Characteristic Study of Friction Stir Welding of Aluminium Alloy AA7075 Using H13 Surface Hardened Tool Steel with Variable Tool Pin Design

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Abstract. Friction Stir Welding is a solid-state process where a tool which is not consumable rotates between two metals or alloy. In FSW process heat is generated because of the friction that is developed between the tool and the work piece below the melting point of the material. Compared to conventional welding this FSW process can be used for welding alloys such as aluminium, copper, etc. In this process, we can even weld two different types of alloy together which is not possible in conventional welding. Aluminium alloy AA7075 (Al-Zn-Mg-Cu) is a type of alloy which shows high strength and corrosive resistant because of the zinc content in the alloy. This zinc acts as a sacrificial anode for the alloy which forms a outer covering on the surface of the alloy which is the one which gets corroded first and then followed by the alloy. In this FSW the parameters play the significant role that determines the weld characteristics. Here, aluminium alloy of series AA7075 of thickness 6mm is welded by Friction Stir Welding Process. This alloy contains zinc with a minimum amount of 5.8%. This zinc acts as a sacrificial-anode in sub-marines application, where this zinc forms like an outer covering layer on the surface of the submarine. So, this zinc gets corroded first keeping the sub-marine safe for a long period. After the Friction Stir Welding Process is completed, different tests are performed in the welded portion of the alloy. The test starts with the Ultimate Tensile Test followed by the Impact hardness test and the microstructure of the welded portion is studied. The welding parameter such as rotational speed, transverse speed is optimized in this process by using the Taguchi analysis. Taguchi method greatly improves the design and engineering productivity. This method is very effective on regard of its simple experimental design and systematic approach to produce better quality at lower costs. The optimum results can be obtained by providing the input functions and can easily produce better results. By this effect of input variables the results can be formed by S/N ratio and response means. The Larger is better criteria is employed to our problems.

1. Introduction
AA7075 has great mechanical properties, good ductility, high strength, toughness and shows good resistance to fatigue. The strength of this alloy is comparable with many steels. Welding is a sculptural process where the metal or plastic parts are united by means of heat or pressure or both. Welding is a process that is suitable for metals and thermoplastics. Welding process is done in high heat there by the base material is melted. High heat causes a pool of molten material which cools to form the weld, weld configuration such as butt, full, penetration, fillet, etc. can be stronger than the parent material. FSW is a process where a tool which is not consumable rotates between two metals or alloy [1]. In
FSW process heat is generated because of the friction that is developed between the tool and the work piece below the melting point of the material. Compared to conventional welding this FSW process can be used for welding alloys such as aluminium, copper etc. In Friction Stir Welding, a tool which consists of a shoulder and a pin is placed between the plates that are to be welded, while rotating the pin and going further at a constant welding speed plastic deformation occurs between the two metal pieces which joins them together.

2. Material properties

2.1. Aluminium alloy AA7075

AA7075 (Al-Zn-Mg-Cu) is a strongest aluminium alloy which has great mechanical properties, good ductility, high strength, toughness and shows good resistance to fatigue. Aluminium alloy is predominant for its fabrication of structures and the components that is low in weight, high strength or electric current carrying capabilities to meet the requirements. This alloy AA7075 has zinc as the primary alloying element. This alloy has a greater application in marines, submarines, aircraft etc. AA7075 is used in the surface of the submarines where the zinc content in the alloy acts as a sacrificial anode and forms an outer coating which prevents the material from corrosion due to salinity in the deep sea.

| Composition | Weight% |
|-------------|---------|
| Zn          | 5.6     |
| Mg          | 2.5     |
| Cu          | 1.6     |
| Cr          | 0.23    |
| Al          | 90.07   |

Table1. Nominal Composition of AA7075

2.2. H13 Tool Steel

The pin which is used here for welding is made of high speed steel H13. H13 is a adaptable chromium-molybdenum hot work steel. High speed steel H13 is used in hot work as well as cold work tooling applications due to its combination of high toughness and its resistance towards fatigue. H13 steel resists thermal fatigue cracking which occurs because of cyclic heating and cooling cycles in hot work tooling application. H13 steel tool shows very less deformation because of its chromium content in it. The hardness of H13 ranges between HRC 38 and 38. The density of the H13 steel is 7.80 grams per cubic centimetre. The melting point of this steel is 1427 degree Celsius.

