OPTIMUM PROCESS PARAMETERS FOR FRICTION STIR PROCRSSING BY USING TAGUCHI TECHNIQUE

V. Mallikarjuna, Assistant Professor, Department of Mechanical Engineering, Annamacharya Institute of Technology & Science, Rajampet, A.P., India

Dr. B. James Prasad Rao, Professor, Mechanical Engineering Department, SMICH, Deshmukh (V), Abdullahpurmet (M), Hyderabad, Telangana State, India

L. Sreenivasa Rao, Assistant Professor, Department of Mechanical Engineering, Joginapally BR Engineering College, Yenkapally (V), Moinabad (M), R.R(dist), Hyderabad, India

Abstract: *Friction Stir Processing (FSP) is a relatively new entrant in the domain of solid state processing technique mainly applied in the manufacturing of hybrid metal matrix composites. Aluminum and its corresponding alloys have got the excellent combination of properties like high strength to weight ratio, good corrosion resistance, high thermal and electrical conductivity, high reflectivity, low emissivity making it as a ideal choice for the aerospace and automotive industries. Some application in these industries requires high wear resistance and high strength to weight ratio. Friction Stir Processing realizes achieving this by introduction of reinforcing particles onto the surface of the metal matrix by the rubbing action of the tool. The process is mainly influenced by the process parameters like tool rotational speed, Traverse speed (feed), Geometry of the tool, Tool material, diameter of the hole, spacing of the hole, tool tilt angle, plunge depth etc. In this work, an attempt will be conducted to identify the optimum process parametric conditions for Friction Stir Processing by using Taguchi Design of experiments technique to enhance surface properties of Aluminum alloys.*

Keywords: *Friction Stir welding, Taguchi method, Aluminium alloy*

1. INTRODUCTION

Although aluminium has been a commercial metal for just a little over 100 years, it is now ranked as second to steel in both worldwide quantity and expenditure and is clearly the most important of the nonferrous metals. It has achieved importance in virtually all segments of the world economy, consumer durables and mechanical equipment.

A number of unique and attractive properties account for the engineering significance of aluminium. These include its workability, light weight, corrosion resistance, and good electrical and thermal conductivity. Aluminium has a specific gravity of 2.7 compared to 7.85 for steel, making aluminium about one-third the weight of steel for an equivalent volume. Cost comparisons are often made on the basis cost per pound, where aluminium is at a distinct disadvantage, but there are number of applications where the more appropriate comparison would be based on cost per unit volume. Since a pound of aluminium would produce three times as many same-size parts as a pound of steel, the cost difference becomes markedly less.

1.2 FRICTION STIR PROCESSING

Friction Stir processing (FSP) was developed as a generic tool for microstructural modification based on the basic principles of Friction Stir welding (FSW).

1.2.1 Basic Principle of FSP

A schematic illustration of FSP is shown in Figure 1. To carry out friction stir processing a location within a plate or sheet is selected and a specially designed rotating tool is plunged into the selected area. The tool has a small diameter pin with a concentric larger diameter shoulder. When descending to the part, the rotating pin contacts the surface and rapidly friction heats and softens a small column of metal. The tool shoulder and length of entry probe control the penetration depth.

During FSP, the area to be processed and the tool are moved relative to each other such that the tool traverses, with overlapping passes, until the entire selected area is processed to a fine grain size. The rotating tool provides a continual hot working action, plasticizing metal with a narrow zone, while transporting metal from the leading face of the pin to its trailing edge. The processed zone cools, without solidification, as there is no liquid, forming a defect- free recrystallized, fine grain microstructure. Essentially, FSP is a local, thermo-mechanical metal working process that changes the local properties without influencing properties in the remainder of the structure.

