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Weld Bead Characterization and influence of process parameters of Friction stir Welds of Dissimilar Materials between AA6061 and AA7175 Al alloys

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Abstract: -
FSW isan advancement in the welding process in which the participating metals are not melted. It created dramatic impact across many industries such as aerospace, ship building, vessels and many others because of its extensive properties like good mechanical properties, low distortion and also eco-friendly. The compatibility of this process extended beyond the range of materials towards low weight alloys such as Al, Mg, etc.
The main objective of this work is to study the Al alloys of different series (AA 6061 & AA 7175) of plates ($150 \times 75 \times 5$ mm) were butt welded by Friction stir welding (FSW) process with various weld speeds and rotational speeds. In particular to observe the effect of process parameters on tensile strength, hardness, microstructure and temperature distribution at various distances from the centre line of the weld bead of the joints were investigated. It wasfound that the highest tensile strength and hardness of the joint was obtained when welding (FSW) was conducted with highest welding speed and tool rotational speed, when AA6061 Alplates were fixed on the advancing side.

Key words: Dissimilar materials, Friction stir welding, Weld bead Characterization, Temperature distribution.

1. Introduction
The principle of friction stir welding uses a specially designed rotating tool (shown in figure 1) having shoulder and pin inserted into the work piece. After starting the stirring motion a frictional heat is generated between the tool and work pieces it causes the plates to be welded together.
Friction stir welding (FSW) was invented in the early 1991 at TWI, which is located in United Kingdom [1].
FSW widely used in many areas including aerospace, ship building, automotive, electronic industries; where fusion welding is not suitable due to various property differences compared to friction stir welding. It is an advancing technology and it avoids the drawbacks of other welding processes [2].
Unlike (fusion welding) FSW has many advantages like it doesn't require shield gases, the generated temperature is less than melting point, thus reduction in residual stresses and distortion in FSW is achieved [3].
The position of the materials affects the dissimilar material properties and quality, which mainly depends on properties of two materials and the welding parameters [4].
Amir Hossein Lofti and Salman Nourouzi revealed that when welding of similar materials under different welding conditions reported temperatures are higher on the advancing side compared to retreating side for all the welded samples. At higher tool rotational speed peak temperature of 440oC was obtained. The joints welded using the FSW process parameters of 1050 rpm rotational speed, 100 mm/min travel speed and 14 mm shoulder diameter exhibited better mechanical properties compare to other samples [5].
The tool pin profiles and welding parameters affect the mechanical properties of dissimilar joints between AA 2024 and AA 5083. In this study tapered hexagonal tool pin gives better properties compared to straight cylindrical tool [6].
The highest joint strength was obtained when welding was conducted with highest welding speed and the plates were fixed on advancing was AA 6061. Temperature profiles near to thermo mechanically affected zone [TMAZ] and in the heat affected zone [HAZ] were also measured using thermocouples and simulated in 3-D computational model results higher temperature (469oC) at 8 mm away from the weld line. Further increasing the welding speed (2 mm/s to 5 mm/s) peak temperature at 8 mm away from the weld line decreases to 378oC [7].
Friction stir welding of AZ61A magnesium alloy joints shows lower tensile strength at slower rotational speed [8].
When FSW was performed at lower tool rotational speed (i. e. 800, 1000 rpm) less mechanical properties was obtained due to lower heat input per unit length. Lower heat input causes lack of stirring motion. Doing this at a higher rotational speed

results receives low work per unit of the weld length. Under such conditions, the plasticized material may be cooler, and less easily forged by the tool [9].
The vertical force increased as the welding speed for all the FSW joints increases for the study of the mechanical and microstructural behaviour of FSW between AA6082 and AA2024. In this study higher tensile and fatigue properties for the joints AA6082 on the advancing side [10].
When FSW was performed for dissimilar materials of AA5086 and AA6061 showed that more efficient material mixing was obtained when AA6061 on retreating side and AA5086 on advancing side[11].
AA 6061 & AA 7175 Al alloys are most widely used lightweight materials in various industries so in the present investigation AA 6061 and AA 7175 Al alloys are taken as base metal to investigate effects of process parameters and mechanical properties, microstructure and temperature distribution at heat affected zone [HAZ] during FSW of dissimilar joints.

