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Experimental investigations of mechanical behavior of friction stir welding on aluminium alloy 6063

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ABSTRACT

The conventional welding of Aluminum alloy 6063 faced many problems related porosity in the fusion zone and loss in Mechanical properties. To overcome these difficulties the Similar Aluminum alloy 6063 were welded by using friction stir welding process and the mechanical characteristics and microstructure were investigated by varying the Tool rotation speed, welding speed and axial force. Microstructure of different zones were analyzed and observed by electron optical microscope. The tensile properties and hardness is evaluated for AA6083 Welded joints. It is found that welding speed 72 mm/min, Tool rotation speed 1000 rpm, axial force 14.5 KN Produces better tensile strength. Welded zones categorizes three different zones are interfacial zone, Nugget zone and parent metal were investigated.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Newer Trends and Innovation in Mechanical Engineering: Materials Science.

1. Introduction

Friction stir welding (FSW) which shows in Fig. 1 is a solid-state joining process invented by the welding institute (TWI) in 1991 [1-3] Diverse applications of aluminum alloys in automobile and aerospace industries dictate significance of choosing their assortment based on welding behavior plus selection of most suitable welding-method. Aluminum alloys of 2xxx, 6xxx, 5XXX, 7xxx series have been considered for substantial use in these industries [4-6] Many specific properties of aluminum alloys including light weight, good structural strength, superior corrosion resistance enable them to be applied for structural parts. The demand of aircraft and automotive industries for light weight materials is met by an aluminum alloys[7-10] The energy input to the FSW process, heat generation, microstructure evolution and the joint properties are controlled by the process parameters like Tool rotation speed, welding speed and axial force and the tool geometry like pin profile, shoulder diameter. The tool life also depends on the process parameters and tool geometry the axial down force, initial temper of the work piece, material of the tool and its hardness, material and thickness of parent metal, type of cooling arrangement and the clamping fixture also affect the FSW process selection of friction stir welding parameters that produces the acceptable mechanical, fatigue and carrion properties is a primary requirement to obtain the efficient and defect less weldments [11-13]. This welding technique involves the joining of metals without fusion or filler materials since it is an autogenous, hot shear process in uses a non –consumable tools harder than aluminum alloys to plasticize and stir the materials to transport from one end to the other end and thus making the sound joint is possible. The frictional heat generated by the rotating tool during welding process raises the temperature of the materials to be joined to the level well below the it's melting point (100℃ less) and hence no melting takes place. This eliminates solidification related problems such as porosity, hot cracking, alloy segregation and partially melting zone [14-18].

In this work is made to join 6 mm thickness of Aluminum alloys AA6083 using Friction stir welding process and investigate the mechanical behavior and microstructure of the similar joints [19-22]. This work will discusses the relation between the mechanical properties and tool rotational speed of friction stir weld.

1.1. Specification of friction stir welding machine

Table 1. Shows the Specification of Friction stir welding Machine.

1.2. Friction stirs welding condition & process parameters

Fig. 2 shows the FSW Machine Rotational speed was 1000&1200 rpm with the weld speed of 60, 72 and 100 mm/min.

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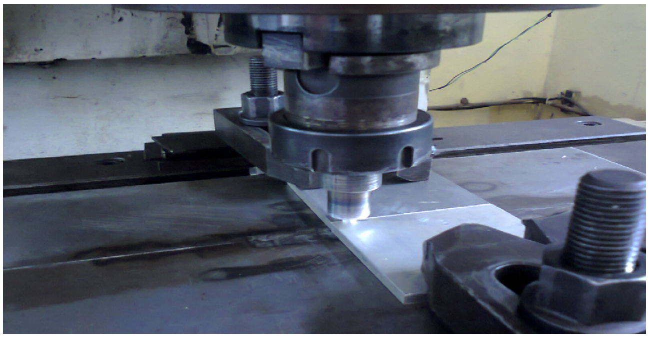

Fig. 1. Friction stir welding.

Table 1
FSW machine specification.

