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Studies on Effect of Tool Design and Welding Parameters on the Friction Stir Welding of Similar and Dissimilar AA6061 and AA5052 Aluminium Alloys

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ABSTRACT

Friction stir welding, a modern and an environment friendly solid - state joining process used to join relatively lighter family of materials, especially Aluminium and its alloys is deals in this study. The characterization of friction stir welded dissimilar Aluminium alloys AA 5052 and AA6061. Here, under the project work the coupons of above metals were friction - stir welded using cylindrical pin tool using at constant speed of 800 rpm and 1200rpm and at two different feed rates of 20 and 40 mm/min. Macrographs showed proper mixing due to effective stirring of cylindrical tool pin while keeping the lower feed rate.

In our project, Tensile test, impact test and hardness measurements were done as a part of mechanical characterization. Correlating mechanical and metallurgical properties it is deduced that the sample welded at lower feed rate performed better in terms of ductility..

Keywords— ***Friction Stir Welding (FSW), AA6061, AA5052, Speed, Feed, Tensile Strength, Impact Strength, Hardness.***

Introduction

Welding can be defined as the process of joining two similar or dissimilar metallic components with the application of heat, with or without the application of pressure and with or without the use of filler metal. Heat may be obtained by chemical reaction, electric arc, electrical resistance, frictional heat, sound and light energy. If no filter metal is used during welding, then it is termed as ‘Autogenous Welding Process'.

There are two groups of welding processes according to the state of the base material during the welding process:

- Solid-state or Pressure welding
- Fusion or Non-Pressure welding

Friction welding is a solid-state welding process that generates heat through mechanical friction between work pieces in relative motion to one another, with the addition of a lateral force called "upset" to plastically displace and fuse the materials. Because no melting occurs, friction welding is not a fusion welding process in the traditional sense, but more of a forge welding technique [1-3], [7].

Aluminium and its Welding:

Aluminium, at about 8%, is the most abundant element in the earth’s crust after oxygen and silicon. Given the material properties of aluminium and its alloys, i.e., extreme durability, low weight, corrosion resistance and recyclability. Aluminium materials have become progressively more widespread in recent years. The development of ever more lightweight parts which must nevertheless meet unchanged strength requirements has given rise to an ever-growing use of aluminium alloys. The latter can be formed into virtually any shape using a

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variety of industrially available processes (casting, rolling, extruding), which opens a wealth of options to the industrial user or processor of aluminium alloys.

In many segments and branches of industry, materials have to meet exacting demands regarding surface quality, environmental performance and safety. Advanced transport systems are no longer conceivable without the use of lightweight aluminium components. In addition, aluminium as a material group perfectly satisfies today's increasingly stringent environmental requirements concerning product recyclability. Hence, aluminium is the metal of the future. Particularly in the field of transport engineering massive application of lightweight materials represents the order of the day. The goal of saving fuel and other energy forms can mainly be achieved through the reduction of vehicle weights. In other application fields, too, its numerous favourable properties make aluminium an appreciated construction material for engineers. The common aspects of all aluminium alloys are:

- They all contain at least 60% pure aluminium.
- Their specific gravity is much lower than that of steel.
- They are usually corrosion resistant.
- They have an excellent electrical and thermal conductivity
- An increasingly numerous user community is aiming for optimum results and maximum cost-efficiency in aluminium machining or processing.

Benefits of Friction Stir Welding:

- Ability to join materials that are difficult to fusion weld
- Process is also suitable for automation and is adaptable for robot use
- Can use purpose-designed equipment or modified existing machine tool technology
- Low distortion and shrinkage, even in long welds
- Excellent mechanical properties in fatigue, tensile and bend tests
- Improved safety due to the absence of toxic fumes or the spatter of molten material
- No porosity and can operate in all positions as there is no weld pool
- Energy efficient
- One tool can typically be used for up to 1000m of weld length in 6XXX series aluminium alloys
- No filler wire required and no gas shielding.
- Some tolerance to imperfect weld preparations - thin oxide layers can be accepted
- No grinding, brushing or pickling required in mass production
- Can weld aluminium and copper of >75mm thickness in one pass

Limitations of FSW:

- Exit hole left when tool is withdrawn.
- Large down forces required with heavy-duty clamping necessary to hold the plates together.
- Less flexible than manual and arc processes (difficulties with thickness variations and nonlinear welds).
- Often slower traverse rate than some fusion welding techniques, although this may be offset if fewer welding passes are required.

