Mechanical and bending characteristics of dissimilar friction stir welded AA 2024 T6 - AA 7075 T6 butt joints

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ABSTRACT

Friction stir welding has proved as one of the best solid state joining method for materials such as aluminium and magnesium. Some of the aluminium alloys which are not weldable (Al-Cu, Al-Zn-Mg alloys) by fusion welding techniques, and or produce defects and reduce the mechanical properties, could be welded using friction stir welding (FSW) successfully with excellent joint efficiencies. However, the process parameters exert significantly on the properties of weldment and therefore needs to be investigated thoroughly.

In this study, friction stir welding of dissimilar aluminium alloys AA2024 & AA7075 are selected. The welding process were conducted on varying the welding process parameters such as Tool rotation speed (rpm), Welding speed (mm/min), Downward force (kN) and Tool pin profiles. The mechanical properties and bending behavior on welded plates were studied and compared with the base metal. Experiments were performed with rotational speeds 600, 700, 800 and 900 rpm at six welding speeds i.e. 20, 30, 40, 50, 60 and 70mm/min keeping constant axial load 2.5kN and tool tilt angle 0°. It was found that there is no defect concentration for the tool speed rotation of 600 rpm, welding speed 30 mm/min and 2.5 kN downward force. Tensile and bend test values were also reported.

Keywords: Friction stir welding, Tool rotation speed (rpm), Welding speed (mm/min), downward force (kN), Tool pin profiles, Aluminium alloy 2024 and 7075.

1.0 INTRODUCTION

AA 2024 –T6 alloys are high strength aluminium (Al), copper (Cu), and magnesium (Mg) alloy have wide applications. Alloys of this class are not easy to weld due to suffering of severe softening in the heat affected zone(HAZ) with their precipitates dissolution during the thermal cycle. To improve the mechanical properties it is necessary to overcome the HAZ softening. AA 7075-T6 is an age- hardenable aluminium alloy widely used in aerospace applications due to its high strength. In the fusion welding process such as conventional GTA and laser welding processes, dendritic structure develops in the fusion area leading to drastic decrease in strength. The friction stir welding process is a solid state welding process in which solidification related microstructure and the presence of brittle inter-dendritic and eutectic phases are eliminated. FSW therefore can be used to improve weldabilty of such aluminium alloys without losing mechanical properties.

Friction Stir Welding (FSW) permits a wide range of parts and geometries to be welded and was invented by W. Thomas and his colleagues at The Welding Institute (TWI), UK, in 1991. FSW has a wide application potential in ship building, aerospace, automobile and other manufacturing industries. The process proves predominance for welding heat treatable or powder metallurgy aluminum alloys, which are difficult to weld by the fusion welding. Thus fundamental studies on the nugget formation and the relation between microstructure, mechanical properties and process parameters have recently been started. Above all, the great advantage of FSW is in

