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Influence of Welding Parameters on Weld Timings, Temperature Variation and Mechanical Strength of Friction Stir Welded AA6061 and AA6082 Alloy

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Abstract

Friction stir welding is a type of welding that creates friction using a stirring tool while the work-pieces are held together in the welding joint configuration. Friction stir welding is a solid-state welding process. It is one of the efficient ways of joining technology of materials. The friction forces at a microscopic level to change the inner structure of metal properties and it is done by using the kinetic energy of friction in welding methods. This work is majorly carried out to optimize the process parameters like tool rotational speed, Feed, ultimate tensile strength of friction stir welded joint on AA6061 and AA6082 alloy. Welding speed and temperature variation in the workpiece during the welding is recorded for different trials. Failure analysis was carried out for different fractured surfaces by using Scanning Electron Microscope (SEM) revels ductile fracture due to micro void coalescence. The maximum ultimate tensile strength was at a speed of 900 rpm, feed 31.5 mm/min indicates high joint efficiency. Welding speed is more at the feed 90mm/min. Maximum rise in the temperature is at speed 2000 rpm and feed 90 mm/min.

Keywords: *AA6061, AA6082, Dissimilar Tool, Fracture Analysis, Friction Stir Welding, Temperature Variation, Weld Timings*

1.0 Introduction

The first friction stir welding started in the year 1991 with less residual defects[1]. Friction stir welding is a solid-state joining technique. In this process weld joint is produced due to the heat generated because of the interaction between the workpiece and the tool. Friction stir welding technique is well known for its great properties like environment friendly, error free, excellent mechanical properties and corrosion properties. Hence the process parameters which affect the strength of welded joints should be optimized to get a high strength welded joint[2,3]. Even friction stir welding is also called as a green technology[1]. Friction stir welding gaining very high importance due its applications in railway[4], automotive[5,6] aerospace[7,8].

The flow of material during the welding has a major effect on the quality of the welded joint. This flow of material is majorly influenced by the tool profile, tool rotational speed, traverse speed, and tool offset. Initially friction stir welding was done on the aluminum alloys due to their high variety of applications. One more major advantage of friction stir welding is dissimilar material welding. The major point of this dissimilar welding is to combine the various properties of metals and there to increase the productivity of the structure[9,10]. B. Ravi Sankar *et al.*,[2] optimized the parameters such as tool rotational speed, welding speed and pin tool diameter

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by analyzing mechanical properties like hardness and tensile strength for friction stir welded AA6061 alloy. S. Rajendra Prasad *et al.*,[10] studied the effect of tool shoulder geometry, tool traverse speed and tool pin profile by keeping tool rotational speed constant on microstructure and mechanical properties of friction stir welded 2014-T6 aluminum alloy. Yuving Mao *et al.*,[11] and G Singh *et al.*,[12] evaluated the degree of dynamic Ductility of the material was evaluated by percentage of elongation. Rotational speed effects temperature variations, microstructure and mechanical properties of friction stir welded alloys[13]. El-Moayed *et al.* review clears the geometry of the tool[14]. Tool tilt angle also influence material flow and heat transfer[15]. P. Satish Kumar *et al.*,[16] studied the effect of tool rotational speed on mechanical properties and micro structure of friction stir welded 5083 aluminium alloy. Ning Guo *et al.*,[17] examined the microstructure of aluminium 5406 alloy by optical microscope, electron back scattered diffraction and transmission electron microscope. Strength of the joint is analyzed by tensile test and the fracture surface analysis was done by scanning electron microscope. Huihang Liu *et al.*,[18] analyzed microstructure of β – type titanium alloy at thermo-mechanically affected zone, stir zone and the strength of the material is calculated by analyzing the mechanical properties. There are few studies available related friction stir welding in water-cooling condition will improve the tensile strength and hardness of the joints[19,20]. Few research findings also reveal cooling method has no effect on hardness with increase with tool stir speed[19]. Improved tensile properties due to increased hardness in heat affected zone[21,22].