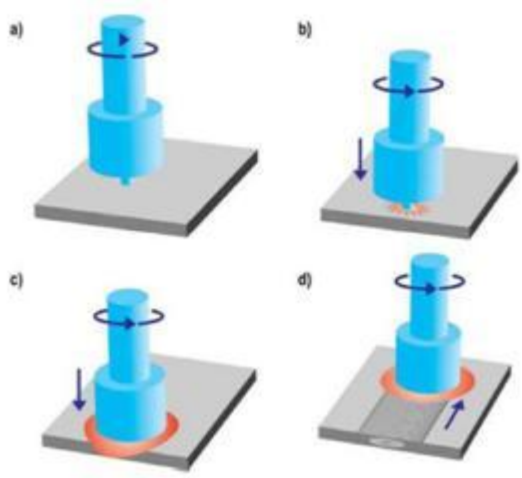

Figure 1: Schematic illustration of friction stir processing: a) rotating tool prior to contact with the plate; b) tool pin make contact with the plate, creating heat; c) shoulder makes contact, restricting further penetration while expanding the hot zone; d) plate moves relative to the rotating tool, creating a fully recrystallized, fine grain microstructure (courtesy of Mahoney and Lynch 2006)

1.3 PROCESS PARAMETERS

FSP involves complex material movement and plastic deformation. Tool geometry and processing parameters exert significant effect on the material flow pattern and temperature distribution, thereby influencing the microstructural evolution of material.

1.3.1 Tool Geometry

Tool geometry is the most influential aspect of process development. The tool geometry plays a critical role in material flow and in turn governs the traverse rate at which FSW/FSP can be conducted. An FSW/FSP tool consists of a shoulder and a pin. In the initial stage of tool plunge, the heating results primarily from the friction pin and workpiece. Some additional heating results from deformation of material. The tool is plunged till the shoulder touches the workpiece. The friction between the shoulder and workpiece results in the biggest component of heating. From the heating aspect, the relative size of pin and shoulder is important, and the other design features are not critical.

1.3.2 Rotational Speed and Traverse Speed

For FSP, two parameters are very important: tool rotation rate (N) in clockwise or counter clockwise direction and tool traverse speed(S) along the line of joint/processing. Higher tool rotation rates generate higher temperature because of higher friction heating and results in

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more intense stirring and mixing of material. However, it should be noted that frictional coupling of tool surface with workpiece is going to govern the heating. So, a monotonic increase in heating with increasing tool rotation rate is not expected as the coefficient of friction at interface will change with increasing tool rotation rate.

2. STATISTICAL MODELLING

2.1 Importance of Design of Experiments (DOE)

Increasing productivity and improving quality are important goals in any business. The methods for determining how to increase productivity and improve quality are evolving. They have changed from costly and time-consuming trial-and-error searches to the powerful, elegant, and cost-effective statistical methods.

Design of Experiments (DOE) techniques enables designers to determine simultaneously the individual and interactive effects of many factors that could affect the output results in any design. DOE also provides a full insight of interaction between design elements; therefore, it helps turn any standard design into a robust one. Simply put, DOE helps to pin point the sensitive parts and sensitive areas in designs that cause problems In Yield

2.2 Goal of experiments

- Experiments help us in understanding the behavior of a (mechanical) System
- Data collected by systematic variation of influencing factors helps us to quantitatively describe the underlying phenomenon or phenomena.

The goal of any experimental activity is to get the maximum information about a system with the minimum number of well-designed experiments. An experimental program recognizes the major “factors” that affect the outcome of the experiment. The factors may be identified by looking at all the quantities that may affect the outcome of the experiment. The most important among these may be identified using a few exploratory experiments or from past experience or based on some underlying theory or hypothesis. The next thing one has to do is to choose the number of levels for each of the factors. The data will be gathered for these values of the factors by performing the experiments by maintaining the levels at these values.

2.3. MATRIX EXPERIMENTS

A Matrix experiments consists of a set of experiments where the setting of several product or process parameters to be studied changed from one experiment to another.

