EXPERIMENTAL INVESTIGATION & IMPROVING MECHANICAL PROPERTIES OF AL 6061 METAL MATRIX COMPOSITE WITH CERAMICS AS REINFORCEMENT

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Abstract :

Aluminum 6061-based metal-matrix composites (MMCs) have received considerable attention for automobile and industrial sector applications because of the low density and high stiffness. Improvement in fuel consumption rate requires a reduction in vehicle weight. Research and development for materials substitution in the braking system, from the conventional cast into aluminum, has been undertaken. A composite material is a material system composed of a suitably arranged mixture or combination of two or more Nano, micro, or macro constituents with an interface separating them that differ in form and chemical composition and are essentially insoluble in each other. They have characteristics like high strength to weight ratio, hardness and wear resistance.

In the present investigation, an AI6061 alloy is using as the matrix and ceramic as the reinforcement. The composite is fabricated using stir casting technique. Aluminum composites are a new generation of metal matrix composites that have potential of satisfying the recent demands of advanced engineering applications. These demands are met due to improving mechanical properties, amenability to conventional processing technique and possibility of reducing production cost of aluminum composites.

The casting components are machining to specimen dimensions and are subjecting to various material testing and finding the mechanical properties. In different weight fraction of ceramic reinforced materials.

By conducting various materials testing like scanning Electron Microscopy (SEM). Pin-on-disc test, Universal Testing Machine (UTM), X-ray diffraction. The results will show as

The best results have been obtained at Track Dia =55, Load=10N, Speed=600rpm, and reinforcement=7% by wt. proportion of Sic as a reinforcement.

The formation of cluster is observed in when 3% siC+graptie` used as reinforcement in the Al6061 matrix which are observed in SEM photograph.

The hardness value is higher, due to 7% of SiC+Graphite as reinforcement, with homogenous distribution of particles as shown in EDS report.

The surface roughness is more for the specimen having 3% reinforcement.

From the UTM test, If reveals that 7 %(sic+graphite)would have good strength of tensile.

***Keywords*- MMC, Stir casting, SEM Analysis, Brake Rotor, Pin-on-disc test.**

I. INTRODUCTION:

The fabricated stir casting setup was used for making metal matrix composites. The AMMCs are fabricated with three different reinforcement particles namely silicon carbide, graphite. The fabricated composites were subjected to heat treatment for enriching their properties. The wear behaviour of heat treated composites was tested on Pin-on-disc wear test rig. The wear experiments were conducted as per the design of experiments. The wear rate and coefficient of friction was calculated and their results are presented.

A brief description of the raw materials used in the synthesis of composite is presented as follows:

MATRIX MATERIAL:

A commercial casting grade aluminum alloy (6061) containing mainly 6.72%Si, 0.2%Cu was employed as the matrix material. This alloy has been selected because of its good fluidity as well as due to the presence of silicon. Since the silicon content of 6061 alloy is sufficiently high, it can be maintained in the liquid state at typical casting temperature for certain periods 40 of time without giving rise to the extensive formation of Al4C3. A low silicon content coupled with a high SiC level accelerates the formation of Al4C3 which is detrimental the fluidity and hence cast ability of the composite alloy. Increasing the silicon level from 6 to 11% improves the cast ability through a significant decrease in Al4C3 content (Samuel et al 1995). The presence of Mg in the alloy is thought to improve the wetting of the reinforcement by the liquid alloy.

Table:1 Composition of aluminum alloy (6061)

Elements	Cu	Si	Mg	Mn	Fe	Ni	Zn	Ti	Pb	Sn	Al
Wt.%	0.2	6.72	0.5	0.3	0.4	0.1	0.1	0.2	0.1	0.05	Balance

PHYSICAL AND CHEMICAL PROPERTIES OF ALUMINUM:

Aluminum is a soft, silvery light metal. It is very reactive so that in the atmosphere a thin but equally protective oxide layer forms rapidly. For this reason it is very resistant to corrosion. By a special treatment, anodizing, i.e. an electrolytic oxidation process, the aluminum surface protected by the oxide layer can even be strengthened and made more resistant to corrosion.

Aluminum reacts strongly with hydrochloric acid and caustic soda. The reaction with sulphuric acid is weaker, while it remains passive in contact with cold nitric acid. Aluminum possesses good thermal and electrical conductivity, in each case about two-thirds of the values for pure copper. Due to its electronic configuration the element has three valencey electrons; its oxidation number is therefore +3.

