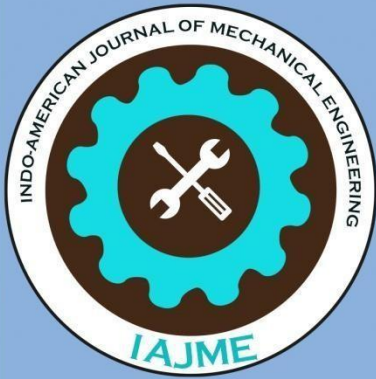




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EXPERIMENTAL INVESTIGATION AND TRIBOLOGICAL PROPERTIES OF METAL MATRIX MATERIAL USING WEAR TEST

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ABSTRACT

Aluminium Metal Matrix composites finds several applications in automobile, aerospace and other engineering application due to its mechanical and tribological properties. To improve wear resistance and mechanical properties has led to design and selection of newer variants of the composite. The present investigation deal with the study of wear behaviour of Al-Sic-mg MMCs for varying reinforcement content, applied load, sliding velocity. Aluminium MMCs reinforced with three different percentages of reinforcement 5, 10, 15% wt. Sic and 3% wt.mg prepared by stir casting method. Wear test was performed by using “pin on disk” apparatus. A plan of experiment based on L₉ Taguchi orthogonal array is used to acquire the wear data. An analysis of variance is employed to investigate the influence of three controlling parameters, Sic content, Normal load, sliding velocity on dry sliding wear of the composites. It is observed that Sic content, sliding velocity and normal load significantly affect the dry sliding wear. The optimal combination of the three controlling parameters is also obtained for minimum wear.

Key words: Metal matrix composites; Al-Sic-Mg; Stir casting; Wear; Optimization

1. INTRODUCTION:

METAL MATRIX COMPOSITE:

A metal matrix composite (MMC) is composite material with at least two constituent parts, one being a metal. The material may be a different metal or another material, such as ceramic or organic compound. When at least three materials are present, it is called a hybrid composite.

MMC's are made by dispersing a reinforcing material into a metal matrix. The reinforcement surface can be coated to prevent a chemical reaction with the matrix.

The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as Aluminium, Magnesium or titanium, and provides complaint support for the reinforcement. In high temperature high applications Cobalt and Cobalt-Nickel alloy matrices are common.

The reinforcement material is embedded into the matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound), but it is also used to change physical properties such as wear resistance, friction coefficient or thermal conductivity. The reinforcement can be either continuous, or discontinuous. Discontinuous MMC's can be isotropic and can be worked with standard metal working techniques, such as extrusion, forging or rolling. Continuous reinforcement uses monofilament wires or fibres such as carbon fibres or silicon carbide. Because the fibres are embedded into the matrix in a certain direction, the result in an anisotropic structure in which the alignment of material affects its strength. One of the first MMC's used Boron filament as reinforcement.

Usually Metal Matrix Composites are composed of a metallic matrix (Al, Mg, Fe, Cu etc) and a dispersed ceramic (oxide, carbides) or metallic phase (Pb, Mo, W etc). Ceramic reinforcement may be silicon carbide, boron, alumina, silicon nitride, boron carbide, boron nitride etc. whereas Metallic Reinforcement may be tungsten, beryllium etc. MMC's are used for Space

Shuttle, commercial airliners, electronic substrates, bicycles, automobiles, golf clubs and a variety of other applications. From a material point of view, when compared to polymer matrix composites, the advantages of MMC's lie in their retention of strength and stiffness at elevated temperature, good abrasion and creep resistance properties. Most MMC's are still in the development stage or the early stages of production and are not so widely established as polymer matrix composites. The biggest disadvantages of MMC's are their high costs of fabrication, which has placed limitations on their actual applications. There are also advantages in some of the physical attributes of MMC's such as no significant moisture absorption properties, non-inflammability, low electrical and thermal conductivities and resistance to most radiations. MMC's have existed for the past 30 years and a wide range of MMC's have been studied.

2 MATERIALS SELECTION AND FABRICATION METHODOLOGY:

Material selection is a step in the process of designing any physical object. In the context of product design, the main goal of selection is to minimize cost while meeting product performance goals. The material selection process is the key to engineering any application and/or part design. Material selection is the foundation of all engineering applications and design. This selection process can be defined by application requirements, possible materials, physical principles, and selection.

The design or function of the part/application is the application requirements. The application requirements are specific given the application. The possible materials are simply the only materials that can be used in the application. Possible Materials are defined by the application requirements. For an example you cannot use cloth to build a bicycle.

