Study and Analysis of the Fatigue Behaviour of Friction Stir Butt Welded Dissimilar Aluminium Alloys

G C Rajesh ME[1], Jithin M [2]

[1] Assistant Professor, Department of Mechanical Engineering,
Sree Venkateswara Hi-Tech Engineering College, Tamilnadu, India.
[2] Student, Department Of Mechanical Engineering,
Sree Venkateswara Hi-Tech Engineering College,Tamilnadu, India

---***---

Abstract - *To get an efficient, competitive, safe and sustainable public transport system, one of the key strategies are building lightweight structures. Fuel consumption is significantly reduced due to this weight saving and CO_2 emission per passenger-kilometer also reduced. Friction Stir Welding (FSW) is a solid state process enabling to develop a good weld for lightweight metallic materials. This study was conducted to improve the life cycle costs of the under frame of a passenger vehicle. The major objective of the research was to study about the tensile strength, the fatigue behaviour of dissimilar welded joints and microstructure analysis based on two different aluminium alloys AA6082 and AA5754. Fatigue tests performed on dissimilar joints show low tensile strength and low fatigue strength when compared with base materials AA5754 and AA6082, but comparable with the tensile and fatigue strength of AA5754. The fatigue performance of AA6082 and AA5754 FSW welded joints suggests a shallower S–N curve with an improvement in fatigue performance for lower applied stress ranges.*

Key Words: **Friction stir welding, Dissimilar aluminium joints, Fatigue.**

1. INTRODUCTION

The successful development of new welding processes and the good results shown by their applications in light alloys led to an increasing interest on these new technologies. Friction Stir Welding (FSW) is perhaps the most remarkable and potentially useful new welding technique to be introduced in the recent past.

FSW is a solid-state joining process developed and patented by The Welding Institute (TWI) in 1991. It is a major breakthrough in the metal joining technology field, since it allows welding materials that are hard or even impossible to be welded by common arc-welding methods with good mechanical properties.

FSW is a mechanical process delivering high quality assurance when technological conditions are correctly set-up. Because all the processing takes place in visco-plastic solid phase, all the problems related with solidification of a conventional weld bead are avoided. It is clean, ecological, does not depend on operator skills and produces weld seams of the highest quality. It offers further advantage of being suitable for joining dissimilar metallic materials that were previously extreme difficult by fusion methods without voids, cracking and excessive softening of Heat Affected Zone. Since the passenger vehicle components are subjected to dynamic or cyclic stresses in service, the fatigue properties of the friction stir welded joints must be properly evaluated to ensure the safety.

The two main joint configurations used in FSW are: butt and lap joints. Butt joints are widely used in assemblies of parts in public transport system. Therefore this paper deals with the mechanical properties and fatigue behaviour of FSW dissimilar butt joints. The main objectives of this study were:
-Produce FSW butt joints in dissimilar conditions with different sets of welding parameters.
-Compare the specimen's experimental behaviour when subjected to static loads,
- Obtain S–N curves and determine fatigue life of the specimens made using FSW process.

2. REVIEW OF LITERATURE

From this literature review, it is understood that lot of research work has been carried out on fatigue and fracture behaviour of Aluminium joints, but dissimilar welding with different grades of Aluminium and other alloys is very limited. Hence, an attempt is being proposed in this work to investigate the fatigue behaviour of dissimilar Aluminium alloys.

1. Yeswanth Kumar Y,Aditya Kumar and Rajyalakshmi. In this paper joints properties of friction-stir-welded Al 5083 and Al 6082 alloys were studied with various tool rotating speeds and different tool pin profiles with constant traverse speed (20mm/min). It is observed that the increase in tool rotation speed and the tool axial force result in increase of ultimate tensile strength (UTS) up to a maximum value. Square tool profile achieves higher strength than that of circular tool profile at higher speeds.

