Influence on the Tensile Properties of AA7075-T6 under Different Conditions during friction stir welding process

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Abstract.
The main idea is to study the outcome parameters of FSW on finest quality of AA7075-T6. The welding of AA7075 is done by vertical milling machine with using different tools. Different welding parameters are studied on fluctuating tool rotational speed which varies 900 to 1750 (rpm), having tool shoulder diameter between 15 to 20 mm and transverse speed of the table which is under the range of 30 to 45 (mm/min). Taguchi technique is used for optimizing the welding parameters. In this present investigation three factorial and three level designed are used for optimization through the Taguchi Technique. The result which are detected defines that due to increase in rotational speed the tensile strength of welded joint increases and tensile strength decrease due to the frictional heat which is generated during the FSW process.

Keywords: FSW, Aluminium Alloy, Tensile Strength, Taguchi technique, Microstructure, and Mode of fracture.

1. Introduction
Friction stir welding (FSW) which is a solid state practice for amalgamation of different aluminium alloys. The friction stir welding (FSW) process is developed by the Welding Institute (TWI) of UK in 1991[1]. In FSW process, rotating tool moves with speed along the welding centre line so that plunge depth has a very important influence on the joint strength [2]. In recent years, aluminium alloy (AA 7075) is mostly used in automobile, aerospace and aircraft industries since of their brilliant strength to weight ratio, corrosion resistance, good ductility, and cracking resistance in hostile environment [3].The literature reviews reveals that many researchers have attempted to calculate the process parameters in friction stir welding. Rao et al. studied the effect of tool profile and rotational speed on mechanical properties of aluminium alloy. They revels that on increasing axial force, tensile strength of weldment decreases [4]. Radisavljevic et al. influenced on tensile strength quality and mechanical properties by using FSW process and find out the tensile strength of base material which is higher as compared to the weld joints, and the maximum competence in terms of UTS and elongation respectively [5]. Song studied on Mechanical Properties by using friction stir welding (FSW) process and found that the grain refinement which have an influence on increase of mechanical properties like that micro hardness and tensile strength considerably improved than the base material[6].

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Varma et al. investigated on dissimilar aluminium alloy by use of FSW process and optimized the process parameters by selecting an L₁₆ orthogonal array consisting of 8 experimental runs by Taguchi technique [7]. Xu et al. investigated the mechanical properties and microstructure of aluminium alloy and showed that grain sizes of particles through the thickness of WNZ and also find out the tensile strength and yield strength of joints with growing rotary speed from 800 rpm to 1300 rpm [8]. Haiyan Chen et al. influenced on rotational speeds for mechanical properties and microstructure and it was observed that the grains size is having a significant refinement of grains in the nugget zone and thermo-mechanical affected zone as well nugget zone as compared with the base metal [9].

2. Material and Experimental set up

AA 7075-T6 aluminium alloy material with a 6 mm thick plate (AA-7075) is selected for experimental work. Specimen is use in size 150mmx125mmx6mm for experiment work in FSW process. AA 7075-T6 aluminium alloy mostly use in aerospace, aircraft and automobile respectively. Tool play very important role to carry out the main mechanical properties and microstructure of the joint. The FSW tool with a different shapes and size which is made of En-31 used to perform the weld joints at various speeds by friction stir welding. The shoulder dia of the tool is 20 mm, pin dia is 5mm at the root and pin length of 5.75 mm is used for FSW process. The length and shape of the pin together with shoulder diameter influenced on both the material flow and heat generated by friction due to the rotating tool at the high speed as well as fast plastic deformation. The alloy’s chemical composition is reported in Table 1. Rotating tool is penetrate into the work piece 0.5 mm and take 1 minute so that this process take 0.5 interval in this way heat is generate to get a best welding joint on vertical milling machine given below in Figure 5. Friction stir welds joint 6mm thick AA-7075 was made in the mechanical engineering department (University Polytechnic), Jamia Millia Islamia, New Delhi, India on a Hercules vertical milling machine for performing FSW as shown in Fig 1. The plates were machined for required size (150x62) mm. Different tools geometry are shown in Fig 2. The chemical composition by weight (wt. %) of AA-7075 which is used for performing FSW experiment is reported in Table 2.

