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Non Conventional Machining of Al/Al2O3 Metal Matrix Composite

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Abstract: Metal Matrix Composite (MMC) Reinforced with ceramic particles offer significant performance over pure alloys. Metal Matrix Composite can be divided into one of the three categories, namely particle reinforced MMCs, short fiber reinforced MMCs and continuous fiber reinforced MMCs. In recent years, aluminum alloy based metal matrix composites (MMC) are gaining importance in several aerospace and automobile applications. Aluminum has been used as matrix material owing to its excellent mechanical properties coupled with good formability. Addition of Al2O3 as reinforcement in aluminum system improves mechanical properties of the composite. In the present investigation, Al7075- Al2O3 composite was prepared by stir casting. Most of their current applications are in transportation, defence, aerospace and space industries. A major goal in manufacturing of MMC is to achieve highest strength to weight and stiffness to weight ratio in a low cost light material, but in some application metal matrix composite are not best suited because of low ductility and toughness.

The terms MMmC (Metal Matrix micro Composite) in which metal or alloys are combined with metallic and non-metallic micro scale reinforcement. The main advantage of MMmC include excellent mechanical properties, good wear resistance, low creep rate and high toughness. Major concentration of this work n micro-metric particle dispersion for producing strengthened composites.

In this project with the help of different percentage of reinforcement added on the matrix. We performed machining through EDM.

Keywords: MMC, MMmC, EDM, Wear resistance, Creep etc.

I. INTRODUCTION

Metal Matrix Composite (MMC) Reinforced with ceramic particles offer significant performance over pure alloys. Metal Matrix Composites can be divided into one of three main categories, namely particle reinforced MMCs, short fiber reinforced MMCs and continuous fiber reinforced MMCs. Most of their current applications are in transportation,

Defence, aerospace and sport industries. A major goal in manufacturing of MMC is to achieve highest strength to weight and stiffness to weight ratio in a low cost light material, but in some application metal matrix composite are not best suited because of low ductility and toughness. The terms MMmC (Metal matrix micro composite) in which metal or alloys are combined with metallic and nonmetallic micro scale reinforcement. The main advantages of MMC include excellent mechanical properties, good wear resistance, and low Creep rate and high toughness. Particulate Metal Matrix Composites contain reinforcement particles ranging from 10nm to 500µm. MMCs with uniform dispersion of particles in the range of 10 nm – 1µm are termed as Metal Matrix Micro-composites (MMMCs). With t he size of reinforcement scaling down to micro scale; MMMCs exhibit more outstanding properties over MMCs and are assumed to overcome the shortcoming of MMCs such as poor ductility, low fracture toughness and machinability Y.Yang [1] A much research has been done in metal matrix composite with ceramic particles so major concentration of this work on micro-metric particle dispersion for producing strengthened composites. The Toyota diesel piston was first commercial application of Al alloy- Al2O3 composites announced in 1983. Mortensen [2] Fabricated composite used in sport industries such as Racket shaft, automotive parts such as bicycle component, Aerospace, and defence for making M16 rifles. A much studies have done on the mechanical characterization of Al matrix with micro ceramic particles such as Sic, Al2O3, B4C, and TiC which improves the mechanical properties of Aluminum. The major goal in manufacturing of MMC is to achieve highest strength to weight and stiffness to weight ratio in a low cost light material, but in some application metal matrix composite are not best suited because of low ductility,

Toughness and machine ability. So this problem needs to be addressed. The terms MMmC (Metal matrix micro composite) in which metal or alloys are combined with metallic and non

Metallic micro scale reinforcement. The main advantages of MMmC include excellent mechanical properties, good wear resistance, low creep rate and high toughness. MMmC exhibit more outstanding performance over MMC and are assumed to overcome the short coming of MMC such as poor ductility, low fracture toughness and machinbility. The primary objective is to develop a new composite material with micro Al2O3 as reinforcement and combine the mechanical properties of Al such as ductility, toughness, machinability with high temperature stability. The combination may eventually lead to high ductility, strength, toughness, and temperature stability application and can replace a no. of component at particular application such as bicycle frames, badminton shaft, airframes, and in some defence applications, While most of the work done on Al based MMC. A very few work has been done on properties of Al-7075 reinforced with micro alumina particles with stir casting which exhibits good mechanical properties.