- Melting point: 660 °C (for AL 99,99 acc. to composition / alloying higher resp. lower)
- Boiling point: 2500 °C (acc. to composition / alloying higher resp. lower)
- Density: 2,70 g/cm^3
- Relative atomic mass 26,98
- Oxidation number: 3
- Atomic radius: 143,1 pm
- Ionic radius: 57 pm (+3)
- Electrical conductivity: 36 $m/Ohm \cdot mm^2$

REINFORCEMENT MATERIALS:

Silicon carbide, graphite particles were used as reinforcement material. The reinforcement particles size used for the experiment was 3%, 5%, 7% the importance and scope of the reinforcements is presented as follows:

SILICON CARBIDE AS REINFORCEMENT:

Silicon Carbide (SiC) is the only chemical compound of carbon and silicon. It was originally produced by a high temperature electro-chemical reaction of sand and carbon. Silicon carbide is an excellent abrasive and has been produced and made into grinding wheels and other abrasive products for over one hundred years. Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties. It is used in abrasives, refractory, ceramics, and numerous high-performance applications. This produces a very hard and strong material. The high thermal 41 conductivity coupled with low thermal expansion and high strength gives this material exceptional thermal shock resistant qualities. Silicon carbide ceramics with little or no grain boundary impurities maintain their strength to very high temperatures, approaching 1600°C with no strength loss.

Table.2 (A) Chemical composition of silicon carbide particles

Component	SiC	Other Traces
Wt.%	98.50%	0.50%

Table. 2(B) Physical properties of silicon carbide and Graphite particles

PROPERTIES	SILICON CARBIDE	Graphite
Melting point(°C)	2200-2700	3600
Limit of application(°C)	1400-1700	1400
Hardness	9	40
Density(g/cc)	3.2	2.26
Linear coeff. Of Expansion($10\text{-}6^oK$)	4.5	0.3
Fracture Toughness(Mpa-$m^{1/2}$)	4.6	0.2
Crystal structures	Hexagonal	Hexagonal

II. LITERATURE SURVEY:

Maleque M.A in 2010,is about to develop the material selection method and select the optimum material for the application and design of automotive brake disc on these substitution of these cast iron by another light weight material. He found that widely used brake rotor material is cast iron, which consumes much fuel due to its high specific gravity two materials are introduced for material selection such as, cost per unit property and digital logic method. He performed tests on different materials such as cast iron, AL alloy, titanium alloy ceramics and composites. The overall analyses led to AMMC's as the most appropriate material for brake disc system.

Neelimadevi in 2011, Manufacture of silicon carbide (5%, 10%, 15%, and 20%) with aluminium. She noticed that conventional material will fail without indication cracks intiation will take place in short span to overcome this problem conventional material are replaced by aluminium alloy materials. She conducted teile strength experiment and various mass fractions of silicon carbide af found that maximum tensile strength obtained at 15% silicon carbide. She also studied on mechanical and corrosion behaviour of aluminium, silicon carbide alloys.

Kalaiselvan K in 2013, who found that manufacture of the AA6061-B4C by stir casting technique in different contents (4%, 6%, 8%, 10% and 12%), with organic salt K2TiF6 and its friction stir welding. By using of Central Composite Design, optimizing the process parameters for maximizing UTS, Micro hardness& improving the microstructure & wear rate. Optimum parameters: TRS – 968 rpm, WS- 1.29 mm/sec, AF-9.94KN for Al-MMC containing 12% B4C. HCHCr tool with square profile.

III. EXPERIMENTAL DETAILS:

STIR CASTING PROCESS:

A weighted quantity of the Al alloy was melted in clay bonded graphite of 0.5 Kg capacity using a small electrical furnace and the melt was superheated by about 400oC to get the required fluidity. This molten metal was stirred using a mild steel impeller at a speed of 500 RPM to create the vortex. The impeller blades were so designed such that it creates a vortex to achieve the particle mixing. The impeller blades were coated with a zirconium based coating to minimize blade dissolution in molten metal. The stir casting setup and stirring process.