| Elements            | Content (%) |
|---------------------|-------------|
| Chromium, Cr        | 4.75-5.50   |
| Molybdenum, Mo      | 1.10-1.75   |
| Silicon, Si         | 0.80-1.20   |
| Vanadium, V         | 0.80-1.20   |
| Carbon, C           | 0.32-0.45   |
| Nickel, Ni          | 0.3         |
| Copper, Cu          | 0.25        |
| Manganese, Mn       | 0.20-0.50   |
| Phosphorous, P      | 0.03        |
| Sulphur, S          | 0.03        |

Table2. Nominal composition of H13 steel.

2.3. Tool Profiles

Different types of tool profiles such as cylindrical, tapered and hexagonal are used in this experiment. However, different pin profiles are responsible for the difference in strength, macrostructure and
microstructure of the specimen. For the tapered and cylindrical tools there is a higher possibility for tunnel defect while welding has been found. The tapered pin produced narrower stir zones with coarse grains [5].

Figure 1. Various tool profiles

3. Experimental work
The material used for this work is Aluminium alloy AA7075 and was obtained in plate form of size 150 X 100mm with thickness of 6mm. The analysed chemical composition of the parental material is tabulated in Table 1. The material was cut into required dimension by using Wire-cut EDM by using water as the electrolyte, this cutting was done as the plate was having an irregular surface on both sides which makes the welding difficult and therefore results in irregular joining of the work piece.

3.1. Welding of AA7075
The optimized parameters for friction stir welding were found by Taguchi analysis of parameters from the literature survey. A butt joint configuration is done between the two aluminium plates AA7075 of thickness 6mm. The welding process was accomplished at three rotational speeds 1000, 1150, 1400 rpm respectively, the axial feed is 15, 20, 25 mm/sec keeping the axial load of 12KN and tilt angle 0° as constant. Three types of tool profiles are used as cylindrical, tapered and hexagonal tools were machined from H13 steel and were hardened.

Figure 2. Frictions stir welding.
During FSW process a typical welding tool which consists of a shoulder and a probe is used. Totally three types of tool profiles are used in this process. The plate which is going to be welded is placed on the work table. During this process a locally softened material is contained in the weld by the tool shoulder, the backing bar underneath and also the parental material. The probe mixes and fuses the material together as the tool moves along the weld line, and the joint is formed. FSW is superior due to many reasons. It leaves a clean and neat appearance along the face of the weld. Since, FSW is a solid state process it is free of melt related problems such as solidification, cracking or porosity, there is no need of filler wire or shielding gas.

4. Experimental Results

4.1. Tensile Strength

Tensile strength is measured by finding the maximum stress that a material can withstand by stretching or pulling it by applying force. Here tensile test was conducted of alloy AA7075. The plates where welded by FSW by using three different pin profiles. After the welding process the plates were made to cut with the help of Wire-Cut EDM machine with water as the electrolyte in the standard of ASTM-E8. After the EDM cut the work piece was placed in the tensile testing machine and the values were noted. By comparing all the plates tensile values, the best tool is selected [4].

| Sample no | Spindle Speed (rpm) | Traverse Speed (mm/min) |
|-----------|---------------------|-------------------------|
| 1         | 900                 | 15                      |
| 2         | 900                 | 20                      |
| 3         | 900                 | 25                      |
| 4         | 1200                | 15                      |
| 5         | 1200                | 20                      |
| 6         | 1200                | 25                      |
| 7         | 1500                | 15                      |
| 8         | 1500                | 20                      |
| 9         | 1500                | 25                      |
Table 4. Ultimate Tensile Strength.

| Sample no | Spindle speed (rpm) | Traverse speed (mm/min) | Tensile strength (MPa) |
|-----------|---------------------|-------------------------|------------------------|
| 1         | 900                 | 15                      | 145.40                 |
| 2         | 900                 | 20                      | 133.91                 |
| 3         | 900                 | 25                      | 94.00                  |
| 4         | 1200                | 15                      | 136.56                 |
| 5         | 1200                | 20                      | 96.06                  |
| 6         | 1200                | 25                      | 52.68                  |
| 7         | 1500                | 15                      | 95.04                  |
| 8         | 1500                | 20                      | 104.58                 |
| 9         | 1500                | 25                      | 136.48                 |

Figure 5. Tensile Test Results.