II. LITERATURE SURVEY

Physical and mechanical properties of al based metal matrix composite.

A. Physical Properties

Al based composite containing Al2O3, SiC are denser than the base alloy because of the higher densities of these particles, density of composite depends upon the weight percentage reinforcement. Rohatgi [3].

B. Mechanical Properties

The mechanical properties of a Metal matrix composite depend on many factors such type of reinforcement, shape, size, quantity of reinforcement etc. The actual knowledge of the mechanical behavior is thus necessary as they are employed in different fields. Composite containing ceramic particles such as Al2O3, SiC, glass, B4C, Zircon are harder than the base alloy. Tensile properties of the composite are generally higher than the base alloy and increasing with increase in weight percentage of reinforcement. Mechanical properties of composite may be lower or higher than that of base alloy depend upon the nature of particle matrix interface. Modi O.P [4].

C. Studies Related to mechanical properties of Al based metal matrix composites

S.A. Sajjadi [5] has compared the mechanical properties of stir cast Al 356 reinforced with micro (20μm) and micro Al2O3 (50nm). The authors have investigated the density, hardness and compressive strength. The results showed the poor incorporation of micro particles in the aluminum melt prepared by the common condition. However, the use of heat-treated particles, injection of particles and the stirring system improved the wet ability and distribution of the micro particles within the aluminum melt. In addition, it was revealed that the amount of hardness, compressive strength and porosity increased as weight percentage of micro Al2O3 particles increased. The authors has measured the theoretical density of composite and revealed that the amount of porosity in the composite samples increases with increasing weight percentage of Al2O3 particles and decreasing the size of particles. The porosity is generally because of some principles such as:

1) Increase in surface area in contact with air caused by increasing the weight percent and decreasing the particle size.
2) Gas entrapment during stirring.
3) Gas injection of particles introduces a quantity of gas into the melt.
4) Hydrogen evolution.
5) The pouring distance from the crucible to the mold, and
6) Shrinkage during solidification J.Hashim [6].

By increasing in Al2O3 percentage, the compressive strength shows an increasing trend.

Al/Al2O3composites fabricated by stir-casting process and examined the density, porosity,

UTS and hardness. H.R. Ezatpour[7] The density measurements shown in that the porosity in the composites increased with increasing the mass fraction of Al2O3 stirring speed and decreased by extrusion process. Hardness, yield and ultimate tensile strengths of the extruded composites increased with increasing the particle mass fraction to 7%, while for the composites without extrusion they increased with particle mass fraction to 5%.

D. Conclusion From The Literature Review

From the above literature review it is cleared that the mechanical behavior of Al based metal matrix and micro composite is affected by the type, size, and wt% of reinforcing

particles. Reinforcements such as Al2O3, SiC, TiC, B4C etc. improve the mechanical properties of Aluminum. Addition of Al2O3 particles improves mechanical and tribological properties in terms of base material. On the basis of literature review Al 7075 has been selected as a matrix, because Al 7075 exhibits excellent mechanical properties compare with

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Other grades of Al shown in table 2 Most of the work is done on Al based MMC. A very few work has been done on properties of Al-7075 reinforced with micro alumina particles with double stir casting which exhibits good mechanical.

TABLE: 1 Mechanical and physical Properties of Al_2O_3

Properties	Aluminium Oxide(Al_2O_3)
Melting Point	2072 °C
Hardness(Kg/m2)	1175
Density(Kg/cm3)	3.669
Coefficient of thermal expansion(µm/m°C)	8.1
Fracture Toughness (MPa-m1/2)	3.6
Poisson's ratio	0.22
Compressive Strength	2100
Size	100nm
Colour	White

E. Size Selection of Reinforcement.

Camargo Pedro [8] certain size effects which govern the following properties of material:

1) Less than 5 nm for catalytic activities.
2) Less than 20 nm for making hard magnetic materials.
3) Less than 50 nm for refractive index changes.
4) Less than 100 nm for achieving super magnetism.
5) Less than 100 nm for mechanical strengthening or prevent matrix dislocation movement.
6) Less than 100 nm for producing toughening.
7) Less than 100 nm for modifying hardness and plasticity.