Applications of FSW:

- Automotive (Wheel rims)
- Aerospace (Fuel tanks of space vehicles)
- Ship building (Hulls and superstructures)
- Defense (Helicopter landing Platforms)
- Recreation (Sailing boats)
- Transportation (Railway carriages, Aluminium bridges)
- Containers (Truck bodies)

Objective of the project:

The objective of the project is to make welding of Aluminium AA6061 and AA5052 alloy plates using friction stir welding process and to evaluate the parameters of the weld through experimental analysis as well as simulation software. FSW of the plates is made

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using a high strength steel H13 Taper Cylindrical Threaded tool using variable speeds and feeds, keeping the load constant. In experimental study, the strength, hardness and bending tests have been conducted. The effects of rotational speeds and feed rates on the strength and hardness of the weld is studied through experimental study of weld characteristics and analysis of the weld is also done [5], [9].

literature review

Raj Kumar. V et al. discussed about the characterization of friction stir welded dissimilar Aluminium alloys AA 5052 and AA6061. The coupons of above metals were friction stir welded using cylindrical pin tool using at constant speed of 710 rpm and at two different feed rates of 28 and 20 mm/min. Macrographs showed proper mixing due to effective stirring of cylindrical tool pin while keeping the lower feed rate. Further, extensive micro structural examination showed variation of grain size in each zone and their influence on mechanical properties. Tensile test and hardness measurements were done as a part of mechanical characterization. Correlating mechanical and metallurgical properties it is deduced that the sample welded at lower feed rate performed better in terms of ductility. [1].

Problem Description & Solution

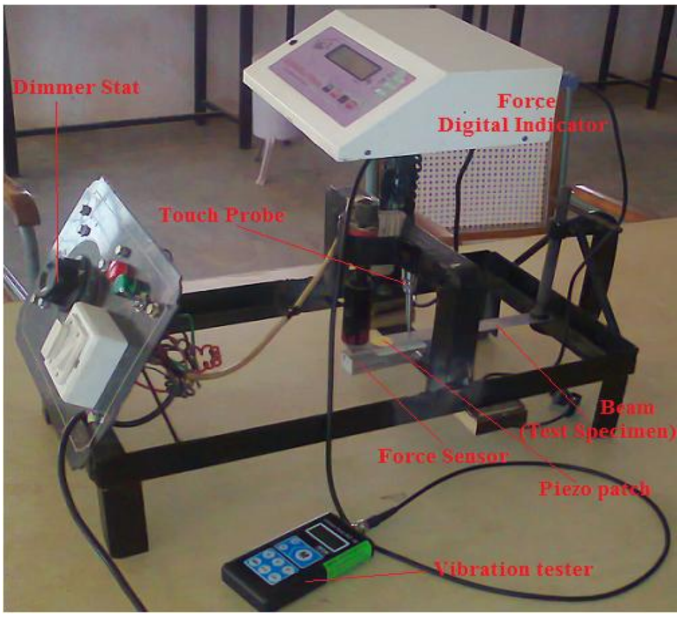
Aluminium alloy 6061 is one of the most extensively used of the 6000 series aluminium alloys. It is a versatile heat treatable extruded alloy with medium to high strength capabilities. It has very good corrosion resistance and weldability although reduced strength in the weld zone. It has excellent joining characteristics and good acceptance of applied coatings. Not suitable for very complex cross-sections. Typical properties of aluminium alloy 6082 include:

- Medium to high strength
- Good toughness and surface finish
- Excellent corrosion resistance to atmospheric conditions and to sea water
- Good weldability and brazability and workability
- Widely available.

Tool Material and its properties

The material used for tool is H-13 tool steel. It is considered due to its high toughness and very good stability in heat treatment. It is a versatile chromium-molybdenum hot work steel that is widely used in hot work and cold work tooling applications such as inserts, cores, and cavities for die casting dies, die casting shot sleeves, hot forging dies, extrusion dies, and plastic mold cavities and components that require high toughness and excellent polishability [11].

Experimental Set – up



The major components of the system are:

- **Cantilever Beam**
  - ✓Aluminium beam of length 250 mm (working span)
    Sizes: 25.4 mm X 1 mm
    25.4 mm X 2.04 mm
    25.4 mm X 2.18 mm
  - ✓ Density of the aluminium beam :2700 kg/m^3
  - ✓Youngs modulus of aluminium beam:69 GP$_a$
- **Force sensor**
  - ✓ Capacity: 40 kg
  - ✓ Material : Alloy of aluminium
- **Dimmer stat**
  Dimmer stat operates on a nominal voltage of 240 V A.C & can give output voltage anywhere

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between 0 – 290 V, by a simple transformer action. The basic Auto Transformer is meant for operation off a nominal voltage of 240 V A.C & can give output voltage anywhere between 0 – 240 V or upto 290 V, by a simple transformer action. Three such Variable Auto transformer when connected electrically in star & mechanically in tandem, became suitable for operations of 415 V 3 Phase A.C. supply & to give output of 0 – 415 V or upto 470 V.