A matrix experiments consists of a set of experiments where we change the settings of the various product or process parameters. We want to study from one experiment to another. After co]1nducting a matrix experiment, the data from all experiments in the set taken together are analyzed to determine the effects of the various parameters. Conducting matrix experiments using special matrices called orthogonal arrays, allows the effects of several parameters to be determined efficiently and is an important technique in robust design.

In statistical Literature matrix experiments are called designed experiments and the individual experiments in a matrix experiment are sometimes called runs or treatments settings also referred to as levels and parameters as factors.

2.4 Methods of D.O.E

- Factorial
- Response surface
- Mixture
- Taguchi

2.5. Taguchi design: A Taguchi Design or an orthogonal array is a method of designing experiments that usually requires only a fraction of the full factorial combinations. An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be evaluated independently of all the other factors, so the effect of one factor does not influence the estimation of another factor.

The experiment is carried out by running the complete set of noise factor settings at each combination of control factor settings (at each run). The response data from each run of the noise factors in the outer array are usually aligned in a row, next to the factors settings for that run of the control factors in the inner array. For an example, see data for analyze Taguchi design.

2.5.1 L9 (34) Taguchi Design:** -

The L9 (3**4) Taguchi design which is considered For Analysis of friction welded joint is:

Table 2.1: L9 (34) Taguchi Orthogonal Matrix**

FACTORS	C1	C2	C3	C4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

2.3.2 (3**4) REPRESENTS

- L9 9 RUNS
- 3 3 LEVELS
- 4 4FACTORS

3. EXPERIMENTATION

Items Used for Experimentation

1. **Machinery equipment**
   i. Vertical milling machine (Friction stir processing Machine)
2. **Tools**
   i. Friction stir processing Tool
3. **Raw materials**
   i. Aluminium Alloy 7075 plates of 8 mm thickness
4. **Reinforcing powders**
   i. Silicon Carbide ceramic reinforcement particulates

3.1 Equipment's, material and chemicals used for metallurgical testing's

1. Digital image Optical Microscope
2. Disc Polishing Machine
3. Tissue paper or smooth cloth
4. Etchants

3.2 Description of Friction Stir Processing Machine: The below figure 3.1 machine is used during the work process of friction stir processing. The model of the machine is HMT FM-2V. The capacity of machine is 10 HP. The range of the speed is 35 rpm minimum and 1800 rpm maximum. The feed capacity is minimum 16mm/min and maximum 800 mm/min and the bed size of 800 mm in “X” direction, 400 mm in “Y” direction and 400 mm in “Z” direction.

3.3 Friction Stir Processing Tool and Tool Material

The tool material used in the experiments was Tool steel grade of H13. It was used as a friction stir processing tool. Friction stir processing tool was machined on CNC lathe machine according to the considered dimensions as shown in figure 3.2. The tool was hardened to 55 HRC to withstand wear and heat during processing. The shoulder diameter is of 22 mm, the pin profile is of 5 mm diameter at the top and 2.5 mm dia. at the bottom with cylindrical taper pin with 2mm to 3mm diameter over 4.5 mm length. The length of the pin is of 4.5mm.The designed and the prepared tool is as shown in figure 3.1. The chemical composition of tool was indicated in table

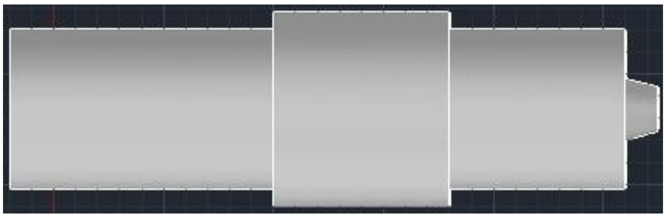

Figure 3.1: Solid model of FSP tool

Figure 3.2: Prepared FSP tool

Table 3.1: Chemical composition of H13 tool steel

Element	C	Mn	Cr	Mo	V	Si	Fe
Weight (%)	0.40	0.35	5.20	1.30	0.95	1.0	90.8

3.4 Work Piece Materials

Aluminium alloy 7075

Commercial Aluminium Alloy 7075 plate of 8 mm thickness was purchased as raw material at Andhra steels located at Hyderabad. Raw material has been cut on shearing machine according to the considered sizes of 110 mm x 30 mm each plate as shown in figure 3.5