![Fig1. FSW set up used for FSW Process.](image-url)

The non-consumable (FSW) tool with a different shapes & size made of En-31 was used to perform the weld joints during this experimentation; it’s having high temperature, good thermal conductivity and high strength. The tool used in an experiment work which have the tool shoulder dia of 20 mm, pin dia of 5 mm at the root and pin length 5.75 mm. In FSW, the plastic deformation takes place due to the rotating tool which generates heat due to friction, that results in local plastic deformation. Function of the pin and the tool is to generate the heat which helps in material softening and material flow control for defect free weld.
Fig 2. (a) Cylindrical tool (b) Taper tool (c) Triangular tool (d) cylindrical threaded tool (e) Taper threaded tool.

Table 1. Chemical composition of En-31 for tool conferring to spectrometer analysis (wt. %)

| Element | C     | S     | Mn    | Cr     |
|---------|-------|-------|-------|--------|
| wt.%    | .09-1.20 | 0.10-0.35 | 0.30-0.75 | 1.00-1.60 |

Table 2. Chemical composition of AA7075-T6 conferring to spectrometer analysis (wt. %)

| Element | Si | Fe   | Cu    | Mn   | Mg    | Cr   | Al   | Zn   | Ti |
|---------|----|------|-------|------|-------|------|------|------|----|
| Required wt.% | 0.3 | 0.4  | 1.2-2.0 | 0.3 | 2.0-2.8 | 0.19-0.29 | 87.1-91.4 | 5.0-6.2 | 0.3 |

Table 3. Process parameter

| Parameters                | Units | Symbol | Levels (rpm) |
|---------------------------|-------|--------|--------------|
| Tool rotation speed       | RPM   | N      | 900 1110 1320 1750 |
| Welding speed             | mm/min| S      | 30 35 40 45 |
| Tool shoulder dia         | mm   | D      | 20 20 20 20 |
| Plunged depth             | mm   | h      | 0.10 0.12 0.14 0.16 |

Fig 3. Figure of the FSW process [10]
Fig 3 shows the schematic illustration of the friction-stir welding process. FSW process was performed on different RPM, plunge depth and feed. The experimentation work is performed on the vertical milling machine and by setting up a suitable setup through which the FSW process is firmly done with precision so that the weld joint quality can be improvised. The surface morphologies of AA-7075 weld joints under a different parameter of friction stir process are shown in Fig 4.

![Fig a. RPM -900, Plunge depth-0.10, Feed-30mm/min](image)

![Fig b. RPM-1110, Plunge depth -0.12, Feed-35mm/min](image)

![Fig c. RPM-1320, Plunge depth-0.14, Feed-40mm/min](image)

![Fig d. RPM- 1750, Plunge depth-0.16, Feed-45mm/min](image)

**Fig 4.** Surface morphologies of AA-7075 weld joints under a different parameter of friction stir Process.
2.1 Tensile Test

The tensile test is generally used to provide basic statistics about strength of material for an acceptance test. It is a very important parameter which comes under mechanical testing due to which the tensile strength is obtained of FSW process. The standard sample for tensile test is shown in Fig 5. Tensile test samples were fabricated as per American Society (ASTM E8M-13a) to evaluate the tensile properties of welded joint and test performed on tensile testing machine as shown in Fig 6.

![Fig 5. Size of tensile test specimen ASTM E-8/E8M-13a [11]](image)

![Fig 6. Tensile testing machine](image)

![Fig 7. Fractured Tensile Test Specimen](image)
Table 4. Tensile testing observation result for AA7075-T6 in FSW

| S.No | Speed (rpm) | Plunge depth (mm) | Feed (mm/min) | UTS (MPa) |
|------|-------------|-------------------|---------------|----------|
| 1    | 900         | 0.10              | 30            | 333      |
| 2    | 900         | 0.12              | 35            | 335      |
| 3    | 900         | 0.14              | 40            | 358      |
| 4    | 900         | 0.16              | 45            | 398      |
| 5    | 1110        | 0.10              | 35            | 400      |
| 6    | 1110        | 0.12              | 30            | 421      |
| 7    | 1110        | 0.14              | 45            | 398      |
| 8    | 1110        | 0.16              | 40            | 400      |
| 9    | 1320        | 0.10              | 40            | 378      |
| 10   | 1320        | 0.12              | 45            | 398      |
| 11   | 1320        | 0.14              | 30            | 389      |
| 12   | 1320        | 0.16              | 35            | 380      |
| 13   | 1750        | 0.10              | 45            | 390      |
| 14   | 1750        | 0.12              | 40            | 387      |
| 15   | 1750        | 0.14              | 35            | 381      |
| 16   | 1750        | 0.16              | 30            | 389      |

