

# Experimental Study on Dissimilar Friction Stir welding of Aluminium Alloys (5083-H111 and 6082-T6) to investigate the mechanical properties

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**Abstract.** Friction stir welding is an innovative technology in the joining realm of metals and alloys. This technique is highly economical and suitable especially for non ferrous alloys compared to ferrous alloys. It finds many applications in various fields of aeronautics, automobile, ship building industries etc. The paper presents the comparative results of mechanical properties such as tensile strength, microstructure, macro structure and hardness on the similar and dissimilar aluminum alloys AA5083-H111 and AA6082-T6 under certain selected variables - constant tool rotational speed, its tilt angle, welding speed using friction stir welding process. It is observed from the experimental results that joint efficiency of dissimilar aluminium alloys is higher than the similar aluminum alloys.

## 1. Introduction

Scientist Wayne Thomas from “The Welding Institute (TWI)” of Cambridge University, England introduced the concept of Friction Stir Welding (FSW) in the year 1991. In this joining technique a non consumable tool (with a shoulder and specific tool pin profile), is rotated between the abutting faces of the materials to be joined. The joint is produced by means of frictional heat generated between tool and work material. In this process the design and selection of FSW tool pin profile is vital to produce weld joints with higher mechanical properties. Many researchers are indeed thought of the best design for tool pin profile in their investigations to boost up the tensile strength and other important parameters of the weld joint. Based on the literature survey, it is understood that the friction stir welding of various non ferrous alloys are being done with different profiles such as cylindrical, threaded cylindrical, taper cylindrical, triangular, square, pentagonal, hexagonal etc. Moreover the selection of material for FSW tool is also an important criterion to avoid the breakage of tool while in operation. Referring to the previous works, many researchers have selected high speed steel, high carbon and high chromium steels etc. by considering a variety of factors like rotational speed, feed/traverse speed, load, and tool tilt angles which have a major impact on joint strength. This FSW process is a solid state welding process where in metal is not actually melted but the joint is formed due to frictional heat generated between work piece and tool thereby reducing major defects such as cracks, blow holes, porosity unlike in fusion welding. FSW finds various applications in diverse sectors of industry, body shop, marine, rail and road vehicles, and containers for nuclear applications. Further many research investigations revealed that this FSW process successfully welded ductile and low melting metal alloys.



## 2. Literature Review

V. Saravanan et al [1] investigated the effects of diameter ratios of pin (d) and shoulder (D) on mechanical properties, microstructure of welding dissimilar alloys AA2024-T6 and AA7075-T6. They concluded that the D/d ratio of 3 exhibited superior tensile behaviour. P. Mastanaiah et al [2] examined that at high tool rotational speed and low welding speed the proper stirring of the two dissimilar aluminium alloys 2219 and 5083 without defects are observed in the weld nugget region with 97 percent efficiency in the welded joint. K. K. Ramachandran et al [3] asserted that tool angle factor ( $0.5^{\circ}$ – $2.5^{\circ}$ ) does not have influence on the ultimate tensile strength of the friction stir welded joint AA5052 aluminum alloy and high speed steel low alloy steel. Thirty one experiments based on design of experiments at five levels and four welding factors using Central Composite design with response surface methodology is conducted. It is found that the ultimate tensile strength is influenced by too rpm, feed and axial load. A Simar et al [4] investigated that joints produced from the dissimilar friction stir welding has high tensile strength when compared to similar joints since the high heat generation in the similar friction stir welding poses serious problem for the tensile strength. Masoud Ahmadnia et al [5] in their paper, discussed about the optimization of mechanical properties in two stages using 6061 and 5010 aluminum alloys using response surface methodology and central composite design technique. The first stage results showed that straight square tool profile yields better tensile strength, hardness and elongation than the cylindrical and triangular tool profiles. In the second stage effects of the tool speed, welding speed and plunge depth on the mechanical properties of welded joints are studied.

Infante et al [6] investigated the fatigue analysis of dissimilar aluminum welds formed by friction stir welding; the alloys tested were AA6082-T6 (2 mm thick) and AA5754-H111 (2 mm thick). The observations made were, shallow S-N curve with AA6082 and AA5754 compared to similar AA6082. Further they understood that fatigue performance increased with lower stress choices. S. M. Bayazid et al [7] applied optimization technique using Taguchi and ANOVA methods on dissimilar friction stir welded aluminum alloys 6063-7075 and produced better tensile strength of 143.59 MPa at tool rotational speed of 1600 rpm and welding speed of 120 mm/min. S. Ravikumar et al [8] analyzed the tensile strength and yield strength of dissimilar friction stir welded aluminium alloys 7075 and 6061 through examining the micrographs from the scanning electron microscope and EDAX method using three different types of tool profiles. The results indicated that the joints produced from threaded taper cylindrical tool at tool rotational speed of 900 rpm and welding speed of 100 mm/min has better strength due to the thorough metallic materials mixing. Further derived that the presence of tunnel defect is common in all the tool pin profiles and remarked a marginal increase in axial force will avoid the tunnel defect. H. Jamshidi Aval et al [9] investigated that tool geometry has plays a vital role on tensile strength, elongation, yield strength and hardness of the welded joint fabricated using two different aluminium alloys 5086–6061. They found that concave shoulder tool consisting of conical probe engraved with three grooves produced better results when compared with other tools. Gurvir Singh Suri et al [10] analyzed the micro hardness of the components fabricated using dissimilar friction stir welding aluminum alloys 6061 and 6082 by applying different range of speeds, feeds and tool pin profile using Taguchi L9 orthogonal array. The results tabulated show average hardness value at nugget zone is lower than that of base alloy.