From the literature survey it is found that there is a lack of information about the influence of different tool material, time required for the welding, increase in temperature during the welding. Hence an attempt has been made in welding aluminum 6061 and 6082 series alloys and the influence of parameters like tool rotational speed, feed and dissimilar tool material is studied.

2.0 Experimental Details

2.1 Materials

To study the effect of process parameters like weld timing, temperature during welding, mechanical properties of welded 6061 and 6082 aluminum alloy plates by friction stir welding. The setup to welding is prepared by reconfiguring existing vertical milling machine shown in Figure 1. The two different materials are selected as tool material namely EN39B and HSS with a conical type of flat end pin profiles shown in Figure 2. The arrangements made for the welding of the samples are shown in Figure 3 and the final welded sample is shown in Figure 4.

Aluminium 6061

Table 1. Chemical composition of AA6061

Mg	Mn	Fe	Si	Cu	Cr	Zn	Ti	Al
0.8-1.2	≤ 0.15	≤ 0.7	0.4-0.8	0.15-0.4	0.04-0.35	≤ 0.25	≤ 0.10	Balance

Mechanical Properties of AA6061 are:

UTS:328 Mpa ;% of Elongation:12-26

Aluminum 6082

Table 2. Chemical composition of AA6082

Mg	Mn	Fe	Si	Cu	Cr	Zn	Ti	Al
0.6-1.2	0.4-1.0	≤ 0.5	0.7-1.3	≤ 0.10	≤ 0.25	≤ 0.20	≤ 0.15	Balance

Mechanical Properties of AA6082 are:

UTS:340-346 MPa ;% of Elongation12-2

Figure 1. Vertical milling machine.

Figure 2. Tool used for welding.

Figure 3. Arrangement of fixture to weld.

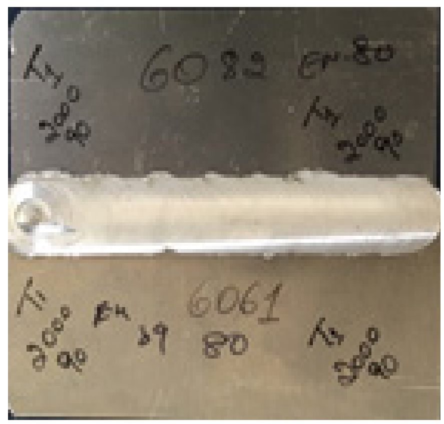


Figure 4. Friction welded specimen.

2.2 Process Parameter Selection

The quality of the joint completely depends on the process parameter so by the literature survey it was found that the tool rotational speed and traverse speed were major parameters which influences the weld quality in FSW. To get an efficient joint, finding the optimum condition is essential. The tool rotational speed and horizontal feed were selected for 2000,1400,900,560 rpm and 31.5,45,63, 90 mm/min to study the quality of welding, and the parameters are listed in Table 3.

Table 3. Process parameter and dimensions of tool

Process Parameters	Values
Tool Rotational Speed (RPM)	2000,1400,900 and 560
Traverse Speed (mm/min)	31.5,45,63 and 90
Length of Pin (mm)	3.8
Tool shoulder diameter (mm)	20
Major diameter of pin (mm)	7
Minor diameter of pin (mm)	3.8

2.3 Physical, Thermal and Mechanical Properties

The strength of the welded joint is calculated by testing the welded joint according to ASTM E8 tensile specimen. The failure analysis is done by taking SEM images of the fractured surface.

3.0 Results and Discussions

The welding parameters like weld timings, temperature variation during the welding, tensile strength of the welded joints at different process parameters are measured and tabulated in Table 4.