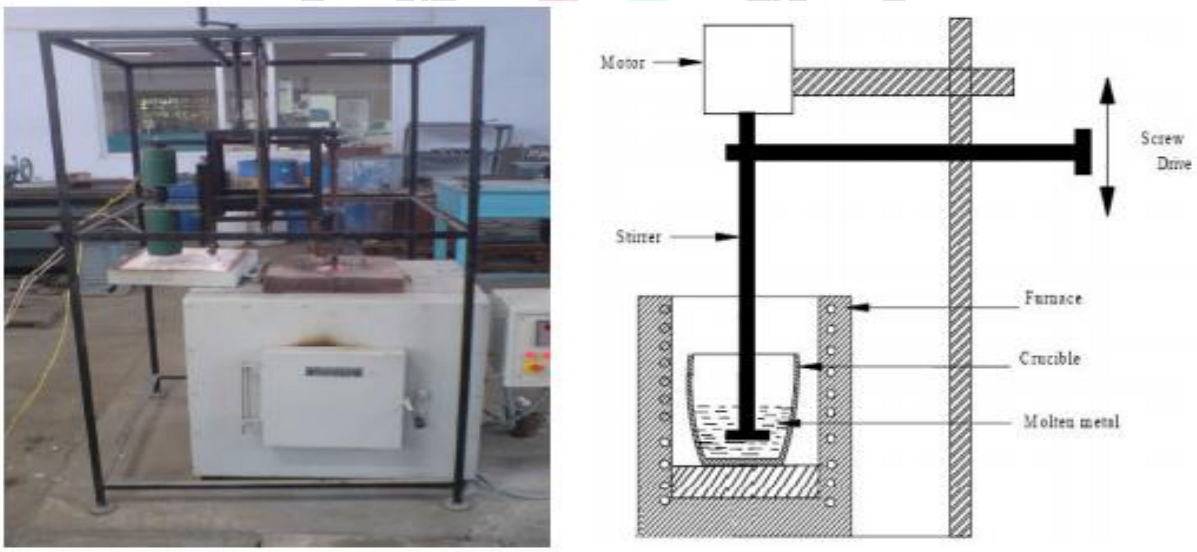


Figure: Mechanical Stir Casting Setup and Stirring Process

During the process, the molten metal was well agitated by a mechanical stirrer to create turbulent motion. The depth of the immersed impeller was approximately 2/3 of the height of the molten metal from the bottom of the crucible and the speed of the stirrer was maintained at 500 RPM. The reinforcement particles were artificially oxidized in air at 800oC for 120 minute to form an oxide layer on them and thereby improve their wet ability with molten aluminium. This treatment helps the incorporation of the particles while reducing interfacial reaction and also avoids the particle rejection from the melt. Preheated reinforcement particles were then added into molten metal by using metal funnel and spoon. The stirring action was continued during the addition of reinforcement particles. The stirring action continued around 5 minutes. The composites have been made for 3%, 5%, 7 % percent volume fraction of reinforcements. The average particle size is taken as 63, 88, 105, 125 and 149 µm. The composite slurry was then poured into the mild steel die, which was preheated to about 400oC. The MMCs were fabricated for the different combination of volume fraction and particle size on three reinforcements namely silicon carbide, zircon and garnet particles.

The combination for MMC fabrication was selected based on wear testing samples requirements, which is selected based on design experiments. The combination of volume fraction and particle size is shown in Table 3.8. To study the SiC particle distribution, microstructure analysis, hardness distribution and density distribution were carried out. Characterization is important for ensuring quality of composite after its fabrication through conventional stir casting process. The uniform distribution of particles on soft matrix is the most important problem in stir casted composites. By evaluating micro hardness and density variation along the length of casted composites and microstructure analysis helps to verify the reinforcement distribution on composites.

Table :Combination of volume fraction and particle size for MMC fabrication

REINFORCEMENT	VOLUME FRACTION IN %	PARTICLE SIZE IN MICRON
SILICON CARBIDE +GRAPHITE	2+1	30 to 40
SILICON CARBIDE +GRAPHITE	4+1	30 to 40
SILICON CARBIDE + GRAPHITE	6+1	30 to 40

PROCESS PARAMETERS FOR WEAR BEHAVIOUR OF AMMCS:

In order to identify the process parameters that may affect the wear behaviour of AMMCs, an Ishikawa diagram (cause and effect diagram) was constructed as shown in Figure 3.3. The process parameters can be listed in four categories as follows:

(i) Extrinsic Factors – Applied load, sliding speed, distance and sliding material (steel or abrasive paper glued disc)

(ii) Intrinsic Factors –Particle type, volume fraction, size and shape

(iii) Manufacturing Factors – Processing route and heat treatment

(iv) Environment Factors – Dry or wet.

