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FABRICATION AND CHARACTERIZATION OF FRICTION STIR WELDING USING AL 3105

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ABSTRACT
In this research study, the characterization of the microstructure evolution of friction stir lap welds (FSLW) of Aluminium incorporated with Titanium Carbide powder to form Aluminium based composites is presented. The Titanium Carbide powder was infused at the weld interface to produce a composite. The FSLW were conducted on an Intelligent Stir Welding for Industry and Research (I-STIR) Process Development System (PDS). Different welding parameters were used for the welding process. Rotational speeds of 1600 rpm and 2000 rpm and transverse speeds of 100 mm/min, 200 mm/min and 300 mm/min were employed. The process parameters were carefully selected to represent a low, medium and high setting for the feed rates. The microstructural evolution of the samples were studied. Optical microscope and scanning electron microscopy (SEM) techniques were used to investigate the particle distribution of the welded samples. The results obtained revealed the influence of the welding parameters on the particle distribution of the welded samples. A homogenous mixture of the materials was observed at higher rotational speed of 2000 rpm.

KEYWORDS: aluminium, friction stir welding, microstructure, Titanium Carbide (TiC)

INTRODUCTION
In recent years, demands for light weight and high strength sheets such as aluminium alloys have increased steadily in aerospace, aircraft and automotive applications due to their extra-ordinary strength to weight ratio with their resistance properties in adverse environments. Friction stir welding (FSW) process is a solid state joining technique considered to be the significant development over the past two decades. The weld is formed by the excessive deformation of the material at temperatures below its melting point, thus the method is a solid state joining technique. There is no melting of the material, so FSW has several advantages over the commonly used fusion welding techniques. In the FSW process, parameter selection and tool geometry are among the key factors that determine the quality of the fabricated joint. Adjusting the values of different parameters, such as welding speed, rotational speed, tilt angle, and pin geometry, could lower the forces exerted from the TMAZ section to the tool. The plastic flow is responsible for obtaining a weld with high tensile strength and fewer defects and therefore the tool geometry plays an important role in achieving a high-quality weld.

PRINCIPLE
The tool is made up of a shoulder and pin. The rotating tool is plunged along the intersection of two metal plates which are rigidly fixed on a backing plate. When the upper surface of the plates comes in contact with the shoulder surface the friction is developed. Plastic deformation of metal occurs at the joint area along the weld direction. This is influenced by the combined action of shoulder and pin. The pin produces a stirring action at the intersection region and then produces the transfer of metal from the advancing side to retreating side and vice – versa.

The side of half plate which faces the clockwise direction of rotation of tool along the welding direction is called the advancing side while the other side is called retreating side. It is found that in most of the cases the hardness of retreating side is lower than the advancing side. This is due to the thermal cycles making repeated material transfer to advancing side gives more refined grains. The major types of joints are butt joint, lap joint and fillet joint. The schematic illustration of friction stir welding process shown in Fig.1 is a butt type of joint ,while the other type of joints are square butt, edge butt, T butt joint, lap joint, multiple lap joint, T lap joint, and fillet joint. The most widely used type of joints is butt joint and lap joint. In a butt weld the half plates are placed adjacent to each other while in lap joint the plates are placed one above the other where as in fillet joint the plates are placed in right angles to each other.