From the above literature review, it is clearly understood that partial contributions were made towards FSW process applied to dissimilar alloys. And very minimal comparative studies are made in specific to dissimilar FSW of AA5083-H111 and AA6082-T6, under constant selected process parameters. Further the researchers have contributed their work in this area mainly on optimizing the process parameters to get the better mechanical properties and less research focus is made with respect to the 5xxx and 6xxx series. In this paper, the authors made an attempt towards the comparative study of mechanical properties on two different friction stir welded aluminium alloys AA5083- H111 and

AA6082-T6 which finds wide applications in shipbuilding, construction and other fabrication industries.

### 3. Experimental Work

The alloys selected (AA 5083, AA 6082) for the comparison are due to the fact that, AA 5083 is known for its extraordinary performance in acute chemical industry and resistant to salt water and AA 6082, structural alloy possessing high resistance to corrosion with highest strength of the 6000 series. The friction stir welding is carried out on the selected alloys to determine and compare the mechanical properties under constant process parameters. The specimens of AA5083- H111 and AA6082-T6, 140x70x4 mm size are selected for the experimental work. The tables 1, 2 display the chemical composition and mechanical properties of the selected alloys.

**Table 1.** Chemical Composition of the Aluminum alloys

Material	Cu	Mg	Fe	Zn	Cr	Mn	Ti	Si	Al
AA5083-H111	0.07	4.7	0.37	0.09	0.09	0.59	0.04	0.28	Remaining
AA6082-T6	0.02	0.98	0.21	0.03	0.12	0.56	0.03	1.01	Remaining

**Table 2.** Tensile Properties of the Selected Materials

Material	UTS	YTS	Percentage Elongation
AA5083 -H111	308 MPa	273 MPa	16
AA6082 -T6	293.21MPa	251.89 MPa	8.12

The similar-dissimilar alloys are joined in six trials in the order of similar alloys 5xxx-5xxx, 6xxx-6xxx and dissimilar alloys of 5xxx-6xxx series of each 2 trails are conducted and total six joints are fabricated as shown in Figure 1.



**Figure 1.** Fabricated Similar & Dissimilar Aluminum Alloys



**Figure 2.** Taper Square Tool

For all the trials, process parameters selected and kept constant, and the values of the parameters are 1200 rpm (tool speed), 63 mm/min (tool feed) and 1° (tool tilt angle). All the joints are fabricated using taper square (TS) tool pin profile in order to obtain highest tensile strength [11, 12]. The taper square tool pin profile is made of high speed steel with nickel coating and hardened for 60HRC. The designed tool is having a flat face shoulder with concentric grooves (at bottom) of 1mm depth and 2mm width which substitutes the effect of concavity. The concavity in the shoulder will direct the flow of material into the pin area thereby avoiding the escape of plasticized material [13]. The TS tool has 18mm diameter of the shoulder, 3.6 mm pin length of and 4mm width of the pin. The photographic view of the TS tool is shown in Figure 2.

The experimental work is carried out on Vertical Milling machine and to acquire superior tensile properties, it is preferred to clamp the higher tensile strength material (AA5083) towards retreating side and lower tensile strength material towards advancing side (AA6082). The alloys clamping and joining process is shown in Figure 3.



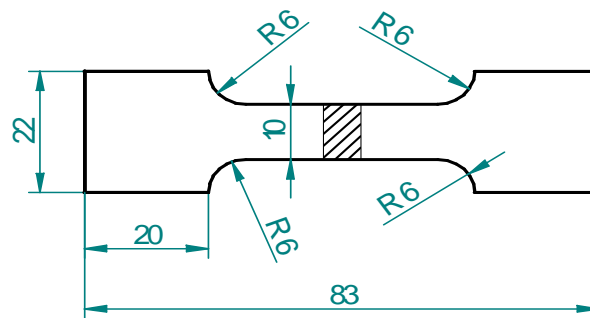
**Figure 3.** Material Clamping and FSW process

#### **4. Results and Discussions**

Two different aluminium alloys were successfully weld joined using FSW. Further to investigate the various tensile natures of the welded components different mechanical tests were conducted.