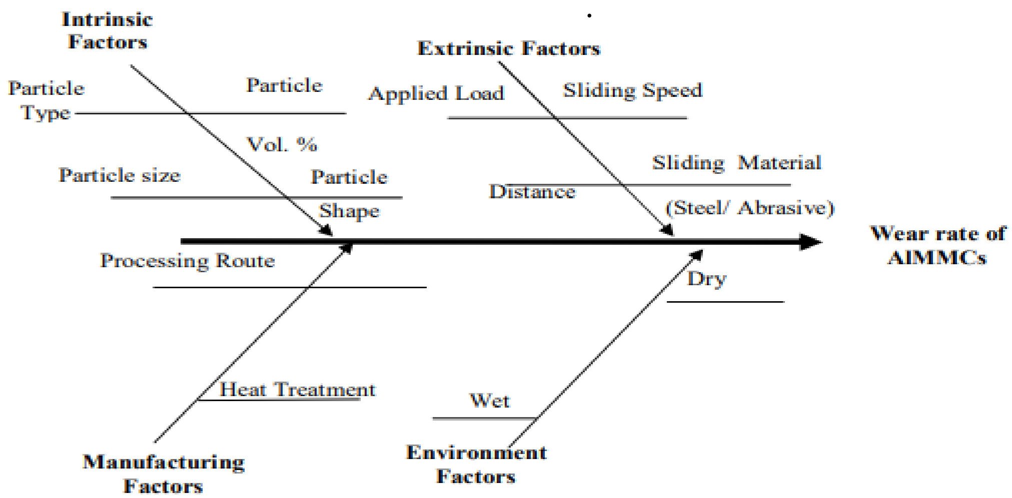


Fig: Cause and Effect Diagram

Table: Process parameters, units, symbols and different levels for sliding wear

S.No	Load	Speed	Reinforcement
1	10	500	3
2	20	500	5
3	30	500	7
4	10	550	3
5	20	550	5
6	30	550	7
7	10	600	3
8	20	600	5
9	30	600	7

Fig: Specimens of Three Different Proportions

SCANNING ELECTRON MICROSCOPY (SEM) ANALYSIS

Microstructure Analysis:

Metallography, also known as materialography is the scientific discipline of examining and determining the constitution and spatial relationships between and the structure of the constituents in metals, alloys and materials. Optical characterization of the microstructures of metals and alloys basically involves identification and measurement of phases, precipitates, and constituents, and determination of the size and shape of the grains, characteristics of grain boundaries and other defects that can be observed. To study the microstructure of a given material, the optical microscope is the most important tool, which uses optical light for illumination even though the evolution of sophisticated electron metallographic instruments is possible. Both Scanning electron microscopy and transmission electron microscopy should be used in conjunction with optical microscope, rather than as a substitute.

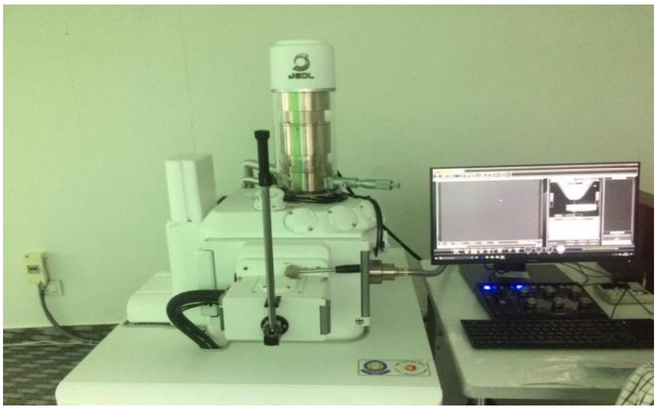


Fig: Scanning Electron Microscopy

Macro-examination of aluminum alloys is accomplished using techniques that are similar to those used for other metals. Macro-examination of cast specimen is used to reveal the degree of refinement of the grain structure; grain size, grain boundary, evidence of abnormally coarse constituents, oxide inclusions, porosity within the composite and in many cases the type of failure that normally occurs due to blow holes etc. From the sectioned, machined and macro-etched specimens, grain size, grain flow and fabricating/casting defects can be observed.