X axis:	1 m to 100 m or more. Up to 5000 mm/min velocity, servo controlled.
Y axis:	1 m standard.
Z axis:	600 mm stroke, force or position controlled, 50 kN axial force.
Tilt:	+/-5°.
Spindle:	15 kW (20 HP) Various speed and torque combinations available.
Rotary Table Axis:	360°.
Control:	Minicomputer control.

double side welding was carried out i.e. both sides welding was carried out. Again here also double side welding was done. Aluminum AA 6083 alloy joints were welded successfully by friction welding process using two different rotational speeds. Some interesting developments of mechanical properties have been found to occur in the elements. The tensile testing of the weld and Vickers hardness number is influenced by the rotational speed and feed of the tool. The effects of tool rotation speeds and feed towards the tensile testing and Vickers hardness of the joints were investigated. The results of the tests are shown in graphs below for the specimen prepared using friction welded joints obtained at the two rotational speeds mentioned below Table 2.

1.3. Tool material: High carbon high chromium

These steels retain their hardness up to a temperature of 425 °C (797 °F). Common applications for these tool steels include forging dies, die-casting die blocks, and drawing dies. Due to their high chromium content, certain D-type tool steels are often considered stainless or semi-stainless, however their corrosion resistance is very limited due to the precipitation of the majority of their chromium and carbon constituents as carbides. Fig. 3 shows the Three Dimensional view of Tool.

2. Material selection

Here Aluminum alloy 6083 is selected as parent metal due to its wide availability and usage in engineering industry widely. The chemical composition of the Aluminum alloy 6083 are given in Table 3.

2.1. Mechanical properties of Aluminum 6083 alloy

Table 4 shows the properties of Aluminum 6083 alloy.

3. Experimental work for AA6083

The dimension of the plate is selected according to the testing procedure of the American Society for Metals. The dimensions are 100 × 70 mm and the thickness of the plate was 6 mm. Here 6 mm thickness was selected because in many of the industries 6 mm plates are being used widely. Fig. 4 shows the before Welding Specimen and Fig. 5 shows the After Welded Specimen.

3.1. Micro-structure

A low-magnification optical micrograph of the weld region is presented. The weld area displayed several micro structurally distinct regions including the stir zone along the weld centerline, the heat-affected zone (HAZ) surrounding the stir zone, and the base

Fig. 2. FSW machine.

Table 2
Process parameters.

Experiment	Rotational speed (rpm)	Welding speed (mm/min)	Axial force (KN)
1	1000	60	12.5
2	1000	72	14.5
3	1000	100	16
4	1200	60	12.5
5	1200	72	14.5
6	1200	100	16

Fig. 3. Three dimensional view of tool.

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Table 3
Chemical composition of parent materials.

Elements	Cu	Mg	Mn	Fe	Si	Al	Zn	Ti
AA6063	0.01	0.50	0.011	0.287	0.45	98.57	0.005	0.014

metal The samples were thoroughly polished and then etched with Keller's reagent. An optical image analyzer was used for this purpose as shown in Fig. 6. The micro-structure has been revealed and the grain size of the different zones of the welded sample was measured.

3.2. Tensile testing

The FSW welds cut according to the ASTM specifications for tensile testing are shown in Fig. 7. The tensile testing of the welds was done using a UTM machine. A universal testing machine, also known as a universal tester, materials testing machine or materials test frame, is used to test the tensile stress and compressive strength of materials. The specimen is placed in the machine between the grips and an extensometer if required can automatically record the change in gauge length during the test. If an extensometer is not fitted, the machine itself can record the displacement between its cross heads on which the specimen is held. However, this method not only records the change in length of the specimen but also all other extending /elastic components of the testing machine and its drive systems including any slipping of the specimen in the grips. Once the machine is started it begins to apply an increasing load on specimen. Throughout the tests the control system and its associated software record the load and extension or compression of the specimen.

Table 4
Properties of Aluminum 6083 alloy.

Properties	AA6083
Tensile strength (Mpa)	215
Yield strength (Mpa)	170
Elongation (%)	10%
Hardness	75

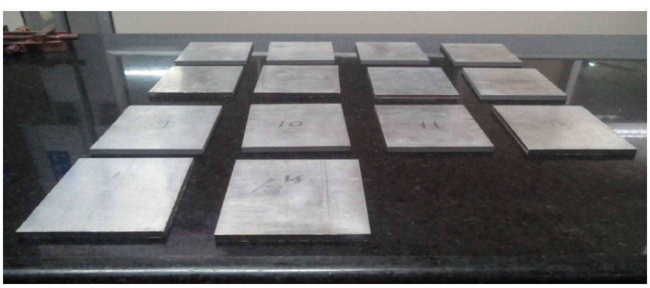


Fig. 4. Before welding specimen.