Fig 1: Arrangement of the tool

2. Experimental Work:

The parent metal that was used in the experiment were dissimilar plates of AA 6061 & AA 7175 Al alloy sheets with a dimension of 150 mm long, 75 mm wide, and thickness of 5 mm (150×75×5 mm). The chemical compositions of these two alloys are mentioned in Table 1. The plates were butted together along the longitudinal direction using a normal vertical milling machine. The welding tool (Non threaded tapered tool) has a diameter of 18 mm shoulder diameter and pin height 4. 8 mm and the shape of the tool shown n figure 2. Different welding speeds and rotational speeds were used to produce the butt joint using friction stir welding Shown in figure 2.
Measurement of the temperature history at weld bead during welding was not possible, because high temperatures were developed in these zones and difficult to set up the thermocouples near to it. The temperature values at the HAZ were measured using K type thermocouples shown in figure. 4. Total 6 holes on each side were drilled with a dia. of 2. 5 mm and depth of 3 mm on each plate. Each hole having distance 65 mm along the weld and from the weld line maintains 12 mm and 15 mm on both side of the weld bead plate. After the holes were drilled the thermocouples were inserted into that drilled holes. The temperature at these thermocouple locations was recorded using temperature indicator. Important FSW parameters used in this study mentioned in Table 2.
The tensile samples were prepared to the required dimensions according to the ASTM E8M-04 standard by an electrical discharge cutting machine. The tensile tests were conducted at room temperature using universal testing machine (UTM). For microstructural study samples were sectioned to required size from FSW joints. The testing samples were polished using different grades of emery papers after that they were etched with Keller's reagent. That reagent made of distilled water 190 ml, Nitric acid (HNO3) 5 ml, Hydrochloric acid (HCl) 3ml, Hydrofluoric acid (HF) 2 ml. Hardness tests were conducting using Vickers micro hardness testing machine.

Fig. 2 Tool profile

Fig. 3 FSW sample

Fig. 4 Arrangement of thermocouples before welding

Table 1

Material&Metal	AA6061	AA7175
Al	REM	REM
Cu	0. 261	1. 699
Mg	1. 137	2. 307
Si	0. 576	0. 116
Fe	0. 299	0. 186
Mn	0. 109	0. 072
Zn	0. 048	5. 647
Ti	0. 022	0. 023
Cr	0. 206	0. 200

Table: 2 Summary of FSW parameters for AA 6061 and AA 7175 alloy plates.

Rotational speeds(rpm)	Welding speeds(mm/min)	Combination
710	63	AA 6061 & AA 7175
1120	80	
1400	100	

3 Results and discussion:

3. 1. Hardness test results:

To investigate the effect of tool rotational speed on the hardness samples of the joints, all the welding tests were carried out at the speed of 63 mm/min, 80 mm/min, 100 mm/min. The rotational speed was varied from 710 to 1400 rpm.

Compare the graphs from fig 5&6, the highest hardness of the FSW weld was achieved at 1400 rpm with all the constant welding speeds such as 63, 80, 100 mm/min for both AA 7175 and AA6061 Al plates were on advancing side. From the above results maximum hardness was obtained for AA 6061 on advancing side compared to AA 7175 on advancing side.

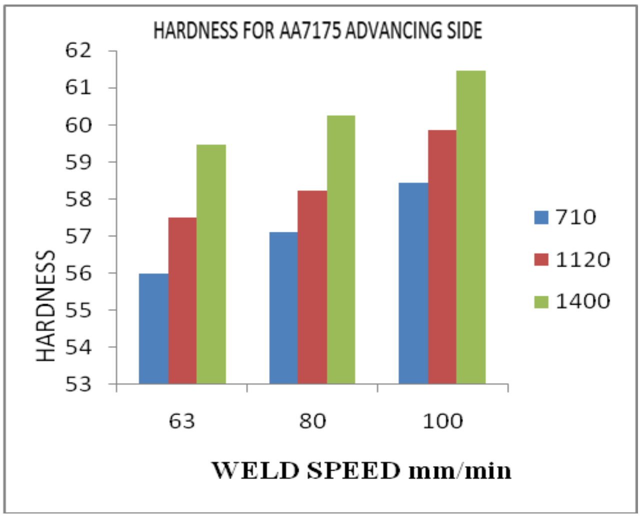


Fig. 5 Average Vickers hardness of FSW sample under various process parameters when AA 7175 on Advancing side

