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Experimental Investigation on Mechanical Properties of Friction Stir Corner Welded 5086-T6 Aluminium Alloy

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Abstract - The Mechanical properties and microstructure of 5086 aluminium alloy corner welded joint by friction stir welding (FSW) were investigated. The process parameters of 160 mm/min traverse speed, 1200 rpm rotational speed and cylindrical threaded tool produced the defect free corner welded joint and the maximum tensile strength and microhardness of 101 Mpa and 84 HV of were obtained at the weld zone. The samples produced by cylindrical threaded tool were defect free welded joints and other samples constitute tunnel defects. The specimens were failed at the heat affected zone of the welded joint during the tensile test. Microstructure revealed that the refined grain formation at weld zone.

Keywords - ***Friction stir welding, Corner joint, Aluminium alloy, Tensile strength, Hardness, Microstructure***

I. INTRODUCTION

Friction Stir Welding was invented by The Welding Institute (TWI) in 1991. The process requires lower energy than conventional fusion welding processes and no consumables such as electrodes and protecting gases are needed and have been successfully applied to the aerospace, automobile, shipbuilding industries, etc. In this process a rotating tool is inserted into the butt of the work piece due to the action of the axial pressure it produces a highly plastically deformed zone through the associated stirring action. FSW is used to weld non-ferrous metals such as aluminium alloys, copper, titanium, magnesium and attempts has been made to weld dissimilar metals and steel. The 5086-T6 aluminium alloy is High strength structural alloy, easily weldable and posses high corrosion resistance property. FSW is successfully applied for different joint designs such as butt,T- joint, lap joint and corner joint. The corner joint is a joint in which two metal parts welded right angles to one another and it is applied to joining of Fuel tank, Chassis, Body frame, Engine cradle, Aluminium Ladder etc. Martin et al [1] investigated the corner joint of FSW using stationary shoulder rotating tool. However there is no adequate research on corner joint in FSW using conventional shoulder welding tool. In addition, it is difficult to understand the process parameters such as traverse speed, rotational speed and tool pin profile for corner joint using conventional shoulder welding tool and fixture [2]. Investigated the mechanical properties and microstructure of the weldments. Depends upon the results of experiments, the corner joints were discussed. In this work, corner joint was produced using friction stir welding on 5086 aluminium alloy.

II. EXPERIMENTAL SET UP

The chemical composition and mechanical properties of 5086 aluminium alloy is given in table 1and 2. The parent metal 5086 AA was cut in to 100×50×6 mm sizes. The D2 tool steel is used as the tool material, which is hot hardened high carbon high chromium tool steel. Process parameters such as tool geometry, tool rotational speed and welding speed are considered for conducting the experimentations [3]. The three types of pin profiles were used such as Tapered threaded, Cylindrical threaded and Straight Cylindrical. The diameter of shoulder and pin are 18 mm 6 mm and length of the pin is 5.8 mm [4]. The experimental process parameters for FSW are listed in table 3. The L9 orthogonal array was used to design the experiments. No defect was observed on the joints fabricated at tool rotational speed up to 1200 rpm and 150 mm/min welding speed. But at the tool rotational speed below than 900 rpm the defects were observed in the weld joints. It was observed, that tunnel defect in the advancing side of the joint at below 900 rpm and it may be due to the insufficient heat generation and insufficient metal transformation [5].

At tool rotational speed above 1300 rpm, tunnel defect was observed. It may be due to the excessive turbulence caused by higher tool rotational speed. Similar types of defects were observed in the tool rotational speed of 1400 rpm. Similarly when the welding speed was decreased below 100 mm/min and increased above 200 mm/min observed the tunnel and crack like defect at the middle of the weld cross section on advancing side were observed. It may due to the excessive release of the stirred material from bottom

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surface to the upper surface. From these observations the range of tool rotational speed was decided from 900 rpm to 1200 rpm and the range of welding speed was considered from 100 mm/min to 200 mm/min for conducting the final experimentations. The rotational speeds are 900, 1000 and 1200 rpm and welding speeds are 110,160 and 240 mm/min. the FSW experiments were completed using vertical milling machine. the schematic diagram of corner joint for FSW is shown in figure 1. a fixture is specially designed and fabricated for locating and clamping the work pieces firmly during welding. in corner joint it is difficult to hold the specimens right angle to each other during welding. the fixture consists a base plate having size of 300×150×12 mm, a backing bar screwed on the back plate having size of 55×46 mm along with this vertical and horizontal specimens of the corner joint were clamped. two strap clamps having size of 15 mm and are used to clamp the horizontal specimen on backing bar. three screws having size of 6 mm are used to clamp the vertical specimen towards the backing bar. stoppers are provided to avoid lateral and longitudinal movement of specimen during welding. mild steel was used to fabricate the fixture. the fixture is clamped on the table of vertical milling machine by means of t bolts.