Table 4. Weld timings, temperature variation and tensile strength at different conditions

Trial #	Tool Material	Speed (RPM)	Feed (mm/min)	Weld Timings (min)	Initial Temp (°c)	Final Temp (°c)	UTS (MPa)	Elonga tion (%)	Weld Strength (%)
1	EN39	2000	31.5	2.26	30	262	141.3	12.478	40.12
2	EN39	2000	45	1.54	30	268	167.0	16.676	47.39
3	EN39	2000	63	1.14	30	272	147.0	12.065	41.72
4	EN39	2000	90	0.53	30	276	148.8	12.379	42.25
5	EN39	1400	31.5	2.30	30	252	123.8	9.655	24.67
6	EN39	1400	45	1.56	30	259	148.9	13.062	42.27
7	EN39	1400	63	1.16	30	262	113.4	5.661	32.19
8	EN39	1400	90	0.55	30	270	122.9	8.417	34.48
9	EN39	900	31.5	2.34	30	225	220.8	17.084	62.66
10	EN39	900	45	1.53	30	229	169.3	15.09	48.07
11	EN39	900	63	1.12	30	232	157.8	13.062	44.78
12	EN39	900	90	0.54	30	240	130.6	7.198	37.08
13	EN39	560	31.5	2.31	30	202	148.9	12.379	42.27
14	EN39	560	45	1.52	30	209	105.5	6.559	29.96
15	EN39	560	63	1.15	30	213	92.8	6.554	26.35
16	EN39	560	90	0.55	30	219	90.0	5.77	25.56
17	HSS	2000	31.5	2.26	30	263	153.0	11.102	43.43
18	HSS	2000	45	1.55	30	269	164.0	15.09	46.54
19	HSS	2000	63	1.12	30	274	138.9	10.277	39.44
20	HSS	2000	90	0.55	30	278	152.7	11.724	43.34
21	HSS	1400	31.5	2.32	30	254	137.9	10.069	39.14

22	HSS	1400	45	1.59	30	260	160.6	11.587	45.59
23	HSS	1400	63	1.16	30	263	150.9	11.512	42.83
24	HSS	1400	90	0.54	30	269	137.9	9.987	39.14
25	HSS	900	31.5	2.29	30	213	177.7	15.58	50.42
26	HSS	900	45	1.55	30	219	145.3	11.429	41.24
27	HSS	900	63	1.12	30	221	134.9	9.505	38.29
28	HSS	900	90	0.56	30	229	129.2	9.127	36.67
29	HSS	560	31.5	2.29	30	203	120.8	10.111	34.29
30	HSS	560	45	1.43	30	206	123.8	9.646	35.16
31	HSS	560	63	1.14	30	211	112.8	9.045	32.01
32	HSS	560	90	0.55	30	219	102.0	7.622	28.95

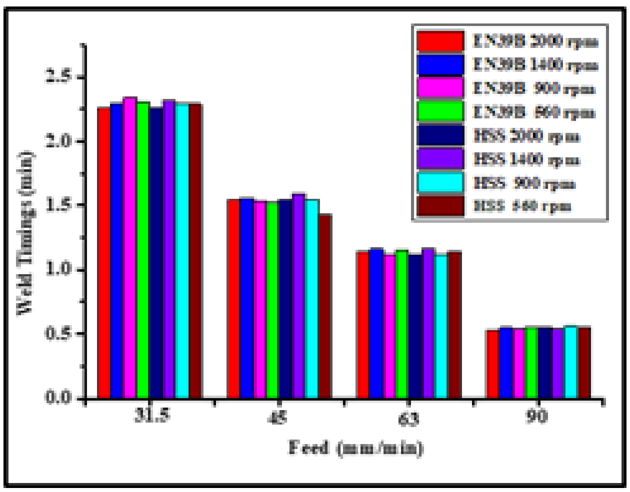


Figure 5. Variation of weld timings at different speeds, feed and tool material.

3.1 Weld Timings

Timings are required to weld plates of length 100 mm by the friction stir welding process at different tool rotational speed, traverse speed and different tool materials.