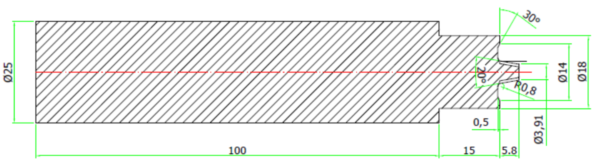
- **Piezo patch**
  - ✓ The piezoelectric effect is reversible in that materials exhibiting the *direct piezoelectric effect* also exhibit the *reverse piezoelectric effect*
  - ✓ Lead zirconate titanate crystals will exhibit a maximum shape change of about 0.1% of the original dimension.
  - ✓ Lead Zirconate titanate ($Pb[Zr_x\ Ti_1{-}x]O_3$ $0<x<1$)—more commonly known as *PZT*, lead zirconate.
  - ✓ Size of the patch ϕ 27 mm
- **Vibration tester with touch probe**
  - ✓ Hand held probe TPR 11
  - ✓ Vibration tester AVD-80
  - ✓ Velocity: 0.1 to 199.9 mm/s
    True RMS, Peak-Peak
  - ✓ Acceleration: 0.1 to 199.9 m/s^2
    True RMS, Peak-Peak
  - ✓ Displacement: 0.5 to 2800µm
    True RMS, Peak – Peak
  - ✓ Frequency range: 10 to 1000Hz
  - ✓ Resolution: 0.1 mm/s
  - ✓ Accuracy: 2% ± 0.2
  - ✓ Power supply: 9V (Alkaline)
  - ✓ Display LCD display
  - ✓ Temperature range: 0^0C to $+55^0$C
  - ✓ Weight : 300g (Approx)
  - ✓ Connector type: BNC
- **Force digital indicator**
  - ✓ Minimum capacity: 100 g
  - ✓ Maximum Capacity: 100 kg
  - ✓ Error in digital: 5 g

Experimental Procedure

The set will be initiated as shown in the figure and procedure to perform the experiment is as follows:

- ✓ The test specimen (beam) is fixed at one end with help of C –clamp and the other end is free to oscillate with respect to the fixed end.
- ✓ The external exciter (Electric hammer) is held rigidly at the free end of the beam by keeping at an appropriate high from the free end.
- ✓ The force is set to apply at the free end by adjusting the indicator of the dimmer stat at a particular point [12].
- ✓ The hand held touch probe (TPR – 11) is kept above the beam at an appropriate position which will give the displacement, velocity and acceleration of the beam after it excited.
- ✓ After supplying the power the hammer will hit the beam at the free end and the displacement of the beam from its mean position, i.e. peak – peak values are noted down by using the vibration tester. These displacements are corresponding to the frequency of the beam with respect to its mean position.
- ✓ The similar process will be continued for the beam without piezo patches first. The corresponding first three natural frequencies are calculated and the same procedure is repeated by keeping the patch at the three modes for each time.
- ✓ Similarly the same procedure is repeated for the various beams of different thicknesses for the same material.

Tool geometry



Tensile test

One material property that is widely used and recognized is the strength of a material. It is probably the most

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fundamental type of mechanical test you can perform on material. Tensile tests are simple, relatively inexpensive, and fully standardized. By pulling on something, you will very quickly determine how the material will react to forces being applied in tension as shown in the Fig. 4.7.3 As the material is being pulled, you will find its strength along with how much it will elongate [10].

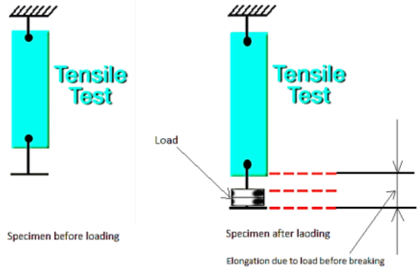

Fig. 4.7.3: Tensile test process

Universal Testing Machine (UTM)

Both the tensile and impact tests are performed on Universal Testing Machine and Impact Testing Machine are available in Mechanics of Solids lab of GMR Institute of Technology as shown in the following Fig. 4.7.3.1.

Fig. 4.7.3.1: Universal Testing Machine

The specifications of the UTM machine are given in the Table 4.7.3.1

Table 4.7.3.1: Specification of Universal testing machine

Machine	Computerized Universal Testing Machine
Make	Rockwell Testing Aids
Model	TUE-C100
Measuring Capacity	100 kN
Measuring range	0-10 kN
Resolution of piston movement	0.01 mm

Testing for tensile strength

The specimen was loaded in Universal Testing Machine. Tests were conducted on four specimens of AA6061 alloy plates and ultimate tensile strength is measured. For conducting a standard tensile test, a specimen that has been measured for its cross-sectional area and gauge length, is placed in the testing machine and the extensometer is attached. Simultaneous readings of load and elongation are taken at uniform intervals of load. The following figure shows the tensile test process. (Fig. 4.7.3.2)

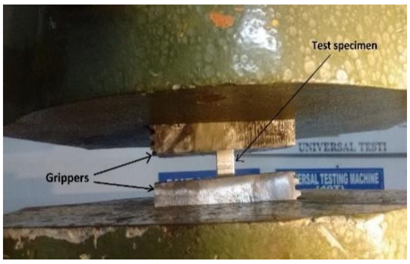

Fig. 4.7.3.2: Tensile test in progress

After the tensile test has been conducted, the specimen are measured for elongation in the length. The results are tabulated for yield strength, ultimate strength and elongation or change in length due to the tensile force. Fig. 4.7.3.2 (a) shows the test specimen after the tensile test. The tensile was conducted for parent metal also for comparison purpose.

