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Influence of Cu Powder in Joining of Dissimilar Aluminium Alloys by Using Friction Stir Welding

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Abstract

In this research article, aluminium alloy plates of 6mm thickness AA5052 and AA6061 are to be joined by using friction stir welding (FSW). Present study aims at investigating the influence of the process parameters on the mechanical properties such as tensile strength and hardness of the dissimilar metal adding of copper powder. Using design of experiments Taguchi's experimental L_9 layout was used to carry out the experiments with addition of copper powder. Threaded pin tool geometry was used for conducting the experiments. Based on the results and Taguchi analysis it was found that 900 rpm and welding speed of, 40 mm/min, 4KN, 2^0 degree was found for the maximum tensile strength (162.233N/mm^2), with addition of copper powder. 1000 rpm and welding speed of, 45 mm/min, 4KN, 1^0 degree was found for the maximum hardness (18 HRA), with addition of copper powder

Keywords

Aluminium Alloy, Friction Stir Welding, Tensile Strength, Micro Hardness, Taguchi's Method, Theaded Pin Tool

1. Introduction

It was invented and experimentally proven at The Welding Institute UK in December 1991. TWI holds patents on the process, the first being the most descriptive

Friction-stir welding (FSW) is a solid-state joining process (the metal is not melted) that uses a third body tool to join two facing surfaces. Heat is generated between the tool and material which leads to a very soft region near the FSW tool. It then mechanically intermixes the two pieces of metal at the place of the joint, then the softened metal (due to the elevated temperature) can be joined using mechanical pressure (which is applied by the tool), much like joining clay, or dough.

FSW is an innovative solid state welding process in which the metal to be welded is not melted rather the two parts of weld joints are brought into contact and the interface is strongly forged together under the effect of heavy plastic deformation caused by the inserted rotating stir probe pin.

It is primarily used on aluminium, and most often on extruded aluminium (non-heat treatable alloys), and on structures which need superior weld strength without a post weld heat treatment.

In FSW a rotating cylindrical shoulder tool (H13) with profiled probe penetrates into the material until the tool shoulder contacts with the upper surface of the plates specimen to be fixed in the clamp which are butted together as shown in Figure 1.

Frictional heat is generated between the wear resistant welding tool and the material of the work pieces. This heat does not allow to reach the melting point but allows traversing of the tool along the weld line. [8-9]

In FSW, tool rotation rate (rpm) in clockwise or counter clockwise direction and tool traverse speed (mm/min) along the joint are the most important parameters for the effective welding. [1]

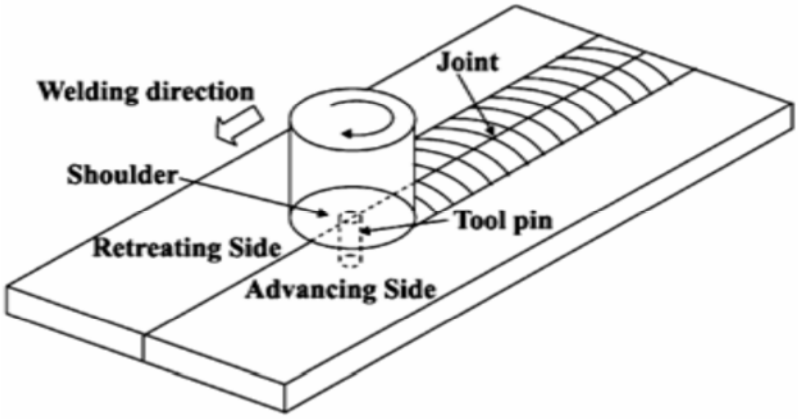

Figure 1. *Schematic illustration of FSW process diagram.*

2. Literature Review

Siva Kumar et al [1] review has demonstrated the extensive research effect that continuous to progress the understanding of FSW of aluminium alloy and its influence on their microstructure and its properties.

V. Balasubramanian et al [2] discuss the influence of tool pin profile & tool shoulder diameter on the formation of friction stir zone in AA6061 using 5 different tool pin profile & with different shoulder diameter have been used to fabricate the joints.