The variation of the timings is represented in a bar graph shown in Figure 5. Results show that the time required to weld at feed rate 31.5 mm/min is more and at feed rate 90 mm/min is high. Weld timing depends only on the feed rate, and it is completely independent of tool rotational speed and material of the tool. Since at the feed rate 90 mm/min table, on which the fixture is mounted moves faster, hence the time required to weld is lesser and in the same way at feed rate 31.5 mm/min table moves slower hence it requires more time to weld. Figure 5 clearly shows that there is no influence of tool material and tool rotational speed. Welding speed is completely influenced by only one factor, that is feed rate (mm/min).

3.2 Temperature Variation

Table 4 contains the temperature recorded at different tool rotational speed, feed rate and tool material. Figure 6 explains the variation of temperature at various tool rotational speeds, feed rate and tool material. At speed 2000 rpm and feed 90 mm/min there is a highest increase in the temperature and at speed 560 rpm and feed rate 31.5 mm/min there is lowest increase in the temperature when compared with the other trials for both the type of tool material. This shows that temperature increase in the workpiece during the time of welding depends on the tool rotational speed and feed rate. Tool materials do not have any influence on the temperature variation during the welding.

Since at the speed 2000 rpm and feed 90 mm/min there is a very fast movement of tool and the table therefore it leads to the generation of very high friction that intern leads to the generation of very high friction that interns leads to the increase of heat, by this the

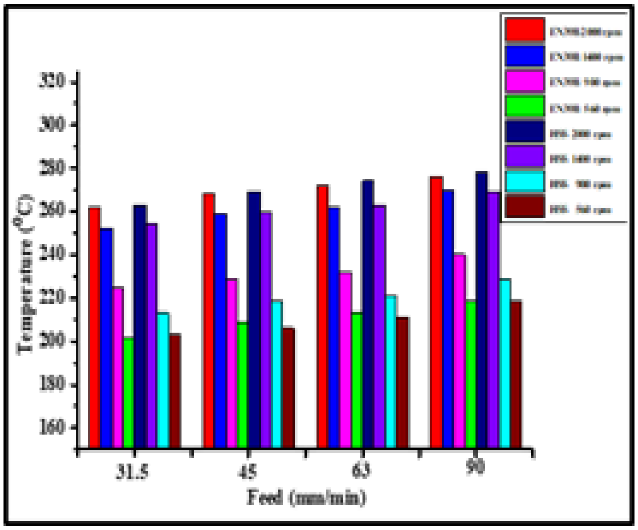


Figure 6. Variation of temperature during welding at different speed, feed and tool material.

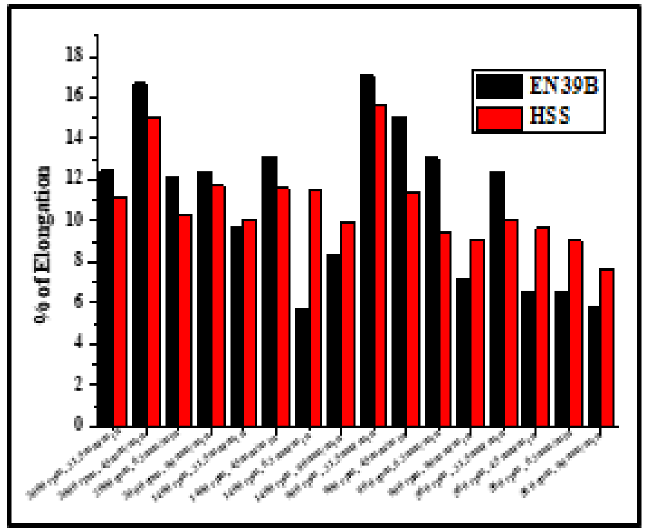


Figure 8. Percentage elongation at different speed, feed and tool material.

temperature during the welding increases but in case of speed 560 rpm and feed 31.5 mm/min both tool and table moves slowly that creates a less friction hence the increase in temperature is less compared to other trials.