The standard composite rule of mixtures is when the standard matrix is soft/pliable and the reinforcing material is tensile strong. One of the major reasons for the prevalent use of composite materials in construction is the adaptability of the composite to many kinds of applications. The selection of mixture proportions can be aimed to achieve optimum mechanical behavior of the hardened product. Selection can result in the change of the strength, consistency, density, appearance, and durability.

The alloying of metals is one of the oldest and most fundamental material processing techniques. An Alloy is a solid solution that is

composed of two or more elements. There is a solvent (majority composition) and a solute. The Solute element can strengthen the overall solid solution by different element size, density, and other material properties.

Given the application requirements, possible materials, and physical principles we can select the best material. Thus in the selection of a material: First, we decide on the requirements of the application. Second, we decide on the possible materials we can use in the application. Third, we decide what changes in the material properties are needed. Lastly, we decide which material out of the possible materials best fulfills the requirements of the application given possible changes in the material properties.

The selection of a composite material depends on cost, availability, uses and their material properties which are described below:

2.1 MATERIALS DESCRIPTION

1. PURE ALUMINIUM

Aluminium is the world's most abundant metal and does the second most common element comprise 8% of the earth's crust. The versatility of Aluminium makes it the most widely used metal after steel.

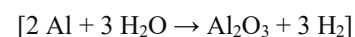
Aluminium is derived from the mineral bauxite. Bauxite to aluminium oxide (Alumina) via the Bayer process. The alumina is to alumina metal using electrolytic cells and the Hall Heroult process.

Applications of Aluminium

Pure aluminium is soft, ductile and corrosion resistant and has a high electrical conductivity. It is widely used for foil and conductor cables, but alloying with other elements is necessary to provide the higher strengths needed for other applications. Aluminium is one of the lightest engineering metals, having strength to weight ratio superior to steel.

By utilizing various combinations of its advantageous properties such as strength, lightness, corrosion resistance, recyclability and formability, aluminium is being employed in an ever-increasing number of applications. This array of products ranges from structural materials through to thin packaging foils.

Aluminium is oxidized by water to produce hydrogen and heat:



This conversion is of interest for the production of hydrogen. Challenges include circumventing the formed oxide layer, which inhibits the reaction and the expenses associated with the storage of energy by regeneration of the Al metal.

Corrosion Resistance of Aluminium

When exposed to air, a layer of aluminium oxide forms almost instantaneously on the surface of aluminium. This layer has excellent resistance to corrosion. It is fairly resistant to most acids but less resistant to alkalis.

Property	Value
Melting point [$^{\circ}\text{C}$]	660.32
Coefficient of thermal expansion [$\text{m/m}^{\circ}\text{C}$]	23.5×10^{-6}
Thermal conductivity [$\text{W/m}^{\circ}\text{K}$]	204.2
Density [g/cm^3]	2.70
Modulus of elasticity [GPa]	70
Poisson's ratio	0.35

Table 1: Properties of Aluminium

2. SILICON CARBIDE

Silicon Carbide (SiC) in particulate form has been available for a long time. It is quite cheap and commonly used for abrasive, refractory, and chemical purpose. SiC particle reinforcements are two types round and angular morphology

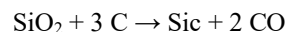
Silicon Carbide Formula

Silicon carbide, also known as carborundum, is a unique compound of carbon and silicon and is one of the hardest available materials.

Formula and structure: The chemical formula of silicon carbide is SiC. Its molecular formula is CSi and its molar mass is 40.10 g/mol . It is a simple compound with the carbon atom attached to silicon through a triple bond, leaving both atoms with a positive and negative charge. However, the bonding between them has a predominantly covalent character, rather than ionic. Solid silicon carbide exists in many different crystalline forms, with the hexagonal crystal structure being the most commonly found one.

Occurrence: Silicon carbide occurs naturally as the rare mineral moissanite.

Preparation: Silicon carbide is prepared industrially by the Acheson method, in which pure silica sand (SiO_2) and finely ground coke (carbon) are mixed together and heated to very high temperatures in an electric furnace.



Uses: As a very hard substance, silicon carbide is widely used as an abrasive. It is used to make various materials such as sandpapers, grinding wheels, cutting tools, hard ceramics, automobile parts, refractory linings, high temperature bricks, heating elements, wear-resistant parts for pumps and rocket engines, and even jewelry. It is also an important material in the electronics industry and used for making light-emitting diodes (LEDs) and semiconductor devices.

