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Low Cycle Fatigue Strength Analysis of AA7075-T6 and A384.0-T6 Friction Stir Welded Aluminium Alloys of Butt Joint

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Abstract: Friction Stir Welding (FSW) is the fumeless solid state welding technique. In which the materials are joined by placing nearby with tightly clamped and a rotating tool was inserted with longitudinal feed and an axial load. Due to the stirring action, the metals plastically deformed and joined together. In this research the base metals are AA7075-T6 and A384.0-T6 aluminium alloys of 6.35 mm thickness butt joints. A design matrix was developed by using MINITAB-17 Software and the FSW was carried out in a friction stir welding machine. By using the FSW specimens, the Ultimate Tensile Strength (UTS) was conducted and find out the lowest UTS specimen to do fatigue test. The fatigue strength of the base metals of AA 7075-T6, A384.0-T6 and the same combinations of lowest UTS, FSW specimens are tested and analysed in low cycle fatigue strengths of $<10^5$ cycles.

Key words: Friction stir welding, base metals, ultimate tensile strength, low cycle fatigue, fatigue strength, design matrix

INTRODUCTION

When repetitive load or cyclic load occurs in any component, a small crack was developed. If the cyclic load was increased, at a stage the component may fail that load is called fatigue load (Lee *et al*., 2005). It is estimated that the 90% of the component failures occurs at a values of below the yield stress of that component. Cavaliere *et al*. (2005) conducted a cyclic fatigue test in the axial direction with R = 0.1, where "R" is the stress ratio ($\sigma_{min}/\sigma_{max}$). In the study of fatigue test research, the conclusion was the fatigue life is increased in the high cycle regime respect to the FSW 2024-T3 joints and a decrease in fatigue life respect to FSW 7075-T6 ones. Minak *et al*. (2010) investigate the fatigue resistance of FSW joints on as-cast particulate reinforced aluminium based composite (AA6061/22 vol.%/Al_2O_3p). In their research their conclusion was the parameters used to produce the joints with similar microstructure and comparable fatigue behavior. Hassanifard *et al*. (2014) investigates the effectof cold expansion on the improvement of fatigue life of friction stir spot welding joints in AA 7075-T6 plates and concludes the fatigue life of FSSW joints in all load ranges in high cycle regimes improve the fatigue life up to 6 times. D'Urso *et al*. (2014) studied the fatigue behavior of crack growth tests performed according to ASTM-E647 standard on CT specimens with propagation in the middle of joint along the weld nugget. The results show the influence of welding process parameters on mechanical properties and fatigue behavior.

In the fatigue failure, the three basic factors are important. They are the large number of cycles, maximum tensile stress and the fluctuation in the applied load. There are in general three types of fluctuating stresses. They are fully reversed stress cycle, the repeated stress cycleand the random or irregular stress cycle. The fluctuating stress is made up of mean stress or steady stress and an alternating stress or variable stress.

In the fully reversed stress cycle the maximum stress (σ_{max}) and the minimum stress (σ_{min}) are equal which was shown in Fig. 1. In Fig. 1 also shows σ_a is an alternating or variable stress. σ_r or $\sigma_?$ is called the stress range. The stress range is the difference between the maximum

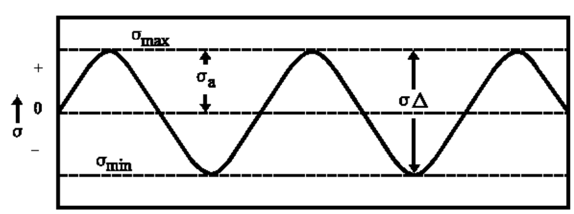

Fig. 1: Fully reversed stress cycle (Campbell, 2008)

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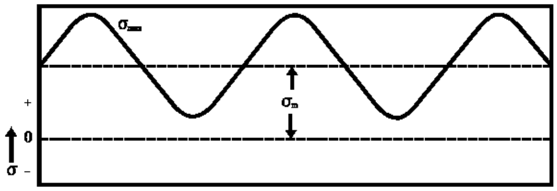

Fig. 2: The repeated stress cycle (Campbell, 2008)

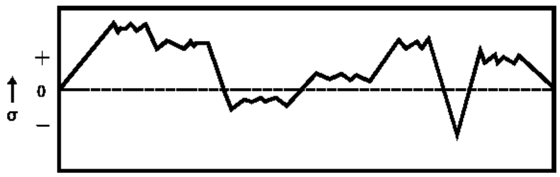

Fig. 3: The Random stress cycle (Campbell, 2008)

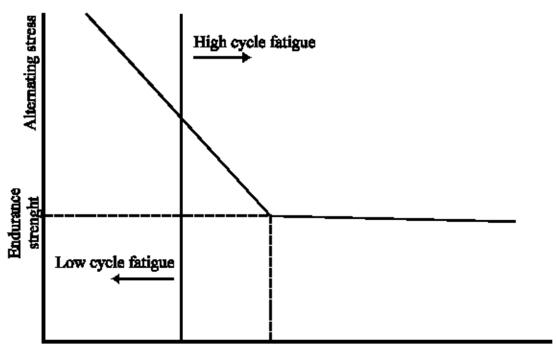

Fig. 4: Low and high cycle fatigue (Agrawal *et al*., 2014)

stress and the minimum stress in a cycle. Symbolically $\sigma_{r=}(\sigma_{max})$-$(\sigma_{min})$. The alternating stress σ_a is having the half of the stress range. Symbolically it is $\sigma_{a=}\sigma_r/2$.