##### *4.1 Tensile Strength*

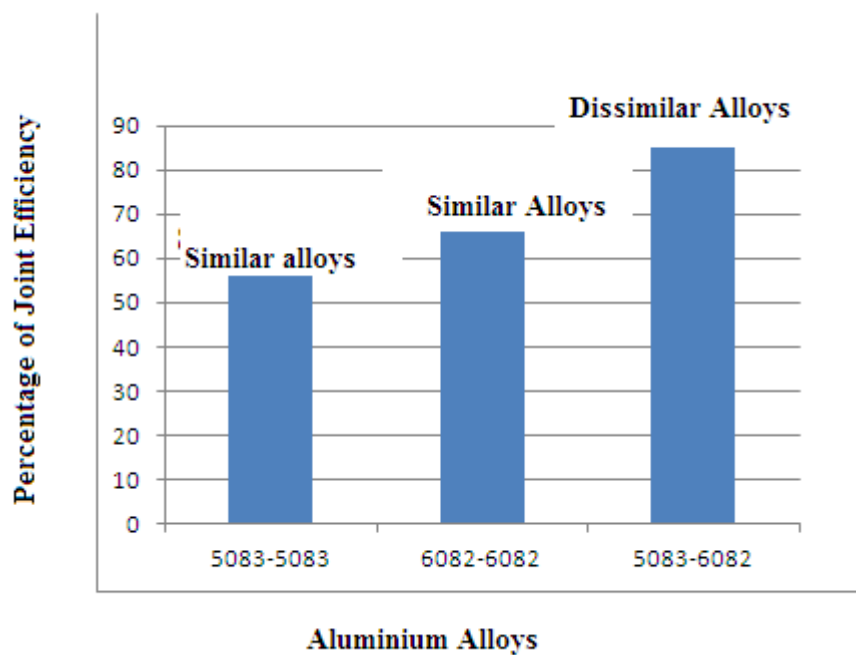
The specimens are cut in transverse to the welding direction as per the ASTM standards and it is shown Figure 4. The Universal Testing Machine (UTM) of 400 KN capacity has been used to conduct tensile and results are tabulated (Table 3). The comparison graph of joint efficiencies between similar and dissimilar aluminum alloys are plotted as shown in the Figure 5.



**Figure 4.** Tensile Specimen ( all dimensions are in mm)

**Table 3.** Tensile Strength Results

Material Combination	Aluminum Alloy	Average Tensile strength (MPa)	Average Yield Stress (MPa)	Average% Elongation	Joint Efficiency
Similar	5083-5083	173.43	138.27	8.9	56%
Similar	6082-6082	195.17	168.6	5.94	66%
Dissimilar	5083-6082	157.54	112.11	4	85%



**Figure 5.** Comparison of Joint Efficiency



#### 4.2 Inference

From the Figure 5, it is observed that the joint efficiency of 5083 – 6082 alloy is 85% which is the maximum value comparatively. The other efficiencies are 5083-5083 is having 56% and 6082-6082 is at 66%. From the result it is clearly evident that the dissimilar alloy is definitely possessing higher joint efficiency in comparison to similar alloys.

#### 4.3 Macrostructure

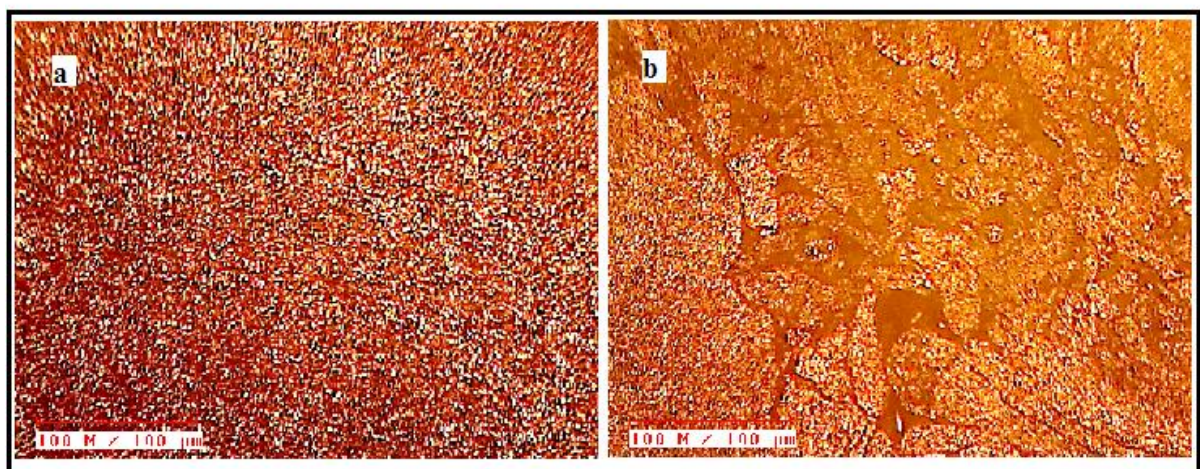
The macro structural examinations of all the test specimen alloys showed that the cross section of the parent metal and heat affected zone has complete fusion and free from defects.