Property	Value
Melting point [$^{\circ}\text{C}$]	2730
Coefficient of thermal expansion [$\text{m/m}^{\circ}\text{C}$]	4.0×10^{-6}
Thermal conductivity [$\text{W/m}^{\circ}\text{K}$]	120
Density [g/cm^3]	3.21
Modulus of elasticity [GPa]	410
Poisson's ratio	0.14

Table 2: Properties of Silicon Carbide

3. MAGNESIUM

Magnesium is the eighth most abundant element in the earth's crust although not found in its elemental form. It is a Group 2 element. Group 2 elements are called alkaline earth metals. Magnesium metal burns with a very bright light.

Magnesium gets its name from the district of Magnesia in Greece where the compound magnesium carbonate was first found

Magnesium is a shiny, silver or gray coloured metal that is light in weight and strong. The density of magnesium is 1.738 g/ml , which means the metal will sink in water, but it is still relatively light weight. Chemical Properties: Magnesium is a silvery white metal

Property	Value
Melting point [$^{\circ}\text{C}$]	650
Coefficient of thermal expansion [$\text{m/m}^{\circ}\text{C}$]	24.8×10^{-6}
Thermal conductivity [$\text{W/m}^{\circ}\text{K}$]	156
Density [g/cm^3]	1.738
Modulus of elasticity [Gpa]	45
Poisson's ratio	0.290

Table 1: properties of magnesium**3. FABRICATION METHODOLOGY:****TECHNIQUES FOR FABRICATION OF METAL MATRIX COMPOSITES**

There are several Techniques for the Fabrication of Metal Matrix Composites is there. These metal matrix composites have many advantages as compared to monolithic metals as discussed above so their applications are increasing day by day in various fields. Various processes are used to manufacture MMCs which are described here. These processes are classified on the basis of temperature of the metallic matrix during processing.

Accordingly, the processes can be classified into five categories:

- (1) liquid-phase processes,
- (2) solid-liquid processes,
- (3) Deposition techniques and
- (4) In situ processes.
- (5) two- phase (solid-liquid) processes.

1. Liquid State Fabrication Of Metal Matrix Composites

It involves incorporation of dispersed phase into a molten matrix metal, followed by its solidification. In order to provide high level of mechanical properties of the composite, good interfacial bonding (wetting) between the dispersed phase and the liquid matrix should be obtained. Wetting improvement may be achieved by coating the dispersed phase particles (fibers). Proper coating not only reduces interfacial energy, but also prevents chemical interaction between the dispersed phase and the matrix

The methods of liquid state fabrication of Metal Matrix Composites:

Stir casting, Infiltration like gas pressure infiltration, Squeeze casting infiltration or Pressure die infiltration

a. Stir Casting

It is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. Stir casting as shown in fig. is the simplest and the most cost effective method of liquid state fabrication. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies.

b. Infiltration

It is a liquid state method of composite materials fabrication, in which a preformed dispersed phase (ceramic particles, fibers, woven) is soaked in a molten matrix metal, which fills the space between the dispersed phase inclusions. The motive force of an infiltration process may be either capillary force of the dispersed phase (spontaneous infiltration) or an external pressure (gaseous, mechanical, electromagnetic, centrifugal or ultrasonic) applied to the liquid matrix phase (forced infiltration)

c. Gas Pressure Infiltration

It is a forced infiltration method of liquid phase fabrication of Metal Matrix Composites, using a pressurized gas for applying pressure on the molten metal and forcing it to penetrate into a preformed dispersed phase. Gas Pressure Infiltration method is used for manufacturing large composite parts.

Squeeze Casting Infiltration or pressure die infiltration – It is a forced infiltration method of liquid phase fabrication of Metal Matrix Composites, using a movable mold part (ram) for applying pressure on the molten metal and forcing it to penetrate into a preformed dispersed phase, placed into the lower fixed mold part. The method is used for manufacturing simple small parts like automotive engine pistons.

2. Solid State Fabrication of Metal Matrix Composites:

Solid state fabrication of metal matrix composites is the process, in which MMC are formed as a result of bonding of matrix metal and

dispersed phase due to mutual diffusion occurring between them in solid state at elevated temperature and under pressure.

a. Diffusion Bonding

It is a common solid-state processing technique for joining similar or dissimilar metals. Inter diffusion of atoms between clean metallic surfaces, in contact at an elevated temperature, leads to bonding. It is also used for fabrication of MMC.

The principal advantages of this technique are the ability to process a wide variety of metal matrices and control of fiber orientation and volume fraction.

b. Powder Processing or Powder Metallurgy

These methods in conjunction with deformation processing are used to fabricate particulate or short fiber reinforced composites. This typically involves cold pressing and, or hot pressing to fabricate primarily particle- or whisker-reinforced MMCs. The matrix and the reinforcement powders are blended to produce a homogeneous distribution.