In the repeated stress cycle the mean stress is applied on the top of the maximum stress and the minimum stress. In this cycle the maximum stress and the minimum stress may not be in equal. The mean stress (σ_m) is the average of the maximum stress and the minimum stress. Symbolically it is $\sigma_m = [(\sigma_{max})+(\sigma_{min})]/2$. It was shown in Fig. 2.

In the random stress cycle or the irregular stress cycle the part or the component is fully subjected to the random loads in its service or the functions. The random stress cycle was shown in Fig. 3.

According to the number of cycles the fatigue was classified into high cycle fatigue and low cycle fatigue. If the number of cycles (N) is more than 10^5 cycles, it is called high cycle fatigue. If the number of cycles (N) is less than 10^5 cycles, it is called low cycle fatigue. It was diagrammatically shown in Fig. 4. For aluminium alloys the high cycle fatigue conducted was usually 5×10^8 cycles.

One of the most effective methods of improving fatigue life is to induce residual compressive stresses on the surface of the part. Due to the number of cycles to failure at a specified stress level is called the fatigue life of the component. Whereas the fatigue strength or the endurance limit is the stress below which failure does not occurs. When the applied stress is reduced, the number of cycles to failure was increased.

MATERIALS AND METHODS

Experimental procedure: The welds prepared for this research was by using the base materials of AA 7075-T6 and A384.0-T6 aluminium alloys of 100×50×6.35 mm thick of butt joint. The welds are done by using a friction stir welding machine. The base materials chemical compositions and mechanical properties are shown in Table 1 and 2, respectively.

The design matrix was developed by using MINITAB-17 Software and the estimated UTS in MPa were tabulated in Table 3. In which the run number-5 shows the lowest UTS this specimen was taken for the fatigue strength analysis.

The specimen made for this fatigue research was flat sheet of 6.35 mmthickness (T) as per ASTM-E606 which is shown in Fig. 5. The prepared specimens was shown in Fig. 6.

The fatigue test was conducted by using a multi axial fatigue testing machine which was shown in Fig. 7. The machine was made by spranktronics, Bangaluru having an axial load capacity of 2 tonnes with dynamic, tension-tension, sine wave, static tensile tests. The torque is +/-100 Nm, angle +/-10°C. The machine is having a servo hydraulics controls with load, torque and angle feed back controls. The specimen used for this machine was a standard dog bone tensile test specimen with thickness range of 2-6 mm. A mechanical wedge gripper for flat and round specimen was attached in the machine which was shown in Fig. 8. For flat specimen the gripper was having a holding capacity of 2-6 mm and for the round shape having a holding capacity of 4-8 mm. In this machine the hydraulic power packs capacity was to drive 2T parallel 2 pumps for 2 actuators.

In this low cycle fatigue research, the applied stress were 80 and 100 MPa in the base metal of A384.0-T6. In the friction stir welded specimen of AA7075-T6 and A384.0-T6 combination, the applied stress was 150 MPa and 180 MPa. Whereas in the base material of AA7075-T6, the applied stress for this research was 250 and 280 Mpa.

Table 1: Chemical compositions of the base metals

Metals/Elements	Mg	Mn	Pb	Zn	Fe	Cu	Si	Cr	Ni	Al
AA 7075-T6	2.29	0.047	0.004	5.44	0.20	1.45	0.071	0.240	0.006	Balance
A 384.0-T6	0.11	0.240	0.540	1.83	0.96	1.54	10.150	0.031	0.099	Balance

Table 2: Mechanical properties of the base metals

Base metals	UTS (MPa)	YS (MPa)	Elongation (%)
AA 7075-T6	581.1	379.8	11.7
A 384.0-T6	102.0	-	1.0

Table 3: The design matrix and the estimated UTS in MPa

	Coded variables			Un coded variables			
	FSW Process parameters			FSW Process parameters			
Run No.	Tool rotational speed (N)	Axial load (F)	Welding speed (S)	Tool rotational speed (N)	Welding speed (S)	Axial load (F)	Estimated UTS in MPa
1	-1	1	-1	680	46	6.8	252.80
2	0	0	0	800	40	8.0	272.96
3	1	-1	-1	920	35	6.8	260.22
4	1	-1	1	920	35	9.2	255.85
5	-1	-1	-1	680	35	6.8	246.33
6	1	1	-1	920	46	6.8	267.80
7	1.682	0	0	1000	40	8.0	261.76
8	-1.682	0	0	600	40	8.0	248.06
9	0	0	-1.682	800	40	6.0	260.60
10	1	1	1	920	46	9.2	277.37
11	0	1.682	0	800	50	8.0	264.02
12	-1	-1	1	680	35	9.2	252.37
13	0	0	1.682	800	40	10.0	271.67
14	-1	1	1	680	46	9.2	260.94
15	0	-1.682	0	800	30	8.0	248.31
16	0	0	0	800	40	8.0	271.00
17	0	0	0	800	40	8.0	271.90
18	0	0	0	800	40	8.0	272.00
19	0	0	0	800	40	8.0	272.10
20	0	0	0	800	40	8.0	271.80