C. Devanathan et. al [3] discuss the use of Taguchi experimental design technique for maximizing tensile strength of friction stir welded AA6063 alloy.

Palanivel et. al [4] discuss the effect of tool rotational speed and pin profile on microstructure and tensile strength of dissimilar friction stir welding and joint were made by 3 different tool rotational speed.

S. K. Park et. al [5] the effect of material location on the properties of friction stir welding joint of two dissimilar alloys was investigated by experiments. The result of microstructure analysis shows the material mixing pattern in the FSW joints are different depending on the location of base materials.

Fie Zhang et. al [6] effect of welding parameter on the microstructure & mechanical properties was investigates sample made of super high strength aluminium alloy with high Zn content were friction stir welded by some welding speed and rotational speed.

Qasim M. Doos et. al [7] discussed the fesibility of weld two pieces of aluminium pipe by friction stir welding process testing include non-destructive test and destructive test for investigate mechanical properties of weld joint.

Mohammed A. M. et. al [8] discuss three- dimensional non linear thermal numerical simulation are conducted for the frictional stir welding of AA7020 – T53, three welding with tool speed are analysed.

Mahabunpachai et. al [9] discussed an ongoing quest to realize low- mass transportation vehicles with enhanced fuel effieciency, deformation characteristics of AA5052 and AA6061 were investigated Mechanical tests are biaxial, hydraulic buge test are carried out for this experiment.

A. C. Somasekharan et al. [10] discussed microstructure in friction stir welded dissimilar magnesium alloys and magnesium alloys to 6061 – T6 aluminium alloys. Light optical metallography was used to observed and confirm the weld zone characteristics unique to dissimilar weld.

3. Experimental Procedure

In this present study aluminium alloy of AA6061 and AA5052 grade was welded with copper powder. Aluminium alloy of size 100mm x 50mm x 6mm was considered for the experiments shown in Figure 2. Copper powder of 325 mesh size was used for the experimentation. Edge preparation of the specimen was carried out when the experiments were conducted with the copper powder. Edge preparation includes drill on the both the plates. Copper powder is filled on both the plate after that using pin less tool close the holes on the top of the surface shown in Figure 3. This was done to prevent the powder being thrown out of the specimen during welding process.

Tool steel (H13) tool material used for the experiments. Taguchi's experimental L_9 layout was used to carry out the experiments with adding of copper powder [2]. Threaded pin tool geometry was used for conducting the experiments [3]. Experiments were performed on Friction stir welding machine.

Figure 2. *Aluminium alloy plates.*

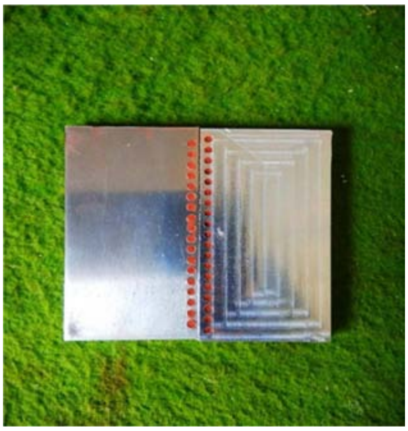

Figure 3. Adding copper powder in to the holes.

3.1. Chemical and Mechanical Properties

3.1.1. Chemical Properties

Table 1. Chemical properties for AA6061.

	Min	max
Magnesium	0.8	1.2
Silicon	0.4	0.8
Iron	0.0	0.7
Copper	0.15	0.4
Manganese	0.0	0.15
Chromium	0.04	0.35
Zinc	0.0	0.25
Titanium	0.0	0.15
Others elements	0.15%	
Aluminium	95.85	98.5

Table 2. Chemical properties for AA 5052.

	Min	max
Magnesium	2.2	2.8
chromium	0.15	0.35
Silicon	0.15	0.25
Iron	0.0	0.2
Copper	0.0	0.1
Manganese	0.0	0.1
Zinc	0.0	0.1
Other elements	0.15	
remainder	96.45	

3.1.2. Mechanical Properties

Table 3. Mechanical properties for both AA6061 and AA5052.

