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# Effect of Mechanical Properties on Friction Stir Processing with Nano Material

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**ABSTRACT:** In recently developed innovative joining process, Friction stir welding (FSW) is connected to make the best quality of strength and hardness of the welded joints. The lightweight nonferrous materials are focused on aircraft hydraulic systems, fuel tank and transportation ventures due to its high strength to weight ratio and corrosion resistance. The joining of aluminium alloys is extremely troublesome in the conventional fusion welding process because of its cementing shrinkage, hot breaking, scatter, fumes and residual stresses. The friction stir processing is connected to enhance the mechanical properties of the friction stir welded joints by the addition of nanoparticles. The investigation was made on the aluminium alloy reinforced with ZnO particulates and determined tensile strength and Micro hardness values at welded zone following sequential operation at digital equipment. The parameters such as feed, depth of hole and speed of tool are considered. The addition of ZnO nano particles at welded zone to obtained better strength via varying hole sizes i.e, 1mm and 1.5mm at interference zone. It can be observed that the tensile and hardness values increased with decreasing the speed of spindle and increased feed rate values.

**KEYWORDS:** Text detection, Inpainting, Morphological operations, Connected component labelling.

## I. INTRODUCTION

In essence, FSW is very simple, although a brief consideration of the process reveals many subtleties. The principal features are shown in Fig.1. A rotating tool is pressed against the surface of two abutting or overlapping plates. The side of the weld for which the rotating tool moves in the same direction as the traversing direction, is commonly known as the 'advancing side'; the other side, where tool rotation opposes the traversing direction, is known as the 'retreating side'. An important feature of the tool is a probe (pin) which protrudes from the base of the tool (the shoulder), and is of a length only marginally less than the thickness of the plate. Frictional heat is generated, principally due to the high normal pressure and shearing action of the shoulder. Friction stir welding can be thought of as a process of constrained extrusion under the action of the tool. The frictional heating causes a softened zone of material to form around the probe. This softened material cannot escape as it is constrained by the tool shoulder. As the tool is traversed along the joint line, material is swept around the tool probe between the retreating side of the tool (where the local motion due to rotation opposes the forward motion) and the surrounding undeformed material. The extruded material is deposited to form a solid phase joint behind the tool. The process is by definition asymmetrical, as most of the deformed material is extruded past the retreating side of the tool [1-2]. The process generates very high strains and strain rates, both of which are substantially higher than found in other solid state metalworking processes (extrusion, rolling, forging, etc.).

Friction stir welding is therefore both a deformation and a thermal process, even though there is no bulk fusion. The maximum temperature reached is a matter of some debate. Thermocouple measurements during FSW of aluminium alloys suggest that, in general, the temperature stays below 500°C. These values must be treated with some care, as the position of the thermocouple in the rapidly moving nugget can be difficult to ascertain. Microstructural evidence seems to corroborate the thermocouple based conclusion that unless extreme processing parameters are chosen, the maximum temperature usually lies between 425 and 500°C. It has been suggested that the temperature of the material in contact with the pin may reach the solidus temperature, although experimental validation is difficult due to the intense

deformation at the interface. There is evidence of incipient melting for some aluminium alloys (*e.g.* 7010) for fast weld speeds. It can also be argued that the peak temperature is inherently self-limiting. The workpiece flow stress will fall rapidly as the solidus is approached, so that heating of the nugget at the tool/workpiece interface limits the available heat generation by reducing the torque[3-4].

