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Effect of Tool Profile, Rotational Speeds and Welding Speed on Mechanical Properties and Weld Quality of Friction Stir Welded 6063-T4 Aluminum Alloy

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ABSTRACT

This chapter is focused on friction stir welding of aluminum alloy 6063-T4 which is very useful in shipbuilding, aerospace, robotics and personal computers. In friction stir welding, rotational speed, tool feed rate and tool pin profile plays an important role to get desired weld quality for the softer materials like AA6063-T4. In this experimental research work, friction stir welding is used for a butt joint five mm thick IS: AA6063-T4 using different tool pin profile (cylindrical, threaded cylindrical and triangular), rotational speeds (600, 800 and 1000 rpm) and welding speed (40, 60 and 80 mm/min) and their effect on tensile strength, hardness and weld quality is studied. The results have been evaluated and compared with that original specimen. The data collected during experiments and analyzed using statistical tool. Regression analysis is carried by taking ultimate tensile strength as dependent variable, and rotational speed and welding speed as independent variable. The results show that rotational speed is contributing more as compared to the welding speed. A t-test statistical analysis shows the significant variation in tensile strength and hardness because of selected tool profiles. Also, another t-test analysis shows that there is significant variation in weld quality due to selected variables. The weld joint quality in cylindrical pin tool and threaded cylindrical pin tool are better than that of thr triangular pin tool in all the cases.

Keywords: 6063-T4 Aluminium Alloy; friction stir welding; Regression analysis; tensile properties; t-test

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1. INTRODUCTION

Today, almost industrial sectors are demanding the products having low weight and better efficiency [1]. This demand is fulfilled through replacing traditional materials by various composite materials. Development and manufacturing process of such materials is one of significant and major interest of worldwide researchers and industries. Aluminum alloy 6063-T4 is one of the promising materials useful for shipbuilding, aerospace, transportation, construction industries, robotics and personal computers because of the high strength ratio and good corrosion resistance [1].

Friction Stir Welding (FSW) is a comparatively new solid state metal joining process, but more beneficial in many aspects and found useful for manufacturing components using most of the aluminum alloys. FSW offers various advantages, including less energy consumption, refined homogenous microstructure, improved mechanical properties, reduced residual stress, better weld quality and environment friendly [2, 3]. The working principle of FSW is illustrated by Fig. 1. Rotating FSW tool consists of a shoulder and tool pin made of harder material than that of the workpiece is inserted in the plates to be joined and moving in the welding direction [4]. The heat is generated because of friction between forwarding rotating tool and workpiece leading to plastic deformation and resulted in the desired components joint. The plasticized material is forced to move on the sides and back of the tool as tool propagates along the welding direction.

The rotational speed of FSW tool, welding speed and tool pin profile plays an important role to get desired weld quality. Poor weld quality is resulted in earlier failure of the component and associated problems. Hence, it is always desirable to have good weld quality for long and safe life design [5-7]. Weld quality is significantly measured in terms of Ultimate Tensile Strength (UTS), yield strength, elongation at failure and the hardness of the welded parts. Various researchers in the field are working to get better and better weld quality for different similar and dissimilar metals joining for various thicknesses. They are trying to find optimized rotational speed, welding speed and tool pin profiles which give better weld quality.

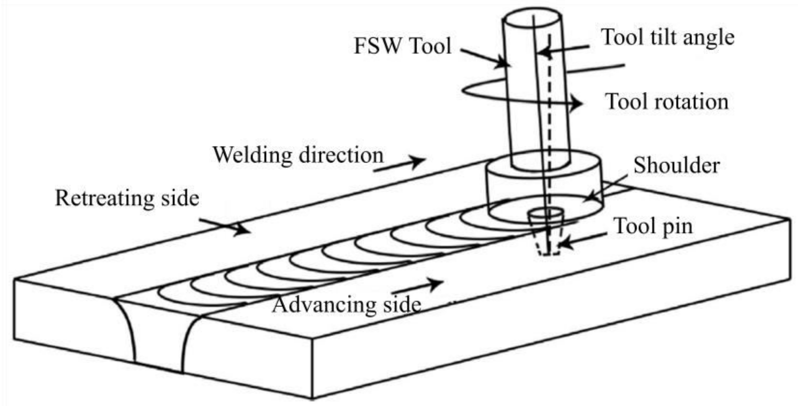


Fig. 1. Principle of friction-stir welding process [4]