3.3. Micro-hardness

The welded samples were tested for micro-hardness and measurements were taken on the cross sections perpendicular to the welding direction. A load of 100gf was kept for hardness measurement. The instrument used for the experiments is shown in the figure fig. The micro hardness of the weld zone and the heat affected zones were measured for the sample which is shown in Fig. 8.

4. Results and discussions

4.1. Hardness test

Vickers Hardness Test (Double Side Welding) The results obtained during double side welding are plotted against the rotational speed of the spindle (FSWTool) of 1000 pm and weld speed of 100 mm/min. It is observed that the Hardness is minimum at the

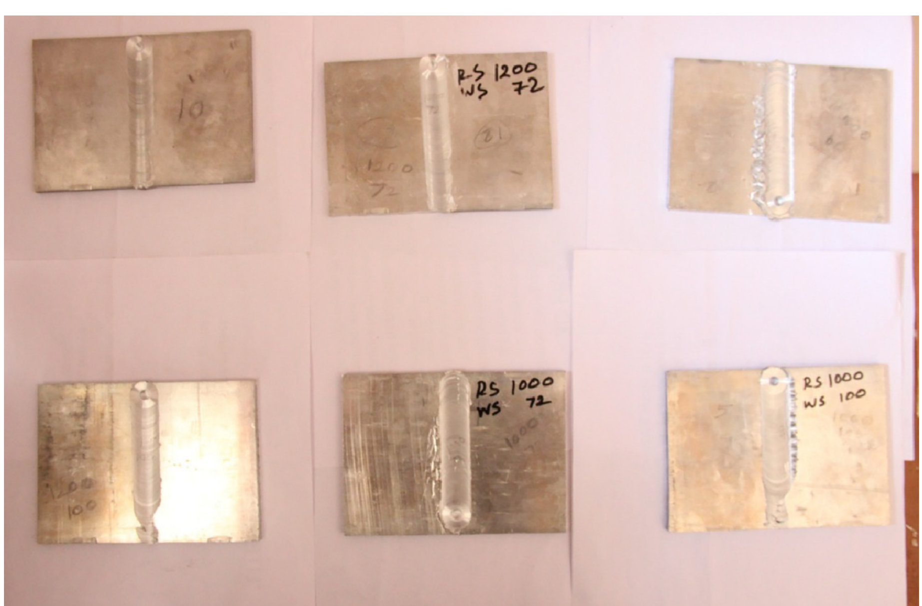


Fig. 5. After welded specimen.

weld centre i.e. at the centre of the weld nugget. Hardness values reduced at the centre weld then parent metal shown in Table 5.

4.2. Tensile strength test

In both the above cases, Increase in rotational speed has resulted in increase of tensile strength. Primary reasons that higher the speed, higher will be the deformation and heat generation in the weld. This will result in finer grain structures, because of which tensile strength is increases. The results of tensile test which were observed during the experiment were tabulated which are shown in Fig. 9 and Table 6 shows the Tensile Test Specimen.

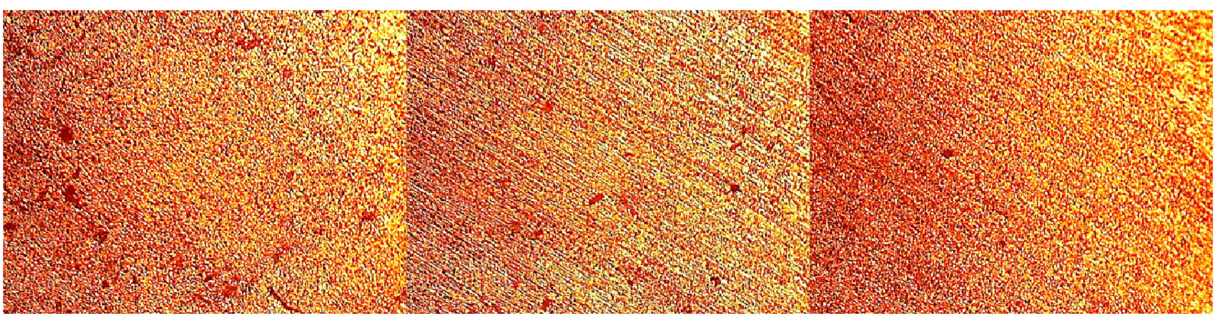
Fig. 10 shows the Tensile strength Vs No. of trails.