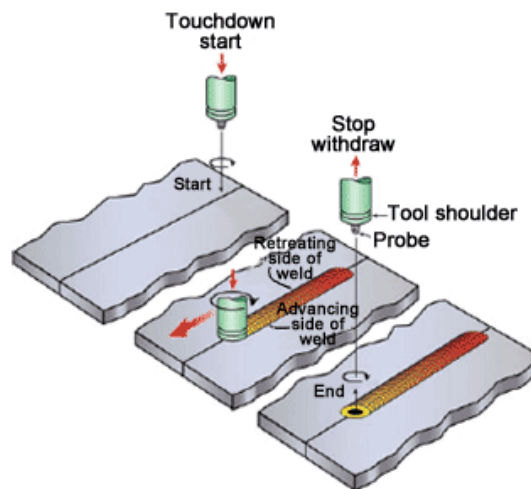


Figure 1 Schematic diagram of FSW process

Coverage of the present review is confined to the FSW of aluminium alloys. A summary of the AWS designations for wrought Al alloy groups and AWS basic temper designations applicable to heat-treatable Al alloys is contained within Table 1. Since FSW is a solid state process, it can be used to join all common aluminium alloys, including the 2xxx, 7xxx and 8xxx series which are normally challenging or impractical to weld by fusion processes. A key distinction is between non-heat-treatable and heat-treatable alloy series. In work hardened alloys (*e.g.* 5xxx), the heat from the friction welding process will allow thermal recovery and recrystallisation of dislocation substructures, although this is partly countered in the intensely deformed region where new dislocation structures are generated. In age hardened alloys, the weld will normally be heated well above the dissolution temperature of the initial precipitates, enabling dissolution, reprecipitation and overaging to occur. Friction stir welded aluminium alloys can therefore contain microstructures covering the entire spectrum of normal tempers [5-7].

Table 1 AWS designations for wrought Al alloy groups and basic temper designations applicable to heat-treatable Al alloys

| Wrought alloy groups |  | Basic temper designations |   |
|----------------------|--|---------------------------|---|
| 1xxx                 | Unalloyed 99% Al   | F                         | As fabricated   |
| 2xxx                 | Copper principal alloying element: gives substantial increases in strength, permits precipitation hardening, reduces corrosion resistance, ductility and weldability | O                         | Annealed: there may be a suffix to indicate the specific heat treatment.  |
| 3xxx                 | Manganese: increases strength through solid solution strengthening and improves work hardening   | H                         | Strain hardened (cold worked): it is always followed by two or more digits to signify the amount of cold work and any heat treatments that have been carried out  |
| 4xxx                 | Silicon: increases strength and ductility, in combination with magnesium produces precipitation hardening  | W                         | Solution heat treated: applied to alloys that precipitation harden at room temperature (natural aging) after a solution heat treatment. The designation is followed by a time indicating the natural aging period, <i>e.g.</i> W 1 h            |
| 5xxx                 | Magnesium: increases strength through solid solution strengthening and improves work hardening ability   | T                         | Thermally aged:<br>T1: cooled and naturally aged<br>T2: cooled, cold worked and naturally aged<br>T3: solution heat treated, cold worked and naturally aged<br>T4: solution heat treated and naturally aged<br>T5: cooled and artificially aged |

|      |   |  |   |
|------|---|--|---|
|      |   |  | T6: solution heat treated and artificially aged<br>T7: solution heat treated and overaged or stabilised<br>T8: solution heat treated, cold worked and artificially aged<br>T9: solution heat treated, artificially aged and cold worked |
| 6xxx | Magnesium-silicon   |  |   |
| 7xxx | Zinc-magnesium: substantially increases strength, enables precipitation hardening, can cause stress corrosion                               |  |   |
| 8xxx | Other elements - Li, for example, substantially increases strength and Young's modulus, provides precipitation hardening, decreases density |  |   |

## II. MERITS, DEMERITS AND APPLICATIONS OF FSW

The key benefits of this newly developed welding process include an increase in joint efficiency and process robustness, as well as a greater range of applicable alloys that can be welded. FSW permits welding of dissimilar alloys and alloys that are difficult to be joined by conventional welding processes. Composite materials are also candidate materials for this welding process. FSW results in low distortion welds with relatively low costs, uses simple energy efficient mechanical equipment, and requires minimal operator expertise and training. FSW can join materials that are difficult to fusion weld, for example 2000 and 7000 series of aluminium alloys. Other advantages are low distortion, no fumes, no porosity and good mechanical properties.

