

# Study of Mechanical Properties of Aluminium Alloys on Normal Friction Stir Welding and Underwater Friction Stir Welding for Structural Applications

Lingaraju Dumpala, Laxmi Mohan Kumar Chintada, Devadas Deepu, Pravin Kumar Yadav

**Abstract**—Friction stir welding is the new-fangled and cutting-edge technique in welding applications; it is widely used in the fields of transportation, aerospace, defense, etc. For thriving significant welding joints and properties of friction stir welded components, it is essential to carry out this advanced process in a prescribed systematic procedure. At this moment, Underwater Friction Stir Welding (UFSW) Process is the field of interest to do research work. In the continuous assessment, the study of UFSW process is to comprehend problems occurred in the past and the structure through which the mechanical properties of the welded joints can be value-added and contributes to conclude results an acceptable and resourceful joint. A meticulous criticism is given on how to modify the experimental setup from NFSW to UFSW. It can discern the influence of tool materials, feeds, spindle angle, load, rotational speeds and mechanical properties. By expending the DEFORM-3D simulation software, the achieved outcomes are validated.

**Keywords**—Underwater friction stir welding, al alloys, mechanical properties, normal friction stir welding.

## I. INTRODUCTION

THE Normal Friction Stir Welding (NFSW) system is a novel solid state joining development that has extensive applications in joining aluminum alloys hard to be weld by conventional joining methods due to the solid-state formation problems such as porosity, hot cracking, and alloy splitting [1]. NFSW is used to overcome the beforehand specified issues. NFSW is to make fabulous, brilliant joints with low contortion and is fit for making either butt or lap joints, in a broader range of material thickness and lengths. The technique is finished by diving a turning apparatus made of a wear-resistant and high temperature resistant material that is changing over into the material to be joined and interpreting it along the pined for weld line. The heat produced by rubbing at the tool surface and plastic dispersal in the distorting portions of the work pieces soften the material to a plasticized state. It is then ousted around the tool and consolidates to frame a weld.

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In the UFSW, the welding zone surroundings are not affected with high temperatures by virtue of using water. DEFORM 3D is a Finite Element strategy based process simulation system designed to examine the different forming and heat treatment methods utilized by metal forming and related enterprises. The experimentation temperature results are validated by utilizing DEFORM-3D.

## II. LITERATURE REVIEW

The experimental examination on under water friction stir welding (UFSW) and NFSW (NFSW) of armour grade, high strength AA2519-T87 aluminum was performed. UFSW is a variation of NFSW process which can maintain low temperature and constant heat along the weld line. The heat conduction and dispersion during UFSW controls the width of TMAZ and HAZ and moreover improves the joint properties [2]. Compared with NFSW, UFSW has significant grain refinement impact. The microstructures in the TMAZ and HAZ for the UFSW are substantially better than those of the NFSW. The elongation, yield strength, and ultimate tensile strength of UFSW AZ91 magnesium alloy with considerably improved grained structure are substantially higher than those of NFSW material [3]. Sakurada et al. [4] utilized under water welding process. In their exploration, they could join Al-6061 underwater in a revolving friction weld. A friction weld is developed by taking a cylinder-shaped tool, rotating at a high speed and pressing it against flat sample. The stirring produces heat, eventually fusing the material to a solidly welded region.

Bahrami et al. [5] examined the influence of pin geometry, in the microstructure and mechanical properties of AA7075/Si-C nanocomposite manufactured by Friction Stir Welding process. NFSW was carried out by utilizing five geometrically distinct pin tools, i.e. threaded tapered, triangular, square, four-flute square and four-flute cylindrical. Moreover, the highest and lowest microhardness were achieved by using threaded tapered and four-flute cylindrical tools respectively. NFSW was performed with each tool at 1250 rpm and 40 mm/min. The metallographic samples were grounded, polished, and etched to study the macro and microstructures of the weld. The maximum uniform distribution of the particles within the stir zone was attained by threaded tapered pin.

