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Experimental Study On Dissimilar Friction Stir Welding Of Aluminium Alloys (AA-6082 And AA-5052) Under Dissimilar Pin Profile To Investigate The Mechanical Properties

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Abstract:
Friction stir welding is a relatively recent welding process for combining similar and different materials while preserving the base metal's characteristics. FSW is an environmentally benign technology for joining comparable and dissimilar materials with no defects and clean welds. In the friction stir welding technique, carefully designed tools and travel in a line along the specimen joint, causing frictional heating that softens the joint zone of material below the tool. Through significant plastic deformation, the moderated material flows transversely the tool and is merged to form a stable and continuous junction. To recover physical qualities from soft materials that are incompatible with additional heat treatment, the FSW technique is frequently used. In this paper Friction stir welding of dissimilar materials AA 6082 and AA 5052 was investigated. The influence of varied tool pin profile and speed on mechanical properties was investigated. A parameter in this investigation was 3 mm two dissimilar alloys plates with constant rotational speed, varied tool pin profile, and varying welding speed. For the experimental examination, cylindrical, taper, and threaded pin profiles with constant rotating speed 710 rpm, various welding speed 17 mm/m and 22 mm/m were used. The hardness was higher in the nugget zone, and the joint generated by the cylindrical pin profile with chamfered profile had the highest tensile strength. While the cylindrical shaped pin profile with straight end has higher hardness and cross over strength. Additionally, it was shown that decreasing the advantages of welding speed resulted in the maximum hardness and malleability values, whilst increasing the benefits of welding speed resulted in increased cross over strength. The parameters listed above were utilized to perform friction stir welding to join two dissimilar materials, and analysis was performed to determine the influence of different tool pin geometries on temperature and power consumption.

Keywords: *Dissimilar Metal Joining, FSW, Tool pin geometry*

Introduction

The friction stir welding (FSW) is solid state welding process for joining the wide range of materials like copper, bronze, alumi[1]num, polymer, magnesium and steel materials which are

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widely used in many industrial applications. The FSW process was invented by The Welding Institute (TWI) of Cambridge, England in 1991 [1]. FSW process is simple in construction, pollution free, cost efficient and becomes very popular in automobile, aircraft, marine and aerospace industries. In FSW process the weight of the joint is minimum as compare to conventional welding processes and in this process no liquid state for weld pool, the welding joint takes place in the solid phase below the melting point of the materials. Thus, the problems related to the fused material eliminated by FSW process. [2] FSW has many advantages over traditional welding techniques. FSW process has ability to weld dissimilar metals especially in automobile industry where there is need of joining steel to aluminum.[3] FSW is performed at temperature under the base metal's melting point. So, all problems relating to re-solidification of welded material, like, brittleness, crack generation and porosity and can be avoided. [4] A non-consumable rotating tool with a specified profiled threaded/unthreaded pin and shoulder is turned at a fixed speed in friction stir welding. The tool is inserted between two pieces of sheet or plate material, and frictional heat is used to locally plasticize the joint region. The tool is then allowed to stir the joint surface in the direction of joining. During the tool plunge, the rotating tool only rotates in one direction until the shoulder reaches the surface of the work material; this is known as the tool's dwelling phase. During this stage of tool plunge, lateral force orthogonal to welding or joining direction is produced. The upper surface of the weld is made up of material drawn by the shoulder from the retreating side of the weld and deposited on the advancing side. Following the dwell period, the tool traverses along the joining path, producing force parallel to the direction of travel known as traverse force. Following a successful weld, the tool enters the termination phase and is removed from the work piece. [5] During the welding process, the pieces must be securely secured to a backing bar in order to prevent neighbouring joint faces from being driven apart. The tool pin should be somewhat shorter than the required weld depth, and the tool shoulder should be in close contact with the work surface. Aside from tight clamping of the weldable elements, the key to success is to select the best parameters, which include welding speed, axial force, rotating speed, tool pin, and shoulder profile. Figure 1 depicts a schematic illustration of the friction stir welding process. It denotes two terms: advancing side and retreating side. The advancing side is when the rotation of the tool is the same as the tool traverse direction along the weld line, and the retreating side is when the rotation of the tool is opposite to the tool traverse direction. The most significant tool in the friction stir welding process is the non-consumable tool, which provides the following functions: heating the work piece, moving the material to form the connection, and containing the hot metal beneath the tool shoulder. Friction stir welding tools are made up of a pin and a shoulder, and each serves a specific purpose.