FSW mechanical properties of 5 mm thick AA 6063-T6 aluminum alloy, UTS 240 MPa are studied using pentagonal, triangular and the helical threaded tool pin at rotational speed 250 & 500 rpm and welding speed of welding speed of 40 & 80 mm/min and achieved highest UTS of 155 MPa, which is 64.58 % that of the base material [1]. Study of the friction stir welded aluminium alloy 6063 of 3.7 mm plate at 800, 1120 & 1600 rpm and welding speed of 200 and 315 mm/min using threaded tool pin profile followed by aging shows enhanced mechanical properties [2]. The maximum UTS of FSW process of Al 6063 at high rotational speed of 2000 rpm and low feed rate 60 mm/min was reported as 41.49 % that of the base material [3]. The mechanical properties of other aluminium alloys, dissimilar metals and composite materials are reported by various researchers. Studies on FSW of AA6061 [10-16], AA2219 [17, 18], AA056 [19], AA65032 [20], AA2024 and AA5086 [21], AA6082-T6 [22], AA2519-T87 [23] are carried out by different researchers to determine mechanical properties at various tool speeds and feeds using different tool pin profiles.

Only few research experiments are reported on FSW of AA 6063. Identifying significant scope, this research work is focused to study FSW of AA6063. This chapter is based on the experimental work carried out to study the effect of rotational speed, feed rate and tool pin profiles on the mechanical properties and weld quality of friction stir welded 6063-T4 aluminum alloy plates (butt joint) of 5 mm thickness.

2. EXPERIMENTAL DETAILS

As stated earlier AA6063-T4 is selected for this research work. AA6063-T4 is suitable for medium strength applications and offers many desired properties such as good strength to weight ratio, machinability, weldability and corrosion resistance. Chemical compensation of selected AA6063-T4 material are is shown in Table 1. and its mechanical properties are shown in Table 2.

Table 1. Chemical composition of AA6063-T4.

Alloy/ Element	AA 6063 – T4
Cu	0.08
Mg	0.55
Si	0.0545
Fe	0.0024
Mn	0.07
Zn	0.08
Ti	0.07
Cr	0.006
Al	Bal

Table 2. Mechanical properties of AA6063-T4

Material	Base Metal
Yield strength (MPa)	117.26
Ultimate Tensile Strength (MPa)	169.65
Elongation (%)	21.04
Hardness (BHN)	66

Aluminium alloy 6063-T4 plates of dimension 300 mm (length), 150 mm (width) and 5 mm (thickness) are selected for experimentation. The basic dimensions of the tool used for friction stir welding for the experiments are shown in Fig. 2 and Table 3.

For the research work presented here, three tool pin profiles of

a) cylindrical,

b) threaded cylindrical and

c) triangular shapes

are selected as illustrated in Fig 3. Using these different tool pin profiles friction stir welding is carried out at three rotational speeds (1000, 800 and 600 rpm) and welding speed (80, 60 and 40 mm/min).