4.3. Microstructure test

The SEM analysis was carried out to determine the material flow path at the heat-affected zone and weld zone of friction stir welded samples. It is noted that the six samples, welded with a traverse speed of 1.2 mm *sec*-1, tool speed of 1000 to 1200 rpm and Magnification of 100X. The samples 1,2,3,4 and 5 shows the Microstructure Test of the specimen.

Sample 1: Rotational Speed 1200 – Welding speed 60 Magnification: 100X

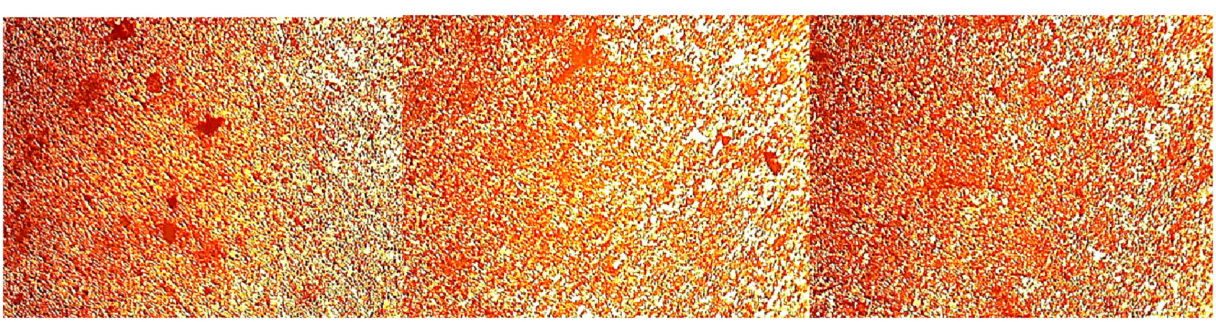
Fig. 6. Electron optical microscope.



Parent metal Nugget Zone Interface zone

Parent metal Nugget Zone Interface zone

Sample 2: Rotational Speed 1000 – Welding speed 72 Magnification: 100X



Parent metal Nugget zone Interface zone

Parent metal Nugget zone Interface zone

Sample: 3 Rotational Speed 1200 – Welding speed 72 Magnification: 100X

Fig. 7. Universal testing machine.

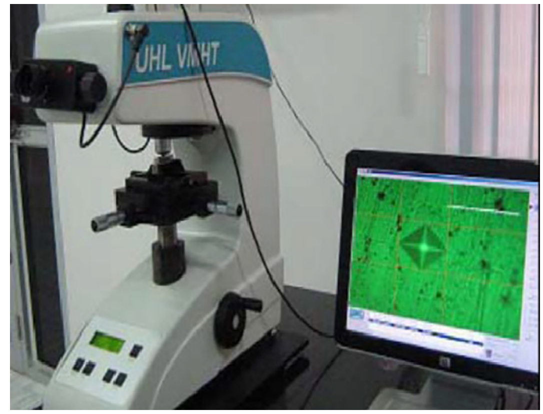
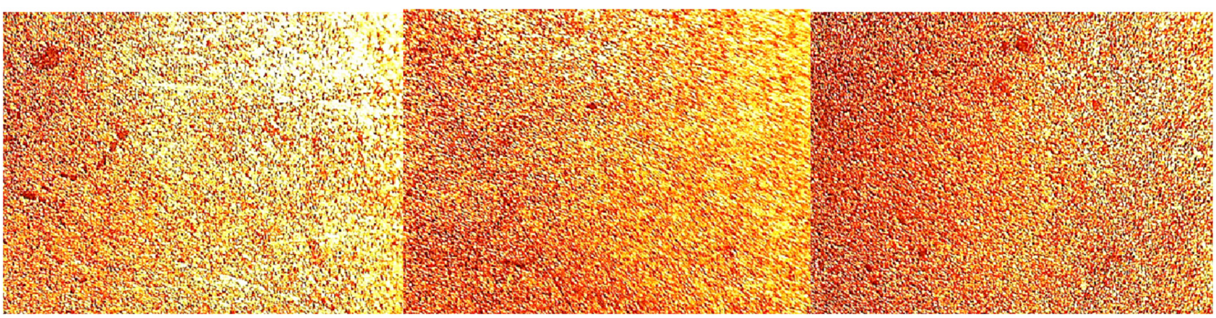


Fig. 8. Micro hardness testing.