Fig :SEM Controller

The Scanning Electron Microscope (SEM) is one of the most versatile instruments for investigating the microstructure of materials. Under electron bombardment, a variety of different signals is generated (including secondary electrons, backscattered electrons, characteristic x-rays, and long-wave radiation in the ultraviolet and visible region of the spectrum) that can be used for materials characterization. Using secondary electrons, scanning electron microscopy (SEM) expands the resolution range to a few nanometers (under favorable conditions), thus bridging the gap between optical (light) microscopy and transmission electron microscopy.

WEAR TEST:

From literature, it is observed that the wear and friction behaviour of MMCs having aluminum as matrix strongly depends on the particles used for reinforcement, its size and volume fraction of particles. The coefficients of friction of the metal matrix composites are high if the rate of reinforcement particle in MMC is low and besides this, the wear resistance increases with increasing volume fraction of reinforcing particulates. If the particulates used for reinforcement bonded well to the matrix, the wear resistance of the composite increases continuously with increase in the volume fraction of ceramics particles and the critical volume fraction mostly depends on the load applied during the wear test.

Fig-Pin on disc machine

A tribometer is an instrument that measures the tribological quantities such as coefficient of friction, friction force, and wears volume, between two surfaces in contact. The simplest of the tribometer is pin-on-disc tribometer, consisting of a stationary pin that is spherical in shape, which will be in contact with the rotating disc for a given load. Coefficient of friction is determined by the ratio of the frictional force to the load applied on the pin.

Table:- 3.4.2 Specification of "pin-on-disc machine" TR-20

Specifications of pin on disc Tribometer(TR-20)	MFG: Ducom Ltd, Bangalore.
Pin Size	3 to 12 mm diagonal
Disc Size	100 mm dia. X 8 mm thick
Wear Track Diameter (Mean)	10 mm to 100 mm
Sliding Speed Range	0.26 m/sec. to 10 m/sec.
Disc Rotation Speed	100-2000 RPM
Normal Load	200 N Maximum
Friction Force	0-200 N, digital readout, recorder output
Wear Measurement Range	4 mm, digital readout, and recorder output
Power	230 V, 15A, 1 Phase, 50 Hz

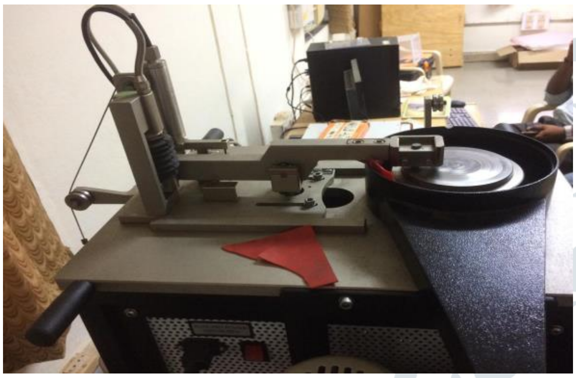


Fig-Specimen Set Up

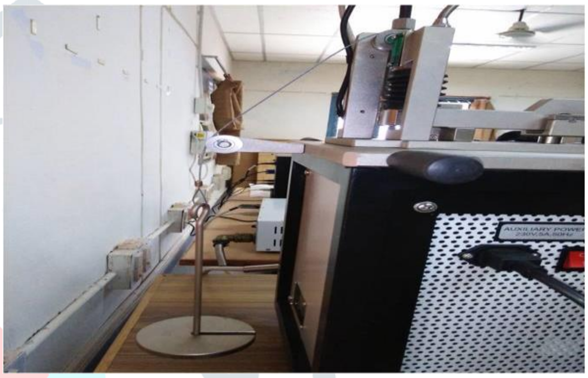


Fig- Load Carrying Unit

EXPERIMENTAL SETUP FOR PIN-ON-DISC:

Experiments have been conducted in the Pin-on-disc wear test rig with data acquisition system, which was used to evaluate the wear behaviour of the composite, against hardened ground EN32 steel disc having hardness 62 HRC and SiC abrasive paper glued disc. It is versatile equipment designed to study wear under sliding condition only. Sliding generally occurs between a stationary composite pin and a rotating disc. A stationary pin mounted on a pin holder is brought into contact against a rotating disc at a specified speed as the pin is sliding, resulting frictional force acting between the pin and disc are measured by arresting the deflecting of pin holder against a load cell. Both normal load and speed can be set as desired. The pin holder having provision for specimen pin size is 8 to 12 mm diameter and 30 to 50 mm length. The disc rotates with the help of a D.C. motor having speed range of 0-2000 rpm with wear track diameter up to 100 mm, which could yield sliding speed 0 to 10 m/sec. Load is to be applied on pin by dead weight through pulley string arrangement. The system has a maximum loading capacity of 200 N and frictional force can be measured up to 200 N. Figure 3.4 shows the schematic representation of pin-on-disc wear test rig and the experimental setup is shown in Figure 3.5.