FSW can use existing and readily available machine tool technology. The process is also suitable for automation and adaptable for robot use. Its other advantages include non-consumable tool, no filler wire, no gas shielding, less operator skill and no grinding and brushing required in mass production. At present the main limitations of the FSW process are moderate welding speeds, complex fixturing, backing plate and keyhole at the end of each weld. Solid-state welding processes are ideally suited for welding of dissimilar aluminium alloys. Because these processes do not involve melting, the issue of weld solidification cracking does not arise. Similarly, solid-state welding processes overcome a variety of other problems in fusion welding of aluminium alloys such as porosity, segregation, brittle inter metallic formation, and heat affected zone liquation cracking[8-10].

The applications of FSW in various fields of engineering are discussed below:

**Shipbuilding and marine industries:** The shipbuilding and marine industries are two of the first industry sectors, which have adopted the process for commercial applications. The process is suitable for the applications like hulls, helicopter landing platforms, off-shore accommodation, marine structures and refrigeration plant.

**Aerospace industry:** At present the aerospace industry is welding prototype parts by FSW. Opportunities exist to weld skins to spars, ribs, and stringers for use in military and civilian aircrafts. This offers significant advantages compared to riveting and machining from solid, such as reduced manufacturing costs and weight savings. Longitudinal butt welds and circumferential lap welds of aluminium alloy fuel tanks for space vehicles have been welded by FSW and successfully tested. The process could also be used to increase the size of commercially available sheets by welding them before forming. The FSW process can therefore be considered for wings, fuselages, cryogenic fuel tanks for space vehicles, aviation fuel tanks and etc.

**Railway industry:** The commercial production of high speed trains made from aluminium extrusions joined by FSW has been reported. Applications include high speed trains, rolling stock of railway, underground carriages, railway tankers, goods wagons and container bodies.

**Land transportation:** The FSW process is currently being experimentally assessed by several automotive companies and suppliers to this industrial sector for its commercial application. A joint EWI/TWI group sponsored project is

investigating representative joint designs for automotive lightweight structures. Potential applications are engine, chassis cradles; spaceframes airfield transportation vehicles and wheel rims.

**Construction industry:** The use of portable FSW equipment is possible for aluminium bridges, window frames and aluminium pipeline.

### III. RELATED WORK

Ajay [5] optimized the various mechanical properties of AA6061 material using different tool profiles. To optimize the process parameter Taguchi technique has been used. Experimental data have been collected according to Taguchi L9 orthogonal array and optimize using S/N analysis. The optimized results shows the significant improvement in mechanical properties by using square pin profile as compared to threaded cylindrical and cylindrical pin profile. It has been observed as transverse speed increases, Ultimate tensile strength (UTS) also increases ductility. Dilkush and Sudhakar [6] aimed at changing the surface morphology by introducing carbide powders (180 mm) of boron, silicon and tungsten on to AA 6061 Al alloy (widely used in automobile components) using friction stir processing. Fabricated surface metal matrix composites (SMMCs) exhibited better wear resistance compared to the base metal. SMMC (127VHN) consisting B4C as reinforcement has shown superior wear resistance among other SMMCs made from WC and SiC respectively. From the SEM analysis, it is clearly observed that abrasion wear is the primary cause for less wear resistance in AA 6061 aluminium alloy while as adhesive wear mechanism is found to be predominant one in all other surface composites resulting in the increase of wear resistance. Thus, it is recommended to use B4C as reinforcing material for surface modification of AA6061 aluminium alloy when compared with other reinforcing materials of WC and SiC.

Aramasyah [9] studied that the process parameters such as welding speed, Feed, tilt angle, etc. play an important role in deciding the quality of weld in FSW. This work aims to investigate the tensile strength of dissimilar AA6061 and AA5052 aluminium sheets joined by FSW. The two aluminium sheets are arranged in a line with perpendicular rolling directions of the tool. The Taguchi L9 experimental method is chosen to construct the numbers of welding experiments. Analysis of variance (ANOVA) analysis is performed to get the optimum range of process parameters and their effects upon the tensile strength of the weld joints.

Pankaj [10] proved in a paper that joints can be formed between AISI304L steel and AA6061 aluminium alloy using FSW with by offsetting the probe towards the steel side (retrieving side), and without its penetrating into the aluminium (Advancing side) substrate. The multi-hole technique with a combination of nano sized zinc filler material and two different pin profiles (single pin and dual pin tools made of WC Pin and ordinary tool steel shank) were used to fabricate the joints. Trials were made on amount of zinc filler material in combination with two different pin profiles. The results in this study are summarised as follows Large number of FSW defects like furrow, grooves, holes and porosities were observed in join fabricated without zinc reinforcement and sound butt joints were achieved with 10 grams of zinc filler material dual pin tool and single hole technique in this study.

