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Effect of Process Parameters in Friction Stir Welding of Dissimilar Aluminium Alloys

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Abstract. Friction stir welding was invented at Welding institute, United Kingdom in the year 1991 and has ever since been proved to be one of the best solid state joining methods for materials such as aluminium and magnesium. Some of the aluminium alloys which are not able to weld (Al-Cu, Al-Zn-Mg alloy) by fusion welding techniques, which produce defects and reduce the mechanical properties on the weld nugget could be welded using friction stir welding (FSW) successfully with excellent joint efficiencies. However effect of the process parameters on the properties of weldment have not been investigated fully. In this study, 5mm thick plates of aluminium alloys AA2024 (4.4%Cu, 0.6%Mn, 1.6%Mg) and AA7075 (2.5%Mg, 1.4%Cu, 0.2%Cr, 5.6%Zn) is selected for investigation. The FSW welding process was conducted on varying the welding process parameters such as tool rotation speed (RPM), welding speed (mm/min) and tool pin profile by keeping downward force (kN) constant. The properties such as defects, macro and microstructure, micro hardness, tensile and bend behavior on welded plates were studied. Sixteen sets of butt welds were produced using straight and tapered cylindrical with left hand threaded FSW tool pins. It has been found out that defect free weld could be produced with the help of tapered cylindrical with left hand threaded tool pin with tool rotation speed of 600 RPM, welding speed of 30 mm/min and downward force of 2.5 kN

1. Introduction

Friction stir welding involves an extensive utilization in aerospace, automobile, shipbuilding, and various production activities. The process shows the domination in non-heat treatable aluminum alloys over the fusion welding which is not feasible [1]. Thus basic survey both on the weld structure and on the relationship between micro structure with mechanical characteristics and process parameters have been initiated. A considerable influence of Friction Stir Welding is that the higher feasibility of welding dis-similar alloys compared to inconveniences with fusion welding procedures. One of the potential functions concerns the welding of strong performance materials, such as particle reinforced aluminium alloy, to wider structures formed from a poorer performance. A uniquely developed tool, formed from material that have a strong and wear resistant with respect to the material being joined, is twisted and plunged into the adjoining edges of the aluminium alloy to be welded. After an access of the tool pin to approximately the depth of the plate of aluminium alloy, the shoulder of the tool will just start penetrate into the aluminium plate due to the rotation of a tool. The rotating pin generates frictional heat on the aluminium alloy and causes the plastic deformation and movement of material flow from the advancing side of the tool to the retreating side where it relaxes and develops to a strong weld. [2-14].

2. Experimental Work

The friction stir welding of AA 2024 and AA7075 were preceded with butt joint configuration on

FSW machine which is displayed in Figure 2.1. The machine specifications are

1. Motor capacity : 12kW / 440V AC drive.
2. Spindle speed : 200 to 2000 RPM.
3. Downward Force : 0.5 to 10 kN.
4. Traverse feed : 10 to 150 mm/min.

Figure 1. Friction stir welding machine

2.1. Welding parameters

In this investigation, aluminium alloys AA2024 and AA7075 welding criteria such as transverse speed and rotation were altered and the downward axial force is maintained constant. The welding criteria are indicated in Table 2.1.

Table 2.1 Weld parameters – Friction stir weld of Dissimilar aluminium alloys

S.No.	Weld parameters	Values
1	Downward Force (kN)	2.5
2	Welding Speed (mm/min)	20,30,40,50,60
3	Tool Rotation Speed (RPM)	600,700,800,900

Tool parameters

The FSW tool pin were formed by M**2** HSS and which was hardened and tempered to 50 HRC. Three different pin profiles (i) straight pin (cylindrical with left handed threading) and (ii) taper pin (cylindrical with left handed threading) were used and are shown in Figure 2.2 (a-b).
The chemical composition for the tool pin is given in Table 2.2. Tool dimensions for the three pin profiles are given in Table 2.3.