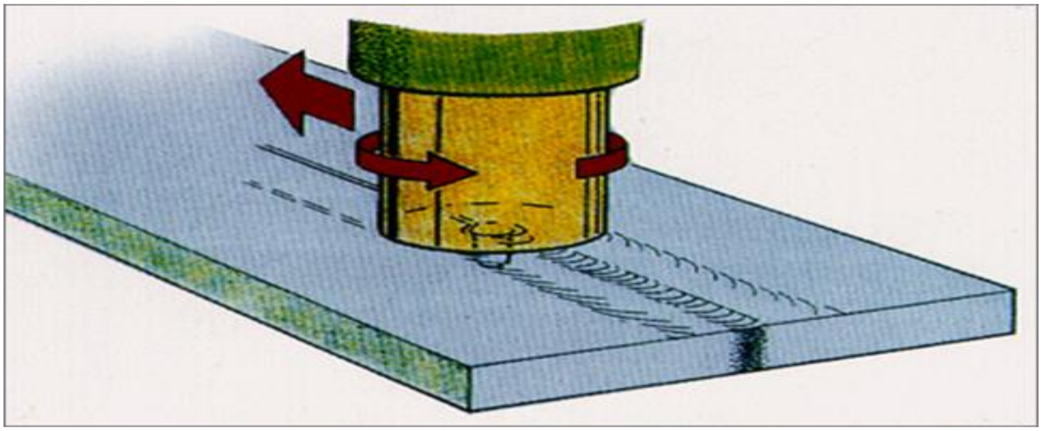

Fig 1: Butt Joint through FSW

A typical macrostructure of FSW weld showing four distinct zones namely base metal (BM), heat-affected zone (HAZ), thermo mechanically affected zone (TMAZ) and Weld nugget (WN) as shown in the Fig.2. Swirl zone (SWZ) is formed mainly due to the thermally induced surface oxidation during welding.TMAZ zone is formed due to thermo mechanical cycles and HAZ is the zone which is affected by the frictional heat produced by the shoulder. WN is the region formed due to the stirring action of the pin. Frictional heat produced by the tool makes the plastic deformation of material and grain boundary sliding. Excessive heat formation leads to tool wear which results in loss of material in the tool. Loss of tool material will be formed as an inclusion in the weld region. Feed rate, material flow and heat transfer favours the tool wear to emerge along the weld direction. Tool wear can be reduced bypreheating the work piece and by choosing appropriate tool material for the particular workpiece.

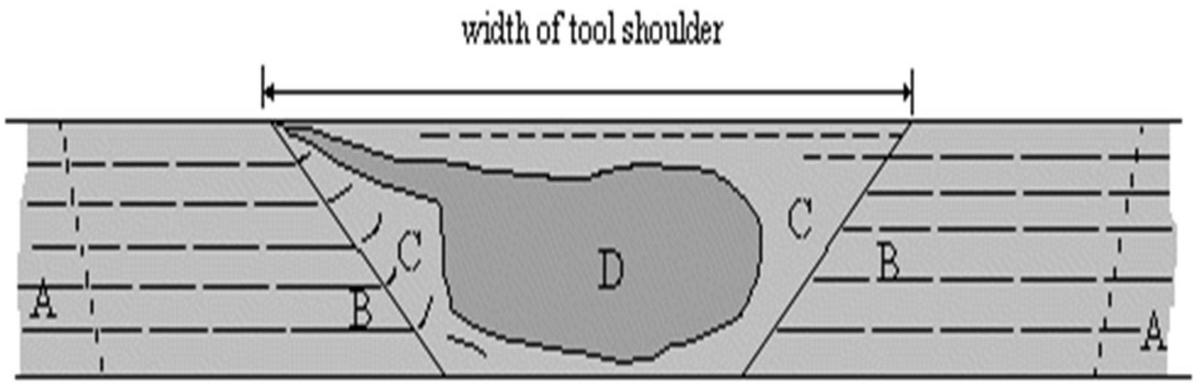

Fig.2: Weld Zone

MATERIALS AND METHODS

On the basis of literature review, very few researcher had been investigated the effect of Al-3105 alloy. This alloy is widely used in aircrafts, mobile housing, residential sidings and bottle caps. Here we review and critically examine several important aspects of FSW tools such as tool material selection and geometry.

COMPOSITION OF AL 3105

Si - 0.32
Mn - 0.44
Fe - 0.31

Cu - 0.064
Zn - 0.050
Zr - 0.0041
Mg - 0.32
Al - 98.49

LITERATURE REVIEW

Liu et al.[1] in their research paper discussed the friction stir weld ability of the 2017-T351 aluminium alloy and determine optimum welding parameters, the relations between welding parameters and tensile properties of the joints. Researchers found that the tensile properties and fracture locations of the joints are significantly affected by the welding process parameters. When the optimum revolutionary pitch is 0.07 mm/rev corresponding to the rotation speed of 1500 rpm and the welding speed of 100 mm/min, the maximum ultimate strength of the joints is equivalent to 82% that of the base material. Though the voids-free joints are fractured near or at the interface between the weld nugget and the thermo-mechanically affected zone (TMAZ) on the advancing side, the fracture occurs at the weld centre when the void defects exist in the joints. Kovacevic (2003) In their research friction stir welding (FSW) is a relatively new welding process that may have significant advantages compared to the fusion processes as follow: joining of conventionally non-fusion weld able alloys, reduced distortion and improved mechanical properties of weld able alloys joints due to the pure solid-state joining of metals. In this paper, a three-dimensional model based on finite element analysis is used to study the thermal history and thermo mechanical process in the butt-welding of aluminium alloy 6061- T6.

HuseyinUzun et al.[2] investigated that the joining of dissimilar Al 6013-T4 alloy and X5CrNi18-10 stainless steel was carried out using friction stir welding (FSR) technique. The microstructure, hardness and fatigue properties of fiction stir welded 6013 aluminium alloy to stainless steel have been investigated. Optical microscopy was used to characterize the microstructures of the weld nugget, the heat affected zone (HAZ), thermo-mechanical affected zone (TMAZ) and the base materials.