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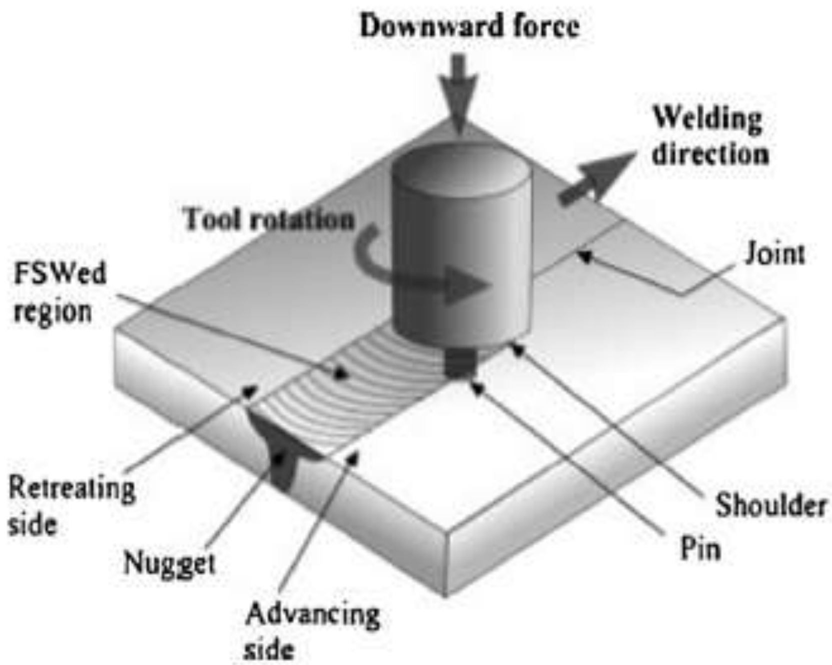


Fig.1 Schematic representations of friction stir welding [6]

2. Literature Review

2.1. Process Parameters

In FSW strategy process parameters are assumes significant job. Some significant procedure parameters are Tool rotational speed, Tool transverse speed, axial force and Tilt angle of tool. tool rotational speed (N)", estimated in "rpm" in "clockwise" or "counter clockwise" just as "tool traverse speed (v)", always estimated in "mm/min" over the weld joint in the welding heading are the most noteworthy procedure parameters of FSW process. "Mixing" just as "blending" of material happens about the apparatus test due to turning activity of the tool. While the consequent material is moved from front-end to the backside, because of tool probe movement, in this way finishing the activity. High temperature is seen because of extra frictional warmth at more noteworthy rotational speeds, which causes outrageous material-mixing and blending. A suitable apparatus tilt point (α) is been given, to ensure that tool probe holds the material and enable it to move viably from textual style end to backside, during the cross movement. A proper "addition profundity" to a great extent subject to the test length, is likewise been considered so as to produce better welds. Yanni Wei et al. [7], while actualizing "Friction stir lap welding" on Al and Ti compound, saw that with an ensuing ascent in "tool traverse speed" the "failure load" likewise expanded and is greatest at 300 mm/min, anyway on further increment in traverse speed disappointment burden shows a diminishing pattern. Shultz EF et al. [8], broke down the impact caused on the weld joint viability because of the FSW tool probe tilt point alongside the contraption quiet submission, while applying FSW on "5083-H111 Al composite". Francesco Lambiase et al. [9], while actualizing FAJ on AA5053 Al composite moved sheets and (PVC) plate, saw that "joint quality" just as effectiveness of the vitality consumed in the proper method of welding procedure improved, with the utilization of securing casing having lower thermal conductivity(wood). It was in this way surmised, a more prominent estimation of "joint quality" having moderately littler "heating time" and synchronous decrease in "absorbed energy" is conceivable adequately with a subsequent utilization of wood as the affixing outline material. M.Muthu Krishnan et al. [10], saw that with a resulting ascend in "tool rotational speed" and "axial load", improved the components, for example, elasticity just as hardness up to a specific point, yet thus gets decreased as most extreme point is accomplished; while utilizing "Response Surface Methodology (RSM)" and " Artificial Neural Networks (ANN)" strategy to assess the ideal welding variables of Al amalgams AA6063 and A319 implied for FSW. Nonetheless, an unfortunate impact on reactions was distinguished because of ascend in "tool traverse speed".