The aim of current research is that to determine the tensile strengths and hardness of AA6061 after reinforced with the zinc oxide nano-material during Friction stir welding (FSW) process and to do mechanical properties on friction stir welding of aluminium alloys. To study the influence of input parameters Tool speed, welding speed/feed, tilt angle.

### IV. METHODOLOGY

General 6061 characteristics and uses: Excellent joining characteristics, good acceptance of applied coatings. It combines relatively high strength, good workability, and high resistance to corrosion, widely available. The T8 and T9 tempers offer better chipping characteristics over the T6 temper. It have used in various applications such as Aircraft fittings, camera lens mounts, couplings, marines fittings and hardware.

Zinc oxide is an inorganic compound with the formula ZnO. It is a white powder that is insoluble in water. ZnO is present in the Earth's crust as the mineral zincite. That being said, most ZnO used commercially is synthetic.

Zinc oxide is commonly found in medical ointments where it used to treat skin irritations. In more recent times zinc oxide has transcended to use in semiconductors, concrete use, ceramic and glass compositions and even cigarette

filters.



Fig. 2. Single pin H13 tool

Chromium hot-work tool steels are classified as group H steels by the AISI classification system. This series of steels start from H1 to H19. H13 chromium hot-work steel is widely used in hot and cold work tooling applications. Due to its excellent combination of high toughness and fatigue resistance H13 is used more than any other tool steel in tooling applications. The FSW tool is used in this study shown in Fig.2. The physical properties of H13 tool steels are given in the following Table 2.

Table 2 Physical properties of H13 tool steels

| Properties            | Values                 |
|-----------------------|------------------------|
| Density (20°C /68°F)  | 7.80 g/cm <sup>3</sup> |
| Melting point         | 1427°C                 |
| Modulus of elasticity | 215 GPa                |
| Poisson's ratio       | 0.27-0.30              |
| Tensile strength,     | 1200 - 1590 MPa        |

The FSW equipment has the strongest work holder totally we need to fasten the 6 nut and bolts to fix the work piece on the table. The long grooves are for the adjustment of the fixing depending upon the size of the work piece. As the ASME standards we can fix and remove the work piece. For the purpose of tensile testing, we need to make dumbbell shapes, and I have followed the ASME standards as shown Fig.3.

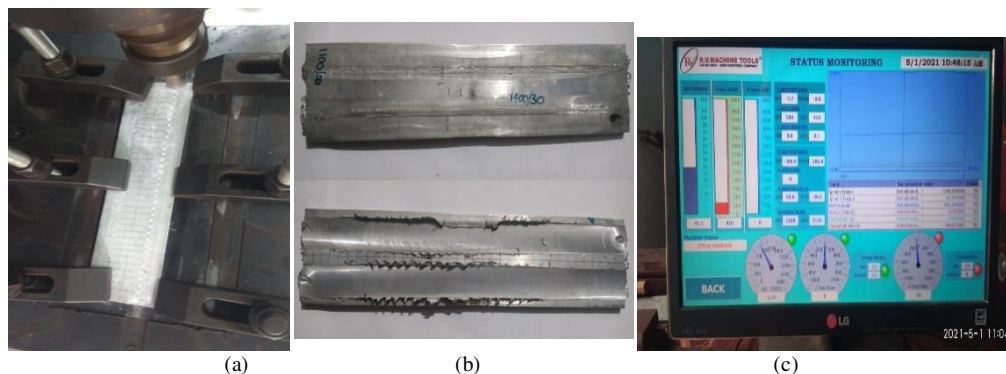


Fig. 3. The details of (a)work bench (b)prepared work piece (c) machining process