The blending stage is followed by cold pressing to produce what is called a green body, which is about 80% dense and can be easily handled. The cold pressed green body is canned in a sealed container and degassed to remove any absorbed moisture from the particle surfaces. The material is hot pressed, uniaxially or isostatically, to produce a fully dense composite and extruded.

3.1 PREPARATION OF COMPOSITE

For Al-Sic-Mg composite preparation pure Aluminium (99.99%), Silicon Carbide (99.95%), Magnesium (99.99%) are used. The reason for using high purity metals was to minimize the amount of impurities. In the present study the fabrication of aluminium metal matrix composite was done by using with the help of a pit furnace. pit furnace is a device used for high-temperature heating to melt the materials.

1. Initially Aluminium was taken in the form of rods having with diameter 6mm ,were broken into small pieces and poured into a graphite crucible and allowed them to melt ,the melting point of the aluminium is kept at 650⁰c , later it was super heated by 100⁰c. , so the temperature set up at 750⁰c.

2. After the material has been melted completely, silicon carbide having particle size of 80 μ m were

placed in another crucible and then preheated to a temperature of 1000⁰c in second furnace ,finally magnesium having particle size of 70 μ m was preheated to its melting temperature and later both the mixtures were added to the molten Aluminium.

3. The silicon carbide particles addition was made before the melt gets viscous.

4. The weight percentage of silicon carbide is 5%, 10%, 15% and magnesium were taken as 3 % of weight.

5. The time for each of the addition was about 4-6minutes. A pre-heated graphite stirrer was placed below the surface of melt and rotated with a speed of 500 rpm for about 10minutes with the help of a mechanical stirrer for the proper distribution of the particles into the matrix.

6. The fabrication of the finished composite slurry was followed by gravity casting.

7. The finished molten metal flows into the cast iron mould and gets solidified.



Figure 1: Stir Casting On Pit Furnace

3.2 Steps involved in metal matrix composite preparation

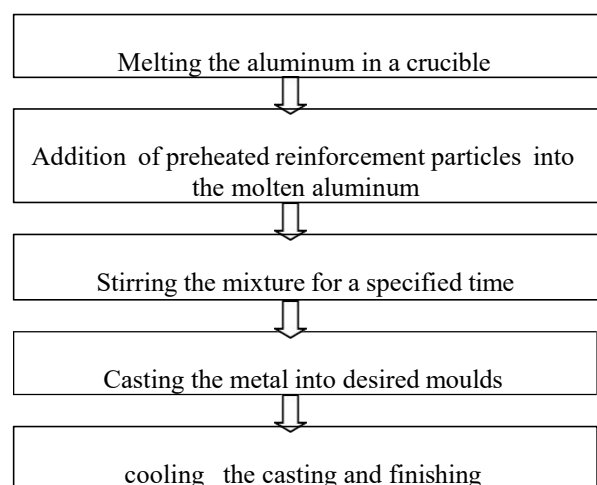
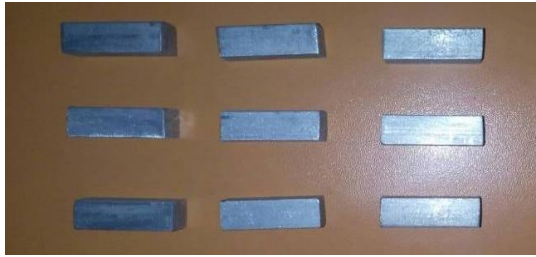


Table 2: Specimen composition

**Figure 2:** Test specimens

3.3 EXPERIMENTAL WORK:

The objective of the experiment was to develop a mathematical model to predict the influence of abrasive wear parameters on the weight loss of the experimental composites. The dry sliding wear experiments were conducted based on the plan generated by Taguchi technique. The influence of various parameters on the wear rate was analyzed using Signal-to-Noise (S/N) ratio and Analysis of Variance (ANOVA). The model was organized based on statistical approach by using Minitab package [15]. Regression equations were developed to correlate each response with the wear parameters. Validation tests were also conducted by using the parameters in between the low, medium and high levels to confirm the adequacy of the developed regression equation. Finally, multi-response optimization was done to optimize abrasive wear characteristics of the composites.