Figure 3.3: AA7075 Plates

Table 3.2: Chemical composition of AA7075

Element	Mg	Si	Fe	Cu	Cr	Mn	Zn	Ti	Al
Weight (%)	2.5	0.4	0.5	1.6	0.23	0.30	5.60	0.30	rest

3.5 Reinforced Particulates

In the present research silicon carbide powders were used as reinforced particulates at interface. Silicon carbide (SiC) is the main reinforcing materials among ceramics. It have high elastic modulus and can be used to strengthen low-density, low modulus metals such as aluminium and magnesium

In this research, particles reinforcement was used to make composite at process interface to enhance mechanical properties. Ceramic reinforcement of SiC is used during FSP operation for metals of aluminium alloy 7075 to make metal matrix composite.

3.6 Silicon carbide (SiC)

Silicon Carbide powder particulates incorporated in the weld zone before the friction stir processing of aluminium alloy 7075. Silicon carbide particles of 400 mesh size were added in the holes of metals. Silicon carbide powder particles are as shown in figure 3.8.

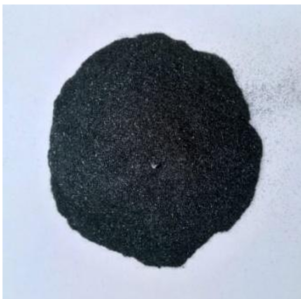

Figure 3.4: Silicon Carbide powder particulates

3.7 Specifications of machine: The machine is used during the work process of friction stir processing. The model of the machine is HMT FM-2V. The capacity of machine is 10 HP. The range of the speed is 35 rpm minimum and 1800 rpm maximum. The feed capacity is minimum 16mm/min and maximum 800 mm/min and the bed size of 800 mm in "X" direction, 400 mm in "Y" direction and 400 mm in "Z" direction.

3.7.1 Factors to be considered for Taguchi design of matrix:-Tool rotational speed

- Transvers speed (feed)
- Diameter of the hole
- Tool tilt angle

3.7.2 Response variables:-

- Tensile strength
- Hardness

3.7.3 Friction-processing factors used For 3 Levels:-

Table 3.3: Friction processing factors for 3 levels

Levels / Factors	High	Medium	Low
Speed (R.P.M)	1100	910	720
Transvers speed (feed)	60	50	40
Diameter of the hole	3	2	1
Tool tilt angle	2	1	0

3.8 Constant Factors in Experiment:

- Spacing of the hole 10mm
- shoulder dia 22mm
- Plunge depth 4.5mm
- Axial load 5 KN

3.9 Factors for DOE:-

- Rotational speed C1
- Transvers speed (feed) C2
- Diameter of hole C3
- Tool tilt angle C4

3.10 DESIGN OF EXPERIMENT:-

Taguchi Design: Type of design: - 3 Level design (2 to 13 factors)

Taguchi Orthogonal Array Design L9 (3**4)

NO of Factors: 4

NO of Runs: 9

NO of Levels: 3

Columns of L9 (3**4)

Array1 2 3 4

Taguchi Orthogonal Array Design L9 (34): -**

Table 3.4: Taguchi Orthogonal Array Design L9 (34)**

A	B	C	D
1	1	1	1
1	2	2	2
1	3	3	3
2	1	2	3
2	2	3	1
2	3	1	2
3	1	3	2
3	2	1	3

3.11 Experimental set up of Friction process-

Fig. 3.5: Vertical milling machine (Friction process Machine)