The specimen are cut by electron discharge machine (EDM) to carry out the tensile test for determining the tensile strength in a computer controlled universal testing machine at a crosshead speed of 1.5 mm/min. a clamp specially designed and fabricated for clamp the samples of tensile test since the specimens of corner joint cannot hold in universal tensile testing machine for tensile test. the clamp is designed such a way that the center line of leg of the clamp and center line of vertical aluminium specimen are similar during test. Microstructure at weld zone was observed by De-wintor inverted Trinocular optical microscope. Vickers microhardness distribution conducted under the load of 500 g.f. for 10s at weld zone, 1 mm from weld zone and 6 mm from weld zone using Wilson Wolpert microhardness tester with a load testing range of 10 gms to 1 kg and least count of 0.01 microns [6].

Table 1 Chemical composition of 5086 Aluminium alloy (Mass fraction, %)

Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
0.05	0.1	0.5	3.5	0.2	0.4	0.15	0.25

Table 2 Mechanical properties of 5086 AA

Ultimate tensile strength	210 Mpa
Ultimate tensile strength	290 Mpa
Elongation	12%

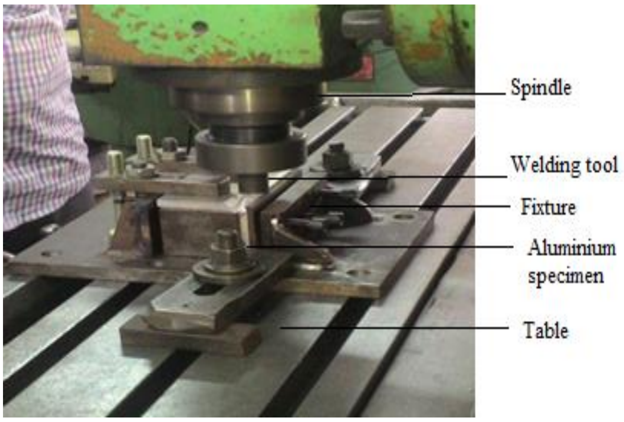

Fig. 1 Fixture for corner joint

Table 3 Experimental process parameters

Sample No.	Rotational Speed (rpm)	Welding Speed (mm/min)	Pin Profile
A	900	110	Cylindrical Threaded
B	1000	240	Cylindrical Threaded
C	1200	160	Cylindrical Threaded
D	900	160	Straight Cylindrical
E	1000	240	Straight Cylindrical
F	1200	110	Straight Cylindrical
G	900	240	Taper Cylindrical
H	1000	110	Taper Cylindrical
I	1200	160	Taper Cylindrical

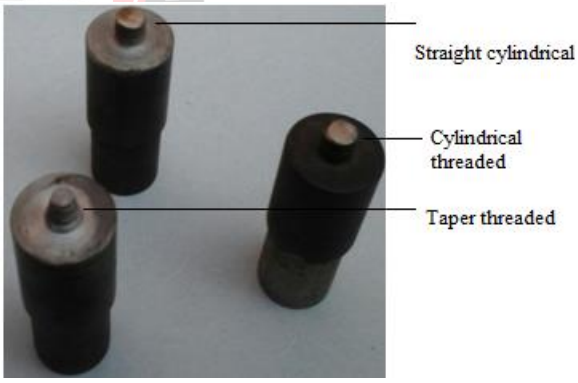

Fig. 2 FSW welding tools

Fig. 3 Schematic diagram of FSW corner joint

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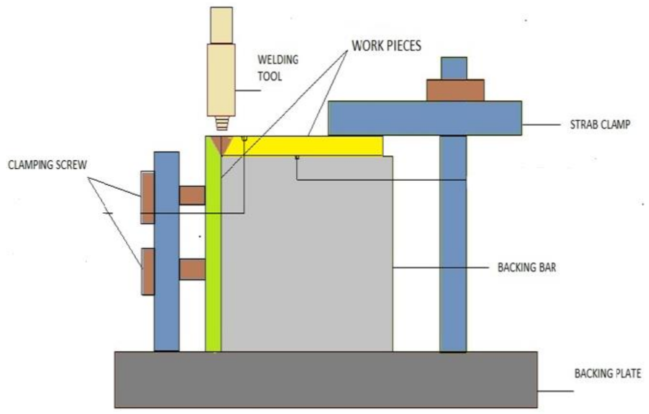

Fig. 4 Specimens after tensile test

III. RESULT AND DISCUSSION

Surface Morphology of the Weldments:

Defect free weld was done successfully by the process parameters of 160 mm/min welding speed, 1200 rpm rotational speed and cylindrical threaded tool. From nine experiments the three samples produced successful weld joint, which was welded by cylindrical threaded tool. The surface morphology of different weld samples shown in figure 5. The sample C showed the defect free and smoother weld surface than other samples. Each process parameter plays vital role during welding. The rotational speed of tool produces frictional heat with stirring and mixing of material around the tool pin. The welding speed promotes the translation of tool that pushes the stirred material from front to behind of the tool pin. Axial force pushes the plasticized material in the weld zone to complete the extrusion process [7], [10].