Indira et al. [6] studied the process parameters of FSW AA 6061 aluminum composite in T6 conditions plates. The tool made up of H11 steel material has frustum formed test with strings. Post-weld heat treatment condition is completed for

the assessment of the mechanical properties such as elasticity, twist property, etc. at room temperature. The microstructure analysis is done by optical microscopy. Based on the shape of FSW tool pin, nugget zone long grains are observed, which contain sub grains, sub-boundaries, and disengagements.

Ilangovan et al. [7] discussed about the solidification difficulties confronted during the fusion welding of distinct heat treatable and non-heat treatable aluminum alloys. These difficulties must be eliminated to achieve the collective advantageous properties of both aluminium alloys under FSW. The microstructure of friction stir welded similar and dissimilar AA6061 and AA5086 aluminium alloys were observed and then investigated by means of optical and scanning electron microscopy. The tensile properties of these joints were assessed and then linked with microstructure features and microhardness values at various weld zones. As dissimilar joints exhibit maximum hardness of HV 115 and efficiency 56%, there was a chance to develop defect free stir zone and strengthening of grain size.

Mofid et al. [8] UFSW has conducted for plates of AZ31 and AA5083 H34 in three distinct situations, i.e. air, water, and liquid nitrogen by maintaining constant rotational speed and welding speed. They observed cracks in the stir zone due to development of brittle intermetallic phases, and hence, poor mechanical properties of the joint were detected. The vital is to control liquation and development of aluminum-magnesium intermetallic compounds in friction stir welding process. This was possible by maintaining the weld zone temperature lower than the eutectic temperature, by lowering the peak temperature. Particularly this submerged FSW is reasonable for those composites that are sensible to overheating. The consequence of the intermetallic compounds in the weld zone was negligible when FSW was performed in keenly chilled environments. This was well supported by inference of scanning electron microscopy (SEM) and X-Ray diffraction (XRD) examination. The fracture was observed at the weld nugget and is also known as Original Joint Line with Severe Plastic Deformation (OJLwSPD). However, air welded specimen has high hardness value when compared with the other two cases.

Jain et al. [9], investigated the influence of a three-dimensional coupled thermomechanical strategy in light of Lagrangian Implicit technique suggested to learn the thermal history, strain dissemination, and thermomechanical process in butt welding of AA2024 by using DEFORM-3D software. Work piece is treated as rigid-viscoplastic material and the condition between the tool and specimen was defined and then adaptive remeshing is used to tackle high mesh distortion. Tool rotational speed and welding speed were assessed. By predicting the temperature distribution on the work piece and tool and it was observed that the maximum temperature was developed on the top surface of the work piece.

Vostrov and Kononov [10] studied and discussed that outcomes of finite element simulation of rolling cylindrical work pieces by using DEFORM-3D software were presented. The stress curves for limiting plasticity of L63 brass related to various schemes were plotted, and distortion paths of

representative areas in a rolled part are evaluated.

### III. EXPERIMENTAL SETUP

NFSW experimental setup is a vertical milling machine 3T limit. In this setup Z-Axis has apparatus drive speed of Maximum of 2500 RPM and maximum of  $7^{\circ}$  tilt angle. In this setup, the three parameters are instrument pivot speed, device sustain rate, and tilt edge. The NFSW setup is changed over to UFSW Setup. The conversion of setup is clarified with layout diagram.



Fig. 1 NFSW Machine

During welding, the inlet and outlet valves are changed in accordance with the control of water stream such that it would keep up the temperature of water underneath  $70^{\circ}\text{C}$  close to the welding zone. The temperatures of the work piece at various separations of progressing and withdrawing side can be measured by utilizing those thermocouples.

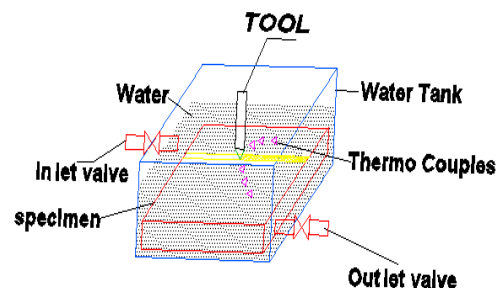


Fig. 2 Layout Diagram of the UFSW



Fig. 3 UFSW Machine

NFSW machine appears in Fig. 1, layout chart of the UFSW appears in Fig. 2, and UFSW Experiment setup appears in Fig. 3. By utilizing this UFSW analyze setup, the two examinations NFSW and UFSW should be possible.