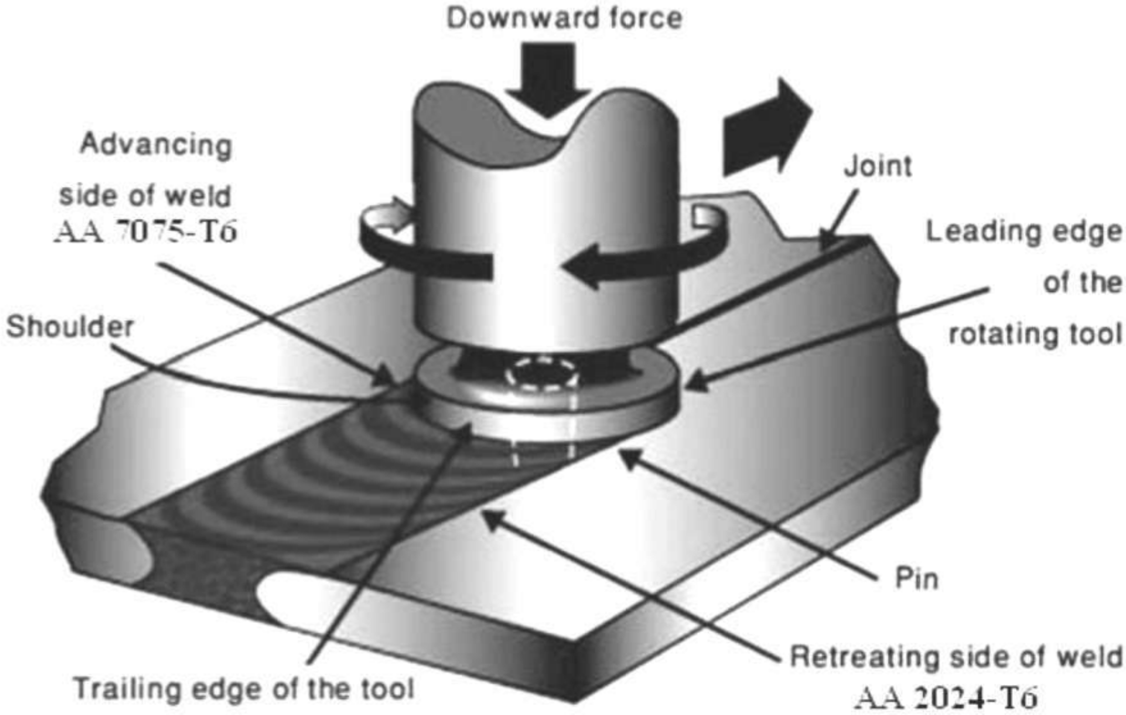

Fig.1 : Schematic illustration of Friction Stir Welding

particular, the possibility of joining dissimilar materials, which are great difficult to weld by classic fusion welding techniques.

Friction stir welding is a relatively simple process as shown in **Fig.1**.

A specially shaped tool, made from material that have a hard and wear resistant relative to the material being welded, is rotated and plunged into the abutting edges of the aluminium parts to be joined. After entry of the tool probe to almost the thickness of the material and to allow the tool shoulder to just penetrate into the aluminium plate, the rotating tool is traversed along the joint line. The rotating tool develops frictional heating of the material, causing it to plasticize and flow from the front of the tool to the back where it cools and consolidates to produce a high integrity weld, in the solid phase. During FSW between two metal sheets, one sheet is on the advancing side (AS) and the other is on the retreating side (RS). At the AS the rotational and welding speed are in the same direction, opposite in the RS.

In FSW the nugget zone is located in the middle and at each side three different zones can be detected. As shown in **Fig.2**, these regions are known as (a) the base metal (b) the HAZ; (c) the thermo mechanical affected zone (TMAZ) and the Nugget zone (NZ). In the FSW process, parameter selection and tool geometry are among the key factors that determine the quality of the fabricated joint. The suitable combination of different

Fig.2 : Typical cross section of the weld (600rpm, 30mm/min, 2.5kN, Taper cyl. threaded tool)

parameters such as welding speed, rotational speed, tilt angle and pin geometry could lower the force exerted from the tool and improves the quality of the weld and can give rise to less energy needed for the process to reach the plastic state. Since the plastic flow is responsible for obtaining the weld with high tensile strength and fewer defects, the tool geometry in addition to welding parameters plays a role in achieving a quality weld [1].

The mechanical properties of the joints evaluated by tensile test showed a net increase in strength in longitudinal direction with respect to the transverse one [2]. The presence of the FSW marking may reduce the fatigue behavior, but compare to the parent materials it is acceptable and allows FSW as an alternative joining technology for the aluminium sheet alloys [3]. Microstructures of A356/6061Al joints showed mixed structures of two materials. The onion ring pattern, which appeared like lamellar structure, observed both at the retreating side and the weld center. Microstructure of the weld zone is mainly fixed at the retreating side material and some of the advancing side material. Hardness of the stir zone is slightly lower than that of 6061Al base and higher than that of A356 alloy base metal [4]. Elangovan and Balasubramanian [5] investigated the effect of different tool pin geometries and rotational speeds on the weld quality of AA2219 alloy joints. They used tensile properties and macrostructure analysis to study the relation between FSW parameters and mechanical properties. Bahemmat et al. studied the effect of the welding parameters on the mechanical and metallurgical properties and fracture characteristics in AA7075-T6 alloy. Cavaliere and Panella [7] investigated the micro hardness, fatigue, and residual stresses in AA2024-T3 and AA7075-T6 dissimilar joints. Also with their co-workers, they investigated the effect of welding parameters on the microstructure and mechanical properties of the dissimilar joint of AA6082–AA2024.