4.2. Hardness

The hardness depends on ductility, toughness, strain, strength. The hardness can then be inferred from the width or area of the indentation. First the work piece which is to be tested is polished and then it is placed in the Vickers hardness apparatus and then the hardness values are found and noted. Load applied was 10kgf for a dwell time of 10seconds. The indenter was diamond tip.
Table 5. Vickers Hardness.

| Sample no | Spindle speed (rpm) | Traverse speed (mm/min) | Vickers hardness (HV) |
|-----------|---------------------|-------------------------|-----------------------|
| 1         | 900                 | 15                      | 99                    |
| 2         | 900                 | 20                      | 90.27                 |
| 3         | 900                 | 25                      | 85.27                 |
| 4         | 1200                | 15                      | 106.50                |
| 5         | 1200                | 20                      | 80.50                 |
| 6         | 1200                | 25                      | 85.91                 |
| 7         | 1500                | 15                      | 87.10                 |
| 8         | 1500                | 20                      | 89.00                 |
| 9         | 1500                | 25                      | 96.00                 |

Figure 6. Hardness Test Results.

Table 6. Taguchi’s L9 Orthogonal Array.

| Spindle Speed (rpm) | Traverse Speed | Tensile Strength (MPa) | Hardness (HV) | SNRA1 | MEAN1 |
|---------------------|----------------|------------------------|---------------|-------|-------|
| 900                 | 15             | 145.40                 | 99.00         | 41.2688 | 122.200 |
| 900                 | 20             | 133.91                 | 90.27         | 40.4943 | 112.090 |
| 900                 | 25             | 94.00                  | 85.27         | 39.0186 | 89.635 |
| 1200                | 15             | 136.56                 | 106.50        | 41.4939 | 121.530 |
| 1200                | 20             | 96.06                  | 80.50         | 38.8159 | 88.280 |
| 1200                | 25             | 52.68                  | 85.91         | 36.0570 | 69.295 |
| 1500                | 15             | 95.04                  | 87.10         | 39.1627 | 91.070 |
| 1500                | 20             | 104.58                 | 89.00         | 39.6321 | 96.790 |
| 1500                | 25             | 136.48                 | 96.00         | 40.9100 | 116.240 |
5. **Anova Analysis**

Anova analysis has been done for the welded samples of aluminium alloy AA7075. For these two parameters (Spindle speed, traverse speed) the F-value and P-value have been calculated using and the error and the total has been found using taguchi’s analysis.
Table 7. Analysis of Variance for spindle speed (rpm).

| Source          | DF | Adj SS | Adj MS | F-Value | P-Value |
|-----------------|----|--------|--------|---------|---------|
| Spindle Speed   | 2  | 1302.30| 651    | 0.67    | 1.545   |
| Error           | 6  | 6433   | 1072   |         |         |
| Total           | 8  | 7735   |        |         |         |

Table 8. Analysis of Variance.

| Source          | DF | Adj SS | Adj MS | F-Value | P-Value |
|-----------------|----|--------|--------|---------|---------|
| Traverse Speed  | 2  | 1669   | 834    | 2.62    | 0.740   |
| Error           | 6  | 6066   | 1000   |         |         |
| Total           | 8  | 7735   |        |         |         |

6. Conclusion
Friction Stir Welding (FSW) of aluminum alloy AA7075 was done successfully for different rotational speed and also with different tool profiles. Based on the results the following can be concluded. The tensile strength for the joints where influenced by the parameters, tool rotation speed 1000 rpm, traverse speed 15mm/min an cylindrical tool profile which influence the property (tensile strength) more. The hardness for the joints where influenced by the parameter, tool rotation speed 1150 rpm, traverse speed 15mm/min and tapered tool profile which influence the property (Hardness) more. Taguchi's confirmation test also conducted for ranges, tool rotation speed 1000 rpm, and traverse speed 15mm/min and tapered tool profile. The ranges gathered from the mean effect plot and it gives the S/N ratio (Efficiency) is 40.5.

7. References
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