Table 3. Dimensions of the tool used for FSW

Shoulder Diameter (D) (mm)	18
Pin diameter (d) (mm)	4.9
Pin Length (L) (mm)	4.9

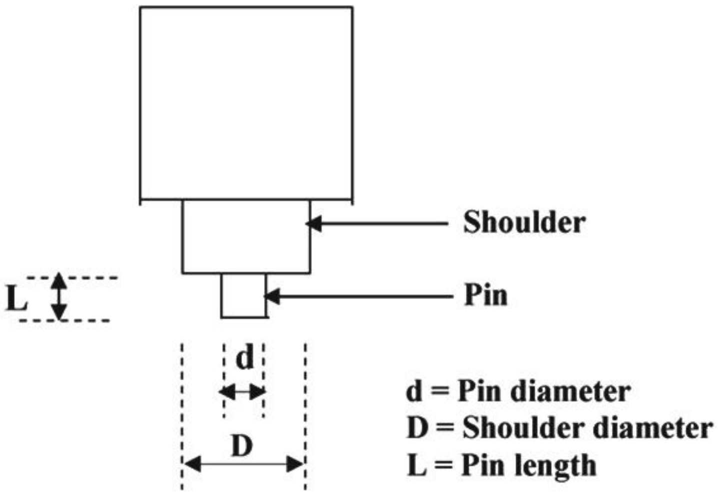
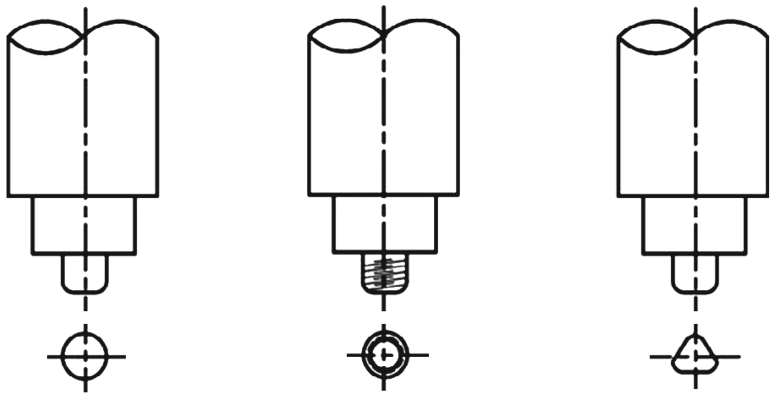


Fig. 2. FSW tool pin geometrical parameters



a) Cylindrical pin   b) Threaded cylindrical pin   c) Triangular pin

Fig. 3. Tool pin profiles used in research

The friction stir welding operation are performed on the AA6063-T4 workpieces which were appropriately clamped to the milling machine bed and welded at selected tool pin profiles, rotating tool speeds and welding speeds. Total 27 experiments were carried out. The prepared samples were tested to determine their ultimate tensile strength and percentage elongation using a universal testing machine. Fig. 4. illustrates the friction stir welded samples tested to determine UTS using selected pin profiles, speeds and feeds.

a) Cylindrical pin profile   b) Threaded cylindrical pin profile   c) Triangular pin profile

Fig. 4. Friction Stir welded samples after UTM testing

3. RESULTS AND DISCUSSION

The results of 27 experiments carried out are presented in the Table 4. The experiments are named using capital letters *C*, *CT* or *T* for cylindrical, threaded cylindrical and triangular shapes tool pin profiles respectively,

r indicates rotational speed

r_1 = 1000 rpm,

r_2 = 800 rpm,

r_3 = 600 rpm,

s indicates welding speed

s_1 = 80 mm/min,

s_2 = 60 mm/min,

s_3 = 40 mm/min

The results, including the ultimate tensile strength (UTS) in MPa, Hardness at 60 kg and percentage elongation of welded samples are presented in the Table 4 and compared with that of the original specimen.

The UTS of testing specimens is presented in the Fig. 5 for specimens with good and moderate weld quality. The samples whose weld quality is very poor are omitted and not included in the Fig. 5. Similarly, the hardness values of tested spemens are presented in Fig. 6 for specimens with good and moderate weld quality.

Regression analysis is carried by taking Ultimate tensile strength as dependent variable, and rotational speed and welding speed as independent variable. This show, model accuracy (r = 0.761) adequate for this preliminary work. This can be improved by increasing the number experiments. This also shows that rotational speed (β = 0.745) is contributing more as compared to the welding speed (β = 0.151).