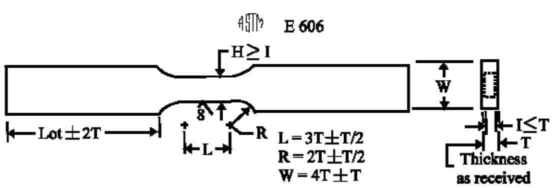

Fig. 5: Flat-sheet fatigue specimen with rectangular cross section; 2.54 mm (0.1 in.)≤I≤T

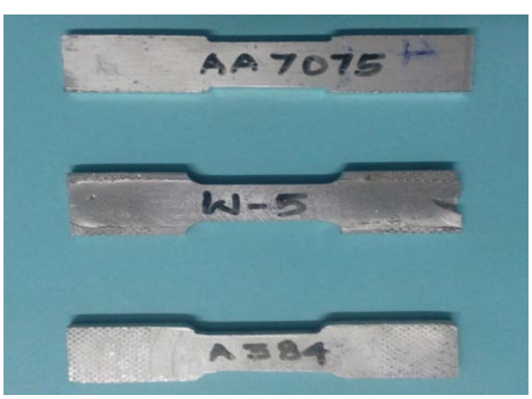

Fig. 6: The prepared specimen as per ASTM-E 606

Fig. 7: Multi axial fatigue testing machine

RESULTS AND DISCUSSION

By using the multi axial fatigue testing machine, the fatigue tests are conducted up to 10,000-12,000 cycles with the plain specimen used at the room temperature. The results are tabulated in Table 4. The cycles vs. stress are made in a semi-log graph and it was shown in Fig. 8 and 9.

Fig. 8: Multi axial fatigue testing machine's mechanical wedge gripper with the specimen in loaded position

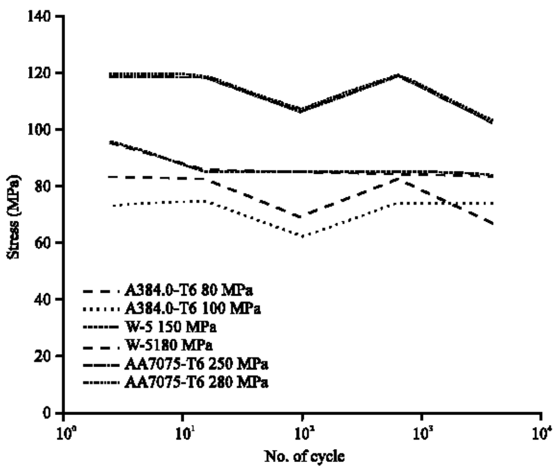

Fig. 9: Cycles vs. stress

Table 4: Cycles vs. stress

No. of cycles	A384.0-T6		Run no.-5		AA7075-T6	
	80 MPa	100 MPa	150 MPa	180 MPa	250 MPa	280 MPa
10^0	72.9	83.1	94.7	95.2	118.7	119.3
10^1	74.2	82.2	85.1	85.7	117.3	118.1
10^2	62.3	69.1	85.5	86.7	106.2	106.9
10^3	73.7	81.5	83.6	84.3	117.7	118.5
10^4	73.7	74.9	83.1	83.5	102.1	103.2

In Table 4 for the same number of cycle in the order of base metal A384.0-T6, AA7075-T6 and A384-0-T6 combination weld run no-5 and the base metal AA7075-T6 aluminium alloys stresses are increased. But when the number of cycles in the same materials and the weld are increased the stresses are not properly reduced. The fatigue tests are conducted <10^5 cycles. So the endurance strength not reached.

From the Fig. 9, the base metal A384.0-T6 aluminium alloy has lower stress and the base metal AA7075-T6 have higher stress. The friction stir welded combination of the aluminium alloys AA7075-T6 and A384.0-T6 stress was in between the base materials.

CONCLUSION

From the above research study of low cycle fatigue strength analysis of AA7075-T6 and A384.0-T6 friction stir welded aluminium alloys of butt joint, the following conclusions were made.

The experimental results are tabulated in Table 4 are obtained by conducting the fatigue test on the specimens made of the base materials AA7075-T6, A384.0-T6 and the dissimilar friction stir welded said aluminium alloys. The fatigue strength is based on the number of cycles applied on the specimens.

For the same number of cycles applied on the specimens, in the order of the base metal A384.0-T6, dissimilar friction stir welded run No.-5 and the base metal AA7075-T6, the experimental stress is increased.

In the low cycle fatigue analysis of the base materials AA7075-T6, A384.0-T6 and the dissimilar friction stir welded said aluminium alloys, if the number of applied cycles are increased the stress is not gradually reduced. The endurance strength of the tested specimens is not able to obtain by conducting the cycles up to 10^4 cycles.

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