#### IV. EXPERIMENTATION

Experimentation is performed at various speeds and feed rates; however, the apparatus is utilized as the same. Aluminum 6061, 6063 composites were utilized as a part of similar and dissimilar circumstances. For Friction stir welding, the work pieces are prepared as per the required measurements 250\*60\*6 mm of AA 6061 and AA 60633 materials. After the material planning, plates are legitimately settled on the base plate with bolts. Experimentations are performed in two distinct conditions, i.e. NFSW and UFSW. The variable parameters are instrument turn speed 1200 and 1400 rpm, Tool feed rate is 22 and 44 mm/min, and tilt edge is 10. Device is fabricated, H13 chromium hot-work steel is utilized, and the device geometry is taper strung.

#### V. RESULTS AND DISCUSSIONS

**Wear Test:** Wear is the proceeding with loss of material from the surface of a strong body because of mechanical activity, i.e. contact and relative development of a strong, liquid or vaporous counter body.

**NFSW AA6061:** The best extent of wear resistance, i.e. 0.000022 g/sec was acquired at a speed of 1200 rpm and nourishes rate of 22 mm/min and plate unrest of 300 rpm.

**NFSW AA6063:** The best extent of wear resistance i.e., 0.000011 g/sec was gotten at a speed of 1200 rpm and encourages rate of 22 mm/min and plate insurgency of 300 rpm.

**NFSW AA6061-AA6063:** The best extent of wear resistance, i.e. 0.0000055 g/sec was obtained at a speed of 1200 rpm and nourish rate of 22 mm/min. furthermore, plate unrest of 600 rpm.

**UFSW AA6061:** The best greatness of wear resistance i.e. 0.000016 g/sec was acquired at a speed of 1200 rpm and bolster rate of 22 mm/min and circle unrest of 600 rpm.

**UFSW AA6063:** The best size of wear resistance i.e. 0.0000083 g/sec was acquired at a speed of 1200 rpm and bolster rate of 22 mm/min and plate upset of 600 rpm.

**UFSW AA6061-AA6063:** The best greatness of wear resistance i.e. 0.000022 g/sec was obtained at a speed of 1200 rpm and sustain rate of 22 mm/min.

TABLE I  
WEAR TEST RESULTS (AT ROOM TEMPERATURE, LOAD = 10 N AND TIME (T) = 1800 SEC)

S. No.	Material	Speed (rpm)	Initial Wt. (x) gm.	Final Wt. (y) gm.	Wear rate (x-y)/t gm./sec
1.	6061	300	2.780	2.760	0.000022
2.	6061	600	2.780	2.750	0.0000166
3.	6063	300	2.510	2.5	0.000011
4.	6063	600	2.510	2.49	0.000011
5.	6061-6063	300	2.640	2.638	0.000022
6.	6061-6063	600	2.640	2.63	0.0000055

TABLE II  
WEAR TEST RESULTS (UNDER WATER, LOAD = 10 N AND TIME (T) = 1800 SEC)

S. No.	Material	Speed (rpm)	Initial Wt. (x) gm.	Final Wt. (y) gm.	Wear rate (x-y)/t gm./sec
1.	6061	300	2.890	2.87	0.000022
2.	6061	600	2.890	2.865	0.000016
3.	6063	300	2.48	2.47	0.000011
4.	6063	600	2.48	2.465	0.0000083
5.	6061-6063	300	2.7	2.68	0.000022
6.	6061-6063	600	2.7	2.68	0.000066

**Rockwell Hardness Test:** In hence technique hardness steel ball (or) precious stone (indenter) is encouraged into a material to be tried under a settled load. After reasonable load is connected on the material, the indenter enters into the given material. For aluminum composites bearing material 1/8 inch ball indenter of a heap 100 kg and dial is used. The test results are given below.