Data of Table 4 concluded that UTS is decreasing with feed and increasing with the rotational speed. The fractured sample of tensile test is shown in Fig 7. At 45mm/min feed, 20mm diameter of tool is give the better result in tensile strength. The parameters which explain by the stress and strain curve obtained on (UTS), tensile test, and yield test and elongates etc. The key influence is to find out the consequence of shoulder diameter of tool in FSW process [12]. The transverse feed is contrariwise proportional to the weld part strength. The main important factor of friction stir welding for better strength is mixing of material in plastic state and for analysis, (DOE) design of experiment of three factor and three level designs is carefully chosen.

3. Optimization of Process Parameter of FSW Welding process

Taguchi optimization technique is applied under the condition that is best strength for analysis of it, (DOE) design of experiment of three factor and three level designs is carefully chosen. The three levels of rotational speeds are 900, 1110, 1320, 1750 rpm, feed 30, 35, 40, 50 mm/min and plunge depth 0.10, 0.12, 0.14, 0.16 mm. From the above design the optimum condition for FSW are 1750 rotational speed, 45mm/min feed and 0.14 plunge depth. P. Vijaya Kumar et al showed that microstructure having relatively closely and coarse space precipitates beside the grain boundaries. The grain boundary hastens are continuous and closely than that in T6 condition due to the creation of an extra grain boundaries [13] Yousif et al. developed a model for the investigation and simulation of the relationship in FSW constraints of mechanical properties and aluminium plates [14]. Through the optimization of the process parameters of FSW welding process the better cum optimized process parameter is identified from all other different combinations of process parameters which results in the betterment of the FSW, that obtained parameter can be used for better quality FSW process. Optimization of the process parameters are required for making the process smooth and more
4. Determining the Single-to-Noise (S/N ratio)
In this study, L16 OA with 4 columns and 16 rows was used. This array can used four level process parameters. Fourteen experiments were performed for investigation by using the L16 OA. In this way the influence of each selected factor was calculated on response and the S/N ratio for each factor. In the present research work, welded specimen’s tensile strength and hardness stood identified as the response for tensile strength “higher the better and normal the best. Fig 8 & Fig 9 show the main effect of plots for means and residual plots of UTS.

5. Effect of Speed
In this investigation, the consequence of input parameters on the tensile strength was analyzed. The single to noise ratio for all the responses are given in Table 5. The analysis of different alteration for tensile strength. It clearly shows that the speed is the most significantly affects tensile strength with response means 52.14 mm and tensile strength 421 MPa at 1110 rpm and plunge depth 0.14 mm. Table 6 represent the analysis of variances for UTS. Different surface plots with respect to speed, plunge depth for yield strength and UTS presented in Fig 10. The effect of speed significantly plays a very vital role on the FSW process which can be easily analysed through the SN plots as shown in Fig.10.

Fig 8. Main Effects Plot for Means

Table 5. Single to Noise Ratio

| Level | Speed(mm) | Plunge depth(mm/min) | Feed(mm) |
|-------|-----------|----------------------|----------|
| 1     | 51.13     | 51.47                | 51.63    |
| 2     | 52.14     | 51.81                | 51.59    |
| 3     | 51.76     | 51.62                | 51.61    |
| 4     | 51.75     | 51.89                | 51.95    |
| Delta | 1.01      | 0.42                 | 0.36     |
| Rank  | 1         | 2                    | 3        |
Table 6. ANOVA for UTS, by Adjusted SS for Tests

| Source       | DF | Seq SS | Adj SS | Adj MS | F   | P   | % P  |
|--------------|----|--------|--------|--------|-----|-----|------|
| Speed        | 3  | 3901.5 | 3901.5 | 1300.5 | 5.77| 0.034| 58.127|
| Plunge depth | 3  | 795.5  | 795.5  | 265.2  | 1.18| 0.394| 11.851|
| Feed         | 3  | 662.5  | 662.5  | 220.8  | 0.98| 0.462| 9.869 |
| Error        | 6  | 1352.5 | 1352.5 | 225.4  |     |     |      |
| Total        | 15 | 6712   |        |        |     |     |      |