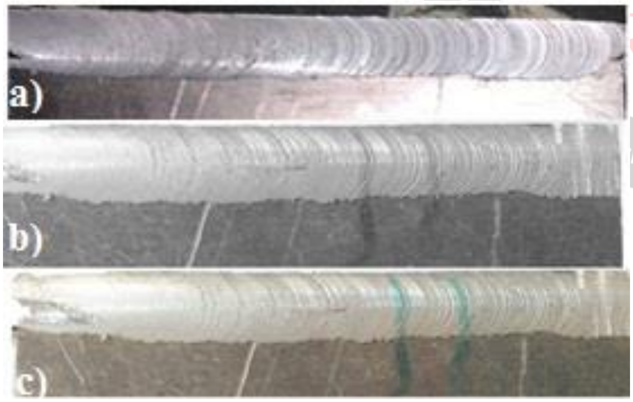

Fig. 5 Surface morphology of weld sample

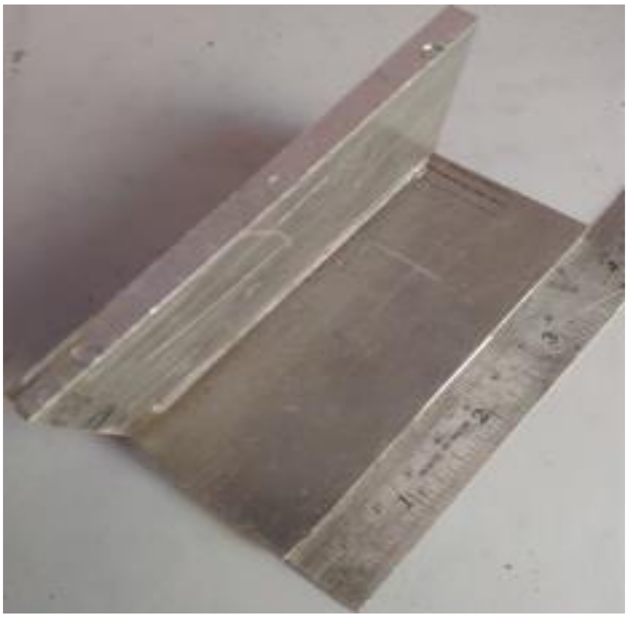

Fig. 6 Friction stir welded corner joint

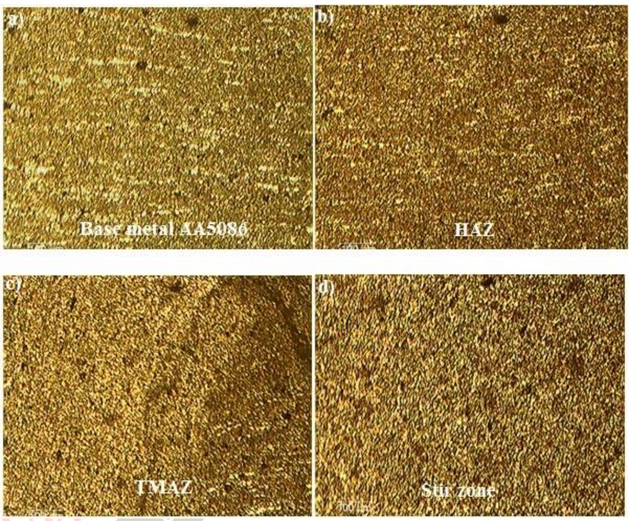

Fig. 7 Micrographs of weld at welding speed of 160 mm/min, rotational speed of 1200 and cylindrical threaded tool

Microstructure of Weld Zone:

Fig. 7 shows the optical micrographs of the cross-sections normal to the tool traverse direction of the weld. Based on the microstructural characterization of grains, three different zones such as thermomechanically affected zone (TMAZ), heat affected zone (HAZ) and stir zone (SZ) have been identified. Figs. 7a shows the microstructure of parent material. Fig. 7b shows the microstructure of heat affected zone. It was difficult to find difference in grain structure of heat affected zone and parent material due to low thermal affectability of the material because the heat is mainly concentrated in stir zone. Fig. 7c shows the microstructure of the thermomechanically affected zone. The boundary between the weld zone and thermomechanically affected zone visible quite clearly in the microstructure. Thermomechanically affected zone

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shows highly elongated grains of aluminum alloy without recrystallized microstructure. Both the sides of the thermomechanically affected zone reveal a similar structure. It is observed from the microstructure that the stir zone separated from the deformed zones of the TMAZ a distinct grain boundary. The TMAZ is affected thermally and plastically deformed but not recrystallized. Fig. 7 (d) shows the micrograph of the stir zone. The grains were refined at the stir zone due to frictional heat and mechanical deformation by stirring action of the tool. The defects such as tunnel, voids, inclusion did not present in the weld.