Table 5. shows statistical analysis for different tool pin geometrical variations. Numbers shown in parentheses indicate that the group was significantly different at the 0.05 level according to the Student t-test and F-statistics and associated significant p-values are derived from one-way ANOVA. In this analysis, even though there is not a significant variation in rotational speed and welding speed in three tools, these are significantly different due to Hardness (F-1.812) and Ultimate Tensile Strength UTS- (F-0.771).

Table 4. Experimental results of FSW samples

Exp	UTS MPa	Hardness BHN	% of elongation	Joint Efficiency	Defect
Cr_1s_3	111	40	1.29	65.42	No
Cr_1s_2	126	43	1.6	74.27	No
Cr_1s_1	137	49	1.51	80.75	No
Cr_2s_3	127	43	1.56	74.86	No
Cr_2s_2	114	39	1.96	67.19	No
Cr_2s_1	147	58	2.4	86.64	No
Cr_3s_3	111	39	1.6	65.42	No
Cr_3s_2	0	57	0	0	Tunnel appears
Cr_3s_1	0	0	0	0	Tunnel appears
CTr_1s_3	135	48	3.2	79.58	No
CTr_1s_2	145	55	2.93	85.47	No
CTr_1s_1	147	58	1.96	56.64	No
CTr_2s_3	144	54	2.23	84.88	No
CTr_2s_2	130	44	3.02	76.63	No
CTr_2s_1	145	53	2.09	85.47	No
CTr_3s_3	110	40	1.73	64.84	Very small void
CTr_3s_2	0	52	0	0	Tunnel appears
CTr_3s_1	0	53	0	0	Tunnel appears
Tr_1s_3	126	43	3.55	74.27	No
Tr_1s_2	112	41	1.87	66.01	Very small void
Tr_1s_1	105	39	1.69	61.89	Very small void
Tr_2s_3	106	39	1.47	62.48	Very small void
Tr_2s_2	110	41	1.69	64.84	Tunnel appears
Tr_2s_1	102	38	2	60.12	Tunnel appears
Tr_3s_3	0	53	0	0	Tunnel appears
Tr_3s_2	0	51	0	0	Tunnel appears
Tr_3s_1	0	57	0	0	Tunnel appears