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Table 2.2 Tool material composition

Material/Alloy composition	C	Cr	W	Mo	V	Fe
M2	0.85	4.0	6.0	5.0	2.0	remaining

(a) Straight Cylindrical Threaded (b) Taper Cylindrical Threaded
Figure 2.2 Tool Pin profiles

Table 2.3 Tool Pin Profile Dimensions

Total length (mm)	Shoulder length(mm)	Shoulder dia (mm)	Pin length (mm)	Pin dia (mm)	Pitch (mm)	Taper pin dia (mm)
100	10	18	4.5	6	0.5	Major : 6 Minor : 5

Sixteen plates of butt-configuration weld were carried out for dissimilar AA2024 and AA7075 aluminum alloys; by altering the weld parameters tool transverse speed, rotational speed and constant downward force with the utilization of straight pin and taper pin. Eight sets of welds were made with the help of straight tool pin (ST1 to ST8) and another eight sets with taper tool pin (TT1 to TT8). The welding process parameter window is given in Table 2.4.

Table 2.4 Welding Parameters for dissimilar welding of AA2024-AA7075

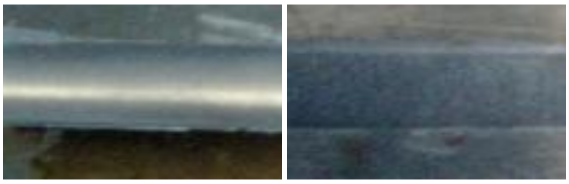
Specimen Code No.	Tool (Cylindrical shaped and threaded)	Tool Rotation Speed (RPM)	Welding Speed (mm/min)	Downward Force (kN)
ST1	Straight Tool	600	30	2.5

ST2	Straight Tool	700	30	2.5
ST3	Straight Tool	800	30	2.5
ST4	Straight Tool	900	30	2.5
ST5	Straight Tool	700	20	2.5
ST6	Straight Tool	700	40	2.5
ST7	Straight Tool	700	50	2.5
ST8	Straight Tool	700	60	2.5
TT1	Taper Tool	600	30	2.5
TT2	Taper Tool	700	30	2.5
TT3	Taper Tool	800	30	2.5
TT4	Taper Tool	900	30	2.5
TT5	Taper Tool	800	20	2.5
TT6	Taper Tool	800	40	2.5
TT7	Taper Tool	800	50	2.5
TT8	Taper Tool	800	60	2.5

3. Result and Discussion

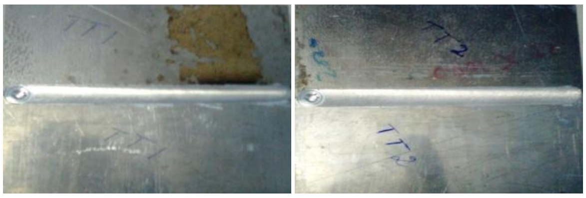
TT1 to TT8 welds were carried out with the taper cylindrical threaded tool pin. Only tool rotation speed is altered in the welds TT1 to TT4 and remaining parameters were maintained constant. In TT5 to TT8 welds, welding traverse speed is altered and other parameters were maintained constant which is presented in Table 2.4. Weld plate TT5 got the worm hole defect in visual inspection which is shown in Figure 3.1, on the other plates no such irregularities were discovered. TT1 weld plate revealed a smooth appearance at the weldment whereas poor surface condition like sand paper display was noted at the weldment of the plates TT2 to TT8; this is due to the tremendous heat caused during welding [2].

Fig. 3.1 Worm hole defect



(a)Smooth surface (b) Poor surface

Fig. 3.2 Surface Qualities at the Weldment



(a) TT1 Weld Plate *(b) TT2 Weld Plate*

(c) TT3 Weld Plate *(d) TT4 Weld Plate*

(e) TT5 Weld Plate *(f) TT6 Weld Plate*

(g) TT7 Weld Plate *(h) TT8 Weld Plate*

Fig. 3.3 TT Series Butt Welded Plates

The particles of aluminium contribute to hold themselves to the surface of the shoulder of the tool and are snatched out of the weld face surface and turned over to another position as shown in Figure 3.2. The welded plates are displayed in Figure 3.3.