F. Characteristics of Aluminum oxide.

The following are the characteristics of Aluminum Oxide

1) Hard and wear resistant.
2) Resist strong acid and alkali attack at elevated temperature.
3) High strength and stiffness.
4) Good thermal conductivity.
5) Excellent size and shape capability.

G. Al_2O_3 (Alumina) as Reinforcement

It is commonly referred to as aluminum oxide or corundum in its crystalline form. Al_2O_3 is a most cost effective and used in the field of engineering. It's most significant application in production of Aluminum alloys. It is also used as an abrasive due to good mechanical and wear properties. Due to its high temperature stability it can be used as refractory applications.

III. WORKING PRINCIPLE OF EDM AND ITS PARAMETERS

TABLE 2: Comparison of properties of Al

Grades of AI	Physical Properties	Mechanical Properties				
	Density(gm/cm3)	Melting Point©	Tensile strength(Mpa)	Yield strength(Mpa)	Hardness (BHN/Hv)	Elongation (%)
Pure AI	2.7	660	65.71	50.25	42BHN	27.8
AI-2024	2.78	638	215	96	46BHN	27
AI-3003	2.73	655	130	125	29Hv	25
AI-5083	2.69	570	250		60Hv	23
AI-5052	2.68	605	193	89.6	60BHN	25
AI-6061	2.7	652	110-152	65.11	30-33BHN	16
AI-6063	2.7	610	131		25BHN	27
AI-6082	2.7	555	130		35BHN	27
AI-7075	2.81	640	276	100	100-110BHN	17

A. Electrical Discharge Machining (EDM)

EDM has been a mainstay of manufacturing for more than six decades, providing unique capabilities to machine difficult-to-machine mate rials with desire shape, size, and required dimensional accuracy. Its distinctive attribute of using thermal energy to machine electrically conductive materials, regardless of hardness, has been an advantage in the manufacturing of mould, die, surgical, automotive and aeronautic components.

It is essential especially in the machining of super tough, hard and electrically conductive materials such as the new space age alloys. It is better than other machining processes in terms of precision, quality characteristics and the fact that hardness and stiffness of a work piece material is not important for the material removal.

Though EDM has become an established technology, and commonly used in manufacturing of mechanical works, yet its

Low efficiency and poor surface finish have been the vital matter of concern. Hence, the investigations and improvements of the process are still going on, since no such process exists, which could successfully replace the EDM.

B. Mechanism of Material Removal in EDM

Electrical discharge machining is the most widely-used non-conventional machining Process. Despite the fact that the mechanism of material removal of EDM process is not yet completely understood and is still debatable, the most widely established principle is the conversion of electrical energy it into thermal energy through a series of discrete electrical discharges occurring between the electrode and work piece immersed inside a dielectric medium and separated by a small

gap. Material is removed from the work piece by localized melting and even vaporization of material.

The sparks are created in between two electrodes in presence of dielectric

liquid. A simple explanation of the erosion process due to the discharge is presented in. There is no mechanical contact between the electrodes (held at a small distance) and a high potential difference is applied across them.

The material removal mechanisms are been reported differently by many authors. Singh and showed that the electrostatic forces and stress distribution acting on the cathode electrode were the

major causes of metal removal for short pulses. Gadalla and Tsai elucidated the material removal of WC-Co composite to the melting and evaporation of disintegrated Co followed by the dislodging of WC gains, which have a lower electrical conductivity on the other hand,

Lee and Lau argued that thermal spalling as well contributes to the mechanism of material removal during the sparking of composite ceramics due to the physical and mechanical properties promotes abrupt temperature gradients from normal melting and evaporation.

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C. EDM process Parameters

As per the discharge phenomena explained earlier, some of the important process parameters which influence the responses are:

D. Discharge current (Ip)

It is the most important machining parameter in EDM because it relates to power consumption of power while machining. The current increases until it reaches a preset level
Which is expressed as discharge current?