3.4 TAGUCHI TECHNIQUE

Taguchi technique is the statistical method developed by Genichi Taguchi to improve the quality of manufactured goods, and more recently also applied to engineering, biotechnology. Taguchi proposes an “off-line” strategy for quality improvement as an alternative to an attempt to inspect quality into a product on the production line. He observes that poor quality cannot be improved by the process of inspection, screening and salvaging. No amount of inspection can put quality back into the product. Taguchi recommends a three-stage process: system design, parameter design and tolerance design. An experimental design methodology that allows you to choose a product or process that performs more consistently in the operating environment. Taguchi designs recognize that not all factors that cause variability can be controlled in practice. These uncontrollable factors are called noise factors. Taguchi designs attempt to identify controllable factors (control factors) that minimize the effect of the noise factors. During experimentation, you manipulate noise factors to force variability to occur and then find optimal control factor settings that make the process or product robust, or resistant to variation from the

Specimen	Aluminum	Silicon Carbide	Magnesium
1	92%	5%	3%
2	87%	10	3%
3	82%	15%	3%

noise factors. Taguchi designs use orthogonal arrays, which estimate the effects of factors on the response mean and variation. Orthogonal arrays allow you to investigate each effect independently from the others and may reduce the time and cost associated with the experiment when fractionated designed are used. In classical designed experiments, the primary goal is to identify factors that affect the meant response and control them to

Desirable levels. Taguchi designs focus on reducing variability, as well as setting the mean to target.

Taguchi method is one of the important tools based on performing evaluation or experiments to test the sensitivity of a set of response variables (independent or variables) by considering experiments in “orthogonal array” with the aim to attain the optimum setting of the control parameters. Orthogonal arrays provide a best set of well balanced (minimum) experiments. Array indicates the number of row and columns it has, and also the number of level in each of the columns. The number of row of an orthogonal array represents the requisite number of experiments. There are five basic phase, applied in Taguchi experiments design technique.

1. Phase 1- Experiment planning,
2. Phase 2- Design Experiment,
3. Phase 3- Conducting Experiments,
4. Phase 4- Analyzing Results, and
5. Phase 5- Confirming Prediction Results

In the present work Taguchi’s parameter design approach is used to study the effect of operating parameters on the wear resisting behavior of Al-Sic-Mg composite.

3.5 DESIGN OF EXPERIMENT

Design of Experiments (DOE) was used for analyzing the impact of various input Parameters on a given output. DOE approach uses Taguchi technique to find the optimal combination of parameters for a given set of response. It



provides an optimized picture to improve the performance, efficiency and cost. This technique was used for evaluating systems based on orthogonal arrays. The technique was widely used because of its ability to analyze and interpret data based on the responses. A standard orthogonal array was chosen based on the number of parameters, and the effect of parameters on the target value. Based on this, experiments were conducted to study the impact of various factors on the response. The variations were identified by means of a signal to noise ratio. This S/N ratio gives the effect of noise on various characteristics.

Exp. No	Load (N)	Sliding Velocity(m/s)	%Reinforcement
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table.5: selected factor and level

Controllable factors	A:Load (N)	B:Sliding velocity (m/s)	C:%Reinforcement
1	10	1	5
2	20	2	10
3	30	3	15

Table 6:L9 orthogonal array

ANOVA was used to determine the percentage of influence of various parameters on the response. It was a quantitative measurement to determine the contribution of each parameter on the response. The experiment was then conducted by varying the applied load, sliding velocity and % reinforcement for three levels as shown in Table5.

SELECTION OF AN ORTHOGONAL ARRAY (OA)

The selection for the array depends on the number of factors involved, the number of levels and the desired experimental resolution or cost limitations. A total of 9 experiments were

performed based on the run order generated by the taguchi model. The response for the model is wear rate. The general layout of L₉ orthogonal array is shown in Table 6. experimental design with a L₉ orthogonal array as suggested by taguchi has been used to carry out experiments with three inputs parameters and for three levels of individual parameters. the inputs parameters used are load (N), sliding velocity(v) and %Reinforcement (%R).As per taguchi experimental design philosophy a set of three levels assigned to each process parameter has two degrees of freedom (Dof). This gives a total of six Dof for three process parameters selected in this work. the nearest three level orthogonal array available satisfying the criterion of selecting the OA is L₉ having 26 Dof. the details of experiments with parameters and levels are given in Table. The first column was taken as the load Applied, the second taken as the Sliding velocity and third as the % Reinforcement.

Exp.No	Load (N)	Sliding velocity (m/s)	%Reinforcement
1	10	1	5
2	10	2	10
3	10	3	15
4	20	1	10
5	20	2	15
6	20	3	5
7	30	1	15
8	30	2	5
9	30	3	10

Table 7:L9 orthogonal array for experiment

3.6 WEAR TEST

The dry sliding wear test was conducted on a pin on disc tester as shown in Figure. The Size of the specimen used for the wear test was of 30 mm in length and 12 mm in width. Before testing of the specimen they were machined and polished as per ASTM standards .The wear track, composite specimens were cleaned thoroughly with acetone before the test.

The experiment was conducted by holding the pin against a rotating disc (EN32 steel) and by adding weights on the left arm of the apparatus. During the test condition the track diameter 100mm and the sliding distance 1500m was as kept constant .