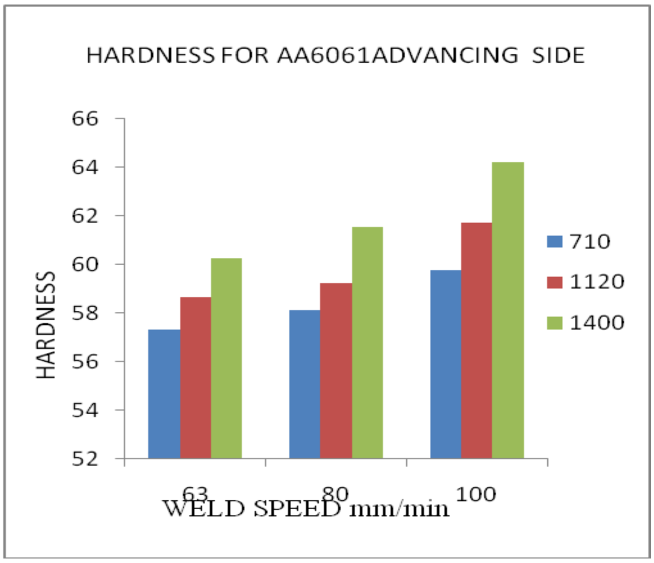


Fig. 6 Average Vickers hardness of FSW samples under various process parameters when AA 6061 on Advancing side

3. 2. Tensile test results:

Figure 7&9 shows tensile test samples after conducting tensile test when AA7175 and AA6061 Al alloys were located on advancing side. Figure 7&9 illustrates mostly all joints failed on AA6061 Al alloy side at positions in TMAZ region except some samples. When dissimilar FSW of other Al alloys, FSW joints usually failure at locations HAZ on the weaker side.

Figure 8 & 10 reveals the effect of welding speed on tensile strength of friction stir welded AA6061 and AA7175 Al alloy joints. At lower welding speed (63 mm/min), the tensile strength of FSW joints is lower compared to other welding speeds (80mm/min & 100 mm/min). The above results reveals that the effect of tool rotational speed on tensile strength of friction stir welded AA6061 & AA7175 Al alloy joints at lower rotational speed (710 rpm), the tensile strength of FSW joints is lower. When the rotational speed is increased from1000 rpm to 1400 rpm, the tensile strength also increases and reaches a maximum at a speed of 1400 rpm and it is observed that when the speed is increased beyond that 1400 rpm the tensile strength is decreasing. Figure 8 & 10 shows tensile values at constant welding speed when AA7175 & AA6061 Al alloys were located on advancing side.