Selection of process parameters is an important issue in the FSW process particularly in joining dissimilar aluminium alloys. In the present paper, the effect of different welding speeds and rotational speeds on the weld characteristics of AA7075-T6 and AA2024-T6 fabricated by two tool pin profiles is investigated. The quality of the joint is evaluated by macrostructural analysis and the reasons for probable defects are clarified. Mechanical characteristics of the weld, including ultimate strength, percentage elongation, and Vickers microhardness for different joints are measured.

2.0 EXPERIMENTAL PROCEDURES

Aluminium alloys of AA7075-T6 and AA2024-T6 were selected for fabricating dissimilar joints using FSW process. The thickness for both AA7075-T6 and AA2024-T6 strips were 5mm.The strips were placed in a butt joint configuration and the welding process was carried out normal to the rolling direction of the plates. The length and breadth of the plates are 200 and 100mm. Chemical compositions of AA7075-T6 and AA2024-T6 are given in **Table 1**. **Table 2** shows the mechanical properties of the base metals. Geometry of the two pin profiles used to perform the welding process is shown in **Fig.3**. The tool is made up of M2 high speed steel which was tempered and hardened to 50 R_c. The welding process was accomplished at six welding speeds; 20, 30, 40, 50, 60 and 70mm/min and four rotational speeds 600, 700, 800 and 900 rpm. The tilt angle is set to 0° for all tests keeping constant axial load 2.5kN. The experimental set up is shown in **Fig.4**.

Table.1 : Chemical composition for the aluminium alloys (Base metals).

Material	Si	Fe	Cu	Mn	Mg	Zn	Cr	Al
AA2024-T6	0.103	0.136	4.416	0.535	1.646	0.011	0.1	Remaining
AA7075-T6	0.062	0.186	1.445	0.019	2.55	5.602	0.195	Remaining

Table.2 : Mechanical properties of the base metals.

Material	YS MPa	UTS MPa	% of Elongation	Hardness (Vickers)
AA2024-T6	327	461	29.5	154
AA7075-T6	498	593	17.7	160

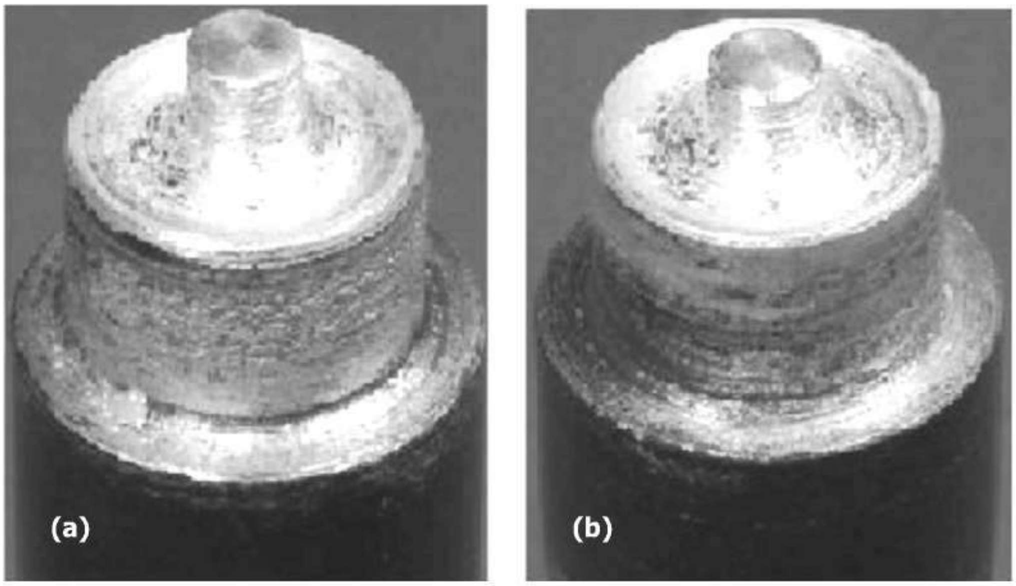

Fig.3 : Tool pin profiles (a) Straight cylindrical threaded (ST) (b) taper cylindrical threaded (TT)