E. Discharge voltage (V)

It is the open circuit voltage which is applied between the electrodes. The discharge voltage de-ionizes the dielectric medium, which depends upon the electrode gap and the strength of the dielectric, prior to the flow of current. Once the current flow starts, the open circuit voltage drops and stabilizes the electrode gap. It is a vital factor that influences the spark energy.

F. Pulse-on time (Ton)

It is the time during which actual machining takes place and it is measured in µs. In each discharge cycle, there is a pulse on time and pause time/Pulse off time, and the voltage
between the electrode and work piece is applied during Ton duration. The longer the pulse
Duration higher will be the spark energy that creates wider and deeper crated.

G. Pulse-off time or pause time (Toff)

In a cycle, there is a pulse off time or pause time during which the supply voltage is cut off as a consequence the Ip diminishes to zero. It is also the duration of time after which the next spark is generated and is expressed in µs analogous to Ton. Since, the dielectric must de-ionized after sparking and regain its strength, it required some time and moreover the flushing of debris also takes place during the Toff time.

H. Flushing Pressure (fp)

Flushing is an important factor in EDM because debris must be removed for efficient cutting, moreover it brings fresh dielectric in the inter electrode gap. Flushing is difficult if the cavity is deeper, inefficient flushing may initiate arcing and may create unwanted cavities which can destroys the work piece. There are several methods generally used to flush the EDM gap: jet or side flushing, pressure flushing, vacuum flushing and pulse flushing.

I. Polarity

Polarity refers to the potential of the work piece with respect to tool i.e. in straight or positive polarity the work piece is positive, whereas in reverse polarity work piece is negative. Varying the polarity can have dramatic effect, normally electrode with positive polarity wear less, whereas with negative polarity cut faster.

IV. EXPERIMENTAL WORK

A. Material

Commercial grade Aluminum alloy powders were obtained from Loba Chemie Pvt. Ltd., India. The Al2O3 particulates were obtained from the market the specifications/
Composition obtained is presented below.

B. Aluminum Alloy

The aluminum alloy contains Al-99.7%, Fe-0.17%, Mg-0.0016%, Zn-0.0053%, Cu- 0.00159% of other materials. And Particle sizes -120 mesh (~20 µm).

C. Al2O3 Particulates

Al2O3 is obtained from the open market with assay 99% (metal basis) and Particle size: 300 mesh (50 µm), 400 mesh (37 µm).

D. Stir Casting

In a stir casting process particulate reinforcement (usually in powder form) are distributed into molten Al matrix by mechanical stirring. This process was initiated in 1968 by S.Ray. S.Ray. introduced alumina particle into a molten Al matrix by mechanical stirring. Mechanical stirring in furnace is the key element of this process. Hai Su et al. (2012) designed a new three step stir casting method for fabrication of nano particle reinforced composite. First the reinforcement and Al particles are mixed using ball mills to break the initial clustering of nano particles. The composite powder is then incorporated into the melt with along with mechanical stirring. After adequate stirring the composite slurry is sonicated using an ultrasonic probe or transducer in order to improve the distribution of reinforced Particles.

Al7075/nano Al_2O_3 composites were fabricated by stir casting process through injection of Al_2O_3 particles into the molten Al alloy by argon gas along with stirring using a mechanical stirrer and fabrication of nano composites with reasonable distribution of Al_2O_3 in the matrix alloy with low agglomeration and low porosity.

Fig1: Stir Casting

A recent development in stir casting technique is a double stir casting or two-step mixing process. In this technique, initially the matrix material is heated to above its liquidus temperature. The melt is then cooled down to a temperature between the liquidus and solidus points to a semi-solid state. At this point the preheated reinforcement particles are mixed and added. Again the slurry is heated to a fully liquid state and mixed thoroughly. In double stir casting technique the resulting microstructure has been found to be more uniform as compared with conventional stirring. The potency of this two-step mixing method is mainly due to its ability to break the gas layer around the particle surface which otherwise impedes wetting between the particles and molten metal. Thus the mixing of the particles in the semi-solid state helps to break the gas layer because of the abrasive action due to the high melt viscosity. The major characteristics of stir casting process are relatively low cost, simple and applicable to mass production of MMC.