3.12 Specimens before Processing:

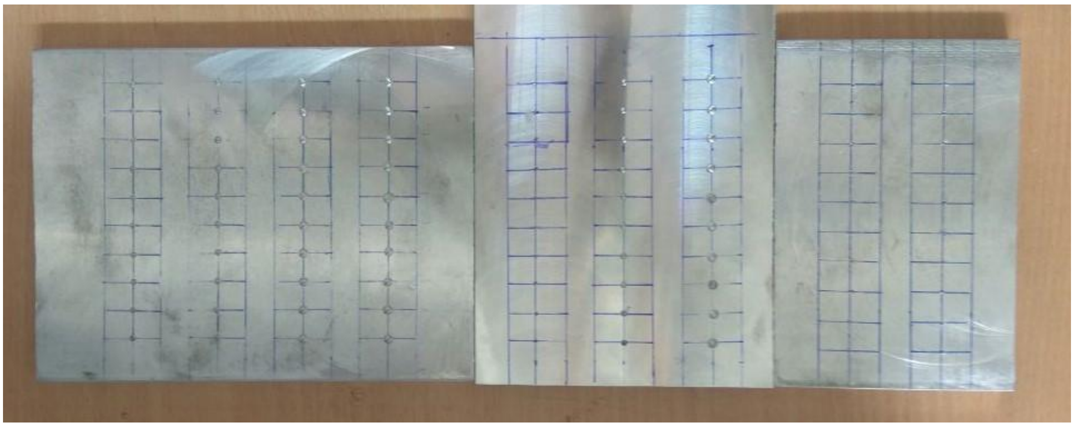

Fig.3.6: Specimens of work pieces before processing (9 experiments)

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3.13 Specimens after Processing:

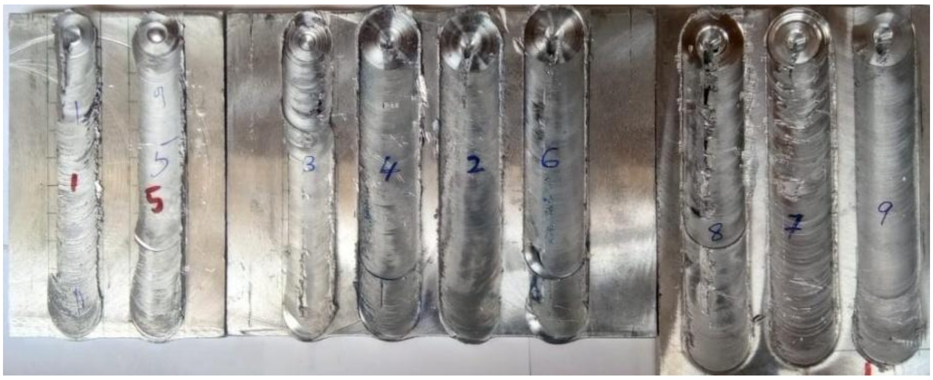

Fig. 3.7: Specimens of Work pieces after processing (9 Specimens)

3.14 EXPERIMENTAL PROCEDURE:

Material used in the experiment is aluminium 7075, cut into bite size of 120x150x8mm.The chemical composite are listed in the table 4.1. A non-consumable tool made up of H13 was used as the tool material, which was use in the friction process. The conical pin used as the stirring tool as shown in the figure 4.1. The tool has shoulder diameter, pin diameter, and pin length of 22mm, 5mm, 4.5mm, respectively. In this study the tool parameters were fixed at 5KN with downward tool plunge force. The parameters of friction stir processing for 7075 aluminium alloys were studied at three different travel speed 60, 50 and 40 mm/min, then different rotational speeds: 1100, 910 and 720 rpm then diameter of holes 3, 2 and 1 mm and the tilt angle 3, 2 and 1 degree.

Friction processing was performed using a single pass Friction processing machine in which one of the work piece is attached on the table then tool is fixed in the spindle. Then tool working starts. The same process repeated for total 9 runs.