Before conducting the test, the pin specimen samples of size 10 mm diameter and 30 mm length are prepared (ASTM G99) from the fabricated composites in CNC lathe and the pin surfaces were polished with emery papers, so that the contact with disc will be smooth. All the wear tests were carried out under un lubricated condition in a normal laboratory atmosphere at 60-70% relative humidity and a temperature of 28-33°C.

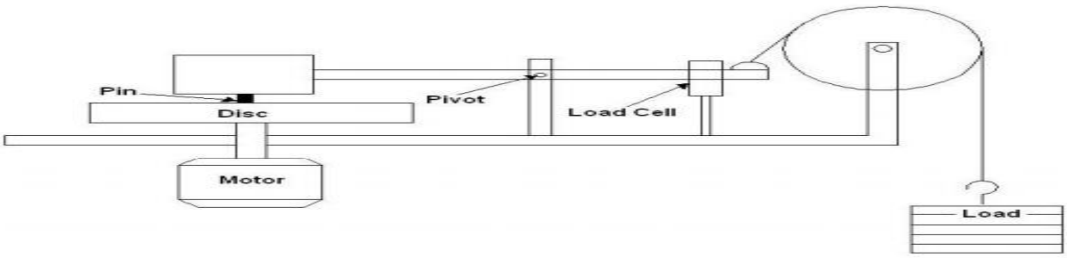


Fig : Schematic representation of Pin-on-Disc wear test rig

Fig :Pictorial view of Pin-on-Disc wear test rig

The fresh track diameter was selected for each experiment and duration of sliding was calculated based on the sliding distance. For abrasive sliding wear, the sliding distance kept constant and the mesh size of abrasive paper was changed depending on the experimental conditions. The sliding speed and duration of sliding was varied and controlled by the controller unit. Frictional force arises at the contact due to applied load through pin was read out from the controller. For a particular type of composite 32 sets of test pieces were tested. Each test was carried out for three times, the average was taken for analysis. The weight loss in the specimen after each test was estimated by measuring the weight of the specimen before and after each test using an electronic weighing machine having an accuracy up to 0.0001g. The pin specimens are cleaned with acetone solution prior and after each test.

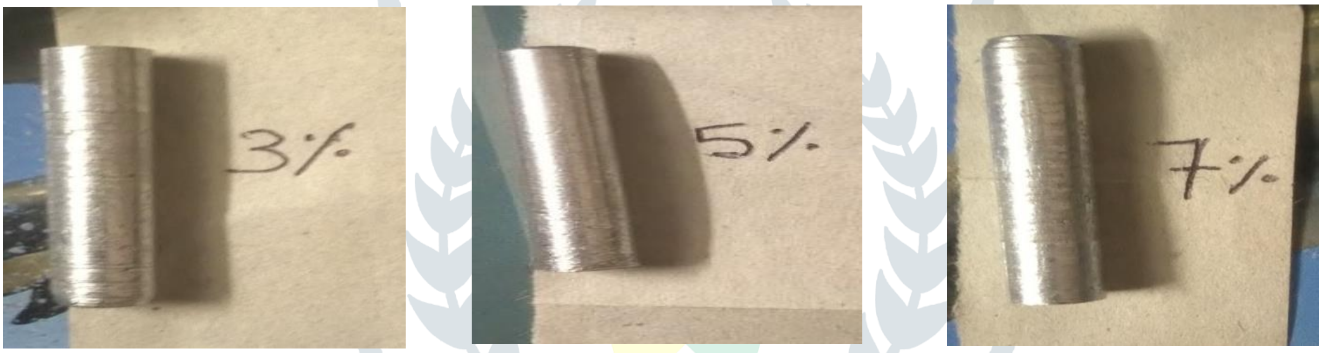


Fig: Specimens Of Three Different Proportions

TAGUCHI METHOD:

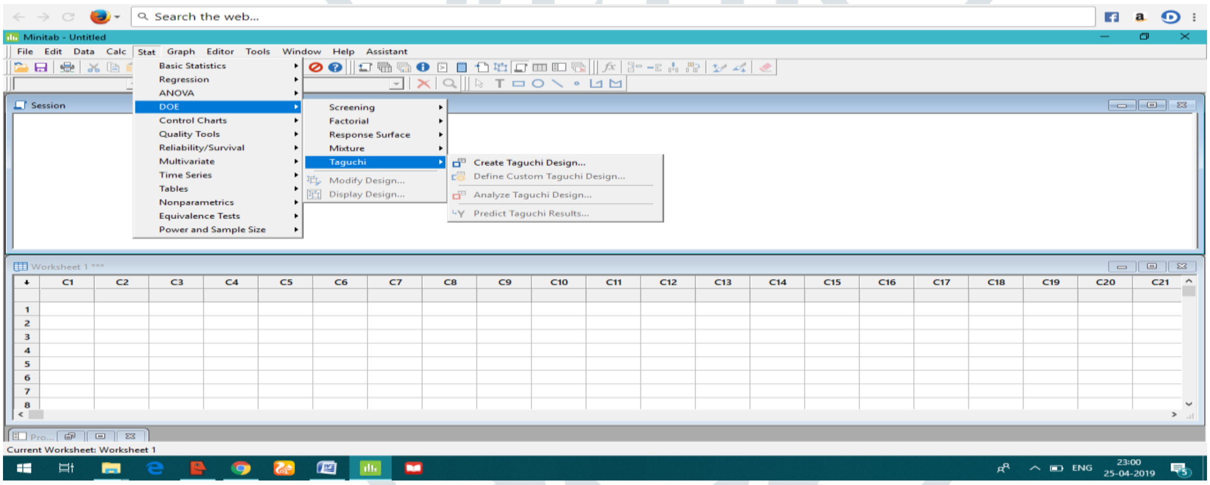
Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on “ORTHOGONAL ARRAY” experiments which gives much reduced “variance” for the experiment with “optimum settings “of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

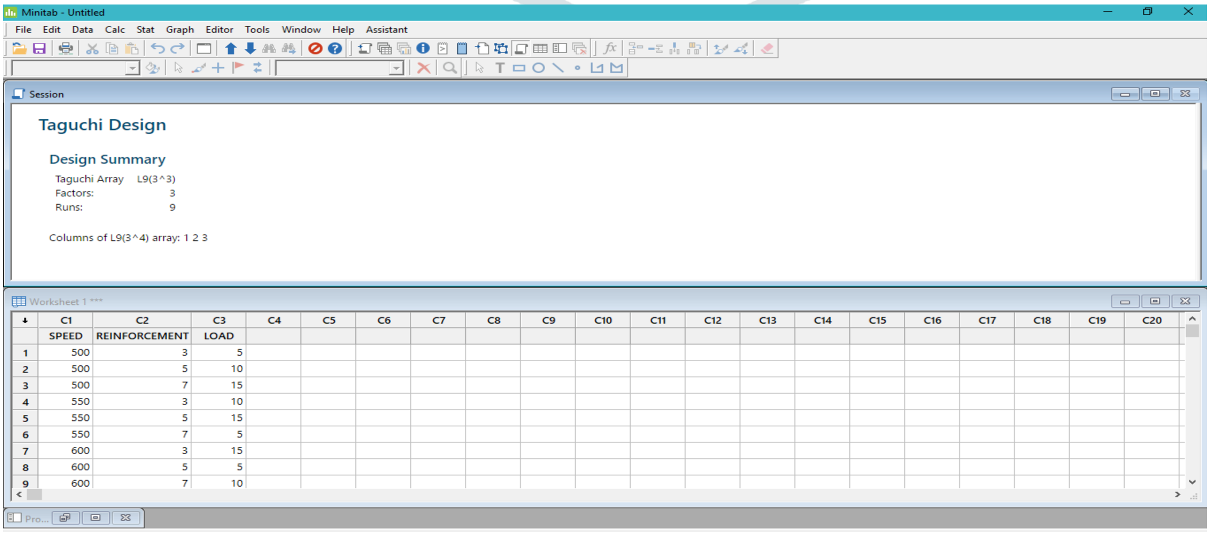
Table:Standard Orthogonal Arrays

Orthogonal Array	Number of Rows	Maximum Number of Factors	Maximum Number of Columns at These Levels			
			2	3	4	5
L_4	4	3	3	-	-	-
L_8	8	7	7	-	-	-
L_9	9	4	-	4	-	-
L_{12}	12	11	11	-	-	-
L_{16}	16	15	15	-	-	-
L'_{16}	16	5	-	-	5	-
L_{18}	18	8	1	7	-	-
L_{25}	25	6	-	-	-	6
L_{27}	27	13	1	13	-	-
L_{32}	32	31	31	-	-	-
L'_{32}	32	10	1	-	9	-
L_{36}	36	23	11	12	-	-
L'_{36}	36	16	3	13	-	-
L_{50}	50	12	1	-	-	11
L_{54}	54	26	1	25	-	-
L_{64}	64	63	63	-	-	-
L'_{64}	64	21	-	-	21	-
L_{81}	81	40	-	40	-	-