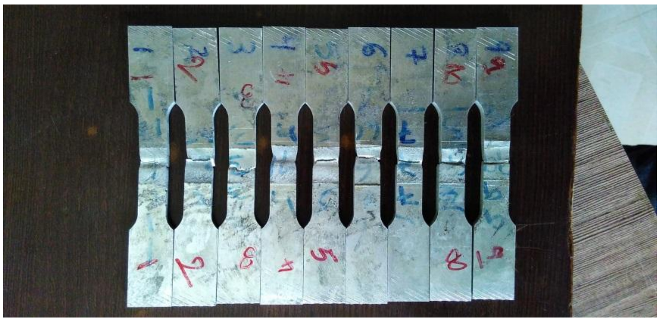


Fig. 7 Tensile test samples AA 7175 on advancing side

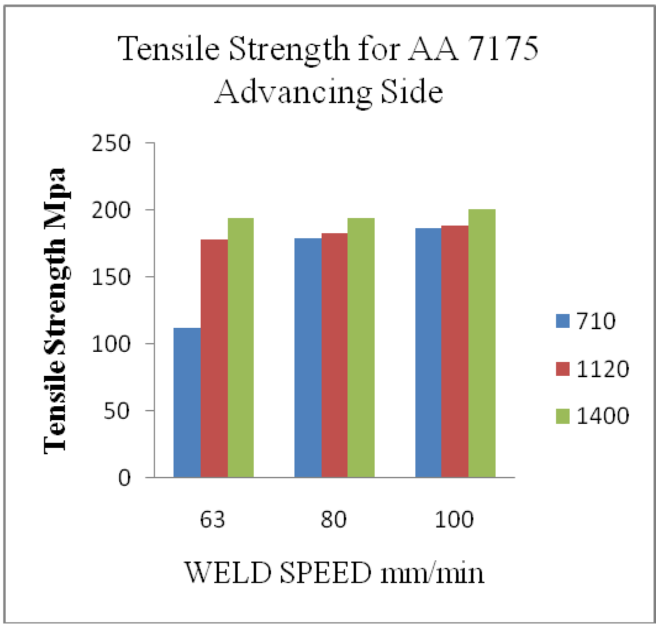


Fig. 8 Tensile test results AA 7175 on advancing side

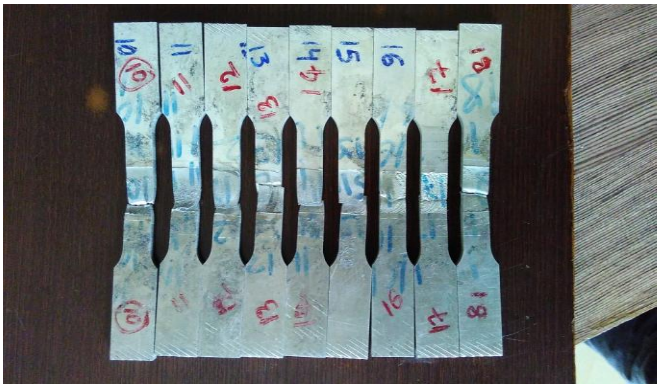


Fig. 9 Tensile test samples AA 6061 on advancing side

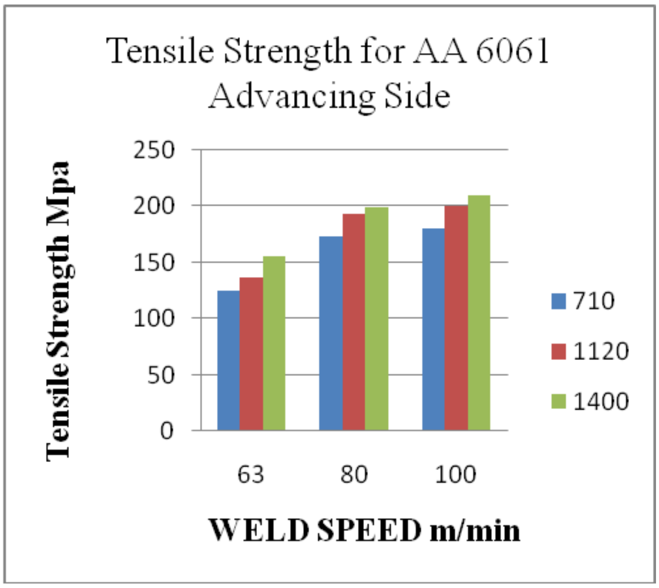


Fig. 10 Tensile test results AA 6061 on advancing side

3. 3 Temperature profiles

The fig 11 shows that when the temperature increases with increasing the tool rotational speed and lower weld speed compared to other combinations of thermo couple locations at heat affected zone. At the same tool rotation and weld speed, slightly higher peak temperature in AA6061 is obtained when AA7175 Al was located on the advancing side.