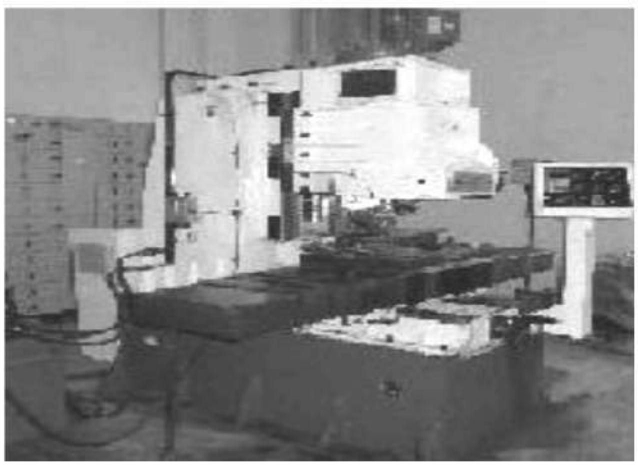

Fig.4 : Set up of the FSW equipment

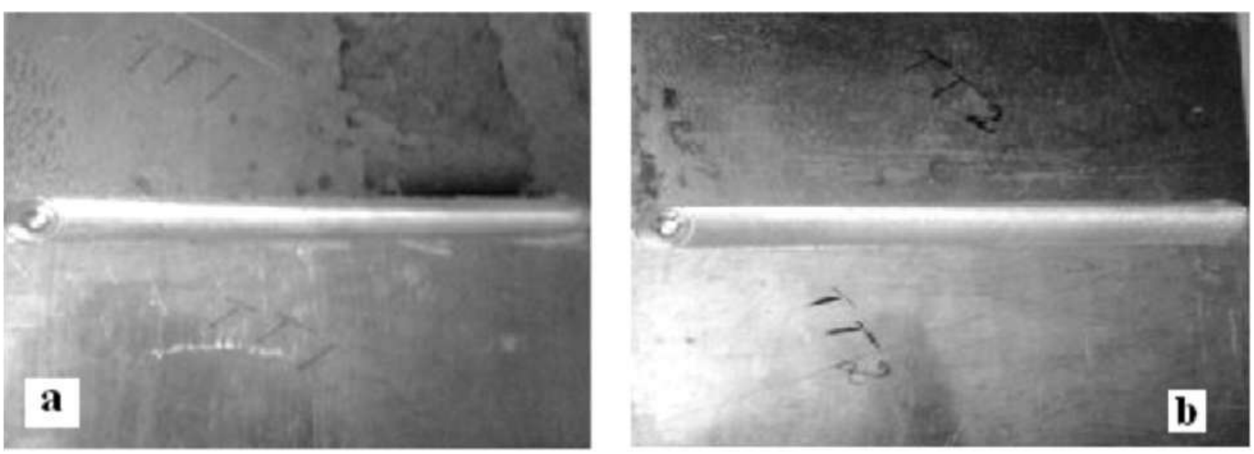

Fig.5 : AA2024-AA7075 weldments for Taper threaded tool
(a) TT1 (600rpm, 30mm/min, 2.5kN) (b) TT2 (700rpm, 30mm/min, 2.5kN)

Table 3 shows the typical parameter combination used for this investigation.

Table.3 : Typical parameter combinations used for investigation

Tool used	Notation used (rpm)	Rotational speed (mm/min)	Welding speed Axial load	Axial load (kN)
Taper threaded	TT1	600	30	2.5
	TT2	700	30	2.5
	TT3	800	30	2.5
	TT4	900	30	2.5
	TT5	800	20	2.5
	TT6	800	40	2.5
	TT7	800	50	2.5
	TT8	800	60	2.5
Straight threaded	ST1	600	30	2.5
	ST2	700	30	2.5
	ST3	800	30	2.5
	ST4	900	30	2.5
	ST5	700	20	2.5
	ST6	700	40	2.5
	ST7	700	50	2.5
	ST8	700	60	2.5

The weldments of AA2024-T6 and AA7075-T6 for two combinations using taper threaded tool are shown in **Fig.5**.