Materials	Tensile strength (Mpa)	Elongation at break (%)	Hardness (HRA)
AA6061	124 – 290 Mpa	12 - 25%	12
AA5052	193 - 290Mpa	7 - 25%	16

3.2. Experimental Setup and Its Specification

Figure 4. Photograph of FSW Machine.

Table 4. Experimental machine specification.

Spindle tapper	ISO40
spindle	3000 rpm
Spindle tile angle	+- 7 Deg
Z-axis thrust force	30KN (max)
Z-axis travel	300mm
X-axis travel	300mm
Y-axis travel	100mm (optional servo)
Travel to spindle node min/max	100mm/400mm
Controller	Rexoth
Data acquisition software	Spindle rpm, torque axis force velocity against time and distance.
Weld able materials	Steel/copper/Aluminium.

3.3. Taguchi Method

Results of these experiments are used to analyze the data and predict the quality of components produced. Here, an attempt has been made to demonstrate the application of Taguchi's Method to improve tensile strength and also hardness of the specimen of components that were processed on a friction stir welding machine. Tensile strength is a measure of the strength of a specimen done in M-30 series machine. And also hardness is a measure of how much harden attained in that specimen also examined from the Taguchi method. 3 level of spindle speed and 3 level of welding speed and 3 load and 3 tilt angle are the factors for L9 Taguchi's method [4]

Table 5. Orthogonal array for L9 Taguchi method.

	TAGUCHI DESIGN				FACTORS			
RUNS	A	B	C	D	A	B	C	D
					Spindle speed (Rpm)	Load (KN)	Welding speed (mm/min)	Tilt angle (degree)
1	1	1	1	1	800	4	35	0
2	1	2	2	2	800	5	40	1
3	1	3	3	3	800	6	45	2
4	2	1	2	3	900	4	40	2
5	2	2	3	1	900	5	45	0

	TAGUCHI DESIGN				FACTORS			
RUNS	A	B	C	D	A	B	C	D
					Spindle speed (Rpm)	Load (KN)	Welding speed (mm/min)	Tilt angle (degree)
6	2	3	1	2	900	6	35	1
7	3	1	3	2	1000	4	45	1
8	3	2	1	3	1000	5	35	2
9	3	3	2	1	1000	6	40	0

3.4. Surface Morphology

Figure 5. *900 rpm and welding speed of, 40 mm/min, 4KN, 2^0.*

Figure 6. *1000 rpm and welding speed of, 45 mm/min, 4KN, 1^0.*

4. Result and Discussion

4.1. Tensile Test

A universal testing machine, also known as a universal tester, materials testing machine or materials test frame, is used to test the tensile stress and compressive strength of materials [7]. It is named after the fact that it can perform many standard tensile and compression tests on materials, components and structures. Model Name: DTRX – 30KN shown in Figure 7.