3.3 Tensile Properties

Tensile properties of the different joints fabricated at various tool rotational speed and feed rate using different types of tool materials is listed in the Table 4 and represented the variation graphically in Figure 6 and 7, by observing the tabulated readings it was found that, for both the materials at tool rotational speed 900 rpm and feed rate 31.5 mm/min the value of ultimate tensile strength and percentage of elongation obtained is very high and at speed 560 rpm and feed 90 mm/min the value of ultimate tensile strength and percentage of elongation obtained is very low. It also found that at very high speed and low speeds the value of ultimate tensile strength and percentage of elongation is less due to insufficient heat input and improper mixing at weld zone. The highest average ultimate tensile strength obtained is 220.8 MPa which is 62.66% of the average base material strength. The reason for the decrease in the strength was found out by conducting fracture analysis with the help of SEM images at fracture surface.

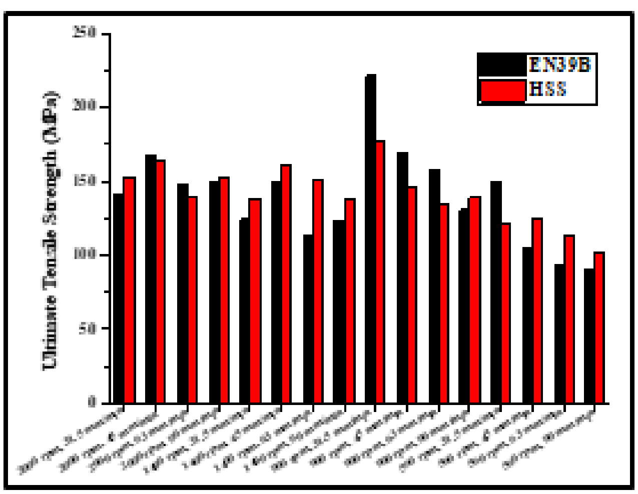
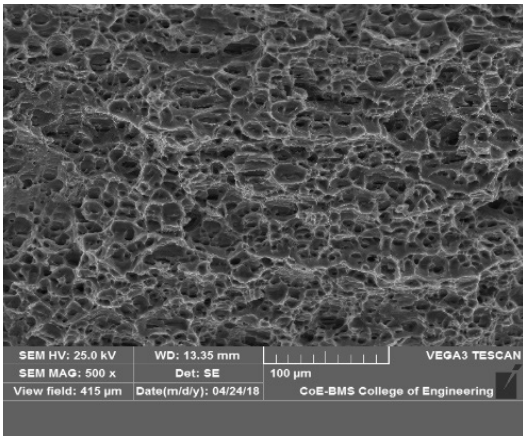


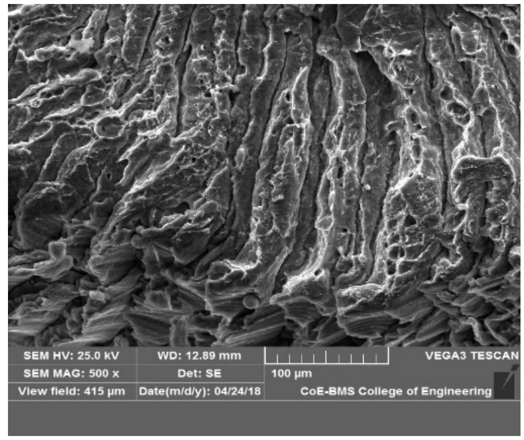
Figure 7. Variation of ultimate tensile strength at different speed, feed and tool material.