2.2. Tool Geometry

In FSW procedure apparatus geometry is one of significant parameter for delivering the ideal joint. It is valuable for age of warmth during procedure and it is likewise useful for material stream as the apparatus is moving consistent in transverse way. The heat produces essentially by uprightness of grinding in the midst of the instrument test and base material, at the early period of the tool plunge. While further heat produces because of work piece material misshaping. The FSW device is permitted to dive up to a minute at which shoulder and material surface are not in contact to one another. Significant part of heat generation is by temperance of grating in the midst of the shoulder-material interface. The device shoulder is characterized by the "shoulder diameter (øs)" estimated in "mm", which might be level, curved, raised or looked over. While, tool probe (or pin) is generally characterized by its "probe diameter (øp)" and "probe length (or insertion depth) (lp)" both estimated in "mm", which might be flat, tapered, threaded or fluted. Yanni Wei et al. [11], executed friction stir lap welding for joining of Al and Ti amalgam with cutting pin has made of tungsten carbide. It has been seen that lap joints with higher quality. While Wu et al. [12], utilized "stationary shoulder friction stir welding (SSFSW)" to join high quality Al alloys.it has been certain that SSFSW had about 30% lesser warmth information contrasted with FSW. Likewise, more slender welds were created having contracted "heat influenced zone (HAZ) width", by goodness of stationary shoulder and better execution in "cross-weld ductile tests" and furthermore uncovered higher surface completion. Shanavas Shamsudeen et al [13] researched the impact of various profiles of tool pin for joining AA 5052 H32 aluminum combination by FSW procedure utilizing reaction surface philosophy and dark social examination. The nature of the welded joint is estimated dependent on the higher estimation of rigidity and hardness of the joint got by experimentation.

3. Experimental Procedure.

3.1 Material Used

The workpiece materials used are dissimilar aluminium alloys AA5052 and AA6082. Their chemical composition is shown in Table 1. Plates with dimensions of 200 mm×100 mm × 3 mm each of AA5052 and AA6082 are butt joined using Friction Stir Welding technique. The combined application of the dissimilar aluminium alloys are widely used in the field of marine, automobile, pipelines and structural applications. The tool used is made of HCr with shoulder diameter of 20mm and pin diameter of 4mm with pin length of 3.8mm. Of the two pin profiles, first one is the cylindrical pin profile with straight end and another one is cylindrical pin profile with chamfered end.

Table1. Chemical Composition of AA6082 and AA5052

Alloy Composition	AA 6082 (Weight %)	AA 5052 (Weight %)
Mg	0.6-1.2	2.2-2.8
Cr	0.25	0.15-0.35
Cu	0.1	0.1
Fe	0.5	0.4
Mn	0.4-1.0	0.1
Si	0.7-1.3	0.25
Zn	0.2	0.1

3.2 Design and development of Fixture.

During the Friction Stir Welding process, due to tool rotation, plunging and advancement of the tool various forces are exerted on the work piece by the tool. Hence it is necessary to clamp the work piece rigidly during the welding process against these forces. In this work a fixture is prepared for holding the work piece on to the milling machine table. The SOLIDWORKS software was used to develop the model of the fixture is shown in the figure 2. The fixture is made of a Mild Steel plate of dimensions 300 X 300 X 3 mm as a base material. The plate is drilled and made into a shape for accommodating the bolted joints. By using these bolted joints, the fixture is fixed on the slots of milling machine table.