A Linear Variable Differential Transformer monitors the motion of the left arm there by helping to determine wear at any given point of time. Once the surface in contact wears out, the load pushes out the arm to remain in contact with the disc. This generates a signal by means of which it monitors the maximum wear on a continuous scale. The weight loss was found by measuring the specimen before and after the experiment on an electronic weighing pan with accuracy of 0.0001g.

The Pin on Disc wear measuring instrument has the following main components:

1. Rotating Disc
2. Pin Holder
3. Load Pan

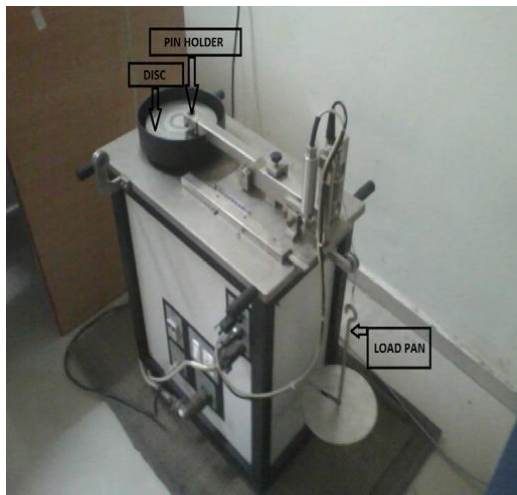


Figure3: Friction wear testing machine

4 CONDUCT THE EXPERIMENTS

The work piece material used for conducting experiments was Al-sic-mg composite is in the rectangular shape form having 12 mm width and 30mm length.

Wear rate values were collected with the help of pin on disc wear measuring instrument. S/N ratio was calculated with the help of following Eq. (1).

$$\text{Wear rate (K)} = \frac{\text{Volume loss}}{\text{Load} \times \text{sliding distance}} \quad (\text{mm}^3 / \text{Nm})$$

Where,

$$\text{Volume loss} = \text{Area} \times \text{weight loss}$$

$$\text{Weight loss} = \text{Initial weight of specimen (grams)} - \text{Final weight of specimen (grams)}$$

$$S/N = -10 \log_{10} \frac{1}{n} (y_{12}^2 + y_{22}^2 + \dots + y_{n2}^2) \quad (1)$$

Where,

$y_1, y_2, \dots, y_i$ are the response of sliding wear; and

n is the number of observations.

The wear behavior of the work pieces obtained by the testing from pin on disc wear measuring instrument. Three responses were taken from each experiment e.g. R1, R2 and R3 responses for each experiment. For the wear resisting feature, the signal-to-noise ratio should be small e.g. smaller the S/N ratio, better will be the wear resisting feature. The response tables for signal to noise ratios show the average of selected characteristics for each level of the factor. The result of L9 orthogonal array from Table 7 is shown in Table 9. ANOVA was performed to determine the percentage effect of each parameter

Exp.No	Initial weight of specimen (grams)	Final weight of specimen (grams)	Weight loss
1	6.77	6.7115	0.05841
2	6.85	6.772	0.07725
3	6.90	6.816	0.0833
4	6.85	6.636	0.213166
5	6.90	6.701	0.19833
6	6.77	6.619	0.1505
7	6.90	6.304	0.595125
8	6.77	6.456	0.313625
9	6.85	6.523	0.3375

Table 8: wear test

Exp. No	Load (N)	Sliding Velocity (m/s)	% Reinforcement	Wear Rate (mm ³ /Nm)	S/N Ratio (db)
1	10	1	5	0.001402	57.0618
2	10	2	10	0.001854	54.643
3	10	3	15	0.0020	53.5555
4	20	1	10	0.002558	51.8458
5	20	2	15	0.002380	52.4647
6	20	3	5	0.001806	54.8706
7	30	1	15	0.004761	46.4441
8	30	2	5	0.002509	52.0149
9	30	3	10	0.0027	51.0567

Table 9: Results of L9 orthogonal array.

5 RESULTS AND DISCUSSION:

The aim of this project is to achieve the minimum wear rate for Al-Sic-mg metal matrix composite using Taguchi method. The Investigation is carried out using three control parameters weight % of reinforcement, applied load, sliding Velocity. Wear depth is taken as system response parameter.

S/N RATIO

In Taguchi designs, signal-to-noise ratio is a measure of robustness used to identify control factors that reduce variability in a product or process by minimizing the effects of uncontrollable factors (noise factors). Control factors are those design and process parameters that can be controlled. Noise factors can be controlled during production or product use, but can be controlled during factor during experimentation, you manipulate noise factors to force variability to occur and from the results identify optimal control factor settings that make the process or product robust, or resistant to variation from the noise factors.