Cavaliere et al.[3] investigated the mechanical and micro structural properties of dissimilar 2024 and 7075 aluminium sheets joined by friction stir welding (FSW). The two sheets, aligned with perpendicular rolling directions, have been successfully welded; successively, the welded sheets have been tested under tension at room temperature in order to analyze the mechanical response with respect to the parent materials. Kovacevic (2005) In their research thermo-mechanical simulation of friction stir welding can predict the transient temperature field, active stresses developed, forces in all the three dimensions and may be extended to determine the residual stress. The thermal stresses constitute a major portion of the total stress developed during the process. Boundary conditions in the thermal modelling of process play a vital role in the final temperature profile.

Driver[4] In the present paper, a three-dimensional thermo mechanical model for Friction Stir Welding (FSW) is presented. Based on the velocity fields classically used in fluid mechanics and incorporating heat input from the tool shoulder and the plastic strain of the bulk material, the semi-analytical model can be used to obtain the strains, strain rates, and estimations of the temperatures and micro-hardness in the various weld zones. The calculated results are in good agreement with experimental measurements performed on a AA2024- T351 alloy friction stir welded joint.

Marzol et al.[5] established a friction stir welding (FSW) process parameters envelope for an AA 6061 alloy reinforced with 20% of Al2O3 particles, and determine properties of the obtained joints. After a brief description of the FSW technique, and the difficulties in joining MMCs, experimental procedure is illustrated. Microstructure has been observed with optical microscope, and images have been analyzed with image analysis software. Micro hardness and tensile tests have been also carried out. The tool's stirring effect has a substantial influence on the reinforcement particles distribution and shape. Tensile testing revealed joint efficiencies over 80% for the Rp0, 2 and of slightly more than 70% for the Rm, with failure outside the stir zone. The parameter envelope determined in the present study resulted in defect free, high strength welds.

Watanabe et al.[6] tried to butt-weld an aluminium alloy plate to a mild steel plate by friction stir welding, and investigated the effects of a pin rotation speed, the position for the pin axis to be inserted on the tensile strength and the microstructure of the joint. The behaviour of the oxide film on the faying surface of the steel during welding also was examined. The main results obtained are as follows. Butt-welding of an aluminium alloy plate to a steel plate

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was easily and successfully achieved by friction stir welding. The maximum tensile strength of the joint was about 86% of that of the aluminium alloy base metal. A small amount of inter metallic compounds was formed at the upper part of the steel/aluminium interface, while no inter metallic compounds were observed in the middle and bottom parts of the interface. The regions where the inter-metallic compounds formed seemed to be fracture paths in the joint. Many fragments of the steel were scattered in the aluminium alloy matrix and the oxide film removed from the faying surface of the steel by the rubbing motion of a rotating pin was observed at the interface between the steel fragments and the aluminium alloy matrix.

Scialpi et al.[7] studied the effect of different shoulder geometries on the mechanical and micro structural properties of a friction stir welded joints have been studied in the present paper. The process was used on 6082 T6 aluminium alloy in the thickness of 1.5 mm. The three studied tools differed from shoulders with scroll and fillet, cavity and fillet, and only fillet. The effect of the three shoulder geometries has been analyzed by visual inspection, macrograph, HV micro hardness, bending test and transverse and longitudinal room temperature tensile test. The investigation results showed that, for thin sheets, the best joint has been welded by a shoulder with fillet and cavity.

EXPERIMENTAL SETUP

EQUIPMENTS USED

VERTICAL MILLING MACHINE

A conventional vertical milling machine was used to attempt the welding process as shown in the Figure 3. The machine must has the ability to apply significant pressure on z axis direction, wide range of spindle speed,enough space for its working table to holding the welding assembly and rigidly during the welding operation.The milling machine used has rotational speed on the head that is suitable to fixing welding tool on it.

Fig 3. Vertical Milling Machine

TENSOMETER

A Tensometer is a device that is used to evaluate the tensile properties of materials such as their young’s modulus and tensile strength. It is usually a universal testing machine loaded with a sample between two grips that are either adjusted manually or automatically to apply force to the specimen. The machine works either by driving screws or by hydraulic ram.