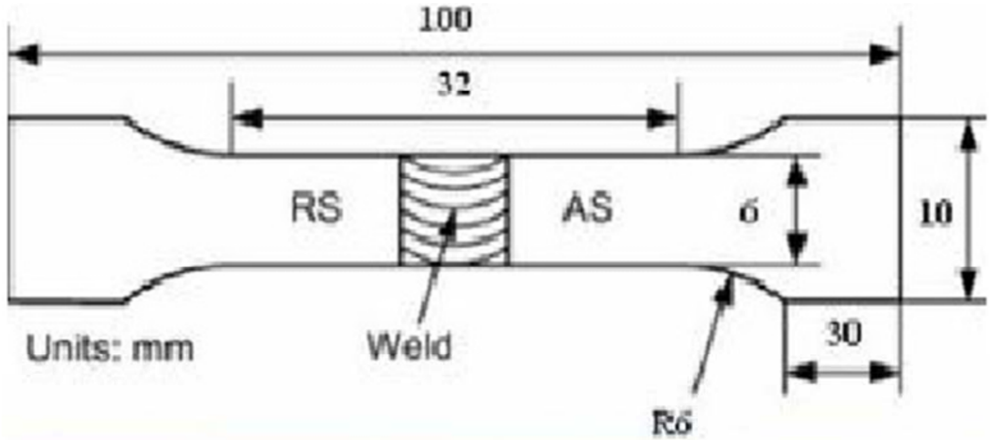

Figure 7. *Tensile test piece with dimension.*

Table 6. *Experimental table (L9 Array) with observed values.*

Samples	Spindle speed (rpm)	Welding speed (mm/min)	Tensile strength (N/mm^2)	Load at peak (KN)	Elongation at peak (mm)
1	800	35	138.799	8.087	5.692
2	800	40	127.117	9.444	5.108
3	800	45	126.690	10.524	5.623
4	900	40	162.233	10.785	6.155
5	900	45	125.178	8.798	5.008
6	900	35	122.319	8.105	5.092
7	1000	45	120.268	8.020	5.037
8	1000	35	150.400	11.197	6.438
9	1000	40	139.921	9.365	6.337

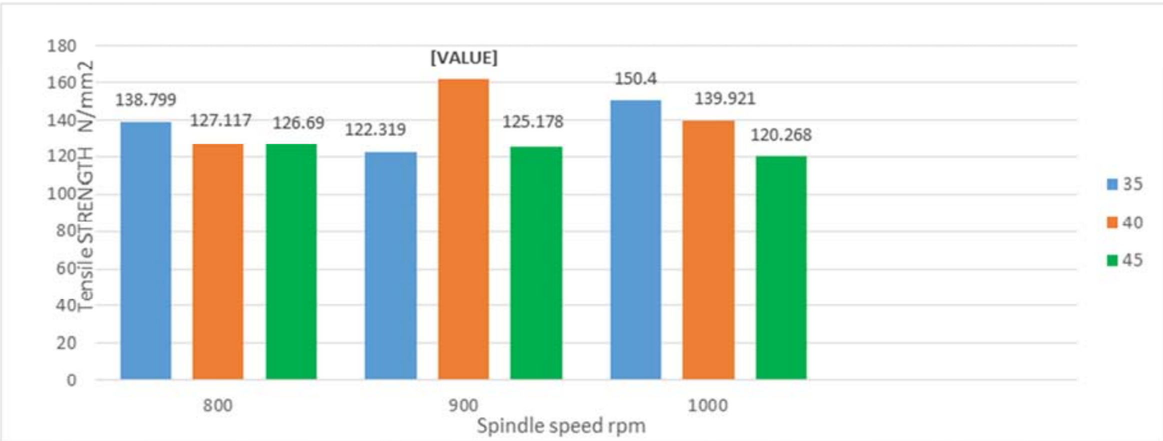

Figure 8. *Tensile strength with varying spindle speed.*

4.2. Hardness Test

The Rockwell scale is a hardness test based on indentation hardness of a material with a diamond cone or hardened steel ball indenter. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. There are different scales, denoted by a single letter, that use different loads or indenters. The result is a dimensionless number noted as HRA, HRB, HRC, etc., where the last letter is the respective Rockwell scale. When testing metals, indentation hardness correlates linearly with tensile strength.

Table 7. *Experimental table (L9 Array) with observed values.*

Sample Runs	Spindle speed (rpm)	Welding Speed (mm/min)	Observed values, HRA			Average HRA
			1	2	3	
1	800	35	16	14	13	14
2	800	40	16	18	17	17
3	800	45	14	14	14	14
4	900	40	17	17	14	16
5	900	45	17	20	15	17
6	900	35	13	16	17	15
7	1000	45	17	19	19	18
8	1000	35	17	18	16	17
9	1000	40	16	16	14	15