The signal to noise ratios is derived from the Taguchi loss function. Taguchi's Signal-to-Noise Ratios are in Log form. Taguchi experiments often use a 2-step optimization process. In step1 use the signal- to -noise ratio to identify those control factors that reduce variability. In step-2, identify control factors that move the mean to target value and have small or no effect on the signal- to – noise ratio. The signal- to- noise ratio measures how the response varies relative to the nominal or target value under different noise conditions. You can choose from different signal-to-noise ratios, depending on the goal of your experiment. for static designs ,Minitab offers four signal –to –noise ratios.

1. Larger is best
2. Nominal is best
3. Nominal is best (Default)
4. Smaller Is Better

Analysis Using S/N Ratio

Experiments were conducted accordance to the orthogonal array and the corresponding values of wear rate was shown in Table9 .The influence of input process parameters on wear rate were determined using S/N ratio. The parameter with the highest S/N ratio gives minimum wear rate . The response table for S/N ratio was shown in Table 10. The difference between the maximum and minimum values of S/N ratio gives delta. Ranking of parameter were done according to the delta value. The parameter with the highest value of delta has the greatest influence on wear rate. From Table9, it was found that load

has the significant impact on wear rate followed by sliding distance and sliding velocity

Level	Load	sliding velocity	%reinforcement
1	55.23	51.78	54.65
2	53.06	53.04	52.62
3	49.94	53.41	50.96
DELTA	5.28	1.62	3.68
RANK	1	3	2

Table 10: Response table for S/N ratio -Wear Rate

The main effects plot for mean was shown in Fig (4). From the plot (Fig 4), it was inferred that wear rate increases with increase in applied load and sliding velocity. Conversely, the wear rate decreases with increase in sliding velocity. As the %reinforcement increases, the material becomes harder and hence less material has been removed from the wear surface. As sliding velocity increases, the contact time between the disc and pin decreases, hence decreased wear rate. The main effects plot for S/N ratio was shown in Fig. (5). The input process parameter value which has the highest S/N ratio gives the optimum wear rate. From the Figure, it was found that L=10 N, V=3 m/s and % R=5 gives the optimum condition

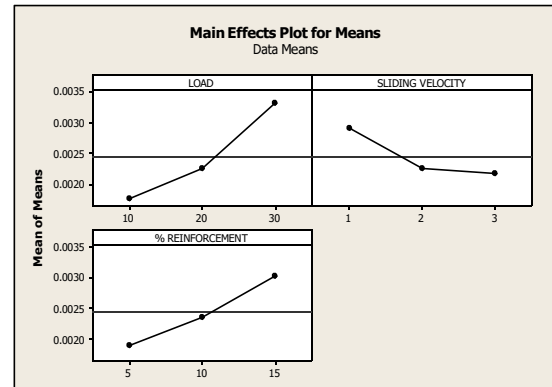


Figure 4: Main effects plot for Means-Wear rate

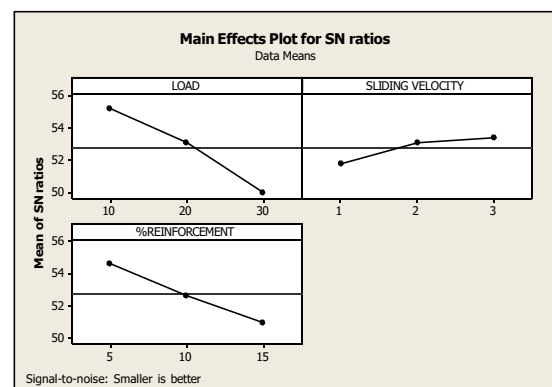


Figure 5: Main effect plot for s/n ratio -wear rate**6 ANALYSIS OF VARIANCE**

The name "analysis of variance" is based on the approach in which the procedure uses variances to determine whether the means are different. The procedure works by comparing the variance between group means versus the variance within groups as a way of determining whether the groups are all part of one larger population or separate populations with different characteristics

Analysis of variance (ANOVA) was used to determine the design parameters significantly influence the wear rate(response).the table11 shows the results of ANOVA for wear rate. ANOVA was used to analyses the effect of control parameters like applied load, sliding velocity and % reinforcement on wear rate on wear rate. The analysis was evaluated for a confidence level of 95%, that is for a significance level of, $\alpha=0.05$ as shown in Table11.

