interface at the centre of the gauge length. The specimen was fitted firmly between the jaws of the machine and load was applied. In this test the specimen was subjected to axial tensile load till failure occurs. The strength of joints was determined by tensile tests. Ultimate strength, yield strength, percentage of elongation, notch tensile strength, notch strength ratio and joint efficiency for tensile specimen details reported in Table 4. It has been observed experimentally that similar joints of AA 2024 specimens were failed at the weld region is shown in Fig. 2. Weld strength in friction welded similar joints of AA 2024 was found less than that of the base material. This is may be due to % of elongation of friction welded similar joints of AA 2024 (6%) was lower than (12%) of elongation AA 2024 parent metal. It is brittle in nature it exhibited in the notch strength ratio which is simple 0.99.

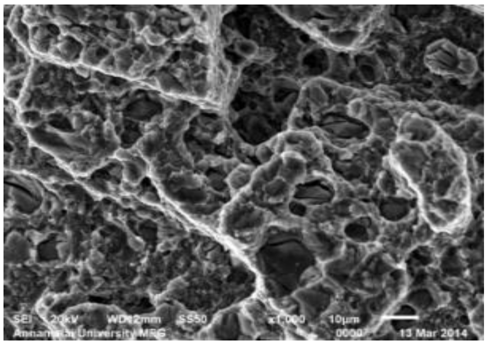
Table 4 Tensile results for friction welded specimens

Materials	Yield strength (Mpa)	Ultimate strength (Mpa)	% of Elongation
AA 2024	313.5	364.5	6
	Notch Tensile Strength (Mpa)	**Notch Strength Ratio**	**% of Joint Efficiency**
	362.5	0.99	63.6

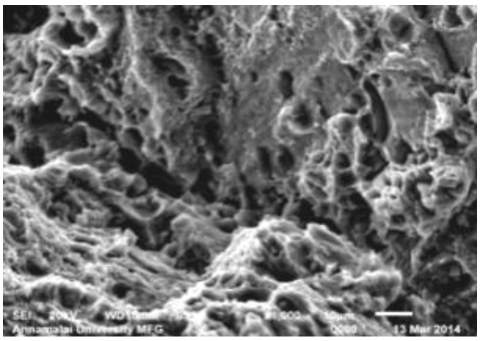
Fig. 2 Similar joints of aluminium alloy 2024 tensile test before and after

3.2 SEM fractograph analysis

To support the visual inspection of failure, the fracture analysis was carried out by the Scanning Electron Microscope (SEM) of make JEOL model no. JSM-6610LV. The SEM analysis has done to show the fracture behaviour of tensile test which justifies the visual inspection results of brittle and ductile failures. The magnified images were captured at the fractured locations taken at 1000 magnification. The effect of tensile strength has been observed on the fractured surface appearance. In the Fig. 3 SEM images at fracture interface after tensile testing. Fig. 3(a) represents fractograph of parent metal tensile specimen. Fig. 3(b) represents friction welded similar joints of aluminium alloy tensile specimen.



(a) Base material of aluminium alloy



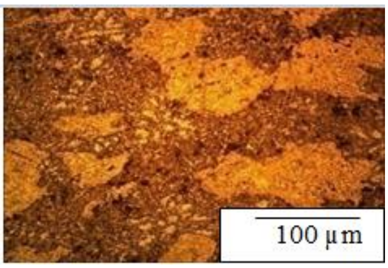
(b) Friction welded similar joints of aluminium alloys

Fig. 3 SEM images at fracture interface during tensile testing

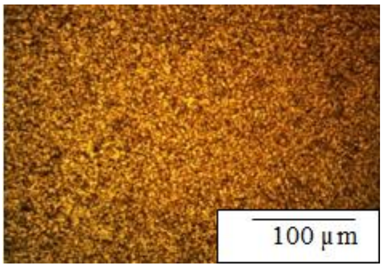
It is observed from the SEM fractograph images Fig.3(b) is less dimpled pattern compare with Fig. 3(a). This is may be due to dimples associated with high ductility because the material is softened due to coarsening and dissolution of precipitates constituent particles presented in alloys. Coarsening occurred by heat generated force followed by air cooling. The ductile fracture mechanism is normally identified by dimples. The brittle fracture mechanism is identified by a relatively featureless fracture surface that may include cleavage. So, friction welded similar joints of AA 2024 ductility is low compare with the parent metal of AA 2024

3.2 Microstructure analysis

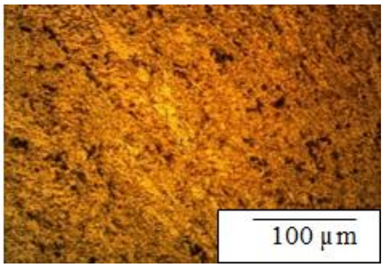
The Microstructure of similar friction welded joints is shown in Fig.4.