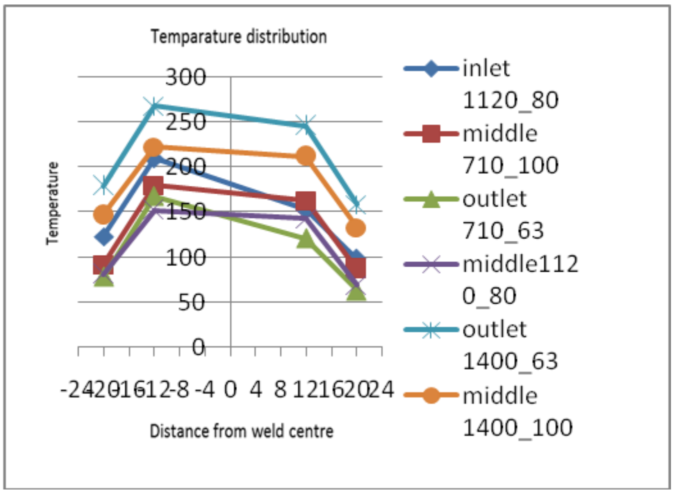
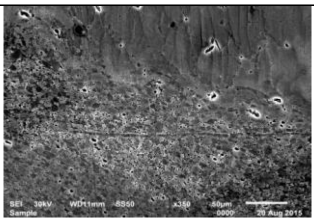
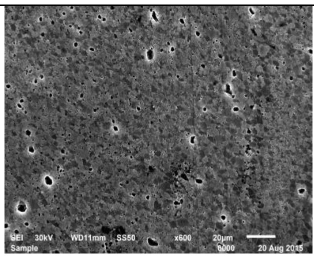
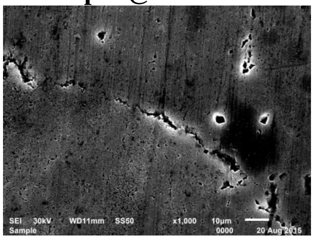
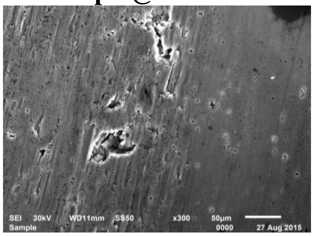
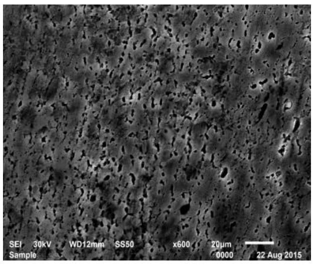
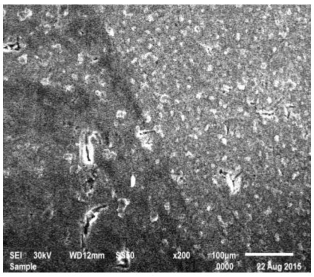


Fig 11; Temperature distribution chart when AA7175 on advancing side

Microstructure evaluation:

Table 3 shows the SEM microstructures of welded joints under different process parameters. Dissimilar welding of AA6061 and AA7175 consists of three different zones. (i) At Heat affected zone microstructure of AA7175 consists of grains of Zn, Mg, Cu, Cr move towards the stirring direction in the matrix of Al. (ii) At heat affected zone microstructure of AA 6061 consists of coarse particles of Mg, Si, Cu, Cr aligned towards the stirring direction in the matrix of Al. (iii) At weld zone microstructure consists of mixture of fine and coarse grains of Zn, Mg, Cu, Cr, Si aligned in the direction of stirring in the matrix of Al. Observation of microstructure helps to study the improvement of tensile strength and hardness. From the observations at higher rotational speed and welding speed (1400 rpm @100 mm/min) microstructure was better compared to other weld speeds and rotational speeds. When grain sizes are decreases it improves the mechanical properties. The cracks are formed at medium weld and tool rotational speed when AA7175 Al alloy on advancing side shown in table 3.

Table 3 shows the SEM microstructures

 **1400 rpm @ 100 mm/min**	 **1400 rpm@ 80 mm/min**
 **1120 rpm@ 80 mm/min**	 **710 rpm@ 63 mm/min when AA6061 on advancing side**
 **1400 rpm@ 63mm/min when AA6061 on advancing side**	 **1400 rpm@ 100mm/min when AA6061 on advancing side**

Conclusions:

Dissimilar AA 6061 and AA 7175 alloys have been friction stir welded with a variety of different process parameters. At variable tool rotational speed of (700 to 1400 rpm), at constant welding speeds (63 to 100 mm/min). The effects of material position and welding speeds on material flow, microstructures, hardness, temperature distributions, and tensile properties of the welded joints were investigated.

Based on the above results and discussions the following conclusions are accordingly

1. The material flow is much more effective when AA 6061 alloy was located on advancing side, and different vortex profiles formed vertically in the nugget centre.
2. The friction stir welded joints exhibited significantly softened welded zones. As the tool speed increased from 700 to 1400 rpm, the hardness of the nugget zone gradually increased with constant welding speeds (63, 80, 100 mm/min).
3. As the tool speed increases tensile strength of the weld bead maximum for dissimilar FSW of AA alloys and compared to location of AA 7175 on advancing side higher tensile strength was achieved at AA 6061 on advancing side.
4. Mostly all the tensile samples are failed on TMAZ of AA 6061 side for all the speeds except some samples.
5. Higher temperatures are obtained when AA6061 Al alloy on retreating side and better micro structure obtained at higher rotational and weld speeds.

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