TAGUCHI METHOD BASED APPROACH FOR IMPROVEMENT IN MECHANICAL PROPERTIES OF FLY ASH REINFORCED ALUMINUM MATRIX COMPOSITES

A Thesis submitted in partial fulfillment of the
requirements for the degree of

MASTER OF ENGINEERING
in
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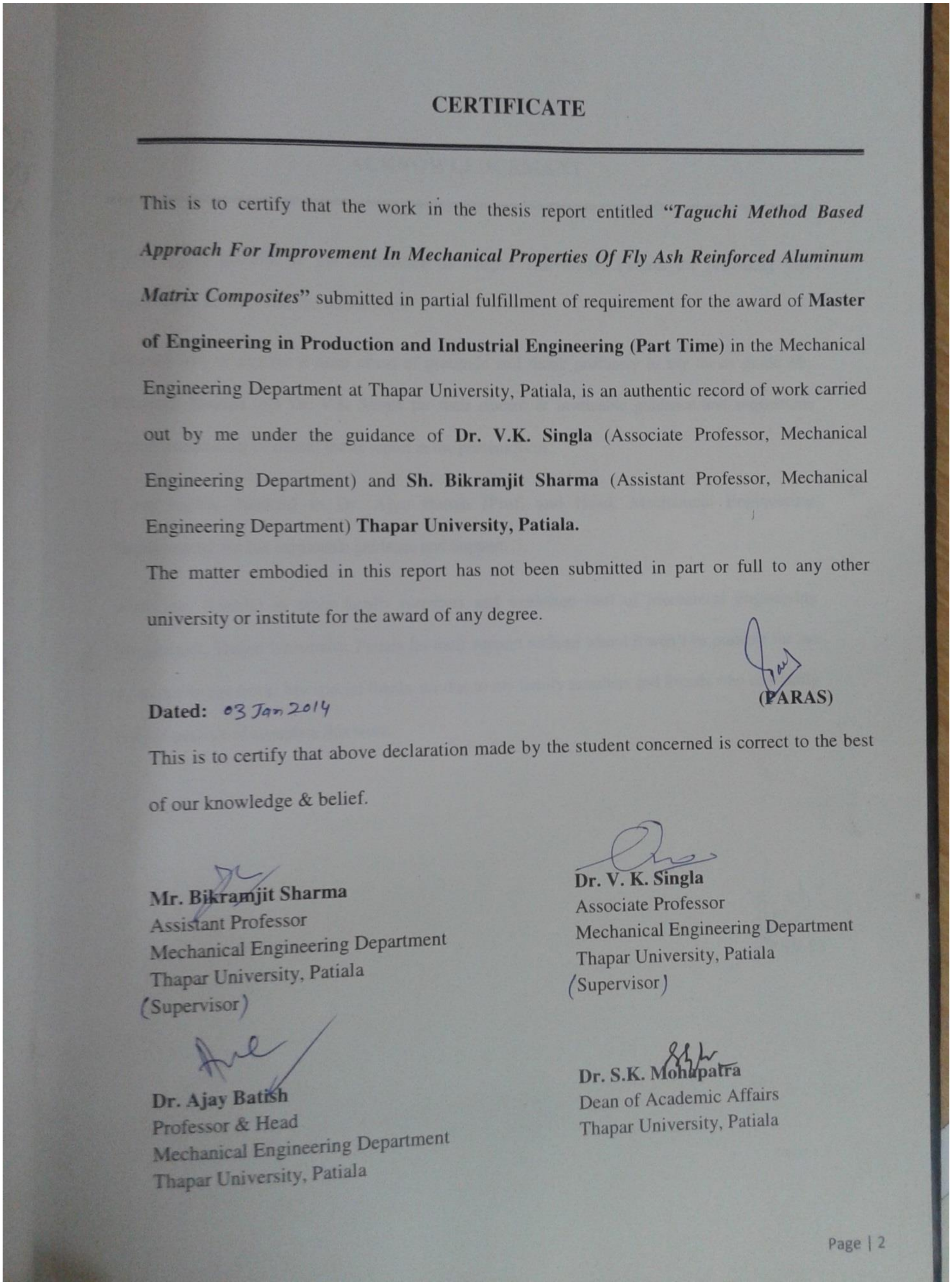