To arrest the movement of the work piece materials due to the force generated by the tool on the work piece, around 12 stopper pins of dimensions of diameter 10 mm and length 35 mm and 12 clamps with bolted joints are used to hold the work piece. The stopper pins are used to constrain the horizontal movement of the work piece materials and clamps are used to constrain the vertical movement of the work piece materials during welding process. Separate cooling arrangement for cooling the workpiece and tool were arranged in fixture.

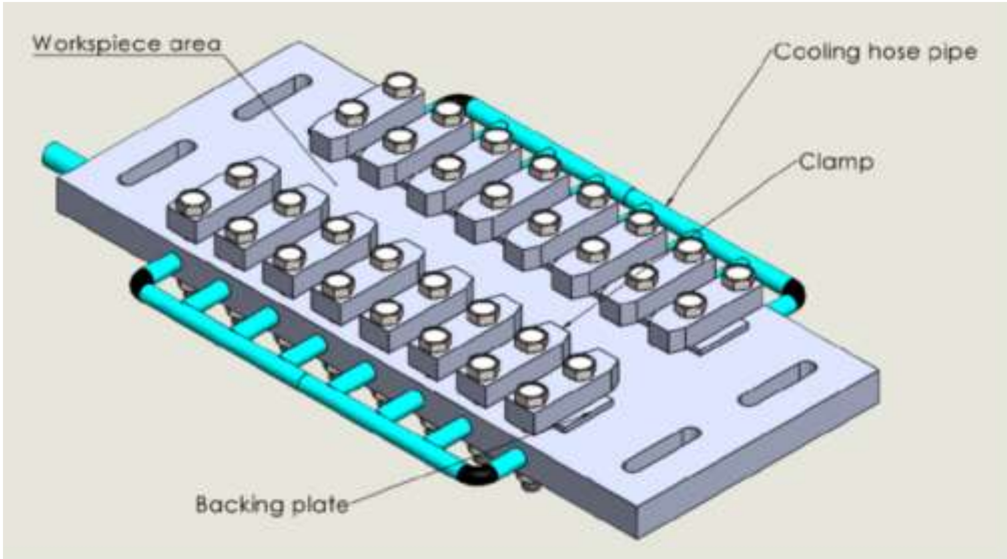


Fig.2-Design of Fixture by using SOLIDWORKS

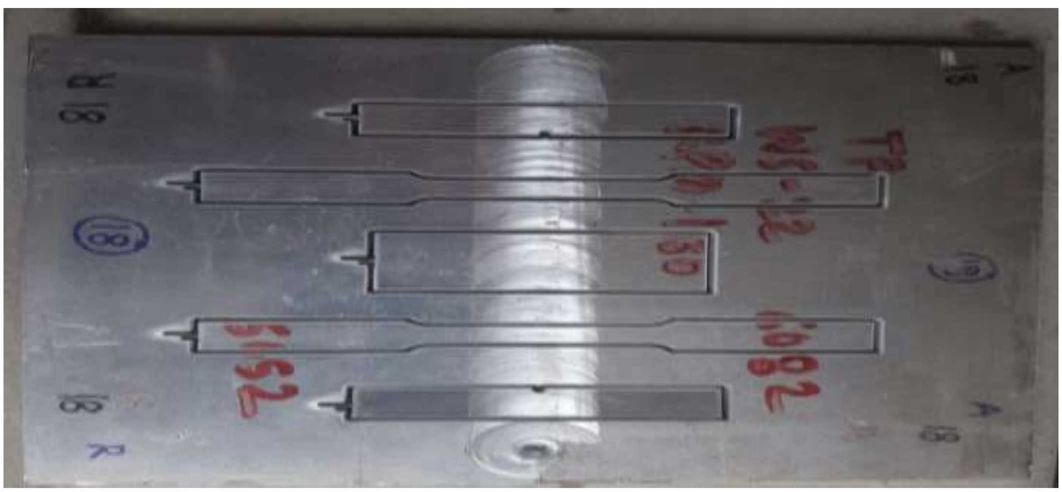
3.3 Experimental work

The two dissimilar alloy plates AA5052 and AA6082 were to be butt joined using vertical milling machine. First the workpieces were made upto the required dimensions of 200mm X100mm X 3mm. Then the workpieces were rigidly clamped with the help of a fixture on the milling table. The purpose of the fixture is to avoid the movement of the workpieces due to lateral forces developed during the welding process. Then the tool is fixed on the spindle and it is positioned on the joint line of the workpieces where the welding has to be made. Four welding joints have been made by considering the following process parameters. For all the joints the tool rotational speed of 710 rpm was kept constant. For the first two joints the cylindrical tool pin profile with straight end was used with varied welding speeds of 17 mm/m and 22 mm/m. The next two joints are made using the cylindrical tool pin profile with the chamfered end by using the welding speeds of 17 mm/m and 22 mm/m**.**