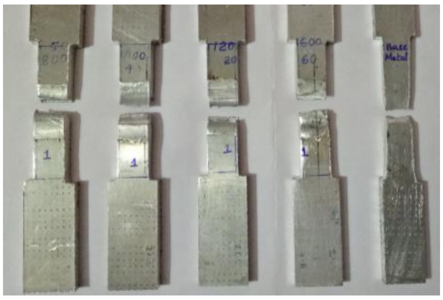

Fig. 4.7.3.2 (a): Tensile test specimen after the test

Impact test

Impact tests for ductility provide a simple way to evaluate the quality of materials by their ability to resist sudden loads. Impact tests were performed on friction stir plates on weld and the results of the specimen were measured and noted. The specimen having rectangular shape with dimensions 60 x 20 mm after machining, have been considered for conducting the test [8].

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Hardness test

Hardness is the property of a metal, which gives it the ability to resist being permanently, deformed (bent, broken, or have its shape changed), when a load is applied. The greater the hardness of the metal, the greater resistance it has to deformation. Indentation hardness measures the resistance of a sample to material deformation due to a constant compression load from a sharp object; they are primarily used in engineering and metallurgy fields [6].

Rockwell hardness tests were performed on AA6061 weld plates to know the hardness of the material by applying 100 kgf load for 10 sec. The hardness was determined at 3 different positions on the weld path and average of them was taken as the hardness of the friction stir welding. Fig. 4.7.5 (a) and (b) shows the hardness testing process and the indentation marks made with diamond tip indent with a diameter of 1/16 inch.

Fig. 4.7.5 (a: Rockwell Test machine with test specimen

Fig. 4.7.5 (b) - Test specimen with indentation marks

Tensile test analysis – AA6061

Before the analysis of the part is done in the simulation software, the Young's Modulus of the different specimen is calculated through the stress-strain curve obtained from the tensile test done on UTM [4] by taking some points on the slope of the curve and averaging the values. Table. 4.7.6 shows the obtained values.

Table. 4.7.6: Young's modulus values from Stress – strain curves

Specimen (Speed – Feed)	Young's Modulus (E) (GPa)	Average of 'E' (GPa)
S 1200 – 40	66.0	59.39
	72.5	
	39.66	
S 1200 – 20	36	56.30
	70.4	
	62.52	
S 800 – 40	72	69.1
	65.30	
	70	
S 800 - 20	34	40.22
	45.67	
	41.0	

The analysis procedure for tensile test made is shown in the following steps with supporting screenshots:

- The part model is constructed based on the dimensions of the test specimen as shown in Fig. 4.7.6 (a) . Also, the material properties such as Young's modulus and Poisson's ration are supplied.

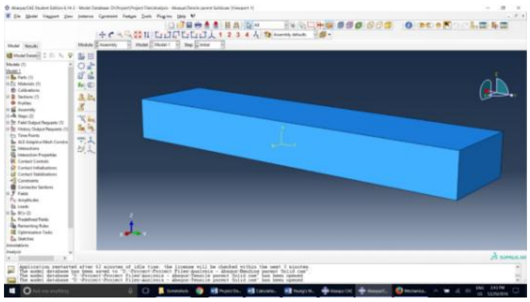

Fig. 4.7.6 (a): Creating a model and assigning material properties

- An individual assembly instance is created and step is created for static behavior of the object.
- Then the loading is done by creating required boundary conditions for tensile test by restricting the movement in other directions except in the direction of the applied load (along the length) as shown in Fig. 4.7.6 (b).

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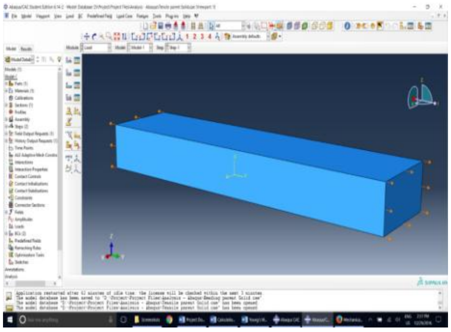

Fig. 4.7.6 (b): Loading done with the boundary conditions

- Then meshing is done as shown in the Fig. 4.7.6 (c).

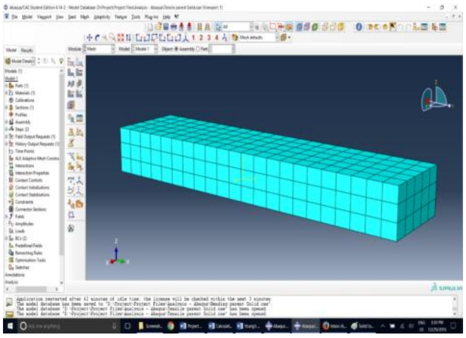

Fig. 4.7.6 (c): Meshing the part

- Job is created for the model developed, checked for errors and then submitted for results. The result is obtained as shown in the Fig. 4.7.6 (d).