2. R.S. Mishra, Z.Y. Ma. In this review article, the current state of understanding and development of the FSW and FSP are addressed. Compared to the traditional fusion welding, friction stir welding exhibits a considerable improvement in

strength, ductility and fatigue and fracture toughness. Moreover, 80% of yield stress of the base material has been achieved in friction stir welded aluminium alloys with failure usually occurring within the heat-affected region, whereas overmatch has been observed for friction stir welded steel with failure location in the base material.

3. M.Gutensohn, G.Wagner, F.Walther, D. Eifler. In their paper, the fatigue properties of AA5454-FSW-joints will be discussed. On the basis of local temperature measurements it was found that the fatigue behaviour is locally different in the welding zone. Fatigue failure can be reliably detected in a very early fatigue state after 30 % N_f, while no significant change in plastic strain amplitude can be observed.

4. *P.* Cavaliere, A. Squillace, F. Panella. In this paper the effect of welding speed (with advancing speed in the range 40–460mm/min) on the mechanical and micro structural properties of AA6082 was studied. A strong variation in the nugget mean grain size was observed by increasing the advancing speed from 40 to 165mm/min up to a plateau corresponding to no further variations by increasing the speed up to 460 mm/min. The yield strength was recorded to increase strongly from the lower speeds to115mm/min and after it starts to decrease by increasing the advancing speed. The ductility of the material followed the same behaviour but restarted to increase after 165 mm/min. The material welded with the advancing speed of 115mm/min exhibited the best fatigue properties and the higher fatigue limit and the SEM observations of the fatigue specimens showed that at higher stress amplitude levels the cracks initiate at the surface of the welds.

3. PROBLEM DEFINITION

Even though the fatigue properties of the weld metal is good, problems can be caused when there is an abrupt change in section caused by excess weld reinforcement, undercut, slag inclusion and lack of penetration and nearly 70% of fatigue cracking occurs in the welded joints. Apart from the mechanical considerations of joint design, the welding process, filler material, heat input, number of weld passes etc., will influence the microstructure of the weld at the joint and in turn will influence the extent of heat affected zone and residual stresses that will build up in the base metal. These factors will invariably affect the fatigue strength by increasing the propensity for crack nucleation and its early growth causing the ultimate failure of the joint. From the literature review, it is understood that enormous research work has been carried out on fatigue and fracture behaviour of Aluminium joints, but the reported literatures on dissimilar welding with different grades of Aluminium and other alloys is very limited. Hence, an attempt is being proposed in this work to investigate the fatigue and fracture behaviour of dissimilar Aluminium alloys.

4. OBJECTIVE

The major objective is to study about the tensile strength and the fatigue behaviour of dissimilar welded joints based on two different aluminium alloys: Aluminium alloys AA 5754 and AA6082. Here the experimental results obtained in two different structures: AA6082-T6 5 mm and AA5754-H111 5 mm thick joints. Fatigue tests were carried out on butt joints specimens with constant amplitude loading with a stress ratio R = 0.1

5. EXPERIMENTAL PROCEDURE

5.1 Material Selection And Friction Stir Welding Conditions.

The materials used in this study were 5 mm thick AA5754 andAA6082 aluminium alloys. The materials and conditions were selected according to the application. The mechanical properties of the two aluminium alloys are presented in the Table below.

Table -1: Mechanical properties of AA5754 and AA6082 aluminium alloys

Material	Yield strength(MPa)	Ultimate Tensile strength (MPa)	Elongation (%)
AA5754	>80	190-240	16
AA6082	>260	>310	7

Dissimilar butt joints of AA5754–AA6082 were produced by friction stir welding and the effect of the welding parameters was investigated. The FSW tool is composed by three main components: body, shoulder and probe (Fig. 1). The tool selected is of a cylindrical threaded type. It has a probe with a 5 mm base diameter with a thread.

Fig.1 FSW Tool Used

Here we converted the conventional vertical milling machine to a mini workstation for FSW. We made a FSW tool according to the thickness of work pieces.

Table 2 shows the FSW parameters and controls used to perform all the welds. Vertical downward force control was used to carry out the welding process. Among the FSW parameters only three parameters were varied: vertical force, tool travel speed and tool rotational speed. These three parameters control the welded seam quality for a given tool geometry and clamping system.