Tensile Strength of the Welded Joints:

The tensile tests were done for the corner joints to determine tensile strength of the weldments [1]. The maximum tensile strength of pull test 101 Mpa was achieved by sample C welded by the process parameters of 160 mm/min traverse speed, 1200 rotational speed and cylindrical threaded tool. The relationship between specimen and tensile strength shown in figure 8. The other specimens A and B produced 83 and 81 Mpa tensile strengths. The samples were failed at heat affected zone (HAZ) during pull test [8]-[9]. The tensile properties of the

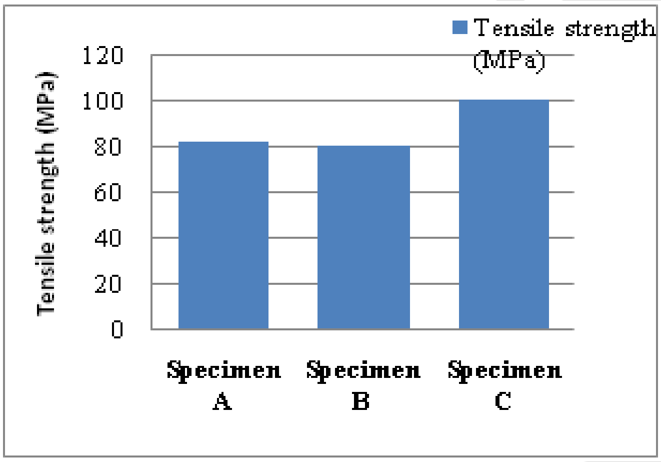

Fig. 8 Tensile strengths of AA5086 welded joints

welded joints are depends on process parameters such as rotational speed of the tool and welding speed, tool pin profile, axial force of the tool and tool tilt angle etc.[6].

Microhardness Distribution:

The Vickers hardness was tested at the weld zone, 1 mm from the weld zone and 6 mm from stir zone (SZ), the maximum microhardness of 84, 82 and 79 HV respectively were found at the stir zone, 1 mm from stir zone and 6 mm from the stir zone by the specimen C. The sample A produced the microhardness values of 81, 80 and 76 HV respectively at the stir zone, 1 mm from stir zone and 6 mm from the stir zone. The sample B produced the hardness values of 78, 76 and 70 HV respectively at the stir zone, 1 mm from stir zone and 6 mm from the weld zone. The maximum hardness 84 HV was obtained on specimen C at welded zone due to fine grain size welded by the process parameters of 160 mm/min traverse speed, 1200 rotational speed and cylindrical threaded tool similarly the maximum hardness was shown at the stir zone of the weldments [12]. Hardness profile of FSW corner joints is shown in figure 9. Low hardness has registered at heat affected zone than nugget zone and all joints failed in heat affected zone region close to the thermo mechanically affected zone due to minimum hardness during tensile testing [8]-[9].

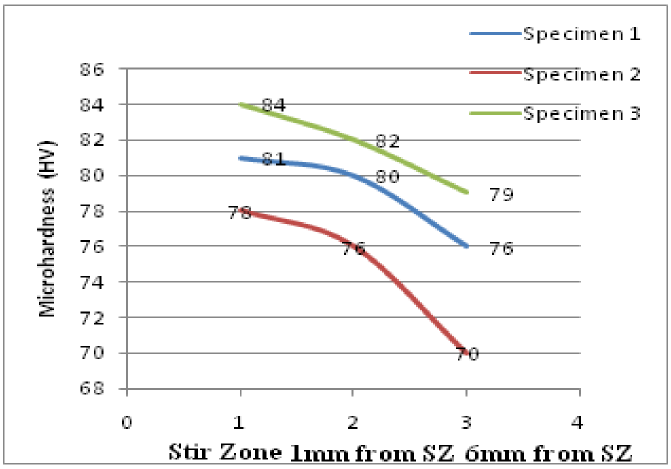

Fig. 9 Microhardness profile of FSW corner joints

IV. CONCLUSION

Successfully the corner joints were welded by FSW process in 5086 Aluminium alloy and observed followings,

1. The process parameters of 160 mm/min traverse speed, 1200 rpm rotational speed and cylindrical threaded tool produced defect free welded joint.

2. The maximum tensile strength of corner joint was 101 Mpa and 84 HV of microhardness were acquired at the weld zone.

3. The microstructure at weld zone reveals that refined grain formation and good weld penetration.

4. Microhardness is maximum at stir zone because the formation of refined grains.

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