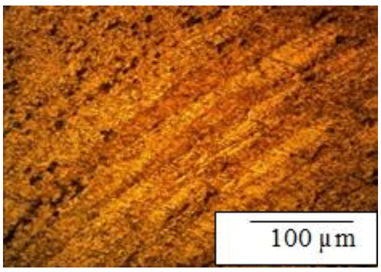
(a) Base material of aluminium alloy



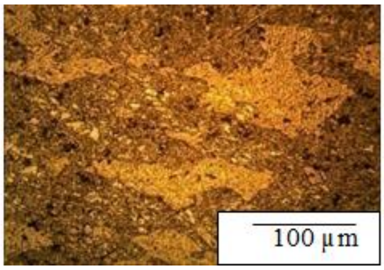
(b) Fully deformed zone



(c) Partly deformed zone



(d) Heat affected zone



(e) Undeformed Zone

Fig. 4 Optical microstructure of similar friction welded joints

Parent metal microstructure is shown in Fig. 4(a). In this study Micro structural examination was carried out using a light optical microscope (Make:MEIJI, Japan, Model: ML7100) incorporated with an image analyzing software (Clemex-Vision). In the optical microscope observation of the welded specimen it is observed that there are no cracks are produced in the similar joints of aluminium alloy. In the friction welding the frictional heat at the interface when dissipated through the parent material would result in a temperature gradient causing zones of material with different microstructure. A finer grain structure can be observed in the Fully Deformed Zone (FDZ) is shown in Fig. 4(b) where, as at the nearby zone called the Partly Deformed Zone (PDZ) is observed from the Fig. 4(c). In the partly deformed zone grain size is coarse compare to the fully deformed zone. The grains at Heat Affected Zone (HAZ) are relatively coarse compare with FDZ and PDZ is shown in Fig. 4(d). The parent material microstructure is presented in Undeformed Zone (UZ) can be easily understood in Fig. 4(e). This is may be due to the temperature of the welded region would be higher and therefore exhibits fine grain structure compare with rest of three zones.

3.2 Macrostructure analysis

In friction welding heat is generated due to the rubbing of the faying surfaces and this heat generation is directly proportional to the relative velocity, which is minimum at the center and maximum at the periphery.

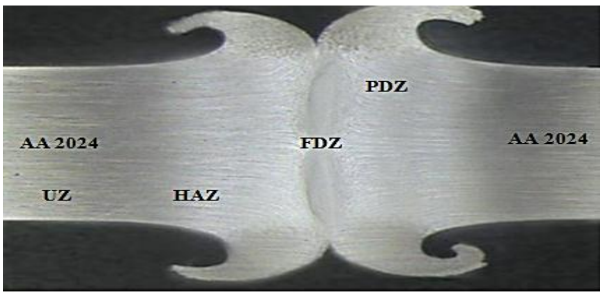


Fig.5 Friction welded similar joints of AA 2024 cross sectional view

However, at the periphery the joints are subjected to convective heat loss to the surrounding and hence the maximum heat generation point can be seen somewhere close to the periphery beneath the surface. Due to which more intermixing takes place at the peripheral region of the weld. In general it is observed that, similar joints of aluminium alloy 2024 exhibited equal flashes (equal deformation) are shown in Fig.5. The formation of flash depends upon the mechanical properties of parent materials.

3.3 Vickers Microhardness test

For micro hardness testing, vickers hardness testing machine was used (Make: Shimadzu, Japan; Model HMV-2T). The micro hardness variation on the weld interface and across the weld interface were obtained by applying a constant load of 50gf. The indentations were made at the weld interface and on both the sides along the axis of the shaft at the regular intervals of 1 mm apart so as to find out the effect of heat on the hardness values. The Micro hardness test was conducted at the interface of the weld and in the regions near the similar joints of aluminium alloy 2024. The test resulted with the horizontal distance from the centre. It has been observed weld interface hardness value nearly close to the parent material hardness value but both sides of the weld region hardness value is higher than the parent material value. The peak hardness of friction welded joints increase with the increase in forging pressure and mechanical properties of parent materials. Fig. 6 shows the variations of vickers micro hardness values through the graphs micro hardness (HV) x distance across the weld interface (mm) for similar joints of AA 2024.

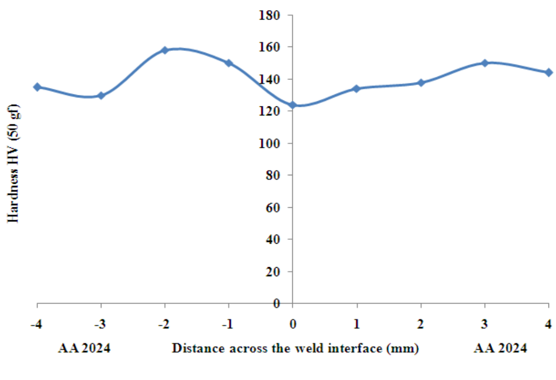


Fig. 6 Microhardness at the weld interface

Conclusions

In the present study, similar joints of aluminium alloys (AA 2024 & AA 2024) were welded successfully. The welding process was investigated by tensile testing, SEM fractograph analysis, micro structure analysis , macro structure analysis and vickers micro hardness test observations with the following results.

1) Similar joints of AA 2024 tensile strength were found. It is lesser than the base metal of aluminium alloy 2024.

2) Similar joints of AA 2024 yielded are low when compared to base metal of aluminium alloy 2024.

3) It is observed from the microstructure test that fully deformed zone grain size is fine than the rest of three zones namely partly deformed zone, heat affected zone and undeformed zone. Further, it is noted that undeformed zone grain size is almost equal to the parent metal grain size.

4) From the macrostructure test, it is observed that equal deformation was observed.

5) The micro hardness test revealed that the hardness of the similar welded joints was found. Weld interface hardness value very close to the base metal of AA 2024.

The results of this study have fundamental importance for the understanding and comprehension of the main characteristics of friction welding process, the bonding mechanisms between similar joints and the feasibility of applying this process in the production of structural joints that will be used in aerospace industry.

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