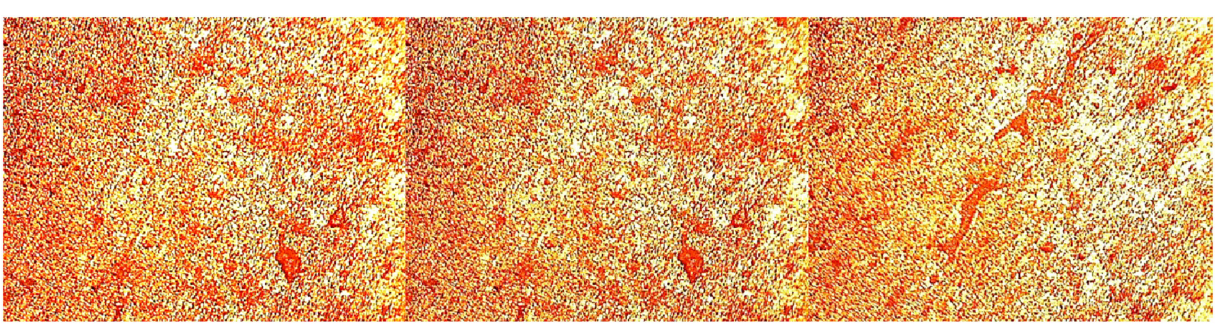
Parent metal Nugget zone Interface zone

Parent metal Nugget zone Interface zone

Sample: 4 Rotational Speed 1000 – Welding speed 60 Magnification: 100X

Parent metal Nugget zone Interface zone

Sample: 5 Rotational Speed 1000 – Welding speed 60 Magnification: 100X



Parent metal Nugget zone Interface zone

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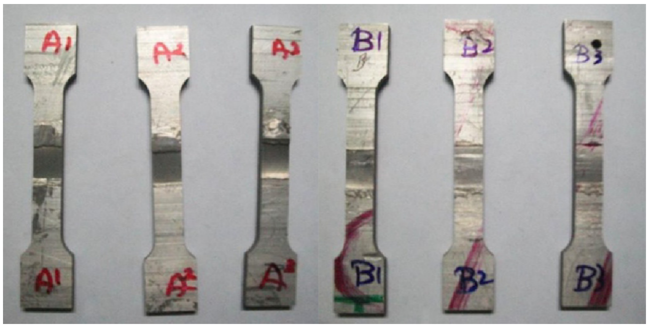
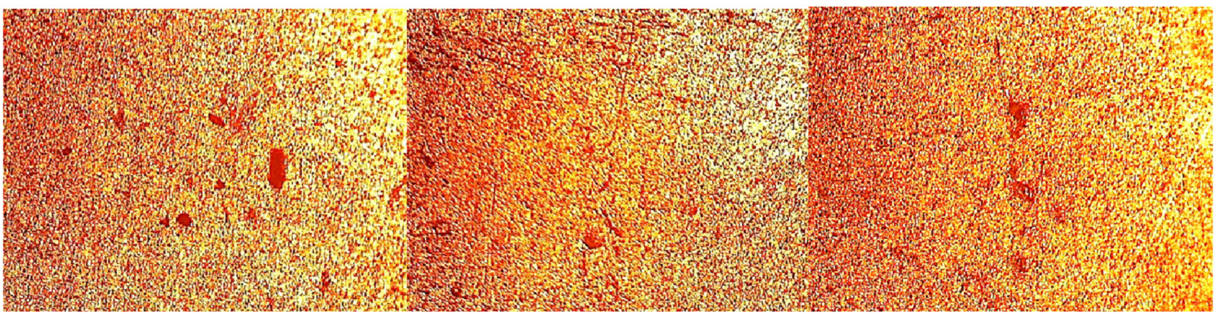


Fig. 9. ASTM standard tensile specimen.

Table 6
Tensile test specimen.