These stir process of Aluminium are taken for Tensile Testing and to study the Micro structure.

To determine the behaviour of the objective function DOE (Design of experiment) was used. In this TAGUCHI design of experiment is used. Here L_9 Orthogonal array is selected. (As shown in table 4.3). The First row indicates the number of factors which will be tested which are 4 in this case. The First column shows the number of Experiments that must be completed for the Experiment, in this case being 9. The other columns underneath show the levels of each factor, in this case 3 i.e. (High-3, medium-2 and Low-1).

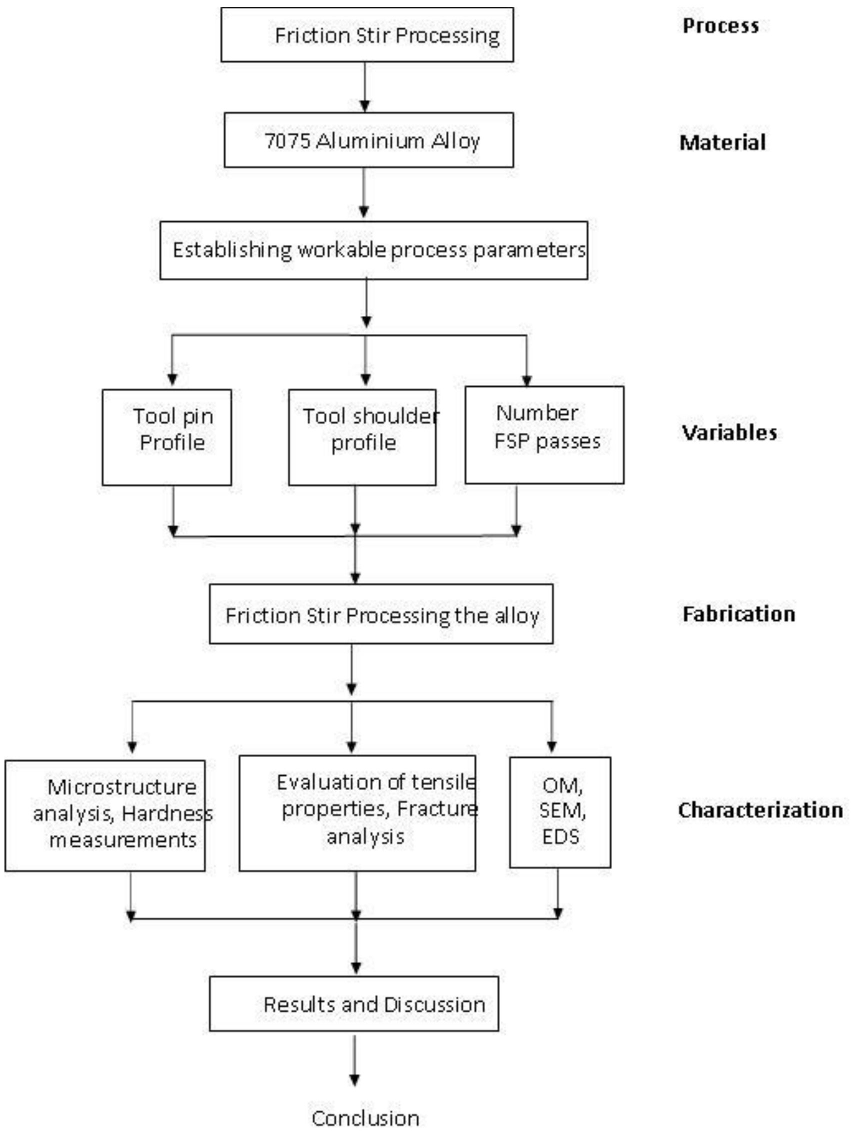

Fig 3.8: Flowchart of the experimental plan

3.15 SPECIMENS BEFORE TENSILE STRENGTH TEST:

Fig 3.9: Specimens before tensile strength test

TENSILE TESTING MACHINE:-

Fig 3.10: Tensile testing machine

4. RESULTS AND DISCUSSION

4.1 Tensile strength: Tensile strength was calculated for various levels of rotational speed, feed, tilt angle and diameter of hole. Geometry of tool, spacing of hole, plunge depth and axial load was maintained constant.