Table 2. Process Parameters

Process parameters	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**
Rotational speed (RPM)	710	710	710	710
Welding Speed (mm/m)	17	22	17	22
Tool pin Profile	Cylindrical	Threaded	Cylindrical	Threaded

Fig.3 Experimental set-up and Sample preparation.



3.4. Hardness Test

The hardness test was done in accordance with ASTM-E10. [14] Hardness test was performed on the welded specimen using the Rockwell hardness apparatus. The test was carried out on five separate locations on the welded specimen utilising a 1/16" steel bar intender and a 100 kg applied load. Table 3 displays the results.

Table 3. Hardness Test.

HARDNESS	Specimen 1 (HN)	Specimen 2 (HN)	Specimen 3 (HN)	Specimen 4 (HN)
AA5052	72	78	76	86
Near 5052	88	86	84	80
Weldment Center	96	94	90	88

Near 6082	98	82	86	80
AA6082	85	78	82	75

3.5. Tensile Test

Tensile testing was evaluated on the weldment by taking three tensile samples from each parameter by cutting across the weld region following ASTM-E8 standard methods [15]. Tensile testing was carried out on a Universal Testing Machine with a capacity of 40 tones. The specimens were then put onto the UTM machine for tensile testing. The tensile test readings are given below:

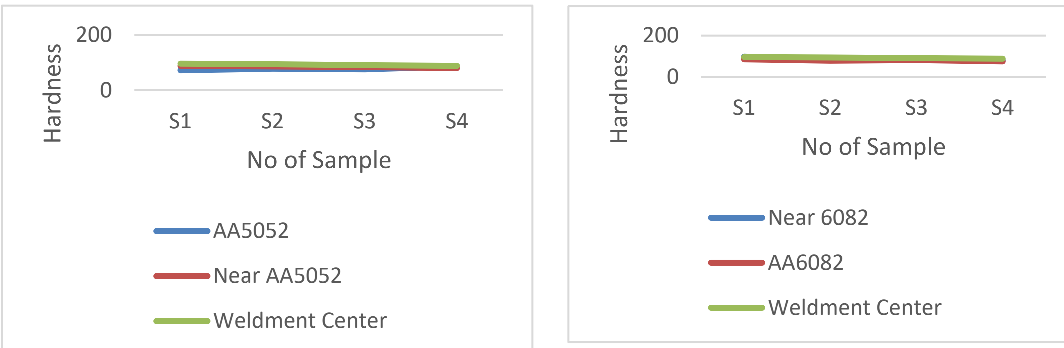
Table 4. Tensile Test.

DATA	Sample 1	Sample 2	Sample 3	Sample 4
Load (kN)	5.60	4.98	4.88	10.60
Elongation (mm)	1.20	0.02	0.05	5.40
Yield stress (N/mm2)	48.22	71.68	78.56	182.56
Load at peak (kN)	16.20	14.20	12.20	14.20
Elongation at peak (mm)	8.20	5.82	6.40	7.80
Tensile strength(N/mm2)	120	210.12	182.60	232.40
Load at break (kN)	4.80	3.66	3.20	4.80
Elongation at break (mm)	7.80	8.20	8.80	16.20