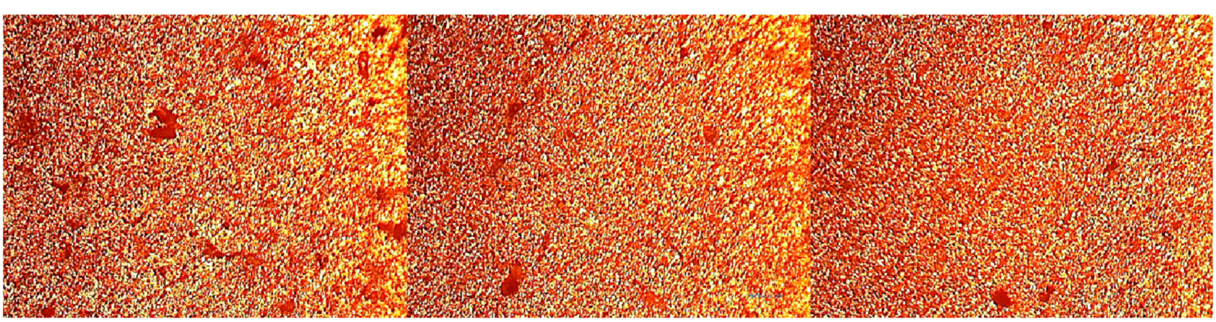
Experiment	Rotational speed (rpm)	Welding speed (mm/min)	Axial force (KN)	Tensile strength (KN/mm$^{2)}$
1	1000	60	12.5	0.081
2	1000	72	14.5	0.092
3	1000	100	16	0.091
4	1200	60	12.5	0.056
5	1200	72	14.5	0.076
6	1200	100	16	0.082



Parent metal Nugget zone Interface zone

Parent metal Nugget zone Interface zone

Sample: 6 Rotational Speed 1000 – Welding speed 60 Magnification: 100X



Parent metal Nugget zone Interface zone

Parent metal Nugget zone Interface zone

Table 5
Hardness values.

Experiment	Rotational speed (rpm)	Welding speed (mm/min)	Axial force (KN)	Vicker hardness value
1	1000	60	12.5	30.5
2	1000	72	14.5	31
3	1000	100	16	31.16
4	1200	60	12.5	30
5	1200	72	14.5	30.4
6	1200	100	16	32.5

5. Conclusion

Welding was done on the AA6083 metal plate joints were investigated according to the selected parameters and the following conclusions were derived.

- Microstructure testing was carried out in the parent metal, Nugget zone and Interface Zone which results that Some insoluble inter metallic of Al_6 (Fe, Mn) also seen as large particle. The nugget zone shows grain orientation along the direction of the tool and the particles of eutectics are fragmented to fine particles. Interface zone: Shows the TMT zone of the interface of the nugget and the parent metal at the advancing side. The particles and grains have re-crystallized partially and grain flow is along the direction of the sir direction

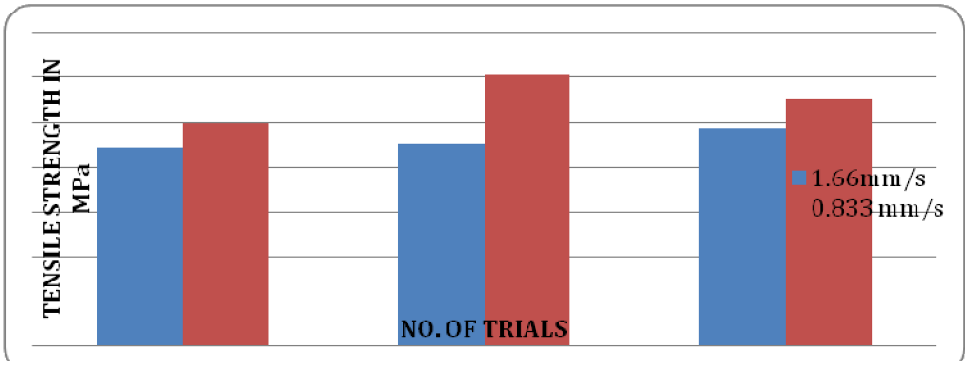


Fig. 10. Tensile strength Vs No. of trails.

- The joints produced at a welding speed of 72 mm/min shows the better tensile properties.
- An improved hardness of VHN 31.6 is obtained at the welding speed of 100 mm/min.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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