Table 3 work piece machining details

| Workpiece | Sample (N) | Speed(s) | Feed(f)   | Hole dia(d) | Depth (D) |
|-----------|------------|----------|-----------|-------------|-----------|
| 1         | N1         | 1100rpm  | 50mm/min  | 1mm         | 4mm       |
| 1         | N2         | 1400rpm  | 30mm/min  | 1mm         | 4mm       |
| 2         | N3         | 1100 rpm | 50 mm/min | 1.5mm       | 4mm       |
| 2         | N4         | 1400 rpm | 30 mm/min | 1.5mm       | 4mm       |
| 3         | N5         | 1400 rpm | 50 mm/min | 1mm         | 4mm       |
| 3         | N6         | 1400 rpm | 50 mm/min | 1.5mm       | 4mm       |

For the purpose of tensile testing, we need to make dumbbell shapes, and I have followed the ASME standards as shown figure below. After the completion of the machining and cutting the samples are shown in the Figure 4.

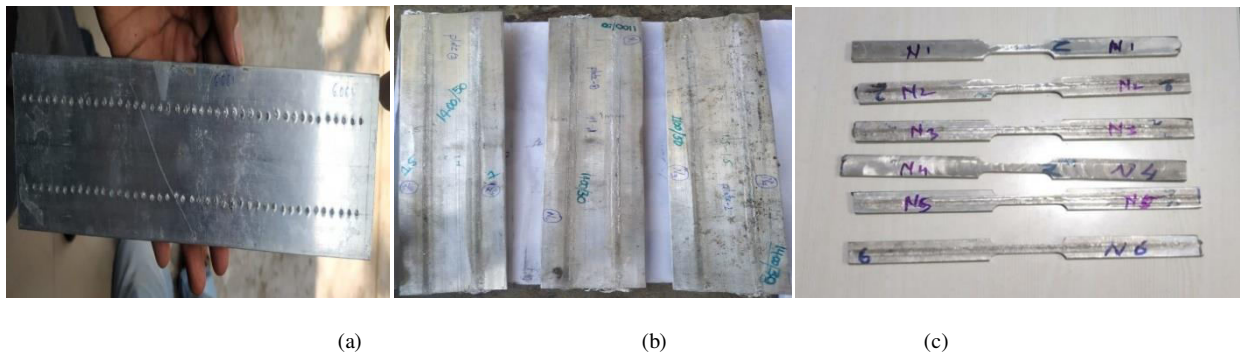


Fig. 4. The details of (a) reinforced addition in base material (b) prepared welded samples (c) Tensile samples

## V. EXPERIMENTAL RESULTS

From the Table 3, the sample notations as N1, N2.....N6 are specified the process parameters and responses. Based upon the results obtained from the testing and made the graph, can be easily make sense and each sample line is differed with various colours which are not same, it can be seen in Fig.5.