TABLE 2. Generic FSW parameters

FSW CONTROL	VERTICAL FORCE
Rotation direction	ccw
Plunger speed	0.1mm/s
Dwell time	3s
Tilt angle	0.5^0

To remove oxide layers, the plates were grinded on contact surfaces having been removed about 50 µm of material. The plates were welded in a butt joint configuration and thereafter machined to fabricate the specimens. The specimens geometry used in monotonic and fatigue tests are shown in Fig. 2.

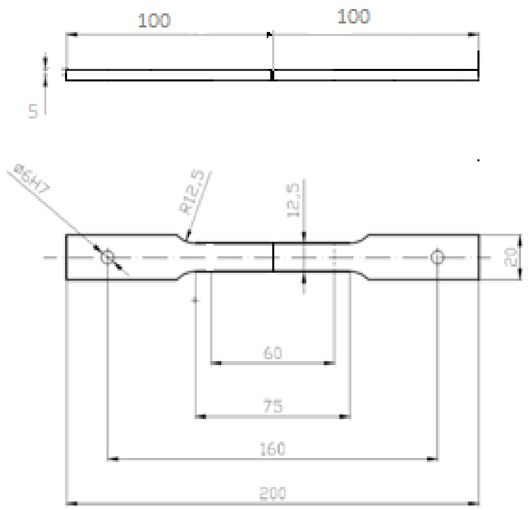

Fig.2 Specimen geometry

To get optimal welding parameter the range of the vertical force, the tool travel speed and the tool rotation speed were selected in between 4000–5500 N, 50–120 mm/min and 800–1200 rpm, respectively. The welding parameters used to weld the dissimilar AA5754–AA6082 joints are shown in Table 3.

Table 3. FSW variable parameters used to weld AA5754–AA6082 joints.

Sample	Vertical force (N)	Tool travel speed (mm/min)	Tool rotation speed (rpm)
dissimilar	4900	120	800

Table 4. FSW variable parameters used to weld AA6082-AA6082 joints

Sample number	Vertical force (N)	Tool travel speed (mm/min)	Tool rotation speed (rpm)
Similar	5000	50	800

In order to select the optimal welding parameters a set of FSW joints were produced by adjusting the vertical force, the tool travel speed and the tool rotation speed in the range of 4000–5500 N, 50–120 mm/min and 800–1000 rpm, respectively. Tables 3 and 4 present the welding parameters used to weld the dissimilar AA5754– AA6082 joints and the similar AA6082–AA6082 joints, respectively. These FSW variable parameters were selected according to the good weld condition [2].

5.2 Tensile Tests

To assess the tensile strength tests were carried out under tensile load on UTM (Universal Testing Machine). Properties that are directly measured by tensile test are ultimate tensile strength, maximum elongation and reduction in area. In this paper we compare the tensile strength of similar and dissimilar weld with the tensile strength of base material. Along with this compare the stress-strain curves of the same.

5.3 Fatigue Tests

In order to assess the dynamic behaviour of the FSW specimens fatigue tests were carried out under sinusoidal axial tensile constant amplitude loading in a ±250 kN capacity servo-hydraulic fatigue test machine and a stress ratio was set to R = 0.1.

Butt joints were produced with 5 mm thick plates. The nominal stress was calculated as force transmitted by the remote section. The stopping criterion considered was the complete failure of the specimens or 5×10^6 cycles.

6. RESULT AND DISCUSSION

6.1 Tensile Data

Tensile test specimens of base materials AA6082, AA5754, similar weld AA6082 and dissimilar weld prepared according to ASTM E8 and along with these collected all relevant data for base materials. All the specimens were tested in UTM. Test results were shown below and the stress-strain curves were plotted.

TABLE 5. Tensile Strength for Tested Specimens

Base material AA6082	300MPa
Base material AA5754	198MPa
Similar weld AA6082	243MPa
Dissimilar weld AA6082-AA5754	181MPa

Tensile strength of the dissimilar weld is found to be 181MPa and is comparable with the strength of base material AA5754.