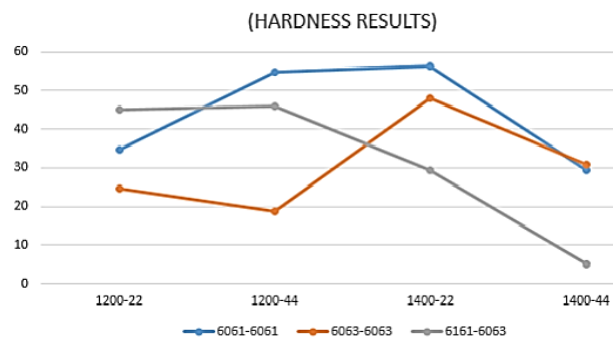


Fig. 4 Hardness Test Graph (at room temperature)

**NFSW AA6061:** The best magnitude of hardness i.e. 56.25 RHN was obtained at a speed of 1400 rpm and feed rate of 22 mm/min.

**NFSW AA6063:** The best Rockwell hardness, i.e. 48.12 RHN was obtained at a speed of 1400 rpm and feed rate of 22 mm/min.

**NFSW AA6061-AA6063:** The best magnitude of hardness i.e. 51 RHN was obtained at a speed of 1200 rpm and feed rate of 44 mm/min.

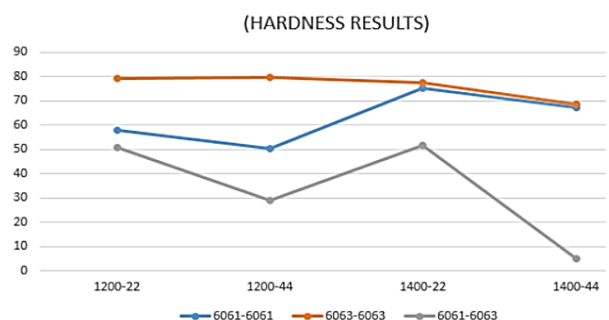


Fig. 5 Hardness Test Graph (UFSW at room temperature)

**UFSW AA6061:** The best magnitude of hardness, i.e. 51.62 RHN was obtained at a speed of 1400 rpm and feed rate of 22

mm/min.

**UFSW AA6063:** The best Rockwell hardness, i.e. 79.75 RHN was obtained at a speed of 1200 rpm and feed rate of 22 mm/min.

**UFSW AA6061-AA6063:** The best magnitude of hardness, i.e. 58.37 RHN was obtained at a speed of 1400 rpm and feed rate of 44 mm/min.

**Impact Test:** ASTM standard strategy for deciding the effect resistance of materials various welded AA (6061 and 6063) was tried for effect resistance under Charpy testing equipment (i.e., Angle of sledge is of 90 degrees). The outcomes acquired from Charpy test for various combinations are the following:

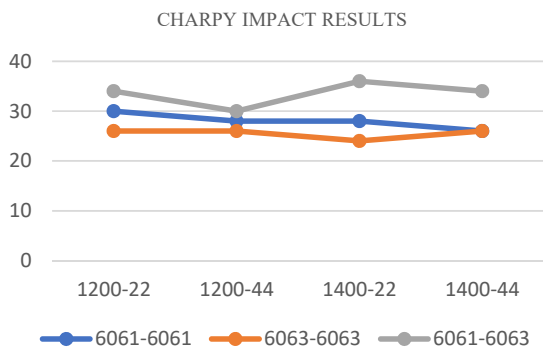


Fig. 6 Charpy test (at room temperature)

**NFSW AA6061:** The best magnitude of impact resistance, i.e. 36 J was obtained at a speed of 1400 rpm and feed rate of 22 mm/min.

**NFSW AA6063:** The best magnitude of impact resistance, i.e. 30 J was obtained at a speed of 1400 rpm and feed rate of 22 mm/min.

**NFSW AA6061-AA6063:** The best magnitude of impact resistance, i.e. 36 N-m was obtained at a speed of 1400 rpm and feed rate of 22 mm/min.