Compare the values by using MINI TAB -18

STEPS FOR TAGUCHI DESIGN





UNIVERSAL TENSILE MACHINE

A universal testing machine is used to test the tensile stress and compressive strength of materials. It is named after the fact that it can perform many standard tensile and compression tests on materials, components, and structures.

Tensile Test: Clamp a single piece of anything on each of its ends and pull it apart until it breaks. This measures how strong it is (tensile strength) how stretchy it is (elongation), and how stiff it is (tensile modulus).

Fig: Universal Tensile Machine

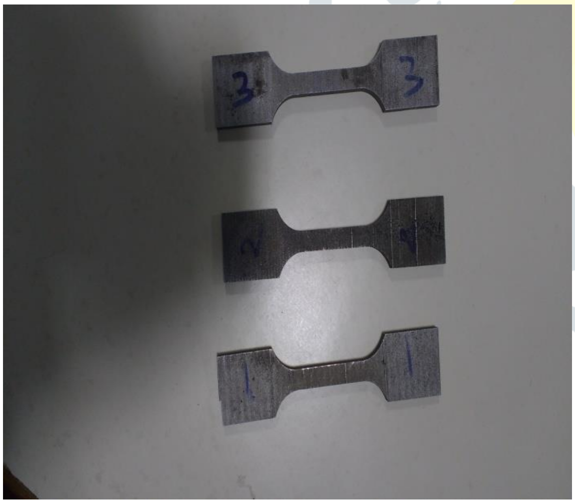


Fig: Specimen before Testing

Fig: Specimen after Testing

IV. RESULTS & DISCUSSIONS:

After casting the specimens with various volume fractions of Sic, Graphite particulate reinforcement, the distribution of SiC, Graphite particulates and graphite particles in the aluminum matrix are studied using optical microscope and scanning electron microscope (SEM). The etchant used is HF solution and a magnification of 250X is used for the optical image. For a reinforcement of 3%, 5%, 7%Graphite given in., the matrix shows the distribution of the particulates in aluminium metal matrix, having fine eutectic particles of Al-Graphite particles. The composite particles are agglomerated at certain locations of the metal matrix. The graphite particles are more grouped together.

The microstructure of the aluminium matrix having a reinforcement of 3%,5%,7% SiC, Graphite shown in Fig, has fine eutectic particles of Al- SiC, Graphite particles. The composite particles are agglomerated at certain locations of the metal matrix. The graphite particles and the boron carbides are grouped together. More particles of Titanium Boride are observed and the distribution is even.

The variation of wear rate for various composition of MMC. From the graph, it is observed that when the reinforcement of SiC, Graphite particulates is increased from 3% to 5% the wear rate is reduced by 39.98% and with further increase in SiC, Graphite reinforcement from 5% to 7%, the wear rate is further reduced by 33.40% due to the change of material behaviour from soft to hard.

V. CONCLUSIONS:

The following conclusion may be drawn from the present work:

- As per the taguchi L9 experimentation, for different % by wt proportion of reinforcement of SiC & Graphite particle with Al-6061 as a matrix, SiC+graphite (7%) by wt would have maximum frictional force & Co-efficient of friction & minimum wear rate.
- The best results have been obtained at Track Dia=55, Load=10N, Speed=600rpm, and reinforcement=7% by wt. proportion of SiC as a reinforcement.
- The formation of cluster is observed in when 3% siC+graptie` used as reinforcement in the Al6061 matrix which are observed in SEM photograph,.
- The hardness value is higher, due to 7% of SiC+Graphite as a reinforcement, with homogenous distribution of particles as shown in EDS report.
- The surface roughness is more for the specimen having 3% reinforcement.
- From the UTM test, If reveals that 7 %(sic+graphite)would have good strength of tensile.

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