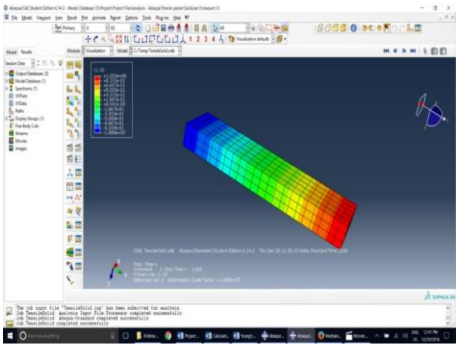

Fig. 4.7.6 (d): Tensile test result

Tensile test analysis – AA5052

Before the analysis of the part is done in the simulation software, the Young's Modulus of the different specimen is calculated through the stress-strain curve obtained from the tensile test done on UTM by taking some points on the slope of the curve and averaging the values. Table. 4.7.7 shows the obtained values.

Table. 4.7.7: Young's modulus values from Stress – strain curves

Specimen (Speed – Feed)	Young's Modulus (E) (GPa)	Average of 'E' (GPa)
S 1200 – 40	60	55.23
	69.30	
	36.40	
S 1200 – 20	32	53.58
	68.5	
	60.24	
S 800 – 40	69	67.11
	64.34	
	68	
S 800 - 20	33	39.22
	44.65	
	40	

The analysis procedure for tensile test made is shown in the following steps with supporting screenshots:

- The part model is constructed based on the dimensions of the test specimen as shown in Fig. 4.7.7 (a) . Also, the material properties such as Young's modulus and Poisson's ration are supplied.

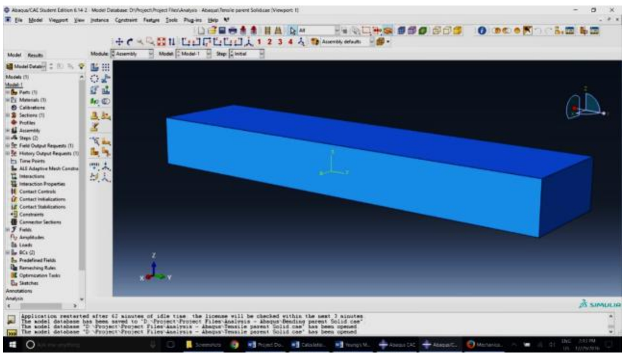

Fig. 4.7.7 (a): Creating a model and assigning material properties

- An individual assembly instance is created and step is created for static behavior of the object.
- Then the loading is done by creating required boundary conditions for tensile test by restricting the movement in other directions

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except in the direction of the applied load (along the length) as shown in Fig. 4.7.7 (b).

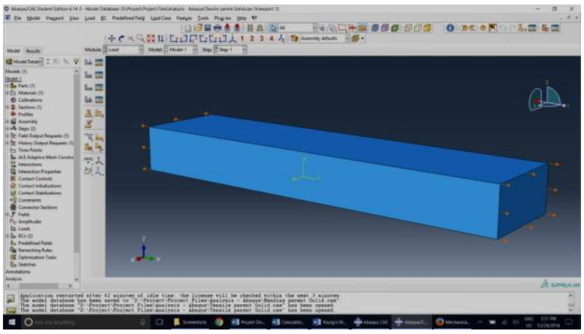

Fig. 4.7.7 (b): Loading done with the boundary conditions

- Then meshing is done as shown in the Fig. 4.7.7 (c).

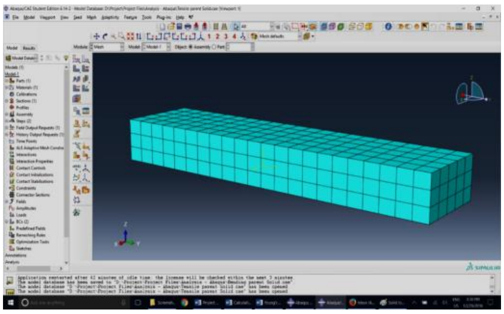

Fig. 4.7.7 (c): Meshing the part

- Job is created for the model developed, checked for errors and then submitted for results. The result is obtained as shown in the Fig. 4.7.7 (d).

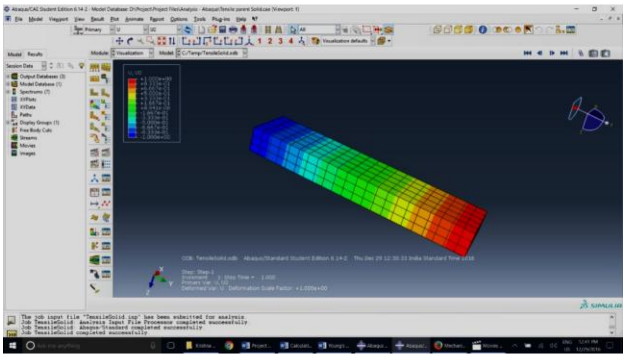

Fig. 4.7.7 (d): Tensile test result

Tensile test analysis – AA6061 & AA5052

Before the analysis of the part is done in the simulation software, the Young's Modulus of the different specimen is calculated through the stress-strain curve obtained from the tensile test done on UTM by taking some points on the slope of the curve and averaging the values. Table. 4.7.8 shows the obtained values.