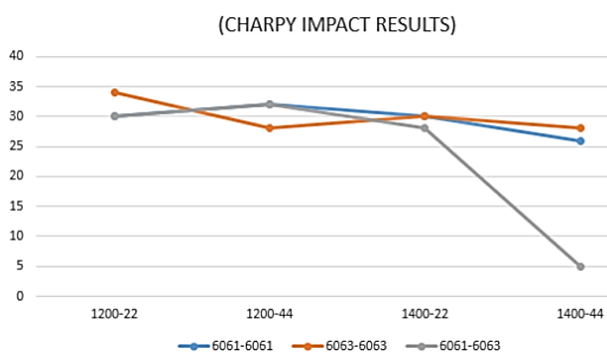


Fig. 7 Charpy test at UFSW (at room temperature)

**UFSW AA6061:** The best magnitude of impact resistance, i.e. 32 J was obtained at a speed of 1400 rpm and feed rate of 22 mm/min

**UFSW AA6063:** The best magnitude of impact resistance,

i.e. 34 J was obtained at a speed of 1200 rpm and feed rate of 22 mm/min

**UFSW AA6061-AA6063:** The best magnitude of impact resistance, i.e. 32 J was obtained at a speed of 1200 rpm and feed rate of 44 mm/min.

## VI. SIMULATION

Temperatures are approved for the materials. Temperatures are found for AA6061 comparative sort, AA6063 comparative sort and AA6061-AA6063 different sort. The procedure accomplished for the assembling was reshaped in the DEFORM - 3D. Different temperatures were obtained for AA6061 and AA6063 when they are made to keep running at 1200 rpm, 1400 rpm at sustains of 22, 44 mm/min. These temperatures are plotted in the figures and they are thought about between the aftereffects of assembling welds and DEFORM-3D apparatus welds.

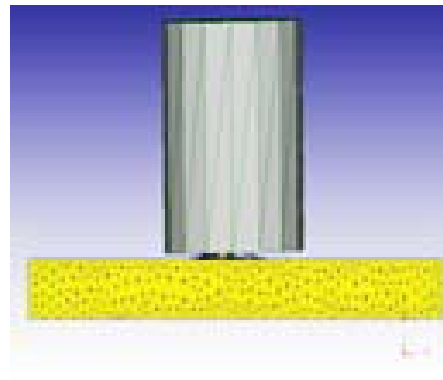


Fig. 8 During Plunging in Simulation

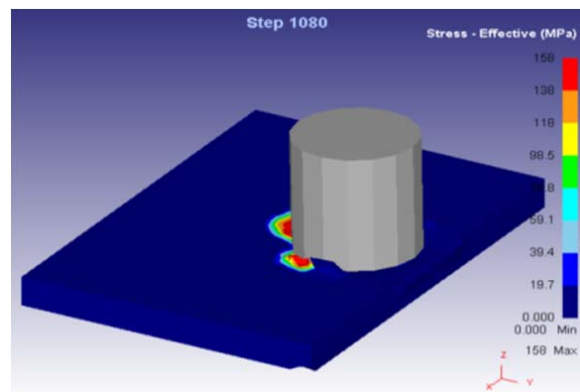


Fig. 9 Stress indications during simulation

## VII. CONCLUSION

In this experimental study, aluminum alloys, namely Al 6061 & Al 6063, are welded in both room temperature and also in under water temperature using Friction Stir Welding. Welding of these alloys is carried out with different speeds such as 1200, 1400 rpm. Parameters speed and feed rate are varied to obtain optimum values.

**During NFSW (at room temperature):**

- For AA6061 and AA6063 joints the mechanical properties were considered and it was found that optimum speed and feed rate for welding was 1400 rpm and 22 mm/min, respectively.
- For AA6061-AA6063 joints, the mechanical properties were considered and it was found that optimum speed and feed rate for welding was 1200 rpm and 44 mm/min, respectively.

**During UFSW:**

- For AA6061 & AA6063 joints, the mechanical properties were considered and it was found that optimum speed and feed rate for welding was 1200 rpm and 22 mm/min, respectively.
- For AA6061-AA6063 joints, the mechanical properties were considered and it was found that optimum speed and feed rate for welding was 1200 rpm and 44 mm/min, respectively.

Moreover, the obtained results are validated using DEFORM-3D simulation software and the temperature results.

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