E. Material removal rate (MRR)

Material removal rate is defined as the ratio of difference between weights of material
Before machining and after machining to the time taken,
MRR is expressed as,

$$= (W_i - W_f)/T$$

Where, W_i = initial weight of work piece, W_f = final weight of work piece, T= machining time
(60 Minutes).

V. METHODOLOGY

In the simplest case, an optimization problem consists of maximizing or minimizing a real function by systematically choosing input values from within an allowed set and computing
the value of the function. The generalization of optimization theory and techniques to other formulations comprises a large area of applied mathematics. An amazing variety of practical
problems involving decision making (or system design, analysis, and operation) can be cast in the form of a mathematical optimization problem, or some variation such as a multi response optimization problem. Indeed, mathematical optimization has become an important tool in many areas. It is widely used in engineering, in electronic design automation, automatic control systems, and optimal design problems arising in civil, chemical, mechanical, and aerospace engineering. Since the late 1940s, a large effort has gone into developing algorithms for solving various classes of optimization problems, analyzing their properties, and developing good software implementations. In this contest, the task is to find a model, from a family of potential models, which best fits some observed data. Here the variables are the parameters in the model. In order to determine the factor
level settings that optimize the performance of the quality characteristics in a single setting, a hybrid optimization technique namely principal component analysis (PCA) coupled with fuzzy inference system are used for combining multiple responses into a single response known as multi-response performance characteristics index (MPCI). Finally, empirical relationship between process parameters and MPCI is derived using Taguchi methodology.

To check the soundness of this hybrid optimization technique, another solo optimization technique called weighted principal component analysis (WPCA) is used. In this context optimal settings from both the techniques are compared and analyzed.

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Development of a valid model helps to search the optimization landscape to find out best possible parametric combination resulting best quality characteristics, which has not been explored during experimentation.

A. Electrical Discharge Machining Process

The study intends to investigate the effect process parameters such as discharge current (Ip), pulse-on-time (Ton), duty cycle (τ) and flushing pressure (Fp) on material removal rate (MRR), tool wear rate (TWR The equipment used to perform the experiments is an Electronical Electraplus PS 50ZNC Die Sinking Fuzzy Logic based Electrical Discharge Machine.

fig 2: edm machine

Commercial grade EDM oil (specific gravity = 0.763, freezing point= 94˚C is used as dielectric fluid. A lateral flushing of machine debris is employed for effective flushing of machining debris from the working gap region. To get more accurate results, each experiment is conducted for one hour.

FIG 3: Copper Electrode

The work piece material used is aluminum silicon carbide metal matrix composite. Straight polarity is adopted due to high MRR. A cylindrical copper tool with a diameter of 12 mm is used as a tool electrode (negative polarity) and work piece material (positive polarity). Density of copper tool taken is 0.00896 kg/m3 S. MRR is calculated using the volume loss from the work piece as cubic millimeter per minute.

FIG 4: Graphite Electrode

During the electric discharge, some of the discharge energy applied to the tool produces a crater in the tool material. TWR is expressed as the volumetric loss of tool per unit time. The

Weight loss is measured by an electronic balance weight measuring machine (Sansui (Vibra), Shinko Denshi Co. Ltd. Made in Japan) with a least count of 0.01g.

A. Electronic Balance Weight.

It is an digital type of weighing machine that measures weight electronically up to accuracy of 0.01 grams.

FIG 5: Electronic weight measuring machine

B. EDM Panel

EDM panel has a screen that displays the depth of cut in X-Axis, Y-Axis, and Z-Axis from top to bottom respectively. We can also see the current and voltage in this panel.

Fig 6: Edm Control Panel

C. Specimens for Machining

We have four specimen made by composition of Aluminum and Al2O3 powder described under:

1) Specimen of pure Aluminum which have only aluminum. It doesn't not contain any reinforcement material.