#### 4.4 Microstructure

The micro structure studies were conducted with optical microscope, magnification of 100X and etchant Hydrofluoric acid solution. The observations revealed as follows,

- The Nugget Zone shows fine fragmented particles of eutectic constituents in primary alpha aluminium solid solution.
- Nugget – parent interface shows TMT zone and the material attained super plasticity due to which grains have oriented along the direction of the tool.
- Further, Heat affected Zone shows the precipitates which dissolved due to heat, re precipitated as large cluster particles.
- The heat affected zone shows large grains and the nugget zone showed finer due to fragmentations.

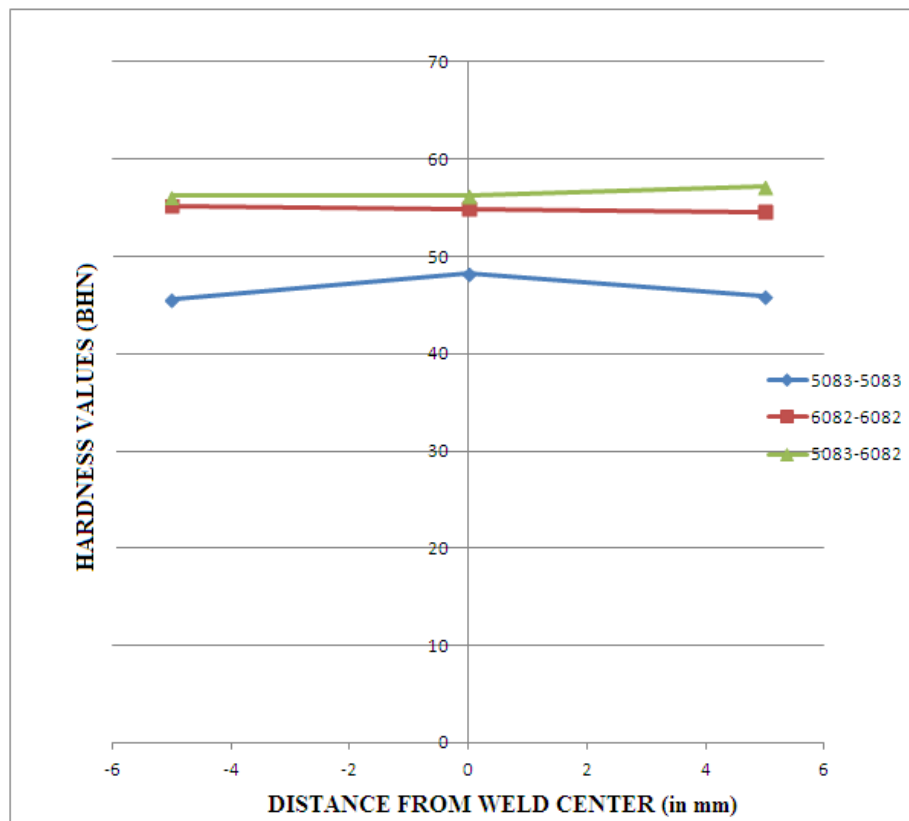
The micro structure of dissimilar aluminum alloy AA5083-H111 and AA6082-T6 is shown in Figure 6.



**Figure 6.** Microstructure of AA5083-H111 and AA6082-T6 (a) Nugget zone (b) Heat Affected Zone and Nugget Interface

#### 4.5 Hardness

The hardness test is conducted using Brinell Hardness Tester with diamond indenter under applied load of 5Kgs and dwell time of 10 seconds. The results are plotted from the weld center to parent metal side. It is observed from the graph that higher hardness of 56.3 BHN is obtained at the weld nugget zone of dissimilar friction stir welding 5083-6082 aluminum alloys compared to the similar friction stir welding alloys. The hardness survey graph is shown in Figure7.



**Figure 7.** Hardness Survey Graph

#### 5. Conclusion

The comparative study with respect to mechanical properties is made on dissimilar and similar friction stir welded of aluminum alloys AA5083-H111 and AA6082-T6, which commonly finds application in shipbuilding, construction and automotive industries. It is concluded that efficiency of the welded joint, hardness of dissimilar alloys tested is superior to the similar aluminum alloys (5083-6082). The morphology of welded work pieces have shown good fusion of inter metallic compounds without any defects.

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