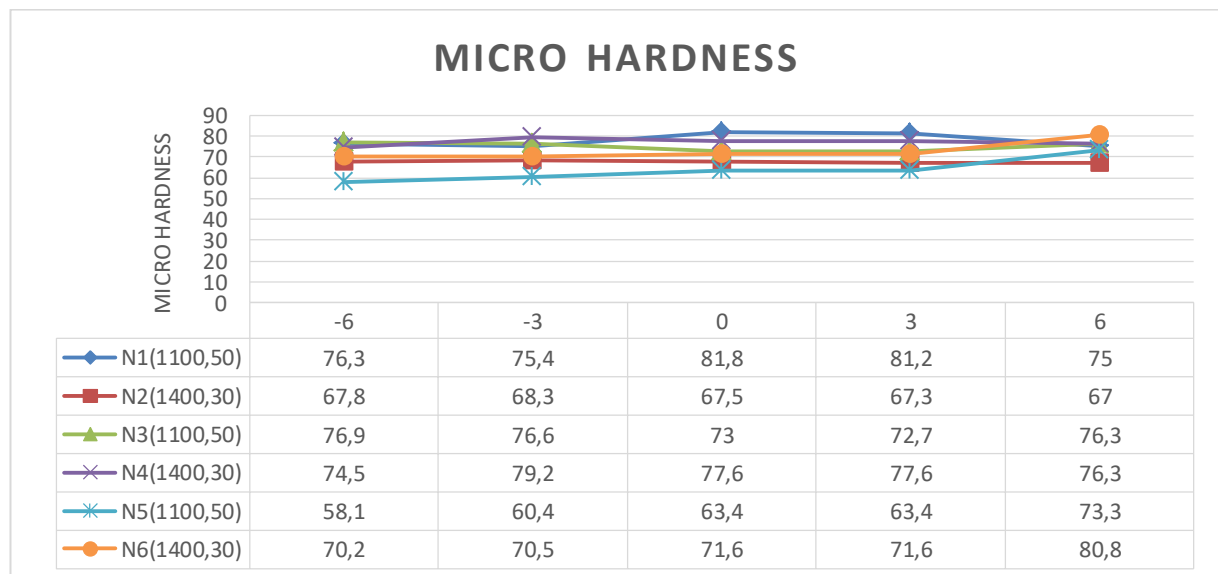


Figure 5 the detailed micro hardness values

From the Fig.5 cleared that, N5 sample shows that least hardness among the other and N1 shows the best hardness value. Similarly, from Fig. 6, it revealed that the sample N4 represents highest tensile strength and N5 shows the least among others.

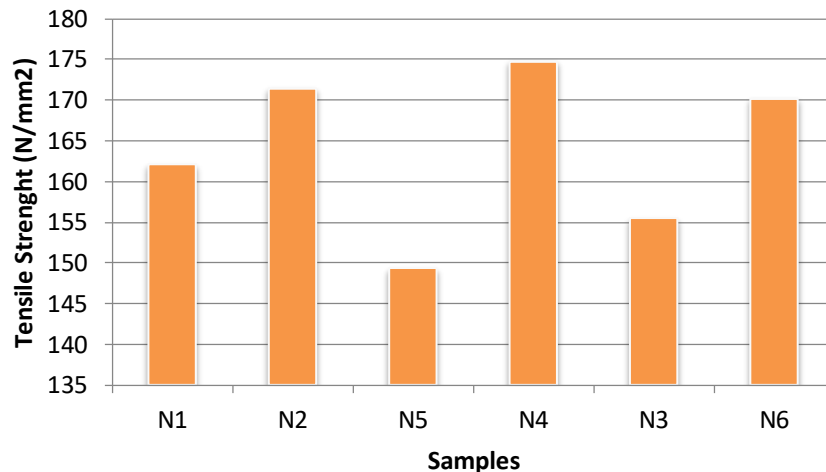


Figure 6 Tensile testing result of reinforced materials

## VI. CONCLUSION

The investigation from this study concluded that, FSW study has been performed on AA6061 with addition of reinforced particles in a solid state form. In this study considered process parameters such as feed, depth of penetration of ZnO particles into base matrix and speed of the spindle whereas responses are tensile strength and hardness values. The following observation has been made and provided an appropriate conclusions

- The tensile strength of samples will be varied upto 20 to 30 N/mm<sup>2</sup>, via considered process parameters such as feed, depth of penetration of ZnO particles into base matrix and speed of the spindle.
- As we have observed that speed and feed rate will definitely effecting the tensile and micro hardness results.
- Increasing the feed, nano material quantity and decreasing the feed results the maximum tensile strength (N4)
- Decreasing of the spindle speed and increasing the feed rate with low quantity of the nano particles also results the high strength in the micro hardness but not satisfied in tensile strength (N1).
- In the case of sample N1, observed that the tensile strength increased because of the decreasing of the speed and increasing of speed with low quantity of the addition of nano particles results less strength and high strength in the micro hardness.
- In case of sample N2, observed that the increase in the tensile strength because of increasing in the speed and decreasing in feed with minimum quantity of the nano particles addition results maximum strength in tensile strength and satisfied in micro hardness.
- While considering the N5 increase in speed, feed and less addition of the filler nano particles results very low strength of the tensile and micro hardness strength only one is up to the mark.
- The sample N3 is decreases the speed of the spindle and increased the feed with normal quantity of nano particles results less tensile strength comparing to the other samples and micro hardness shows maximum at the middle of the nugget portion.
- The sample N6 is processed with increasing speed, feed rate and rate of filler material is added results maximum strengths in the both the tensile and micro hardness as well.



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