Tensile strength of similar weld posses 81% of AA6082 base materials tensile strength.

Stress strain curve of test specimens were plotted below.

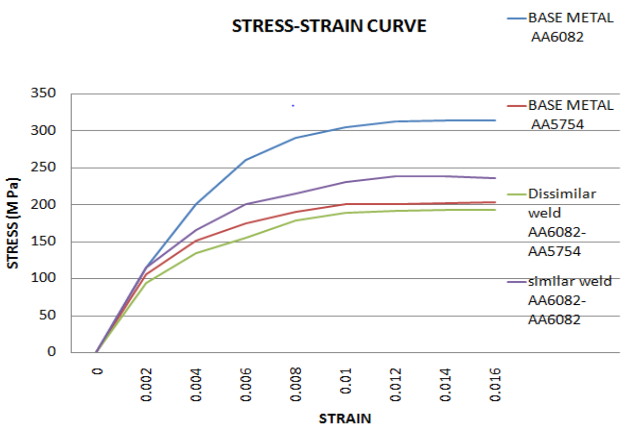

Chart-1 Stress-strain curve for similar and dissimilar joints.

It is found that the dissimilar weld has a lower strength compared with similar AA6082 butt joint. But its tensile strength is comparable with AA5754 base material as AA5754 base material has lower tensile strength.

6.2 Fatigue Data

S–N curves were plotted for the dissimilar AA5754–AA6082 and similar AA6082–AA6082 butt joints. For comparison purposes, Table 5 and Fig.10 also include data for AA6082-T6 base material as well as AA5754 base material [9]. The mean S–N lines were obtained by fitting a linear regression Eq. (1), assuming r as the independent variable. The results are presented in Table 6 and the S–N curves in Fig.9.

$$N_r \sigma^m = K_0 \quad (1)$$

TABLE 6. m and K_0 values for all S–N curves presented.

Condition	m	K_0	Fatigue strength at 2×10^6 cycles (MPa)
BM AA5754	7.576	9.33×10^{18}	47
BM AA6082	9.901	3.55×10^{28}	177
FSW butt AA6082-AA6082	8.333	3.75×10^{22}	90
FSW butt AA5754–A6082	5.464	1.03×10^{14}	26

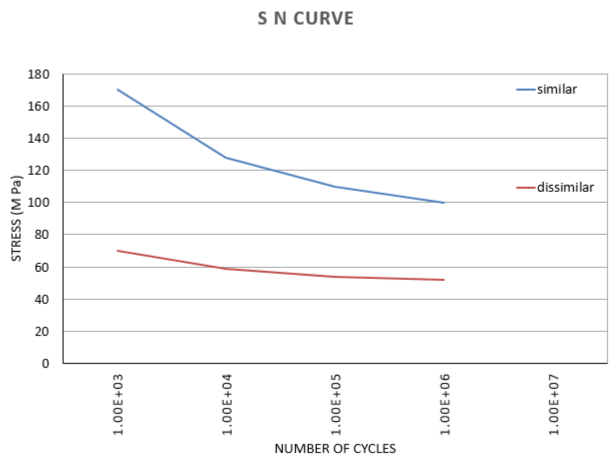

Chart-2 S–N curves at R = 0.1 for dissimilar and similar joints.

This graph shows the variation of S N curve of similar and dissimilar weld. We get a clear picture about the difference in stress versus number of cycles for these different types of welds.

