Joining of non-weldable AA7075 and weldable AA6082 aluminium alloy sheets by Friction Stir Welding

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Abstract. In this work, an attempt has been made to join the AA6082-T651 and AA7075-T651 aluminium alloys by friction stir welding (FSW). The FSW is a solid-state joining process which primarily used on aluminium because the metal is not melted during the process so the base material can not soften. For the welding were using cylindrical pin tool, marble table to avoid the harmful heat conduction, two rotation rate of 500 and 1000 rpm and different traverse speeds of 15, 20, 25 and 30 mm/min to weld butt joints. The aim of present study were to experimentally explore the dissimilar bounds. For evaluations, hardness testing were using to create hardness profiles across the joint in through thickness direction and optical microscope to classify the microstructures and crystallographic textures of base materials (BM). Based on the results obtained it can be stated that the FSW suitable for AA7075 and AA6082 welding by further optimization of the process parameters.

1. Introduction
The difficulty of making high-strength, fatigue and fracture resistant welds in aerospace aluminum alloys, such as highly alloyed 6XXX or 7XXX series, has long inhibited the usability of welding for joining aerospace and military applications such as light combat aircraft (LCA), light combat vehicle (LCV), future main battle tank (FMBT), bridge layer tank (BLT), armored ambulance, submarine torpedo, etc. [1, 2].

Aluminium can generally welded by fusion welded processes, for example the TIG or MIG welding technologies. But in case, the 7XXX series particularly the alloy AA7075 is known as non-weldable, because of the poor solidification microstructure and porosity in the fusion zone. After the invention of Friction Stir Welding (FSW) process in 1991 aluminum alloys that were regarded unweldable were found to be weldable by the FSW, furthermore the welded bonds are very good mechanical properties [3]. “Friction Stir Welding (FSW) is a simple, clean and innovative joining technology for light metals invented by The Welding Institute (TWI), England, U.K. in 1991” [4]. The FSW tool is a non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and traversed along the line of joint. The tool have two primary functions: heating of the workpiece, and movement of material to produce the joint [1]. The Figure 1 represents the tool’ parts and welding process.
After the invention of the FSW there are several studies which investigated the relationships between process parameters and resulting joint integrity [5] or between process parameters and the welded bonds defects [6] and the effect of the tool geometry have also been studied [7]. Based on the studies can be stated that the rotational speed, traverse speed, and vertical pressure on the plates during welding are the main process parameters of FSW. Also the tool geometry has significant characteristic which affects the weld strength. S. M. Bayazida et al. investigated the effect of tool geometry (triangle, square and cylindrical). About their results all of the tool geometry occurs defects but the cylindrical can made the most acceptable bond.

The FSW process generates three distinct microstructural zones: the weld nugget (WN), the thermo-mechanically-affected zone (TMAZ) and the heat-affected zone (HAZ). The WN is the region through which the tool pin passes, and thus experiences high deformation and high heat. It generally consists of fine equiaxed grains due to full recrystallization. The TMAZ adjacent to the nugget is the region where the metal is plastically deformed and also heated, but this is not sufficient to cause recrystallization [3].

In this study, the effects of various rotational speed and traverse speed on microstructural characteristics and hardness parameters of the dissimilar welded joint made from a weldable (AA6082-T651) and non-weldable (AA7075-T651) aluminium alloys were studied.

2. Experimental procedure
Two type of 4 mm thickness rolled plates of AA6082-T651 and AA7075-T651 aluminium alloys were used in the present investigation (Table 1. shows the chemical compositions).

| Alloys      | Si  | Fe  | Cu  | Nm  | Mg  | Cr  | Zn  | Ti  |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|
| AA6082-T651 | 0.4-0.8 | 0.7  | 0.15-0.40 | 0.15 | 0.8-1.2 | 0.04-0.35 | 0.25 | 0.15 |
| AA7075-T651 | 0.4  | 0.5  | 1.2-2.0 | 0.3  | 2.1-2.9 | 0.18-0.28 | 5.1-6.1 | 0.2  |

Many trial experiments were conducted by varying tool rotational speed between 500 - 1000 rpm to find the right value. Finally the 1000 rpm was applied, because in case the right bond was created. To avoid the heat removal the specimens were fixed on a marble table (Figure 2.).
The dimensions of base metal plates were 60 mm width by 120 mm length. The AA6082-T651 alloy was placed in the retreating side and AA7075-T651 plate was placed in the advancing side because AA7075-T651 has higher flow strength than AA6082-T651 aluminium alloy and the high frictional force and high material excavation force created in the advancing side. The welding conditions and process parameters used to fabricate the joints are given in Table 2.

| Parameters                  | Value         |
|-----------------------------|---------------|
| Tool rotational speed (rpm) | 100           |
| Tool shoulder diameter (mm) | 10            |
| Tool pin diameter (mm)      | 4             |
| Tool pin length (mm)        | 3,7           |
| Tool material               | High speed steel |
| Tool traveling speed (mm/min)| 12, 14, 17, 21, 25 |

The microstructure of the specimens was studied by using optical microscope (ZEISS AXIO) and the hardness of the bond by Vickers microhardness tester (Wilson Wolpert 401MVD). The specimens after the polishing were etched using standard Keller’s reagent (5 ml HNO₃, 3 ml HCl, 2 ml HF and 190 ml distilled water) to reveal the microstructure of the bond, the acid treatment takes 20 sec.

3. Results and discussion

3.1. Macrostructure

The macroscopic morphology of friction stir welded AA6082-T651 and AA7075-T651 dissimilar joints by five different feed rate (shown in Figure 3.).

![Figure 3. Macrograph of cross sections](image-url)
FSW are known to have individual defects like cracks, pin hole or tunnel defect. It seems that all of the cross sections contains some tunnel defects and pin hole. The Figure 3. (c) specimen has the smallest defect “pin hole” (marked with red circle) which size of 10x625.53 µm while the other one have tunnel defects and pin hole which are higher than 600x1000 µm. The top and bottom surface of the weld region shows defect free and has equally spaced material ripples. There were large microstructural changes during welding. The interfaces of various regions like HAZ, TMAZ and WN were clearly visible in the Figure 4.

![Figure 4. Microstructural zones (17 mm/min by feed rate)](image)

In the FZ zone the grains finer and orientated perpendicular to the surface. The grains are greatly deformed in the AS-TMAZ region.

3.2. Microhardness
Because between the welded specimens the smallest mistake was produced at 17 mm/min by feed rate, so the hardness measurements were done on this one.

The micro Vickers (HV0.1) measurements were carried out across the weld at three different depths from the surfaces (1 mm, 2 mm and 3 mm) to associate the hardness variations among the welding zones. The hardness profiles are shown in Figure 5.
Figure 5. Hardness measurement of cross section at three different depths from top (17 mm/min by feed rate)

At 1 and 2 mm below the top of the surface hardness values of the weld material seems to be similar while 3 mm from the top, the values moved to the right in the stir zone, so the hardness of the workpiece the lowest under the pin. The hardness is further decreased in TMAZ regions. The microhardness values in the stir zone result in higher hardness values than in TMAZ regions.

4. Conclusions
The effects of feed rates on microstructure and microhardness of friction stir welded dissimilar AA7075-T651 - AA7075-T651 aluminium alloy joints were investigated and the following conclusions are derived:
- the friction stir welding creates a weld nugget zone under the tool’ shoulder which has a fine microstructure
- tunnel defects generated in the retreating zone and a pin hole about 3 mm from top at 17 mm/min by feed rate
- the material hardness was decreased near end of the pin about the microhardness measurements

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