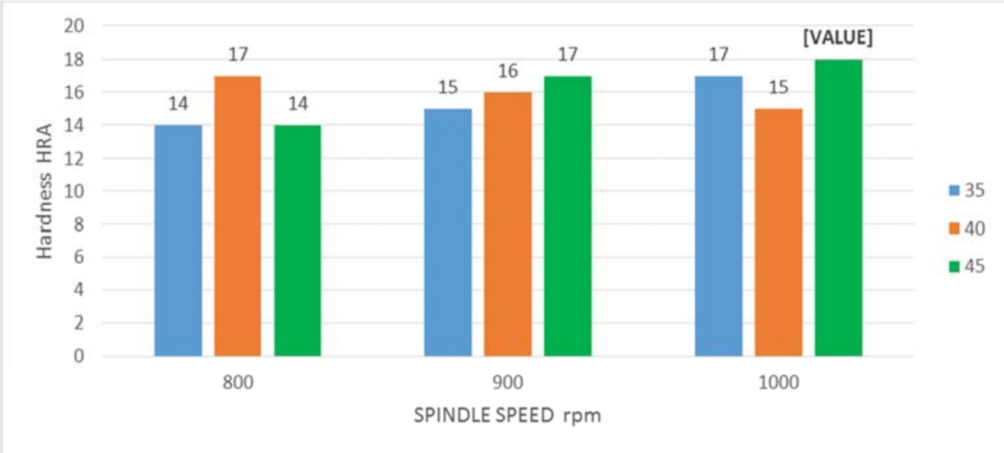

Figure 9. Hardness with varying spindle speed.

4.3. Microstructure

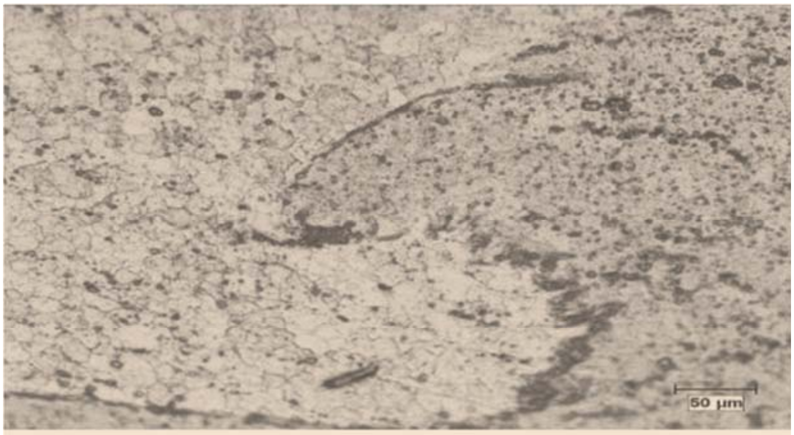

Figure 10. Interface Zone AA6061 and AA5052.

The material location on the properties of friction stir welding joint of two dissimilar alloys was investigated by experiments. The result of microstructure analysis shows the material mixing pattern in the FSW joints are quite different on the location of the base material. Material property mix well when AA5052 in advancing side & then 6061 in retreating side shown in Figure 10. [5-6-10].