The metallographic specimens extracted from FSW joints were etched with the modified Keller reagent after polished by a diamond paste. The macrostructures were taken from the cross section of the welds using optical microscopy. The Vickers micro hardness testing was performed under the load of 0.05 Kgf for 10 s at 1mm neighboring distances. The tensile tests specimens were prepared according to ASTM E-1251.The test specimens were loaded under 100KN at the rate of 1.5 kN /min and the ultimate strengths and the percentage elongations were recorded.

3.0 RESULTS AND DISCUSSION

3.1 Macrostructure for dissimilar joints

Macrostructure observations are used widely for detecting any major defects that occur during the FSW , such as crack, pinhole, tunnelling defect, Kissing bond etc. The macrostructures of the welds produced by different rotational speeds and welding speeds are shown in **Fig.6** and **Fig.7**. In the FSW process, three factors contribute to the formation of the joints. The first factor is the temperature rise in the weld region and thus softens the BMs (both 2024 and 7075) forming the NZ. The second factor is the stirring of plastic materials, the process of accumulating multi-layer plasticized materials behind the tool, affected by the interaction of rotational and welding speeds and the pin profile. The last element is the hot forging of plasticized materials conducted by the shoulder. Any inappropriate adjustment of these factors results in defective joints [8].

The macro structure of the dissimilar welded cross section as shown in **Fig.6** reveals that no defect forms at rotational speed of 600 rpm. However, for 700 and 800rpm worm hole defect is identified probably due to poor mixing of the two base metals in the nugget zone. For the rotational speed 900 rpm, tunnel defect is identified for the entire length of the weld due to poor weld consolidaton. **Fig.7** shows the defect concentration for the different welding speeds i.e. 20, 40, 50 and 60 mm/min.

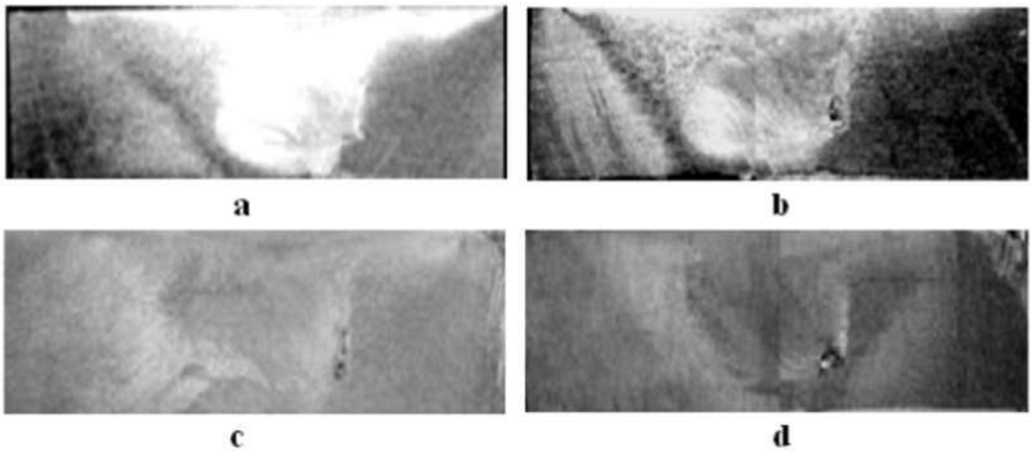

Fig.6 : Macro structure views of the weld cross section for different rotational speeds (a) 600rpm (b) 700rpm (c) 800rpm (d) 900rpm.