Table. 4.7.6: Young's modulus values from Stress – strain curves

Specimen (Speed – Feed)	Young's Modulus (E) (GPa)	Average of 'E' (GPa)
S 1200 – 40	68	59.6
	72.60	
	38.40	
S 1200 – 20	37	55.7
	69.8	
	60.5	
S 800 – 40	71	67.73
	63.20	
	69	
S 800 - 20	34	39.44
	44.87	
	39.46	

The analysis procedure for tensile test made is shown in the following steps with supporting screenshots:

- The part model is constructed based on the dimensions of the test specimen as shown in Fig. 4.7.8 (a) . Also, the material properties such as Young's modulus and Poisson's ration are supplied.

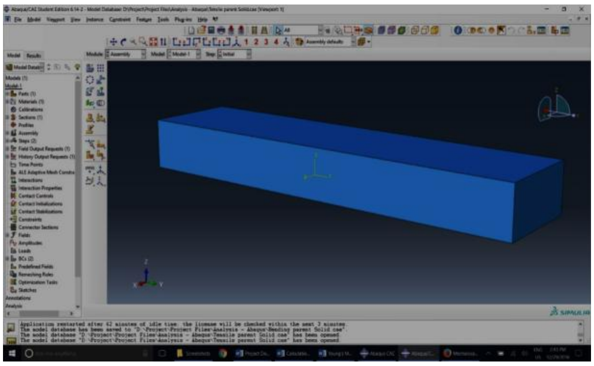

Fig. 4.7.8 (a): Creating a model and assigning material properties

- An individual assembly instance is created and step is created for static behavior of the object.

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- Then the loading is done by creating required boundary conditions for tensile test by restricting the movement in other directions except in the direction of the applied load (along the length) as shown in Fig. 4.7.8 (b).

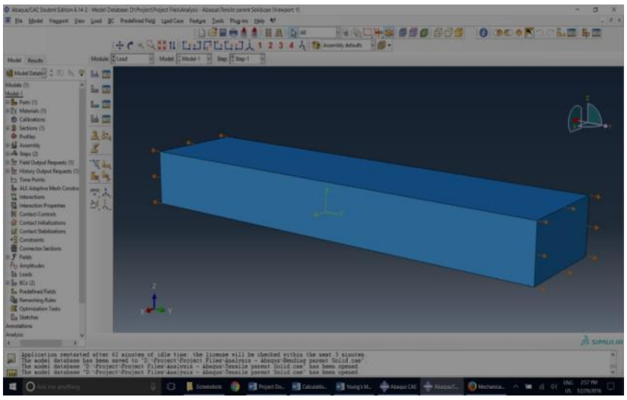


Fig. 4.7.7 (b): Loading done with the boundary conditions

- Then meshing is done as shown in the Fig. 4.7.8 (c).

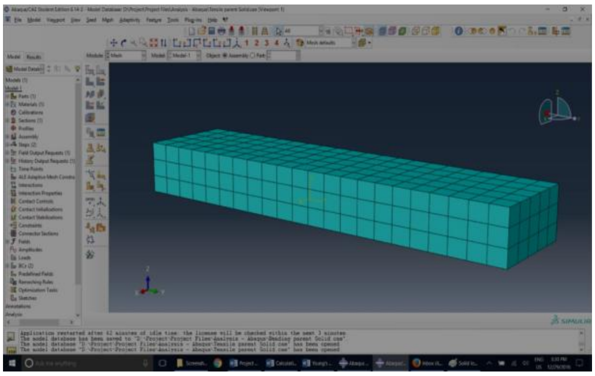


Fig. 4.7.8 (c): Meshing the part

- Job is created for the model developed, checked for errors and then submitted for results. The result is obtained as shown in the Fig. 4.7.8 (d).