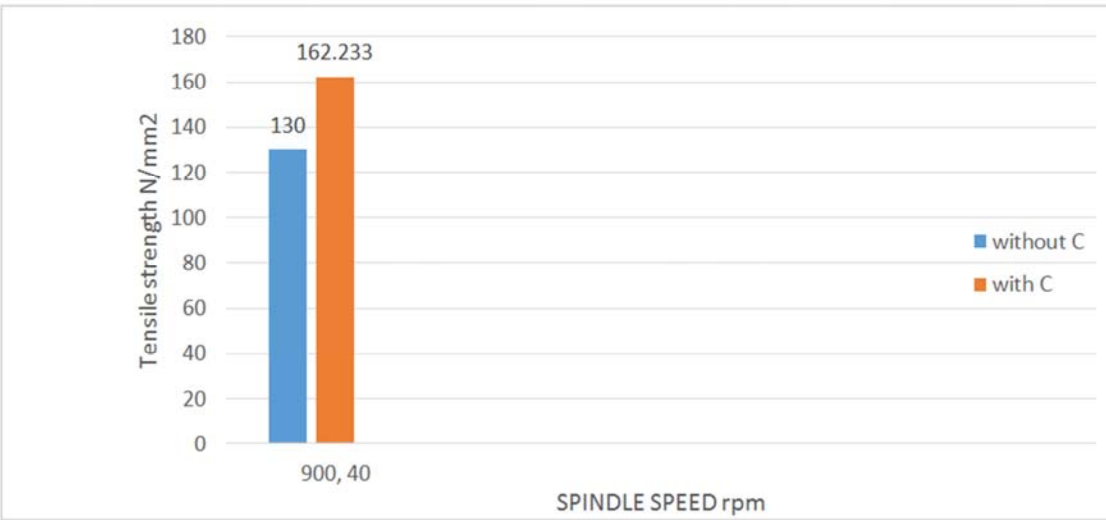

Figure 11. Tensile strength compare with and without adding copper.

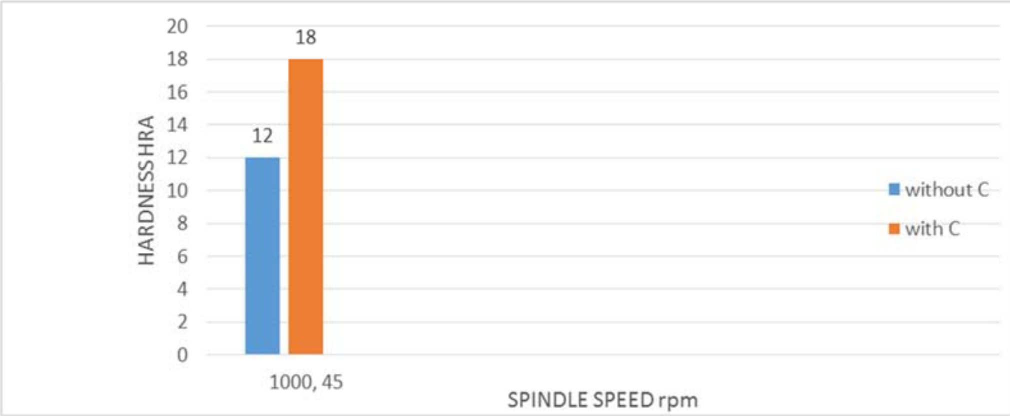

Figure 12. *Hardness compare with and without adding copper.*

5. Conclusion

From results, it is clearly observed that there is different set of combination between the welding speed and spindle speed in order to get a maximum performance of weld joints.

Friction stir welds between AA 5052 and AA 6061 Al alloys having excellent weldability and performance characteristics.

Cylindrical threaded pin has excellent bondage between both alloys (AA 5052 and AA 6061) byeffective friction stir joini

Optimum range of spindle speed, 900 rpm and welding speed of, 40 mm/min, 4KN, 2^0 degree was found for the maximum tensile strength (130.010N/mm^2), without addition of copper powder.

Optimum range of spindle speed, 900 rpm and welding speed of, 40 mm/min, 4KN, 2^0 degree was found for the maximum tensile strength (162.233N/mm^2), with addition of copper powder.

Optimum range of spindle speed, 1000 rpm and welding speed of, 45 mm/min, 4KN, 1^0 degree was found for the maximum hardness (12 HRA), without addition of copper powder.

Optimum range of spindle speed, 1000 rpm and welding speed of, 45 mm/min, 4KN, 1^0 degree was found for the maximum hardness (18 HRA), with addition of copper powder.

Thus the addition of Copper powder Tensile Strength is increased by 24.86% and also Hardness is increased by 50%.

Microstructure evaluations showed the formation of spherical dimple shaped new fine grains and refinement of reinforcement particle in the nugget zone (NZ). This leads to the more ductility and ultimately a possible explanation for the higher tensile strength.

AA 6061 and AA 5052applications in automobiles, aerospace, and metal forming industries that desire high plasticity as obtained through the friction stir process. The Al6061-Al6082-Cu composites may find the applications in the area where high surface hardness is required such as machine components that suffer from wear during the service.

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