4. Results and Discussion

4.1. Analysis of hardness

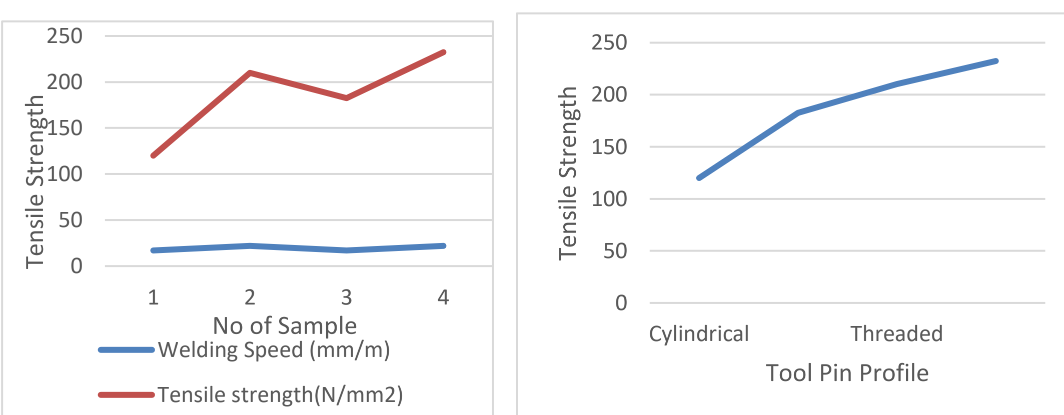
The hardness test on the two base metals yielded hardness values ranging from 70 HV to 98 HV for AA5052 and AA6082, respectively. The mean hardness values rise from 72 to 92.58 HV. This could be due to improved grain refining and mixing at 22 mm/m welding speed, which is consistent with the results published by the author [16]. Also, at the 22 mm/m welding speed precipitation of hardening precipitates was encouraged. At 17 mm/m welding speed, the average hardness of 72 HV obtained was higher than that of the AA 5052 aluminium alloy and below that of AA6082 indicating occurrence of mixing of both alloys at the nugget zone.[17] as perceived in the work of At 22 mm/m welding speed (high speed) the average hardness decreases from 98 to 77 HV, this can be attributed to dissolution of strengthening precipitates [18]. Also, at 22 mm/ m welding speed, the tool traverses faster on the material (dwelling time was low) not giving sufficient time for material coalescence to occur.[19] The obtained hardness mean values at the HAZ of the advancing side are lower than the hardness value of the base metal AA 5052 aluminium alloys, this may be attributed to the effect of heat generated during stirring and mixing stage resulting in the dissolution of the alloy's precipitates and leading to reduction in hardness [20]. On the retreating side, the hardness values were lower than that of the base metal AA6082 and this is in line with the work [21]. The NZ average hardness value was higher than the base metal AA5052 but lower than the base metal AA6082. This is because both allows are mixed in this place. Furthermore, the average hardness at the NZ is greater than the HAZ on both the advancing and retreating sides. This is due to the existence of intermetallic compounds produced during the welding process. [22]



Graph.1. Hardness at different zones

4.2. Analysis of Tensile Strength

At machine welding speed of 17 m/min the total tensile strength of the welds is significantly higher than those of 22 m/mm This may be due to the increase in thermal energy produced by the tool at higher temperature [23] and lower rotational velocity favours higher UTS value and these trends were also noticed in the previous published work [24]. Another finding was threaded pin profile gives better results as compare to cylindrical pin profile. Graph displays the UTS plot at two different tool welding speeds and two effect of pin profile on tensile strength.



Graph.2. Effect of Welding speed and Tool pin Profile on Tensile Strength.

Conclusions

The effect of input parameters on the material properties of dissimilar friction stir welded AA5052 and AA6082 utilising threaded and cylindrical tools was investigated, and the following evidences were discovered:

1] Successful dissimilar friction stir welding joint between AA 5052 and AA 6082

2] With increasing welding speed, the overall tensile strength of the friction stir welded joints rose from 120 MPa at 17 mm/m to 182 MPa at 22 mm/m.

3] The average hardness of the two alloys is higher than the softer AA 5052 alloy but lower than the harder AA 6082 alloy.

4] Based on the results, medium welding speeds promote material coalescence more than higher welding speeds.

5] Threaded pin profile welding tool produces better results as compare to cylindrical pin profile**.**

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