SOURCE	DF	SEQ SS	ADJ SS	ADJ MS	F	P	P%
L	1	0.0000 037	0.0000 004	0.0000 004	3.52	0.201	49.32
V	1	0.0000 007	0.0000 003	0.0000 003	2.21	0.273	9.32
%R	1	0.0000 021	0.0000 001	0.0000 001	1.01	0.421	27.0
L*V	1	0.0000 003	0.0000 005	0.0000 005	4.21	0.176	4.00
L* %R	1	0.0000 004	0.0000 004	0.0000 004	3.09	0.221	5.32
V* %R	1	0.0000 001	0.0000 001	0.0000 001	0.43	0.574	1.32
ERROR	2	0.0000 001	0.0000 003	0.0000 003			
TOTAL	8	0.0000 075					

Table 11: Analysis Of Variance

(NOTES: DF, DEGREES OF FREEDOM; SEQ SS, SEQUENTIAL SUM OF SQUARES; ADJ SS, ADJUSTED SUM OF SQUARES; ADJ MS, ADJUSTED MEAN SQUARES; P, PERCENTAGE OF CONTRIBUTION.)

The ANOVA was shown in Table 11. The last column in the table shows the percentage contribution of each input process parameter on the wear rate. It shows that load (49.32 %) has the greatest contribution on wear rate followed by reinforcement (27 %) and sliding velocity (9.32 %). Further, it was found that interaction of factors also

Exp .No	Load (N)	Sliding Velocity(m/s)	%Reinforcement
1	15	1.5	7
2	22	1.8	9
3	25	2.5	13

have significant effect on the wear rate.

REGRESSION ANALYSIS AND CONFIRMATION TEST

Regression analysis generates an equation to describe the statistical relationship between one or more predictors and the response variable and to predict new observations.

Regression generally uses the ordinary least squares method which derives the equation by minimizing the sum of the squared residuals.

Regression results indicate the direction, size, and statistical significance of the relationship between a predictor and response.

- Sign of each coefficient indicates the direction of the relationship.
- Coefficients represent the mean change in the response for one unit of change in the predictor while holding other predictors in the model constant.
- P-value for each coefficient tests the null hypothesis that the coefficient is equal to zero (no effect). Therefore, low p-values suggest the predictor is a meaningful addition to your model.
- The equation predicts new observations given specified predictor values.

A regression model was developed based on the experimental results and this establishes a correlation between the significant parameters. The regression equation developed for wear rate was:

$$\text{Wear rate} = 0.000386 + 0.00008 L - 0.000338v + 0.000014\%R$$

From the above relation, it was observed that the coefficient associated with load and %reinforcement was positive. This clearly reveals that as load and %reinforcement increases, wear rate of the hybrid composite also increases. The negative coefficient of sliding speed reveals that increase in speed decreases the wear rate. To

validate the conclusions obtained from the analysis, confirmation experiment was conducted and comparison was made between experimental values and computed values developed from regression model. Table 12 and Table 13 show the confirmation experiment and its results.

Based on the confirmation experiment, it was observed that the error associated with experimental values and computed values was minimal and hence this regression model obtained from L_9 array can be used effectively to predict the wear rate of the composites with good accuracy

Table 12: Confirmation Experiment

Exp. No	Exp.Wear Rate (mm ³ /Nm)	Reg.Model Wear Rate (mm ³ /Nm)	%Error
1	0.001991	0.001913	4.01
2	0.002452	0.002602	5.75
3	0.003153	0.003101	1.92

Table 13: Results of Confirmation Experiment.

7 CONCLUSION:

Following are the conclusions drawn from the study on dry sliding wear test using Taguchi's technique:

- 1) Taguchi parameter design can provide a systematic procedure that can effectively and efficiently identify the optimum wear rate of the composite. This paper demonstrates How to use Taguchi parameter design for optimizing wear rate with Minimum cost.
- 2) Incorporation of silicon carbide as primary reinforcement with increasing composition increases the wear resistance of composite.
- 3) Optimal conditions for minimum wear rate were obtained using S/N ratio analysis and ANOVA .The analysis shows that wear rate increases with increase in applied load and % reinforcement and decrease in sliding velocity. From the Main effects plot for means and S/N ratio, it was found that $L=10$ N, $V=3$ m/s and $\%R=5$ gives minimum wear rate. The ANOVA shows the percentage contribution of each control parameter on wear rate. From the S/N ratio and ANOVA analysis, it was found that applied load has the highest significance on wear rate followed by

%reinforcement and sliding velocity. The regression model generated was effectively used to predict the wear rate. Thus the optimized condition can be well utilized to improve the wear resistance of the components and these components can be used in automotive and aerospace industry for wear resistance applications..

- 4) Confirmation experiment was carried out and made a comparison between experimental values and computed values showing a change associated with dry sliding wear of composites . Thus, Design of experiments by Taguchi method was successfully used to predict the tribological behavior of composites.

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