CERTIFICATE

This is to certify that the work in the thesis report entitled ***"Taguchi Method Based Approach For Improvement In Mechanical Properties Of Fly Ash Reinforced Aluminum Matrix Composites"*** submitted in partial fulfillment of requirement for the award of **Master of Engineering in Production and Industrial Engineering (Part Time)** in the Mechanical Engineering Department at Thapar University, Patiala, is an authentic record of work carried out by me under the guidance of **Dr. V.K. Singla** (Associate Professor, Mechanical Engineering Department) and **Sh. Bikramjit Sharma** (Assistant Professor, Mechanical Engineering Department) **Thapar University, Patiala.**

The matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

(PARAS)

Dated: 03 Jan 2014

This is to certify that above declaration made by the student concerned is correct to the best of our knowledge & belief.

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PARAS

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ABSTRACT

Conventional monolithic materials such as aluminium and magnesium are lightweight and have certain properties that give them an edge over their counterparts i.e. iron and steel. But, they do not have the strength requirements necessary for several applications. The main characteristics possessed by aluminium are: low density, good resistance to corrosion, low thermal expansion, and established casting techniques for mass production. The attractive characteristics possessed by these materials forced scientist to do research for enhancing their properties and making these suitable to be used in high end applications, such as automotive and aerospace. As a result of these requirements, invention of MMCs (Metal Matrix Composites) had taken place. Advances in the science of MMCs present scientists with an opportunity to design light-weight aluminum based materials with precise balances of mechanical and physical properties. Furthermore, the MMCs manufactured by dispersing coal fly ash in common aluminum alloys is found to be the most economical method to improve mechanical and physical properties.

Mechanical properties of composites are affected by the size, shape and volume fraction of the reinforcement, matrix material and reaction at the interface. Matrix / reinforcement interface has a major role to play in relation to the mechanical properties of the composites.

In this work, an attempt has been made to determine the influence of volume fraction of fly ash, addition of magnesium (wetting agent) and the effect of stirrer speed on the mechanical properties of MMCs produced by stir casting method. Optimum values of these are identified for attaining better wear resistance, hardness and tensile strength of composites by the application of Taguchi method and Analysis of Variance (ANOVA).

Aluminium is attractive material possessing properties that make it extremely favorable in automotive and other high end applications. In recent years, discontinuously reinforced aluminum based MMCs have attracted worldwide attention as a result of their potential to replace their monolithic counterparts [4].In view of increasing cost of primary metals including aluminum, incorporation of low cost reinforcements/fillers in metals has become essential to meet high strength or stiffness requirements with minimum weight of material. If even 1% of aluminum could be replaced by fillers, the total energy saving could be of the order of 5×1011 kWh, making aluminum foundries more competitive [5]. Fly ash, a waste by-product generated by combustion of coal in thermal power plants, has been successfully dispersed into cast and wrought aluminum alloys to make aluminum alloy – fly ash (ALFA) composites, which have low density and adequate properties for several automotive applications [5, 6]. Fly ash particles can be either solid (precipitator) or hollow (cenosphere). Cenospheres are beneficial in synthesizing lightweight composites. [7] Over 90 million tons of fly ash is produced each year in thermal power plants and most of it is land filled. **Fig. 1** gives a price comparison of various materials used in making aluminum matrix composites. It shows that the cost of fly ash is much lower than any other reinforcing material. Fly ash aluminum composite will also require reduced energy for remelting during recycling since the fly ash will not melt and only the aluminum fraction will have to be remelted. Addition of fly ash can make automotive castings lighter, leading to further energy savings during the use of cars and trucks by means of reduced fuel consumption.