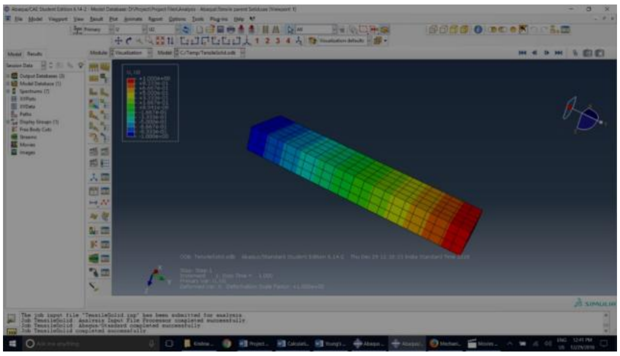


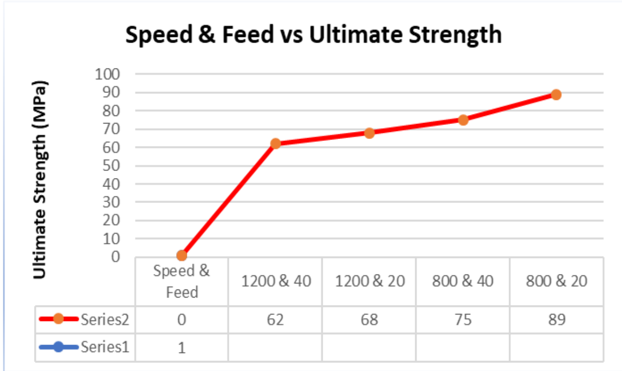
Fig. 4.7.8 (d): Tensile test result

Test results – AA6061

Tensile test Results

Table. 5.2.1 (b) shows the tensile test results obtained from Experimental set-up and analysis respectively.

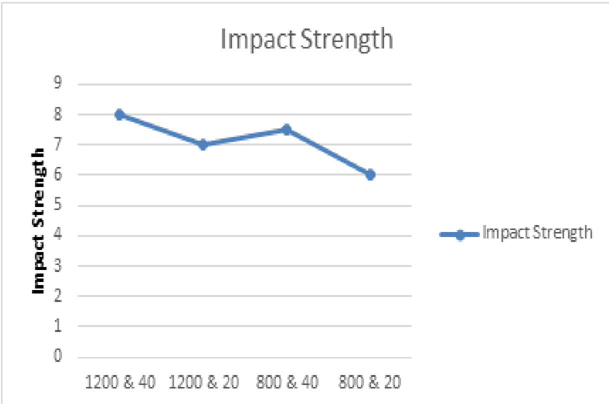
Table: 5.2.1 (b): Tensile test results obtained from Analysis



Graph -1 Tensile strength Vs speed

Impact test results – AA6061

The following Graph-2 is obtained from the bending strength values of experimental set-up and analysis.



Graph – 2: Impact test strength Vs Speed

From the above graph, we can see that the impact strength of the weld is gradually decreasing with increasing speed of the tool.

Hardness test results

Here, we can see that the hardness decreases with increase in speed and then slightly increases as the feed was decreased with increasing speed and later on increased with high speed [2].

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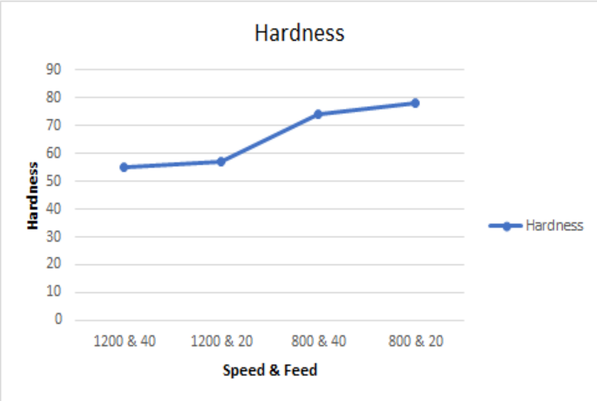
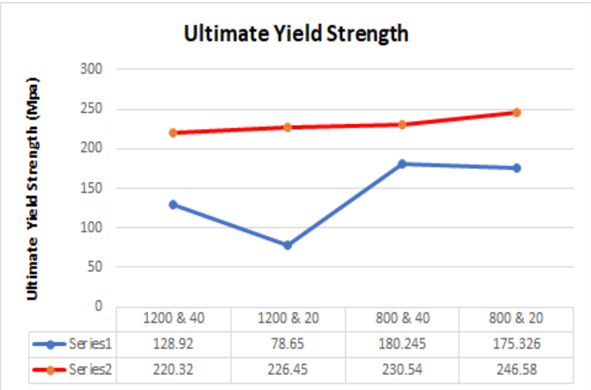


Graph -3: Hardness number Vs Speed

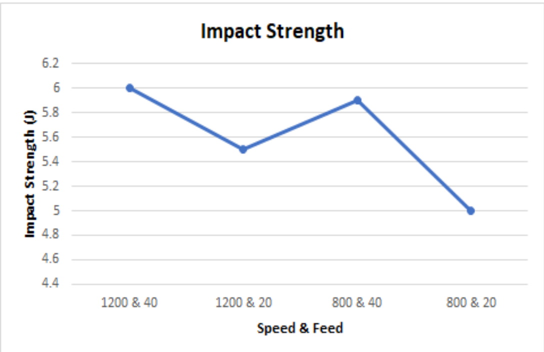
Test results – AA5052
Tensile test Results