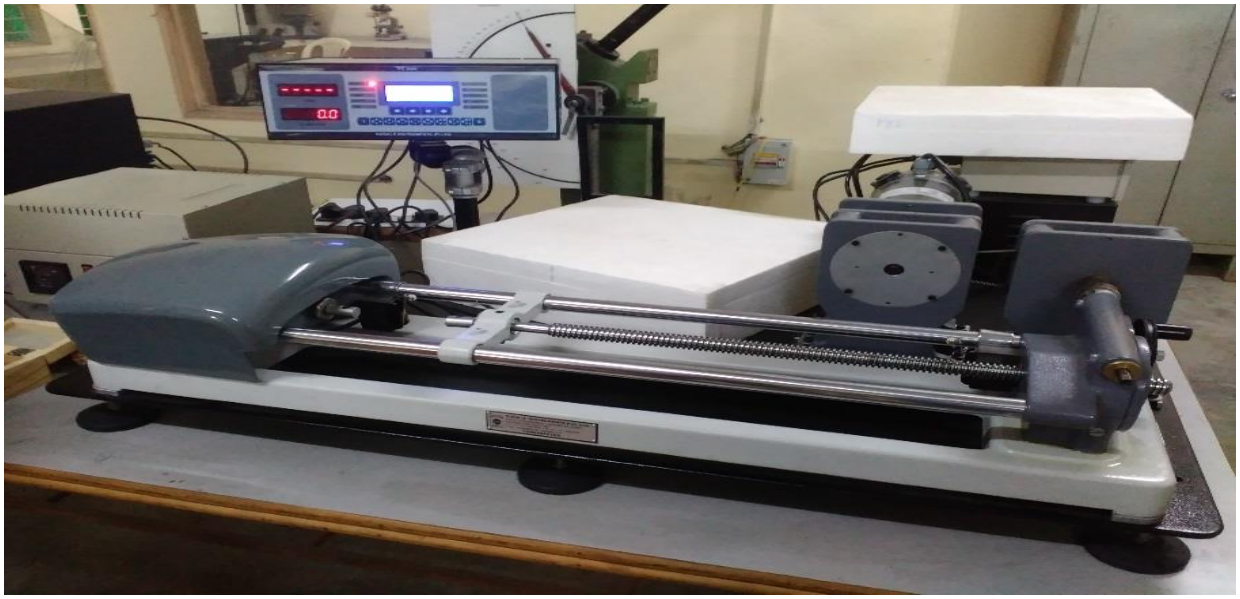

Fig.4 Tensometer

HARDNESS TESTING MACHINE

The Hardness test was carried on according to the Rockwell Hardness testing method in which the hardness is determined by measuring the depth of an indentor under a large load compared to the penetration made by the preload.

Fig.5. Hardness Testing Machine

FABRICATION OF FSW TOOLS

Many of the advanced weldings made in friction stir welding have been enabled by the development of new welding tools. The welding tool design, including both its geometry and the material from which it is made, is critical to the successful use of the process.

Three types of tools were chosen in this study. These are :-

- Straight cylindrical
- Tapered
- Threaded

The Fabrication of these tools were done by the use of the lathe Machine. The dimensional accuracy was achieved with the help of process of indexing.

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Fig.6 Different tool designs

DIMENSIONS

WORKPIECE DIMENSIONS

The aluminium alloy plates that were taken as the workpiece were of the dimensions as specified below.
Length = 120mm
Width = 40m
Thickness = 6mm

Fig 7. Workpiece Dimensions

TOOL DIMENSIONS

The tool material that was selected for the welding process was that of High Speed Steel (HSS). The dimensions that were used for this case were

For straight cylindrical

Diameter - 6mm

Tool Tip Length – 5.7mm

For threaded

Diameter – 6mm

Tool Tip Length – 5.7mm

For tapered

Minimum Diameter – 3mm

Maximum Diameter – 6mm

Tool Tip Length – 5.7mm

Hardness table

Major load = 100kgfMinor load = 10kgf

Ball dia = 1.5 mm

Table 1 Hardness Test Readings

Experiment No.	Hardness value (at base metal)	Hardness value (at edge of weld)	Hardness value (at centre of weld)	Hardness value (at edge of weld)	Hardness value (at base metal)
1.	83	73	84	81	83
2.	76	75	78	77	75
3.	98	100	105	102	95
4.	80	92	100	90	88
5.	82	98	102	91	80
6.	84	88	92	90	85
7.	72	86	90	82	75

8.	92	91	96	100	93
9.	77	94	98	90	78

RESULTS AND DISCUSSION

Analysis of Tensile Strength

The data collected from the tensile test by tensometer has been graphically shown :-