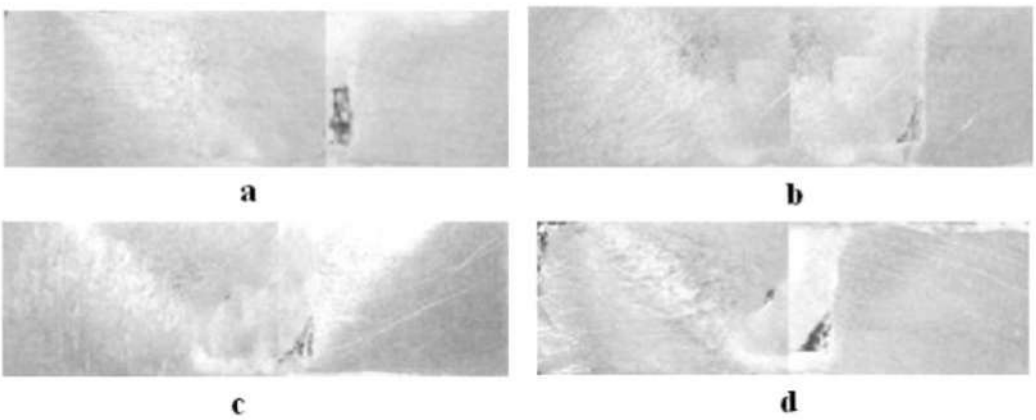

Fig.7 : Macro structure of the weld cross section for different welding speeds (a) 20mm/min (b) 40mm/min (c) 50mm/min (d) 60mm/min.

However, no defect is observed at weld speed of 30 mm/min for 600 rpm with an axial force of 2.5k N.

3.2 Micro Hardness for dissimilar joints

The microhardness distribution across the weldment has been evaluated. It is observed that the hardness at the weld is less compared to the base metal and may be due to annealing effects during welding. The hardness of AA2024 and AA7075 are 154 and 160VHN respectively. For the AA2024-AA7075 dissimilar weld metal the hardness value is approximately 90VHN .

The micro structures of both the parent metals (**Fig.8**) reveal the solution treated and precipitation hardened matrix. The precipitates are likely to be Mg_2Si, $MgAl_2$, $CuAl_2$ which are uniformly present along the direction of the rolling. The nugget zone consists of fine grains due to dynamic recrystallization. The grains have less than 5 microns in size.

3.3 Tensile properties for dissimilar joints

Tensile properties such as tensile strength and percentage elongation have been evaluated for welded plates and compared with base metal. The tensile test results of AA2024-T6 and AA7075-T6 FSW joints for four combinations using straight and taper threaded tool are given in **Table 4**.

For a particular tool geometry, it is observed that as the rotation speed increases the tensile strength decreases at a given travel speed. At a given travel speed as the rpm increases heat input increases. It is well known that grain size increases with increasing heat input and thus tensile strength decreases. Furthermore, **Table 3** also shows large variation in tensile strength due to tool geometry. It is quite obvious that, in case of straight threaded tool material flow will be poor compared to taper threaded resulting in improper mixing and also possible to develop improper plasticization due to insufficient heat generation.

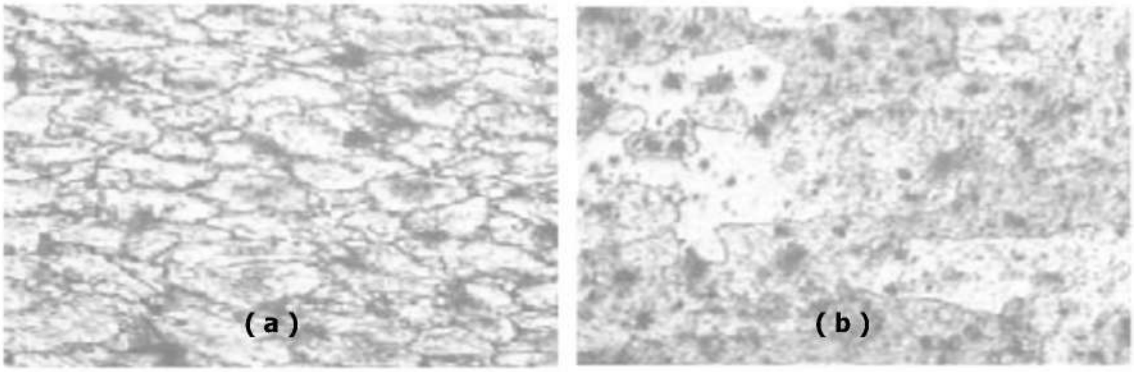

Fig. 8 : Micro structure views of the base metals (a) AA 2024-T6 (b) AA 7075-T6

Table.4 : Tensile properties for typical combinations used for investigation

Combinations	0.2% Proof Stress (MPa)	Tensile Strength (MPa)	Elongation (%)	Joint Efficiency (%)
TT1	319	335	15.5	72.66
TT2	262	278	11	60.30
ST1	113	119	9.2	25.81
ST2	109	117	6	25.37

Tensile test results clearly show that the TT1 joint gives the highest joint efficiency; whereas ST2 joint gives the least joint efficiency. The tensile fractured specimens of AA2024-T6 and AA7075-T6 for four combinations using taper threaded tool are shown in **Fig.9**. In all the tensile specimens, it is observed that the necking occurred at the boundary between thermo-mechanically affected zone (TMAZ) and HAZ.