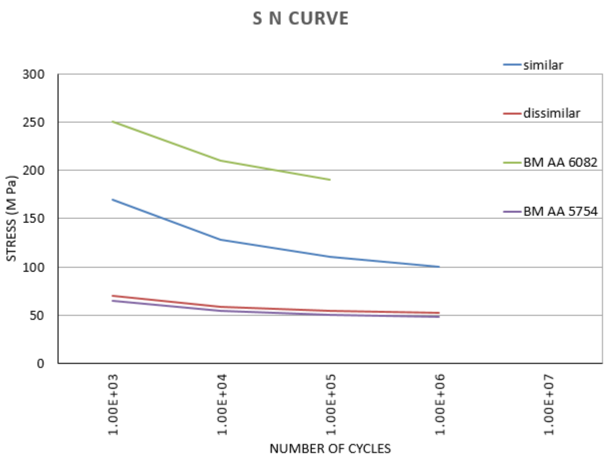

Chart-3 S–N curves at R = 0.1 for butt joints tested along with base materials AA6082, A5754.

Eq. (1) does not take into account the ''infinite'' life specimens. From chart-3 and Table 6 it is observed that dissimilar joints present a lower fatigue than similar AA6082 butt joints. This difference is justifiable when comparing the fatigue life of base material AA6082 and AA5754 as AA5754 base material has considerable lower fatigue strength. I t is found that the friction stir welding process of butt joint configuration causes a reduction in fatigue life.

3. CONCLUSIONS

Fatigue tests performed on similar and dissimilar lap joints show low fatigue strength in comparison with base materialsAA5754 and AA6082. The lower fatigue strength in this joint configuration may be related to the presence of a ''hook'' defect.

Dissimilar AA5754–AA6082 butt joints show lower fatigue strength than AA6082 similar joints, justifiable by the lower fatigue strength of the AA5754 base material. The fatigue performance of AA6082 and AA5754 FS welded joints suggests a shallower S–N curve than for the similar AA6082 FS welded joints which suggest that for lower stress levels the dissimilar joints may have similar fatigue strength.

REFERENCES

[1] Yeswanth Kumar Y,Aditya Kumarand Rajyalakshmi. Optimization of process parameters during Friction Stir Welding of Aluminium 5083 & 6082Alloys. 4144 | International Journal of Current Engineering and Technology, Vol.4, No.6 (Dec 2014)

[2] V. Infante, D.F.O. Braga, F. Duarte, P.M.G. Moreira, M. de Freitas, P.M.S.T. de Castro. Study of the fatigue behaviour of dissimilar aluminium joints produced by friction stir welding. International Journal of Fatigue xxx (2015) xxx–xxx.

[3] R.S.Mishra, Z.Y. Ma.Friction stir welding and processing. Materials Science and Engineering R 50 (2005) 1–78.

[4] Gutensohn, G. Wagner, F. Walther, D. Eifler. The fatigue behaviour of friction stir welded aluminium joints.Welding in the World, Vol. 52, n° 9/10, 2008 – Research Supplement.

[5] P. Cavalierea, A. Squillace, F. Panella. Effect of welding parameters on mechanical and microstructural properties of AA6082 joints produced by friction stir welding, journal of materials processing technology 200(2008) 364–372.

[6] Garware M, Kridli G, Mallick P. Tensile and fatigue behavior of friction-stirwelded tailor-welded blank of aluminum alloy 5754. JMaterEngPerform2010;19(8):1161–71.

[7] Vidal C, Infante V. Optimization of FS welding parameters for improvingmechanical behavior of AA2024-T351 joints based on Taguchi method. J MaterEng Perform 2013;22(8):2261–70.

[8] Papadopoulos M, Tavares SMO, Pacchione M, Pantelakis S. Mechanical behaviour of AA 2024 friction stir overlap welds. Int J Struct Integr 2013;4(1):108–20.

[9] Moreira PMGP, Richter-Trummer V, de Castro PMST. Fatigue Behaviour of FS,LB and MIG Welds of AA6061-T6 and AA6082-T6. In: Sih GCM, editor. Multiscale fatigue crackinitiation and propagation of engineering materials:Structural integrity and microstructural worthiness. Springer; 2008. p.85–111.

[10] Garware M, Kridli G, Mallick P. Tensile and fatigue behavior of friction-stirwelded tailor-welded blank of aluminum alloy 5754. Mater Eng Perform 2010;19(8):1161–71.