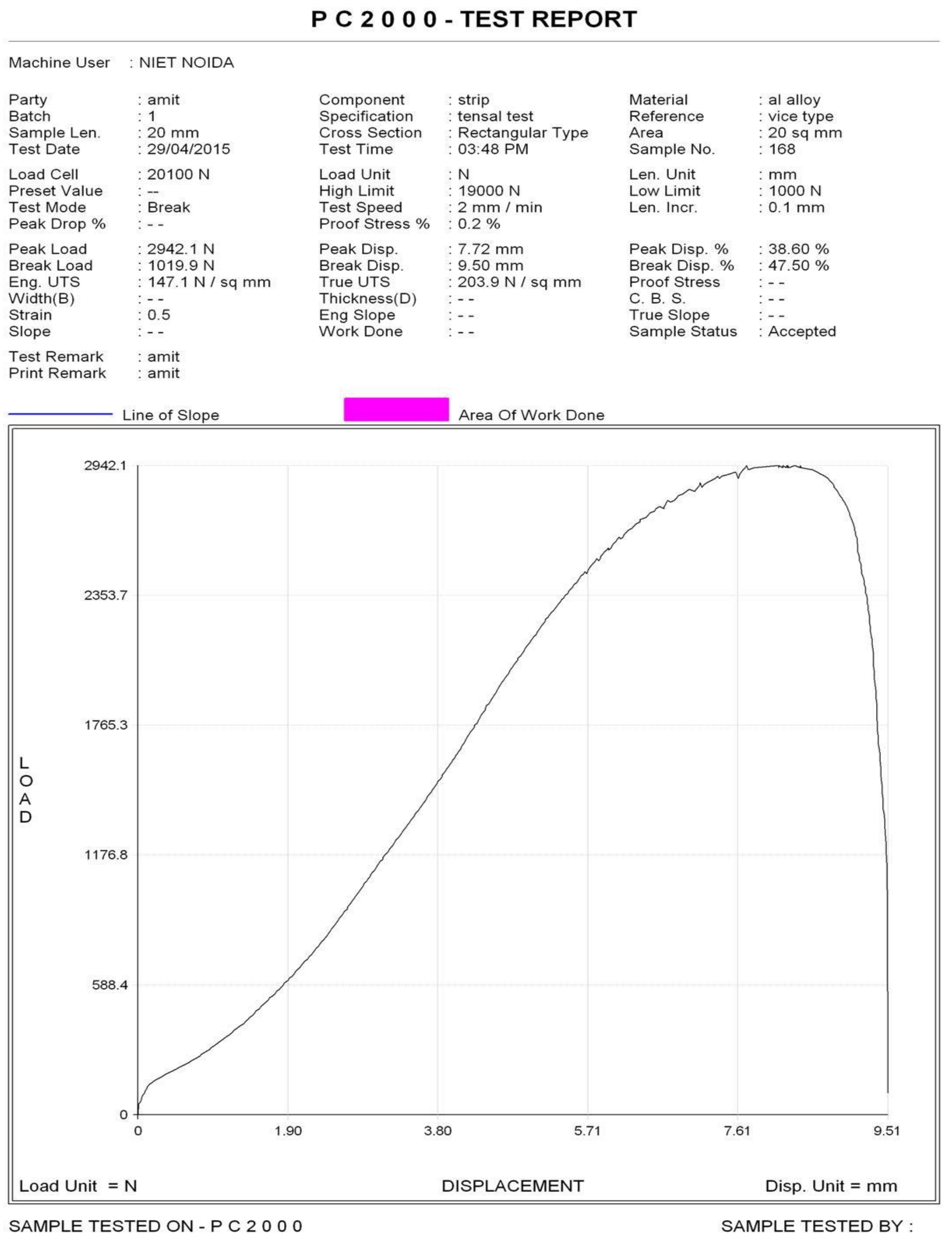


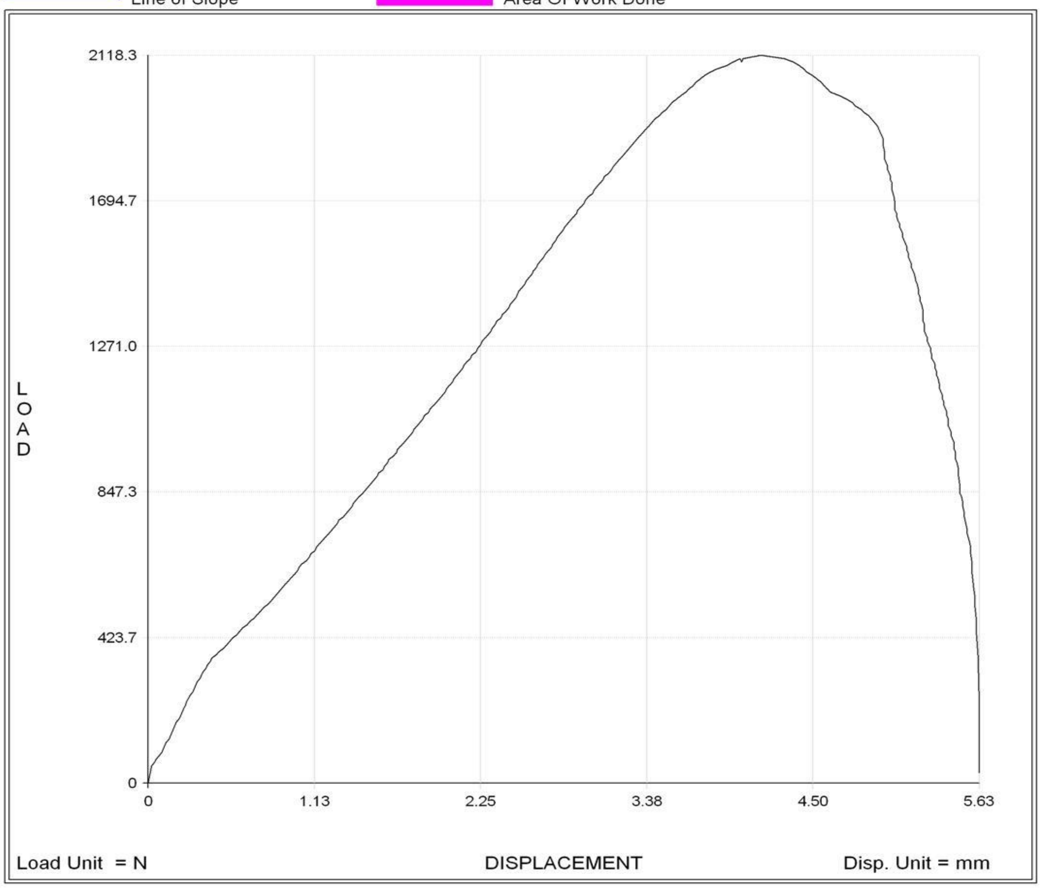
Fig 22. Fig Test Specimen no.1

P C 2 0 0 0 - TEST REPORT

Machine User : NIET NOIDA

Party	: amit	Component	: strip	Material	: al alloy
Batch	: 1	Specification	: tensal test	Reference	: vice type
Sample Len.	: 20 mm	Cross Section	: Rectangular Type	Area	: 20 sq mm
Test Date	: 29/04/2015	Test Time	: 03:55 PM	Sample No.	: 169
Load Cell	: 20100 N	Load Unit	: N	Len. Unit	: mm
Preset Value	: --	High Limit	: 19000 N	Low Limit	: 1000 N
Test Mode	: Break	Test Speed	: 2 mm / min	Len. Incr.	: 0.1 mm
Peak Drop %	: - -	Proof Stress %	: 0.2 %		
Peak Load	: 2118.3 N	Peak Disp.	: 4.15 mm	Peak Disp. %	: 20.75 %
Break Load	: 431.5 N	Break Disp.	: 5.61 mm	Break Disp. %	: 28.05 %
Eng. UTS	: 105.9 N / sq mm	True UTS	: 127.9 N / sq mm	Proof Stress	: - -
Width(B)	: - -	Thickness(D)	: - -	C. B. S.	: - -
Strain	: 0.3	Eng Slope	: - -	True Slope	: - -
Slope	: - -	Work Done	: - -	Sample Status	: Accepted
Test Remark	: amit				
Print Remark	: amit				

Line of Slope   Area Of Work Done



SAMPLE TESTED ON - P C 2 0 0 0   SAMPLE TESTED BY :