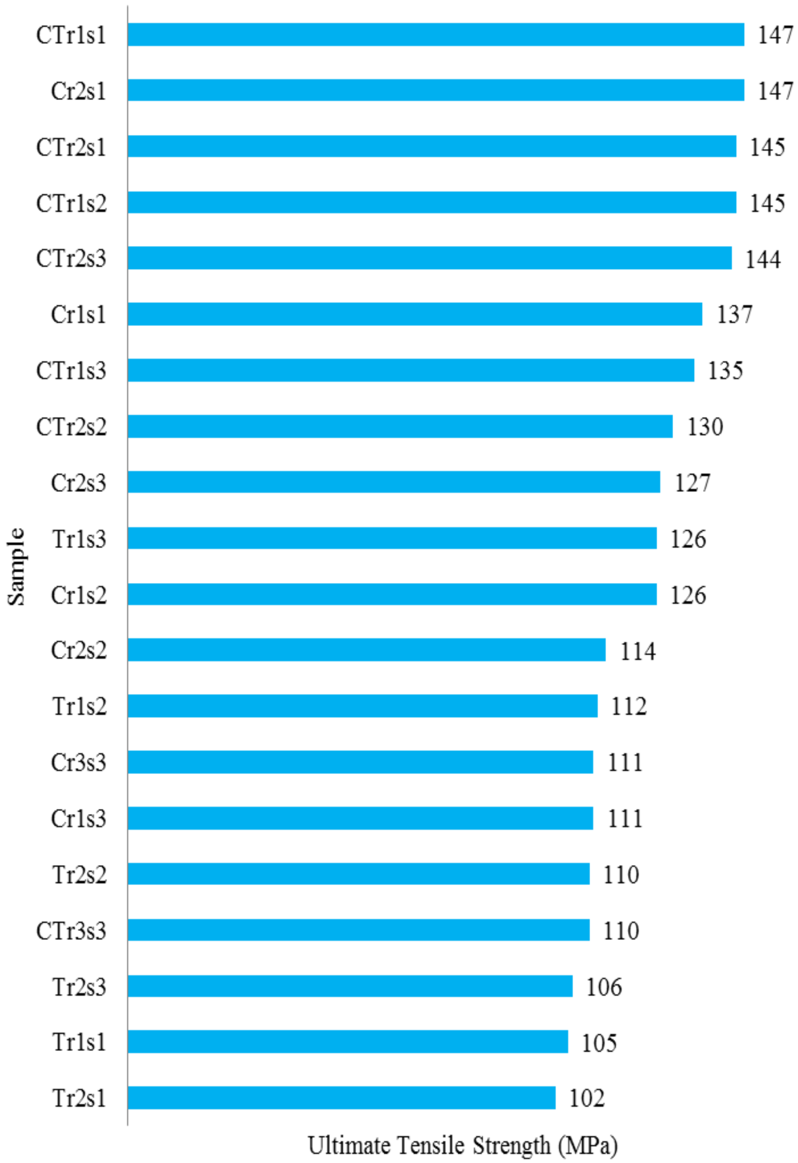


Fig. 5. Ultimate tensile strength of tested samples

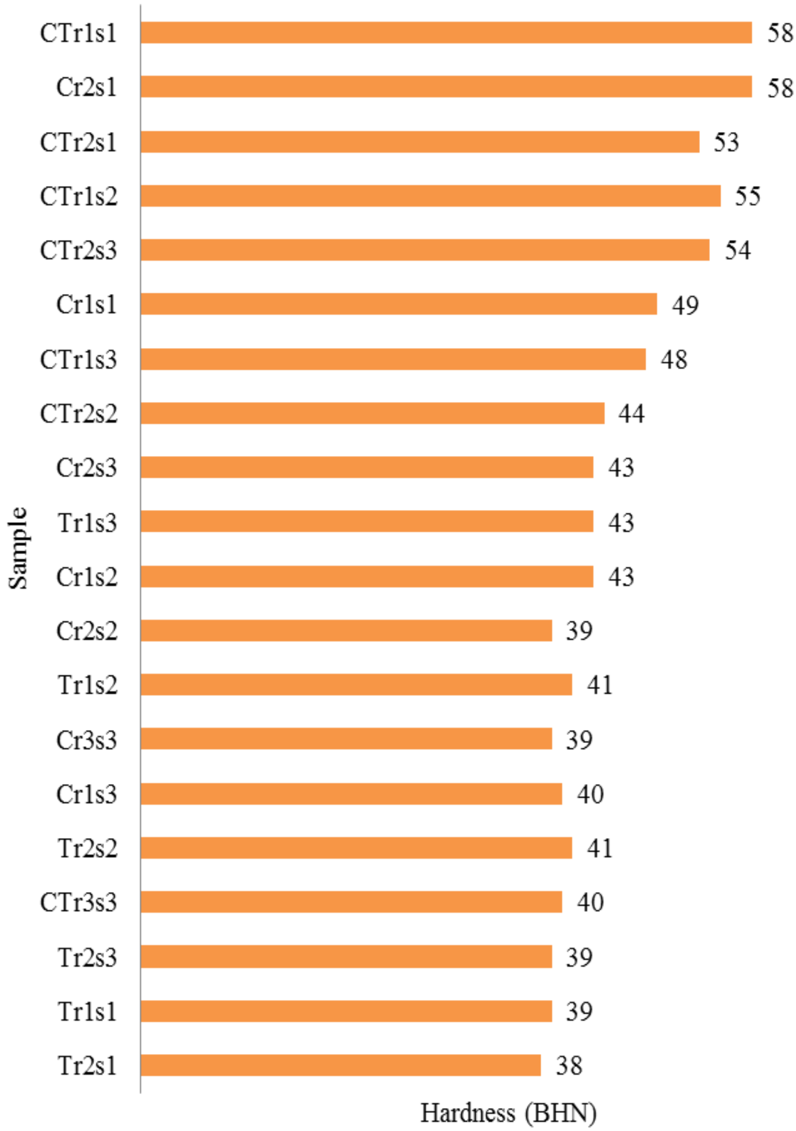


Fig. 6. Hardness of tested samples

Table 5. Statistical analysis for different tool pin geometrical variations.