3.4 Bending tests and properties for dissimilar joints

The bend specimens were cut as per the ASTM B-557. Mandrel base has radius of 4-times of thickness of plate and 180 degrees of bend angle. Bend tests were performed at computer controlled AUTO make Universal Testing Machine. Bend tests were performed on both face and root side of the welds (**Fig. 10**) to understand about the ductility and toughness of friction stir welds. The evaluated bending properties are given in **Table 5** for the typical combination TT1. Most of the welds allow for very high bend angles and no cracking in face bend was observed indicating good ductility. The above result conforms that weld specimens passes the bend test.

4.0 CONCLUSIONS

The quality friction stir welded joint between dissimilar aluminium alloys AA2024 - AA7075 could be produced at 600 rpm tool rotation speed, 30 mm/min welding speed and 2.5 kN downward force using the taper cylindrical threaded tool pin.

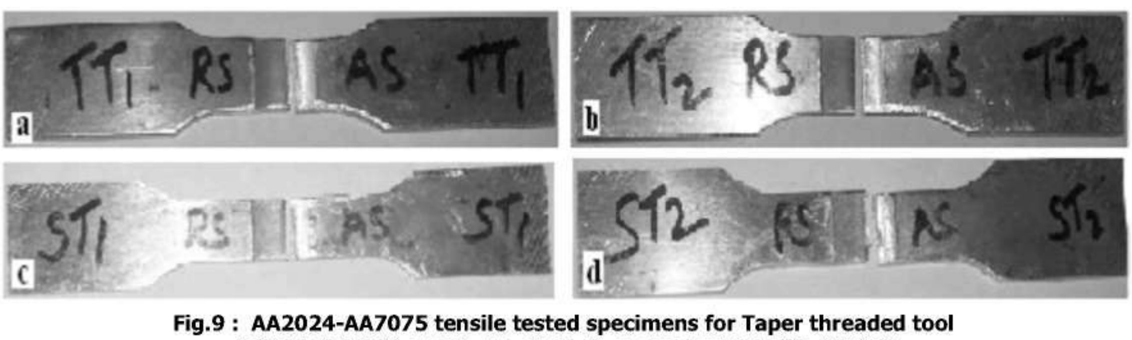

Fig.9 : AA2024-AA7075 tensile tested specimens for Taper threaded tool (a) TT1 (b) TT2 and for Straight threaded tool (c) ST1 (d) ST2

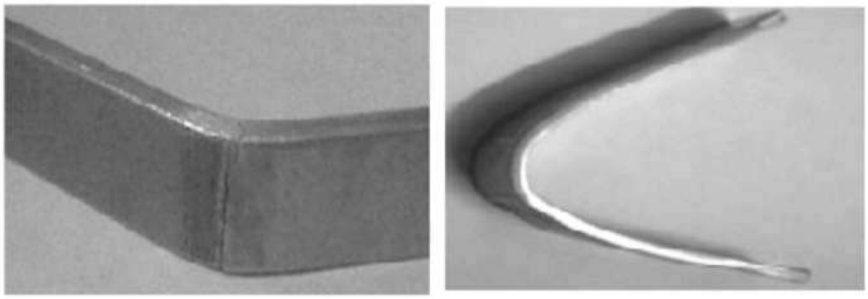

Fig.10 : Bend specimens for TT1 Root and Face Bend Specimens (AA2024-AA7075)

Table.5 : Bend properties for typical combination TT1

Combinations	Tool rotation speed (rpm)	Root bend	Face bend
AA2024-AA7075 (TT1)	600	Crack observed after 42°	No cracks observed

Maximum tensile strength of the friction stir welded joint (TT1) was obtained as 335 MPa compared to the base metal tensile strength of about 461 MPa and thus the joint efficiency is 72.66%. Bend test results of the welded specimens show that only face bend passed allowing for very high bend angles and no cracks were observed in weld nugget. However, cracks were observed after 42° root bend test.

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