ST1 to ST8 welds were made with the straight cylindrical threaded tool pin. Similar to TT series welded plates, particularly tool rotation speed is altered in the welds ST1 to ST4 by holding other parameters as constant. In ST5 to ST8 welds, welding traverse speed is varied and other parameters were kept constant which are given in Table 2.4. Weld plates ST3, ST4, ST5 and ST8 got the worm hole defect during visual analysis, on the other plates no such defects was observed. Like TT series welds poor surface appearance (like sand paper surface) was detected at all the weldment of ST1 to ST8, which is revealed in Figure 3.2 and the welded plates are shown in Figure 3.4.

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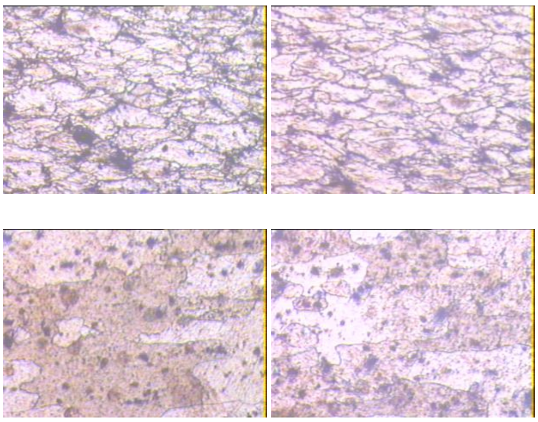
(a) ST1 Weld Plate *(b) ST2 Weld Plate*

(c) ST3 Weld Plate *(d) ST4 Weld Plate*

(e) ST5 Weld Plate *(f) ST6 Weld Plate*

(g) ST7 Weld Plate *(h) ST8 Weld Plate*

Fig. 3.4 ST Series Butt Welded Plates



(a) AA 2024 Aluminum Alloy *(b) AA 7075 Aluminum Alloy*

Fig. 3.5 Base metal microstructure

Microstructure:

The microstructure of the welded joint is properly arranged in to four sectors namely base metal (BM), thermo mechanically affected zone (TMAZ), heat affected zone (HAZ) and weld nugget zone (WNZ). The microstructure of the base alloys is presented in Figure 3.5 and microstructures

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of different region of the weld region for dissimilar aluminium alloy AA2024-AA7075 are shown in Figure 3.6.

The microstructure of AA2024 indicated the presence of elongated grains of mean size of 10µm, whereas AA7075 showed the presence of large grains of mean size of about 40 µm.