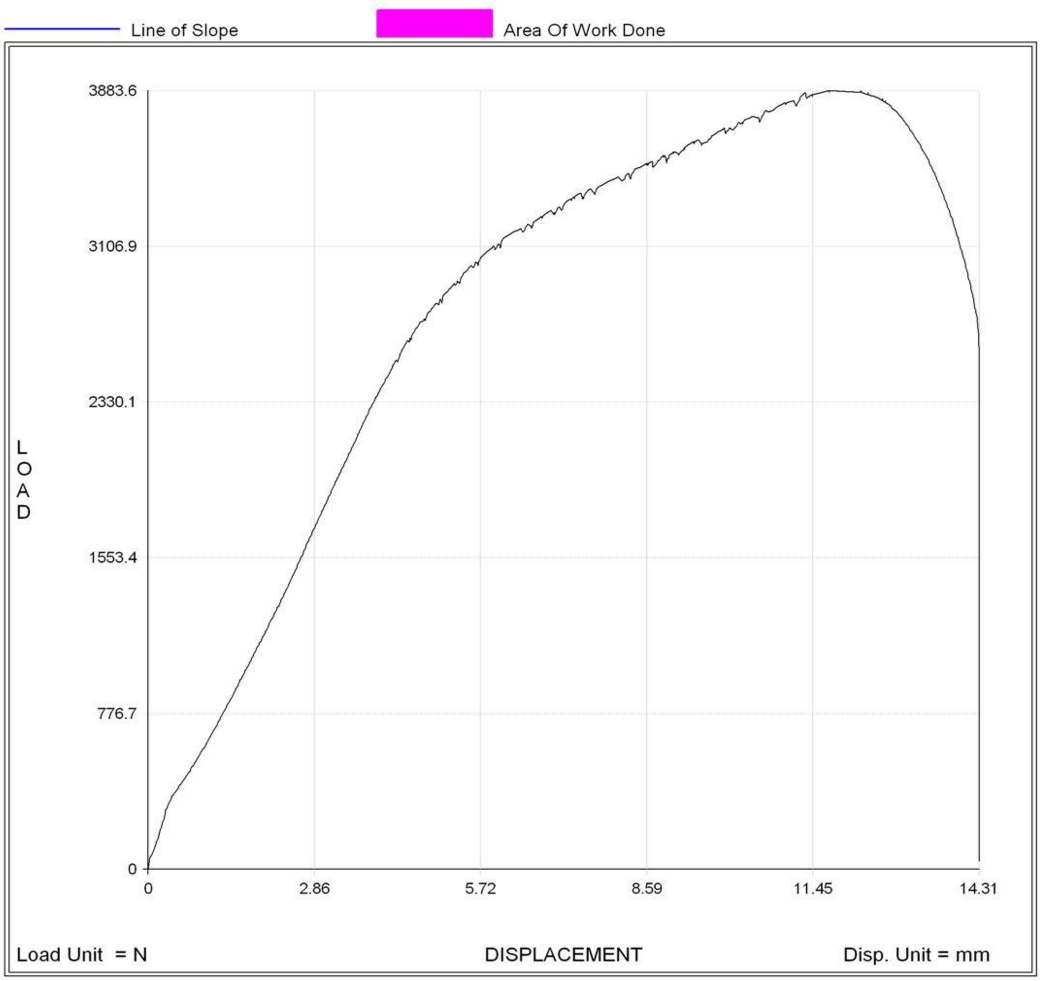
Test Specimen no.2

P C 2 0 0 0 - TEST REPORT

Machine User : NIET NOIDA

Party	: amit	Component	: strip	Material	: al alloy
Batch	: 1	Specification	: tensal test	Reference	: vice type
Sample Len.	: 20 mm	Cross Section	: Rectangular Type	Area	: 20 sq mm
Test Date	: 29/04/2015	Test Time	: 04:04 PM	Sample No.	: 170
Load Cell	: 20100 N	Load Unit	: N	Len. Unit	: mm
Preset Value	: --	High Limit	: 19000 N	Low Limit	: 1000 N
Test Mode	: Break	Test Speed	: 2 mm / min	Len. Incr.	: 0.1 mm
Peak Drop %	: - -	Proof Stress %	: 0.2 %		
Peak Load	: 3883.6 N	Peak Disp.	: 11.72 mm	Peak Disp. %	: 58.60 %
Break Load	: 2608.7 N	Break Disp.	: 14.30 mm	Break Disp. %	: 71.50 %
Eng. UTS	: 194.2 N / sq mm	True UTS	: 308.0 N / sq mm	Proof Stress	: - -
Width(B)	: - -	Thickness(D)	: - -	C. B. S.	: - -
Strain	: 0.7	Eng Slope	: - -	True Slope	: - -
Slope	: - -	Work Done	: - -	Sample Status	: Accepted

Test Remark : amit
Print Remark : amit



SAMPLE TESTED ON - P C 2 0 0 0 SAMPLE TESTED BY :