Graph -1 Tensile strength Vs speed

Impact test results

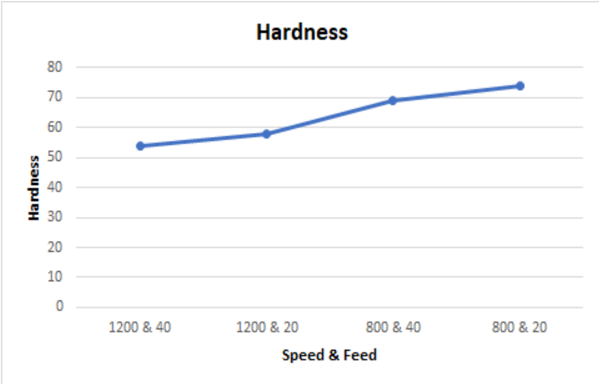
The following Graph-5 is obtained from the bending strength values of experimental set-up and analysis.



Graph – 5: Impact test strength Vs Speed

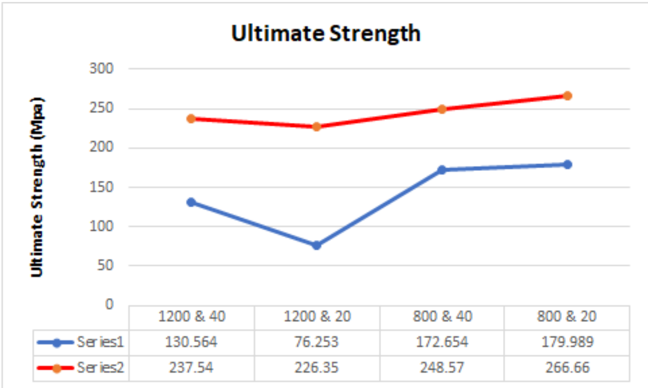
From the above graph, we can see that the impact strength of the weld is gradually decreasing with increasing speed of the tool.

Hardness test results



Graph -6: Hardness number Vs Speed

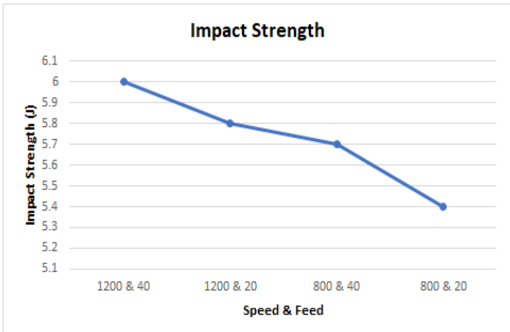
Test results – AA6061 & AA5052
Tensile test Results



Graph -7 Tensile strength Vs speed

Impact test results

The following Graph-8 is obtained from the bending strength values of experimental set-up and analysis.



Graph – 8: Impact test strength Vs Speed

From the above graph, we can see that the impact strength of the weld is gradually decreasing with increasing speed of the tool.

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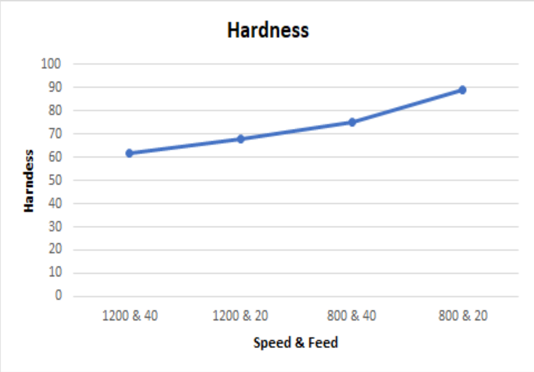
Hardness test results



Graph -9: Hardness number Vs Speed

CONCLUSIONS

- The welded material has shown increase in *Tensile Strength* with increase in the speed of the tool rotation, but later decreased with increase in speed as the feed is also reduced correspondingly.
  Toll rotation speed of 1200 rpm with 40 mm/min feed is found to be efficient parameters for friction stir welding of AA606 & AA5052 if our aim is to maintain the strength of the welded material. Also, the combination, 1200 rpm and 20 mm/min is found to show reasonable material property with respect to tensile strength.
- The *Impact strength* of AA6061 & AA5052 has gradually decreased for the welded material with increase in tool rotation speed. The weld zone is losing its impact strength for as the tool rotation speed increases with corresponding feed values.
  The best parameters for friction stir welding if the impact strength of the material should be increased is low speed and in my study it has been observed as 800 rpm with 20 mm/min feed.
- The Hardness of the welded material has gradually reduced with increase in tool rotation speed and then suddenly increased for high speed (1200 rpm). The hardness has found to be decreasing with increase in the tool rotation speed.
  If the aim is to increase the hardness of the material based on our requirement, then considering low speeds of the tool is the best option, and in this case it is found to be 800 rpm.
- The results show that, until and otherwise any specific property is required for the welded material depending on the job requirement, the FSW parameters, 1200 rpm with 40 mm/min are found to be best suited for welding AA6061 & AA5052 to obtain optimum material properties.

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