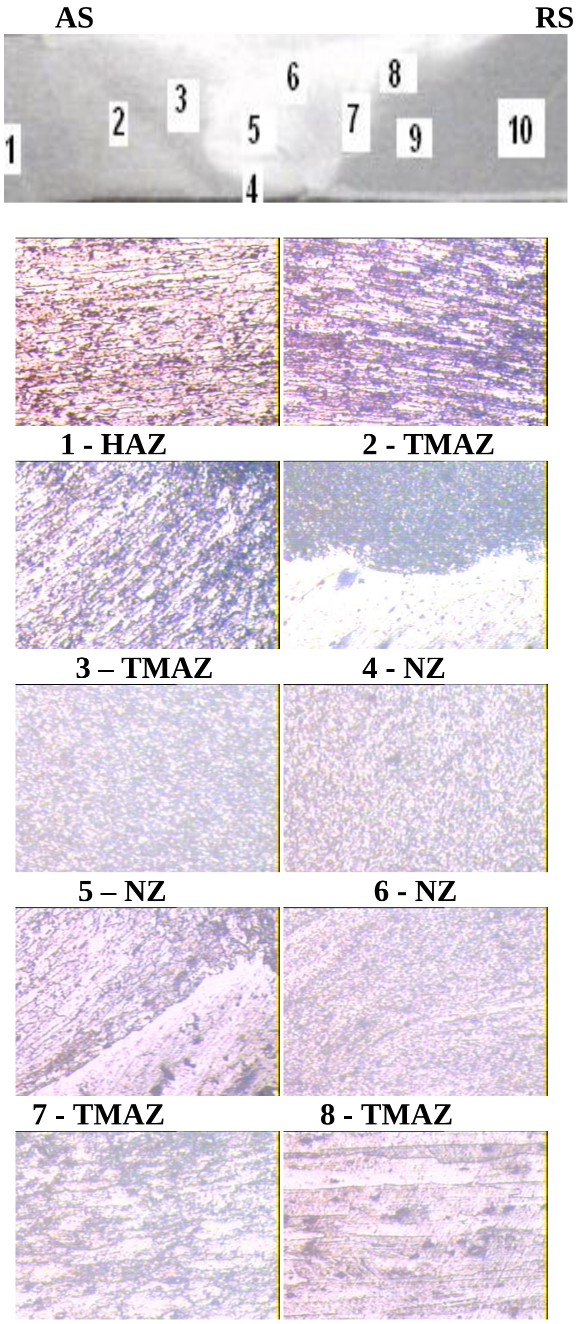

Fig. 3.6 Microstructure of Different Region at the weldment

The microstructure of the various zones of the TT1 welded plate is presented in Figure 3.6. It indicates the microstructure at the weld nugget zone is comprised of the fine equiaxed

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recrystallized grains related to the microstructure of the base metals.

The initial grain and sub grain boundaries are transformed into nearly fine equiaxed recrystalization due to high temperature and high rate of deformation in this region. Whereas in thermo mechanically affected zone and heat affected zone microstructure gets larger, elongated grains boundaries in the both advancing and retreating side.

Microhardness:

The micro hardness test was conducted for TT1, TT2, ST1 and ST2 welded plates. The tests were conducted for every 2 mm gap from the weld center point (on weld nugget). The results are tabulated in Table 3.1 and are shown in Figure 3.7. The hardness values of heat affected zone (HAZ), thermo mechanically affected zone (TMAZ) and the weld nugget (WN) is less than that of base metal (BM). But the hardness in the weld nugget region is considerably increased in correlation to the HAZ and TMAZ which is accountable to the grain refinement in WN, due to intensive stirring which is shown in Figure 3.7. In frequent situations the hardness of the advancing side was observed to be higher than the hardness of the retreating side. This could be due to the initial high hardness of AA7075 (160 VHN) in comparison with the hardness of AA2024 (154 VHN).

Table 3.1. Micro Hardness at the Weldment

Weld Dist. (micro meter)	Retreating side			Centre point			Advancing side		
	-8	**-6**	**-4**	**-2**	**0**	**2**	**4**	**6**	**8**
TT1	122	126	139	149	152	151	147	135	133
TT2	123	130	137	148	153	150	145	131	130
ST1	121	128	135	147	152	150	148	130	125
ST2	120	125	136	148	151	149	141	130	122

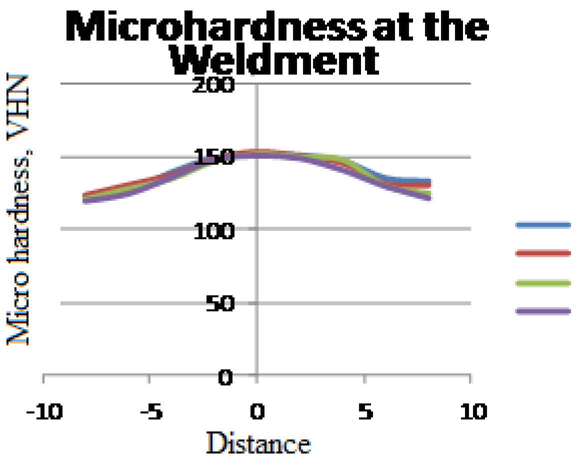


Fig. 3.7. Micro hardness at the weldment

Tensile Properties:

For AA2024-AA7075 alloy, TT1, TT2, ST1 and ST2 welded plates were tested and the results are given in Table 3.2. The tested specimens are shown in Figure 3.8. Compared to base metals, the welded plate TT1 tensile properties were considerably decreased. But in other plates TT2, ST1 and ST2 tensile properties were largely decreased due to the effect of the tunnel defect in the weldment. The fractured surface of the tensile test specimens are displayed in Figure 3.9. The location of the fracture is between the weld nugget zone (NZ) and thermo mechanically affected zone (TMAZ). The fracture surface shows a groove like feature at the bottom of the tunnel defect, similar feature in the fracture surface of the FSW AA6061 and AA2219[4,9].

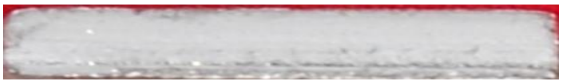
(a) TT1 Specimen

(b) TT2 Specimen

(c) ST1 Specimen

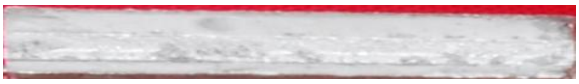
(d) ST2 Specimen

Fig. 3.8 AA2024-AA7075 Tensile Tested Weld Specimen



TT1 Tensile Specimen

TT2 Tensile Specimen



ST1 Tensile Specimen

ST2 Tensile Specimen

Fig. 3.9. Fractured Surface of Tensile Specimen at weldment

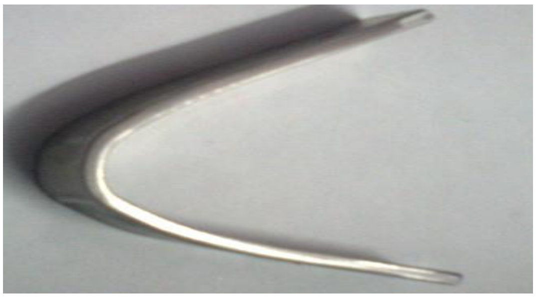
Table 3.2 AA2024-AA7075 Tensile Test Results

Combination	**0.2% proof stress (MPa)**	**Tensile Strength (MPa)**	**Elongation (%)**	**Joint efficiency (%)**
AA2024 **(Base material)**	348	459	20	
AA7075 **(Base material)**	384	439	17	
TT1	319	335	15.5	74.6
TT2	262	278	11	61.9
ST1	113	119	9.2	26.5
ST2	109	117	6	26

Bend behavior:

For AA2024-AA7075 alloy, only TT1 welded plate welded plates were tested for both face and root bend and the results are given in Table 3.3. The tested specimens are displayed in Figure 3.10.

(a) Root bending



(a) Face bending

Fig. 3.10. AA2024-AA7075TT1 Root and Face Bend Tested Weld Specimens

The samples reveal that, face bend of the welded plate allows very high bend angles passes the bend test. In weld nugget no cracks were observed. But in the root bend the cracks were found after 42 degrees of the bend test.

Table 3.3 AA2024-AA7075 Bend Test Results

Combination	Root bend	Face bend
TT1	Cracks observed after 42 degrees of bend	No cracks observed

4. Conclusion

- Quality welds could be produced with the taper cylindrical threaded tool pin, at 600 RPM tool rotation speed, 30 mm/min welding speed and 2.5 kN downward force. No defect occurred in weld nugget region.
- The hardness is increased in the weld nugget zone compared to the other zones due to the fine and equiaxed grains observed in the weld nugget region. But hardness values of WNZ, TMAZ and HAZ is decreased compared to the base metal.
- Tensile strength of the welded plate TT1 decreased to 335 MPa compared to the base metal value of about 450 MPa, but in other welded plates properties were largely decreased.
- The welded specimens passed only face bend test allowing for very high bend angles and no cracks were observed in weld nugget. But cracks were observed after 42 degrees of bend during the root bend test.

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