Test Specimen no.3

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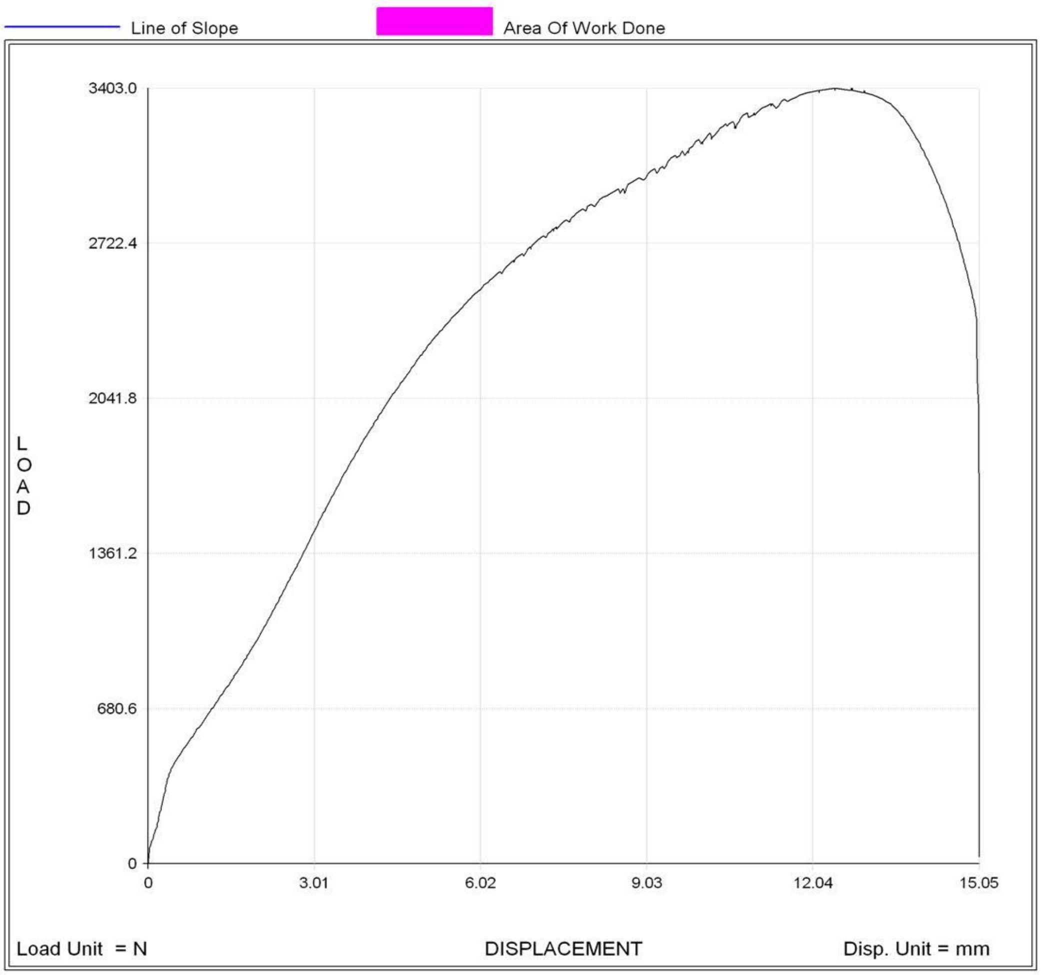
P C 2 0 0 0 - TEST REPORT

Machine User : NIET NOIDA

Party	: amit	Component	: strip	Material	: al alloy
Batch	: 1	Specification	: tensal test	Reference	: vice type
Sample Len.	: 20 mm	Cross Section	: Rectangular Type	Area	: 20 sq mm
Test Date	: 29/04/2015	Test Time	: 04:14 PM	Sample No.	: 171
Load Cell	: 20100 N	Load Unit	: N	Len. Unit	: mm
Preset Value	: --	High Limit	: 19000 N	Low Limit	: 1000 N
Test Mode	: Break	Test Speed	: 2 mm / min	Len. Incr.	: 0.1 mm
Peak Drop %	: - -	Proof Stress %	: 0.2 %		
Peak Load	: 3403.0 N	Peak Disp.	: 12.43 mm	Peak Disp. %	: 62.15 %
Break Load	: 1716.2 N	Break Disp.	: 15.04 mm	Break Disp. %	: 75.20 %
Eng. UTS	: 170.2 N / sq mm	True UTS	: 275.9 N / sq mm	Proof Stress	: - -
Width(B)	: - -	Thickness(D)	: - -	C. B. S.	: - -
Strain	: 0.8	Eng Slope	: - -	True Slope	: - -
Slope	: - -	Work Done	: - -	Sample Status	: Accepted
Test Remark	: amit				
Print Remark	: amit				



SAMPLE TESTED ON - P C 2 0 0 0 SAMPLE TESTED BY :

Test Specimen no.4

CONCLUSION AND FUTURE SCOPE

The various welding joints are prepared in accordance with the taguchi method by varying the rotor speed, tool profile & tool tilt angle. For tensile properties we observe that at higher rotor speed the strength of the weld joint is also higher. Also higher strength of the weld joint is obtained when the tool profile is of tapered type at 3 degree tilt angle and 2262 rpm. The highest tensile strength was observed at a rotor speed of 2262 rpm using a tool profile of threaded type with a tilt angle of 2 degrees. For hardness properties we observe that the most appropriate hardness strength was observed for the tool profile of tapered type.

Currently Friction Stir Welding is used in many areas and fields like automobiles, aviation and shipping industries. The main reason behind the vast application of Friction stir welding is that the weld obtained by this process is light in weight. The materials which we used in the process are aluminium alloys which are easily available in the market.

It can be used in making of Wings of Aeroplanes due to their light weight and easy to form in any shape feature. Since, it is a solid state welding which means the metal is not heated in the process, the application area of the weld increases rapidly. It can be used in making of gear box of cars and bottom part of ships. Since, a better tensile strength and hardness could be obtained with the new welded material, we can expect that Friction stir welding of two similar aluminium alloys will found its applications in most of the metallurgical industry.

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