At early stages of development of metal matrix composite emphasis was given on the preparation of fiber reinforced composite only. Now a days the particulate reinforced aluminium metal matrix composite are gaining importance because of their low cost with advantage like isotropic properties. The aluminum MMCs can be produced either by casting or by power metallurgy. The former has the advantages of producing the composites as lower cost of production and possibility of producing larger components. However, the inherent difficulties of casting route are non-wetability of ceramic particles by liquid aluminum, segregation of particles, higher porosity level and extensive inter-facial reaction due to higher processing temperature [8].

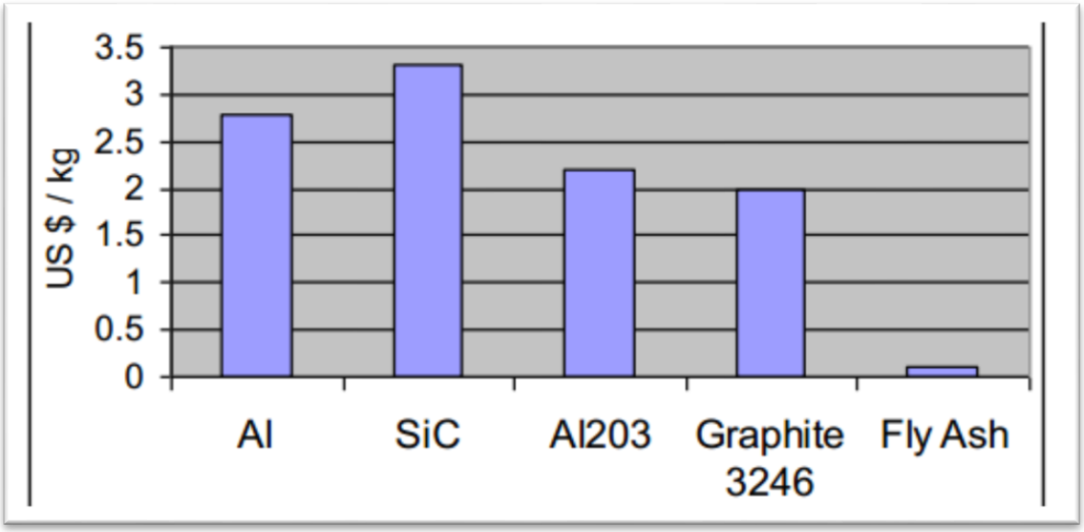


Fig. 1.1 Prices of materials commonly used in making aluminum matrix composites

Tailoring the inter-facial reactions and increasing the wettability in the major area of concern to have even better properties than as cast aluminum fly ash metal matrix composite. The behavior of the composite is the result of following three entities:

I. The reinforcing element

II. Matrix

III. Reinforcement/matrix Interface

The extreme importance of the inter-facial region determining the properties of the composites is on account of the fact that the surface area occupied by interface is quite extensive. It can go as high as 3000 cm^2/cm^3 [9]. The load transfers from the matrix to reinforcement or vice versa takes place through interface. So, nature of interface has great relation in regard to the properties exhibited by the material.

1.1 Composite Material

The composite material can be defined as the system of material consisting of a mixture of combination of two or more micro constituents insoluble in each other and differing in form and or in material composition. These materials can be prepared by putting two or more dissimilar material in such way that they function mechanically as a single unit. The properties of such materials differ from those of their constituents. These materials may have a hard phase embedded in a soft phase or vice versa. Normally in the composite material have a hard phase in the soft ductile matrix where the hard phase act as a reinforcing agent increase the strength and modulus, and soft phase act as matrix material. The requirement for satisfying the above mentioned condition is

1. The composite material has to be man-made
2. The composite material must be a combination of at least two chemically distinct materials with an interface separating the components.
3. It has characteristics that are not depicted by any of the components in isolation.

1.2 Brief History about Composites

In 1960s, because of increased demand for materials having high stiffness and strength, combined with light weight, required in fields such as aerospace, energy and civil construction, need of Composites materials aroused, as no single existing material had the demanded properties. Serious research however started in 1965.

Composite materials generally offer very superior properties at a very less cost, than it can be had by other means. Moreover, energy consciousness, has led to an increasing demand for light weight, yet strong and stiff materials in all walks of life. The only answer to these requirements is composites.