4.2 Taguchi Orthogonal Array Design for L9 (34):-**

Table 4.1: Taguchi Orthogonal Array Design for L9 (34)**

Runs	C1	C2	C3	C4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

The above table 4.1 shows the Orthogonal Array Matrix of L9 (3**4). In this The First row indicates the number of factors which will be tested which are 4 in this case. The First column shows the number of Experiments that must be completed for the Experiment, in this case being 9. The other columns underneath show the levels of each factor, in this case 3 i.e. (High-3, medium-2 and Low-1).

4.3 INPUT Variables for 9Runs, 3Lvels and 4 Factors:-

Table 4.2: Input variables for 9Runs, 3Lvels and 4 Factors

Runs	Speed (R.P.M)	Feed (mm/min)	Tilt Angle	Diameter of Hole(mm)
1	720	40	0	1
2	720	50	1	2
3	720	60	2	3
4	910	40	1	3
5	910	50	2	1
6	910	60	0	2
7	1100	40	2	2
8	1100	50	0	3
9	1100	60	1	1

The Above Table Represents or Explains about the Input variables which were considered for calculating the tensile strength for three levels which are High, medium and low. These 4 factors entered into the table according to Taguchi design matrix which is shown in.

4.4 Constant Factors which were considered in Friction stir process:-

Table 4.3: Constant Factors which were considered in Friction process

Constant Factors	Geometry of the tool (mm)	Spacing of the hole (mm)	Plunge depth (mm)	Axial load (kN)
1 to 9 Runs	22	10	3.5	5

The Above Table 4.3 Shows the constant values which were considered for 4 factors for all 9 runs.

4.5 Ultimate Tensile Strength Test results:

Table 4.4: Ultimate Tensile Strength Test results

RUNS	Peak stress (MPa)
1	**316.302**
2	220.219
3	160.823
4	168.51
5	204.72
6	103.366
7	117.401
8	69.726
9	138.163

The Table 4.4 Which Shows the Ultimate peak stress. In that above Results 9 samples were fractured at the portion. The friction stir processing has the more tensile strength than the base material. In that 1 samples which has more ultimate tensile strength than the other sample. The sample 1 has more tensile strength (316MPa) which was processed at rotational speed 720rpm, feed 40mm, tilt angle 0 and diameter of hole 1mm.

4.5.1 Specimens after tensile strength test:-

Fig.4.1: Specimens after tensile strength test

Hardness Test results: -

Table 4.5: Hardness Test results

RUNS	Hardness value
1	**165**
2	152
3	135
4	143
5	147
6	115
7	120
8	105
9	130

The Table 4.4 Which Shows the hardness. In that above Results 9 samples were tested at the portion. The friction stir processing has the more hardness value than the base material. In that 1 samples which has more ultimate tensile strength than the other sample. The sampl1 has more hardness value (165) which was processed at rotational speed 720rpm, feed 40mm, tilt angle 0 and diameter of hole 1mm.

5. CONCLUSION

The main objective of the paper was metal matrix composite by adding silicon carbide with friction stir processing principle to enhance the surface properties. It was observed that after making composite Mechanical properties to tensile strength and hardness was enhanced. Maximum enhanced observed at speed 720 rpm, 40mm feed, 0 tilt angle and 1 mm diameter of the hole.

SCOPE FOR FUTURE WORK

Similar studies can be conducted on composite materials which have more demand in aeronautics and space applications.

Studies can be conducted on dissimilar materials to reduce the cost of the materials especially in I.C Engines and Chemical industries.

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