FIG 7: 100%Al + 0% Al2O3

2) Specimen containing a 3% reinforcement and rest is Aluminum i.e. 97%Al + 3% Al2O3

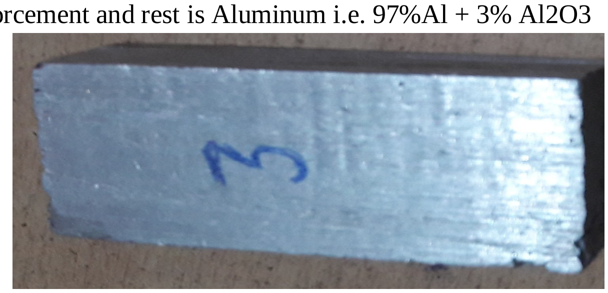

FIG 8: 97%Al + 3% Al2O3

3) Specimen containing a 5% reinforcement and rest is Aluminum i.e. 95%Al + 5% Al2O3

FIG 9: 95%Al + 5% Al2O3

4) Specimen containing a 7% reinforcement and rest is Aluminum i.e. 93%Al +7% Al2O3

FIG 10: 93%Al + 7% Al2O3

VI. RESULTS AND DISCUSSION

A. Physical Properties

Table 3 shows the physical (density, porosity) of the matrix alloy and the composites in as cast condition. Table 3 showed that the comparison of theoretical density obtained by rule of mixture and experimental density values of the composites containing wt% of various reinforcement. From the table it can be concluded that the densities of the composites are higher than that of base alloy, the density increases with increase in the wt% of reinforcement content.

TABLE 3: Physical Properties of Matrix Alloy and Composites

SAMPLE CODES	SAMPLES	DENSITY(gm/cm3)		POROSITY
		THEORETICAL DENSITY	EXPERIMENTAL DENSITY	
S1	Al 7075+0%Al2O3	2.22	2.19	1.35
S2	Al 7075+3%Al2O3	2.34	2.27	2.99
S3	Al 7075+5%Al2O3	1.84	1.8	2.17
S4	Al 7075+7%Al2O3	1.92	1.85	3.64

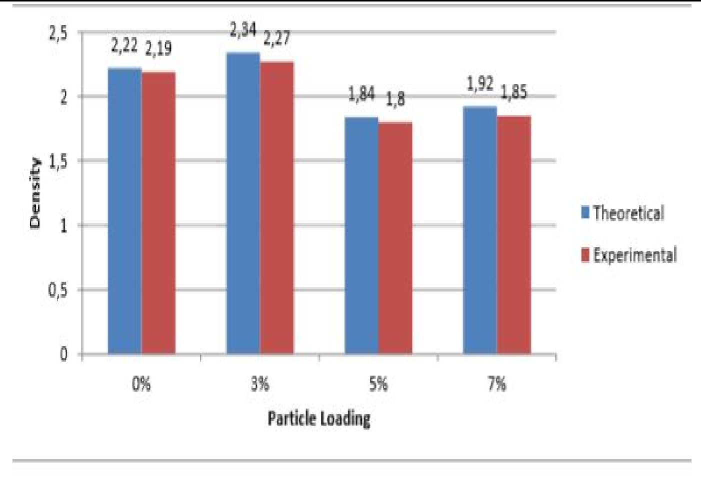

FIG 11: Effect of Percentage Reinforcement on Density

Porosity of the composites samples also illustrated in table3 and results are shown graphically in fig.12. It can be concluded the porosity increases with increasing microAl2O3wt%. The results have also been observed by authors previously in literature review.