Parameter	Mean / SD	Cylindrical pin profile (9)	Cylindrical threaded pin profile (9)	Triangular pin profile (9)	F-Ratio Significance
Rotational Speed	Mean	800	800	800	0.000
	SD	173.20	173.20	173.20	(1.000)
Welding Speed	Mean	60	60	60	0.000
	SD	17.32	17.32	17.32	(1.000)
UTS	Mean	97.00	106.22	73.444	0.77
	SD	56.28	61.31	55.49	(0.474)
Hardness	Mean	40.88	50.78	44.66	1.812
	SD	16.98	5.72	7.07	(0.185)

This paragraph presents the evaluation of experimental work carried out on friction stir welded butt joints of AA 6063-T4. Based on the ultilate tensile strength and hardness presented in Fig. 5 and Fig. 6 it is observed that good UTS and hardness are achived for the combination of threaded cylindrical pin profile, higher roatioanl speed and welding speed. Among the three profiles used, results of UTS are better in case of threaded cylindrical pin profile (Mean = 106.22 MPa, SD = 61.31) as compared to cylindrical pin profile (Mean = 97.00 MPa, SD = 56.28) and triangular pin profile (Mean = 73.44 MPa, SD = 55.49). The values of hardeness obtained for threaded cylindrical pin profile (Mean = 50.72 BHN, SD = 5.72), cylindrical pin profile (Mean = 40.98 BHN, SD = 16.98) and triangular pin profile (Mean = 44.66 BHN, SD = 7.07). In case of 800 rpm and 1000 rpm the better properties are obtained with increase in welding speed. But, in case of 600 rpm the UTS is decreased and hardness is increased with increase in welding speed. For 600 rpm material is not welded properly because of low heat generation and non plasticization.

The results ontained and presented in this chapter are well inline with the research presented on FSW mechanical properties of 5 mm thick 6063-T6 aluminum alloy [1, 2]. The welding efficiencies at low rotational speed and welding speeds are lower and increasing with increase in these parameters [1, 2].

4. SUMMARY AND CONCLUSION

In this experimentation and investigation, an attempt has been made to study the effect of tool pin profiles, rotational speed and welding speed on the mechanical properties of friction stir welding zone of 6063-T4 aluminum alloy. The geometrical shape of the tool pin profile plays significant role to obtain desired quality of welded joint. The weld joints quality in threaded cylindrical pin tool and cylindrical pin tool are better than that of thr triangular pin tool in all the cases. The weld joint quality of threaded cylindrical pin tool is better than that of the cylindrical pin tool. The regression analysis results also show that rotational speed is contributing more as compared to the welding speed to decide mechanical properties of welded joints. The higher rotational speeds and welding speeds resulted in better quality of welded joints compared to lower rotational speed and welding speeds.

Nomenclature

AA	:	Aluminium Alloy
ANOVA	:	Analysis of Variance
C	:	Cylindrical tool pin profile
CT	:	Threaded cylindrical tool pin profile
FSW	:	Friction Stir Welding
SD	:	Standard Deviation
T	:	Triangular tool pin profile
UTS	:	Ultimate Tensile Strength
r_1, r_2, r_3	:	Tool rotational speeds - 1000, 800 and 600 rpm
s_1, s_2, s_3	:	Welding speeds (feed rate) - 80, 60 and 40 mm/min
β	:	Standardized coefficient

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