3.4 Fracture Analysis

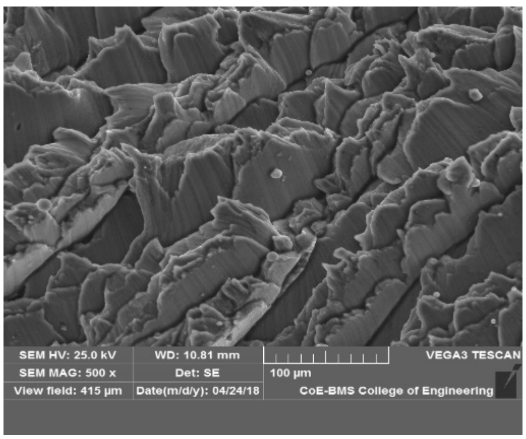
Figure 9 (A), (B), (C) and (D) shows the Secondary Electron Microscope (SEM) images of the fractured tensile specimen. In Figure 9 (A), (B) dimples can be observed in the images this proves that the fracture occurred is of the type ductile. This ductile failure occurs due to the mechanism called micro void coalescence. In case of Figure (C), (D) cleavage pattern also can be observed that shows there is a brittle failure or semi ductile failure. The joint obtained in the weld condition of tool rotational speed 900 rpm and feed rate 31.5 mm/min



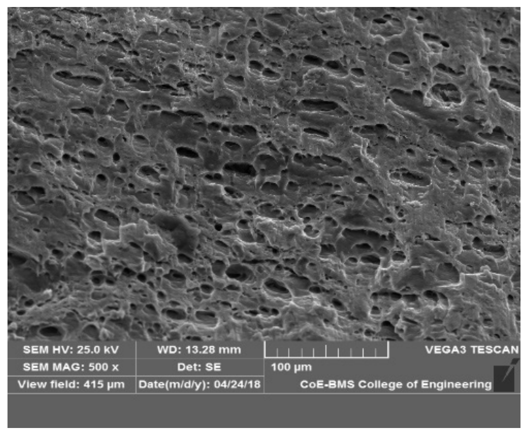
(A)



(B)



(C)



(D)

Figure 9. **(A)**. SEM images of fracture surfaces of tensile specimen having high strength. **(B)**. SEM images of fracture surfaces of tensile specimen having moderate strength. **(C)**. SEM images of fracture surfaces of tensile specimen having low strength. **(D)**. SEM images of fracture surfaces of tensile specimen having very low strength.

experienced the most ductile fracture and the remaining joints fractured in a semi ductile manner.

In Figure 9(C) and 9(D), at fracture surfaces defects like discontinuities and voids can be seen, which happened during the welding process. At the time of welding due to insufficient heat input and mechanical mixing the physical and mechanical properties at weld region is destroyed, by avoiding the fluidity and mobility of the material around the tool pin, this is supported by various results[23].

Due to low rotational speed, there is a less heat generation and lower mixing of the material at the region around the pin hence it avoids the formation of sound joints. Whereas in case of higher speeds the time obtained to fill the material around the pin during the time of welding is very less so the joint obtained at higher speed do not have the proper welding strength, but in case of moderate speed a sound joint can be obtained this is proved with the obtained results.

4. Conclusions

In this present study 4 mm thick AA6061 and AA6082 alloy were successfully butt-welded using friction stir welding. Welding was carried out at different rotational speed like 2000, 1400, 900 and 560 rpm and at different feed like 31.5, 45, 63 and 90 mm/min with the help of two different tool materials such as HSS and EN39B. The obtained results are concluded as follows.

- There is no effect of tool material on weld timings, work piece temperature and strength of welded joint. The only minimum requirement that tool material should pass is, it must be stronger than the base material.
- There is no influence of material of tool, rotational speed on weld timings. Only parameter which influence welding timings is feed rate.
- Variation of temperature depends on the feed rate, rotational speed and it is independent of material of tool.
- Tensile strength of welded joint varies with the tool rotational speed and feed, but it is constant for the tool material.
- Maximum ultimate tensile strength is obtained at tool rotational speed 900 rpm and feed 31.5 mm/min, minimum welding speed can be about at feed rate 90 mm/min, high temperature increase during the time of welding is observed at tool rotational speed 2000 rpm and feed rate 90 mm/min.

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