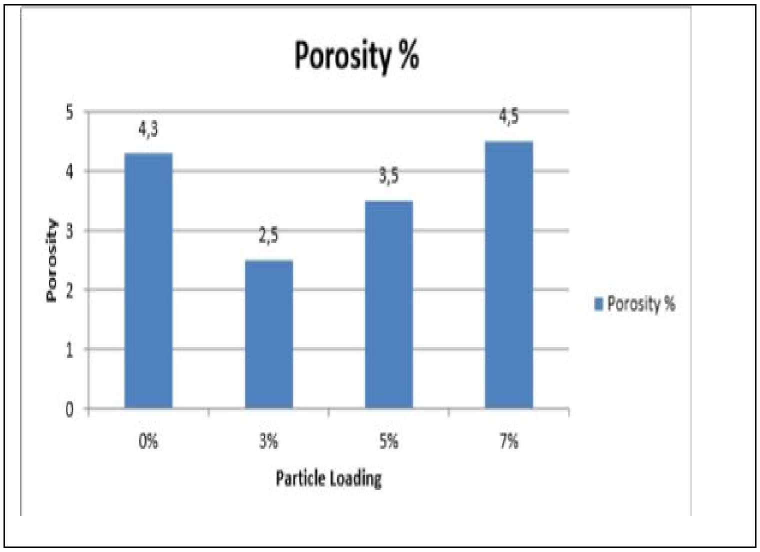

FIG 12: Effect of Porosity

It can be concluded from fig.14 the porosity increases with increasing micro Al2O3 wt%. This is due to the effect of low wet ability and agglomeration at higher content of reinforcement. At 7wt% of Al2O3 micro particles more clusters are produced due to uneven distribution of micro particles. With increasing in viscosity of liquid metal flow associated with the particle cluster led to formation of porosity.

B. EDM Machining with Copper Electrode:

When the machining was done copper electrode, the following observations were made,

TABLE 4: After machining with Copper (Cu) electrode:

Sample code	Samples	Column1	Column2	Column3
		weight of specimen		MRR
		Before Machining	After Machining	
S1	Al7075	76.39	73.89	0.166gm/min
S2	Al7075+ 3% Al_2O_3	61.69	60.11	0.105gm/min
S3	Al7075+ 5% Al_2O_3	55.15	53.68	0.098gm/min
S4	Al7075+ 7% Al_2O_3	66.62	65.33	0.086gm/min

Weight of copper electrode before machining-47.77gm
Weight of copper electrode after machining-47.76gm

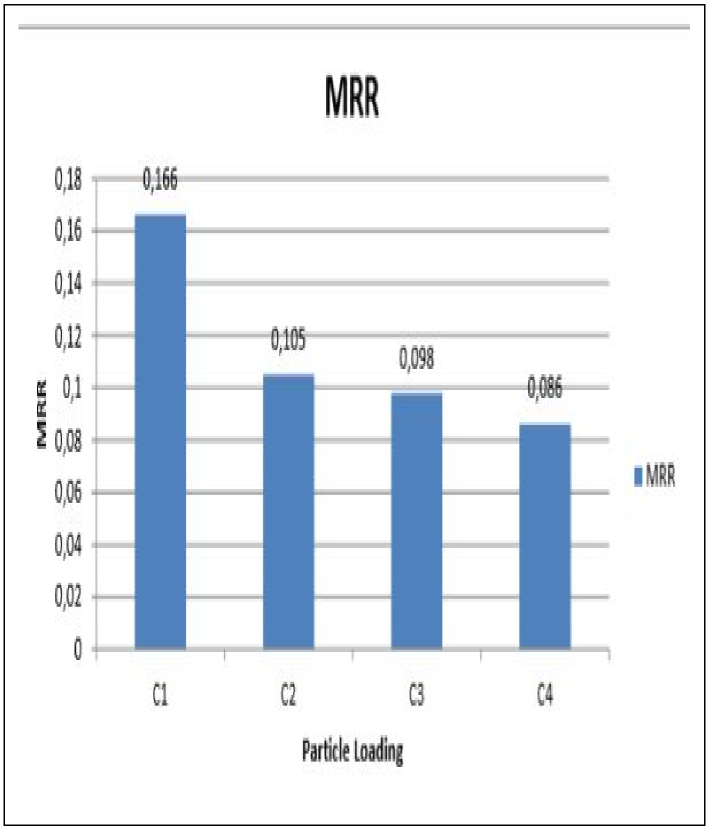

FIG 13: MRR by Copper Electrode

C. EDM Machining with Graphite Electrode

When the machining was done Graphite electrode, the following observations were made,