S = 15.0139  R-Sq = 79.85%  R-Sq (adj) = 49.62%

Fig 9. Residual Plots for UTS

Fig 10. (a) Surface Plot of Yield strength VS Speed, Plunge depth (b) Surface Plot of Yield Strength VS Plunge depth, Feed (c) Surface Plot of UTS VS Speed, Plunge depth (d) Surface Plot of UTS VS Plunge depth, feed
From the above Taguchi design analysis surface plot is carried out from the UTS with rotational speed of tool like that (900, 1110, 1320, 1750) rpm, feed (0.10, 0.12, 0.14, 0.16) mm/min and shoulder diameter of tool 20mm. According to these above given factors of rotational speed, shoulder dia and feed the analysis is carried out.

6. MICROSTRUCTURE
The microstructure investigation was done using an optical microscope through inspecting electron microscope (SEM) Philips 525M. The microscopic interpretations at the optical microscope were executed on the cross-sections that were ground and polished mechanically, and then etched with 2 ml HF, 3ml HCL, 4 ml HNO3, and 190 ml H2O solution. The SEM interpretations (Fig 11) have carried out from the weld nugget and the regions close to the thermo-mechanically exaggerated zone. The SEM studies have steered on polished surface in the cross-section of the joints [15]. The optical micrographs of FSW are taken at (SZ) stir zone of all the joints are established in Fig 12. (A-I). From the micrographs, it is identified that there is a noticeable variation in average grain diameter of weld region in AA 7075. Due to fiction stir welding, the abrasive grains of base metal are transformed in fine grains in stir zone during FSW.

The weld joints contrived with 1750 rpm rotational speed. 50 mm/min welding speed and 0.14 mm plunge depth are having better grains in the weld region as compared to other joints with different parameters. From obtained micrographs, it is concluded that there is significant difference in grain size through the welds; it occurs because of inadequate thermal contact and plastic flow. It is observed during the work that the total impact energy amplified in the FSW of (moderate strength) AA7075 alloy at 1750 rpm and 50 mm/min with respect to the base metal while rotation and crosswise speed have little effect on the influence value.

**Fig 11a**

**Fig 11b**

**Fig 11c**

**Fig 11d**

**Fig 11.** Microstructure obtained by SEM at 900 rpm, 1110, 1320, 1750 (a) 0.1mm below top surface, (b) 0.4 mm below top surface, (c) 0.5 mm below top surface and (d) 0.9 mm below top surface in FSW process.
7. CONCLUSION
In this ongoing research work, the subsequent conclusions can be inferred.

1. The tensile strength is decreasing with increasing feed and increasing with speed. Tensile strength is optimal with tool shoulder diameter 20 mm and 1750 rpm rotational speed and feed 50mm/min for 6mm thick plate, the heat produced will not concentrate near the welded joint area so 20 mm shoulder Diameter does not give the maximum UTS as compared to other dia of the tool.
2. The optimum welding process parameters are carried out at speed 1750 rpm, feed 50 mm/min and plunge depth 0.14 mm.
3. Taguchi design of experiment method is very suitable for optimizing the welding parameter in friction stir welding operations.
4. Tensile strength and maximum hardness is obtained at speed 1750 rpm, feed 50 mm/min.
5. Microstructure shows that numerous sections are created in the joints; though, analogous types of Crystalloid graphic texture are created by the development within the nugget for materials. They vary in Grain size and Intensity. Hardness loss is considerably higher in the case of welds joint in thick Plates, which is because the higher heat obtained throughout the fusing process. Grain refinement results Show the maximum hardness of the weld nugget in weld.
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