TABLE 5: After machining with graphite electrode

Sample code	Samples	Column1	Column2	Column3
		weight of specimen (gm)		MRR
		Before Machining	After Machining	
S1	Al7075	73.89	71.16	0.182gm/min
S2	Al7075+ 3% Al_2O_3	60.11	58.02	0.139gm/min
S3	Al7075+ 5% Al_2O_3	53.68	51.88	0.120gm/min
S4	Al7075+ 7% Al_2O_3	65.33	63.68	0.110gm/min

Weight of Graphite electrode before machining-10.82gm

Weight of Graphite electrode after machining-10.61gm

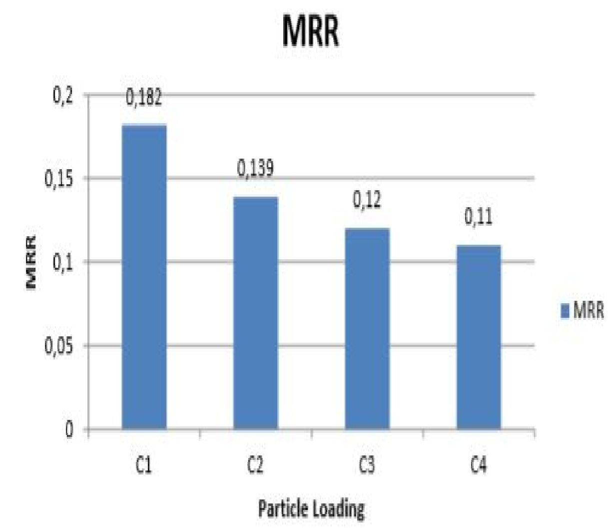

FIG 14: MRR by Graphite Electrode

D. Comparison:

On the following observations made before, We can have the following comparison between the machining done by Copper electrode and Graphite electrode.

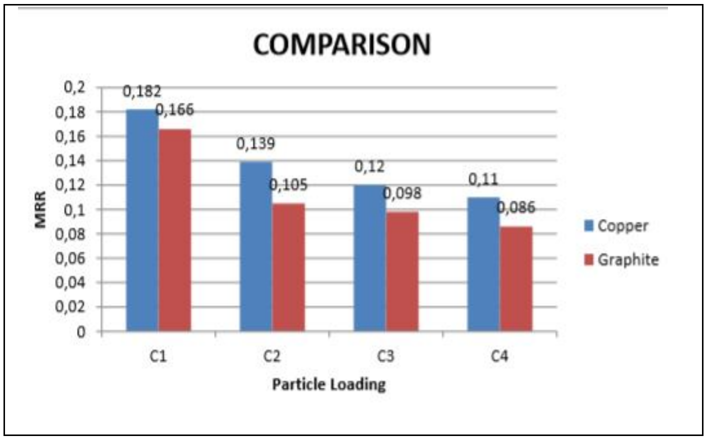

FIG 15: Comparison of Copper and Graphite Electrode

VII. CONCLUSION AND SCOPE

The above results and discussion on Mechanical, tribological, and microstructure properties of Al- 7075 based matrix reinforced with micro Al2O3 particles leads to following conclusion:

A. Al 7075/ Al2O3 micro composites were successfully synthesized by injection of particle – Al2O3 powder into the melt manual stir casting.
B. Synthesis of Al 7075 based metal matrix particle composite leads to significant improvement in physical and mechanical.
C. The densities of the composites are higher than that of base alloy, the density increases with increased in the wt% of reinforcement content.
D. It can be concluded the porosity increases with increasing micro Al2O3 wt%.
E. The hardness values are increased with increase in addition of micro particles

VIII. FUTURE SCOPE

Based on the results and discussion made in this research work following research may undertaken to further enrich the information

A. Same metal matrix micro composite can be fabricated by using other manufacturing techniques like squeeze casting etc
B. . And result compared with the stir casting.We can use different electrodes and then machining can be done on EDM.
C. We can have different compositions of reinforcement.
D. We can change the reinforced powder and further machining can be done on EDM.

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