First Composite: Glass Fiber Reinforced Resins – have been in use since 1940. Glass Fiber Reinforced Resins are very light and strong, but lack in stiffness.

In third quarter of 20th century, emergence of high stiffness fibers took place, such as Boron, Carbon, Silicon Carbide and Alumina. These have been used for reinforcement of resin, metal, and ceramic matrices. Fiber reinforced materials have always been proved to be superior in relation to strength, stiffness and weight considerations as compared to material in any other form.

1.3 Metal Matrix Composites

MMCs are engineered combinations of two or more materials (one of which is a metal) where tailored properties are achieved by systematic combinations of different constituents. Conventional monolithic materials have limitations in respect to achievable combinations of strength, stiffness and density .Engineered MMCs consisting of continuous or discontinuous fibers, whiskers, or particles in a metal achieve combinations of very high specific strength and specific modulus. Furthermore, systematic design and synthesis procedures allow unique combinations of engineering properties in composites like high elevated temperature strength, fatigue strength, damping property, electrical and thermal conductivities, friction coefficient, wear resistance and expansion coefficient.

1.4 Reinforcements

Reinforcements need not to be in form of long fibers. These can be in form of particles, flakes, whiskers, short fibers, continuous fibers, sheets. Many naturally occurring fibers or composites can be and are used in many situations which do not involve very high stresses. These are used because of their availability at low cost. But for advance applications, no naturally occurring composite can fulfill the requirements.

1.5 Classification of Composites

1.5 .1 On the basis of Matrix Material used

a) Polymer-matrix composites (PMCs)

The most common matrix materials for composites are polymeric. Polyester and viny esters are the most widely used and least expensive polymer resins. These matrix materials are basically used for fiber glass reinforced composites. Formation of a large number resin provide a wide range of properties for these materials .The epoxies are more expensive and in addition to wide range of ranging commercials applications, also find use in PMCs for aerospace applications. The main disadvantages of PMCs are their low maximum working temperature, high coefficients of thermal expansion and hence dimensional instability and sensitivity to radiation and moisture. The strength and stuffiness are low compared with metals and ceramics.

b) Metal-matrix composites (MMCs)

The matrix in these composites is a ductile metal. These composites can be used at higher service temperature than their base metal counterparts. These reinforcements in these materials may improve specific stuffiness specific strength, abrasion resistance, creep resistance and dimensional stability. The MMCs is light in weight and resist wear and thermal distortion, so it mainly used in automobile industry. MMCs are much more expensive those PMCs and therefore, their use is somewhat restricted.

c) Ceramic-matrix composites (CMCs)

One of the main objectives in producing CMCs is to increase the toughness. Ceramics materials are inherent resistant to oxidation and deterioration at elevated temperatures; were it not for their disposition to brittle fracture, some of these materials would be idea candidates for use in higher temperature and severe - stress applications, specifically for components in automobile an air craft gas turbine engines. The developments of CMCs has lagged behind mostly for remain reason, most processing route involve higher temperature and only employed with high temperature reinforcements.

1.5 .2 On the basis of type of reinforcement used

a) Particle reinforced composites

Particulate reinforcements have dimensions that are approximately equal in all directions .The shape of the reinforcing particles may be spherical, cubic, platelet or any regular or irregular geometry. These composite can classified under two sub groups:

I Large particle composites

II Dispersion strengthened composites

b) Fiber reinforced composites

A fibrous reinforcement is characterized by its length being much greater than its cross-sectional dimension. However the ratio of length to the cross sectional dimension know as the aspect ratio, can vary considerably. In single layer composite long fibers with high aspect ratios give that are called continuous fiber reinforced composites whereas discontinuous fiber reinforced composites are fabricated using short fibres of low aspect ratio. The orientation of the discontinuous fibres may be random or preferred. The frequently encountered preferred orientation in the case of continuous fibre composite is termed unidirectional and the corresponding random situation can be approximated to by bidirectional woven reinforcement.

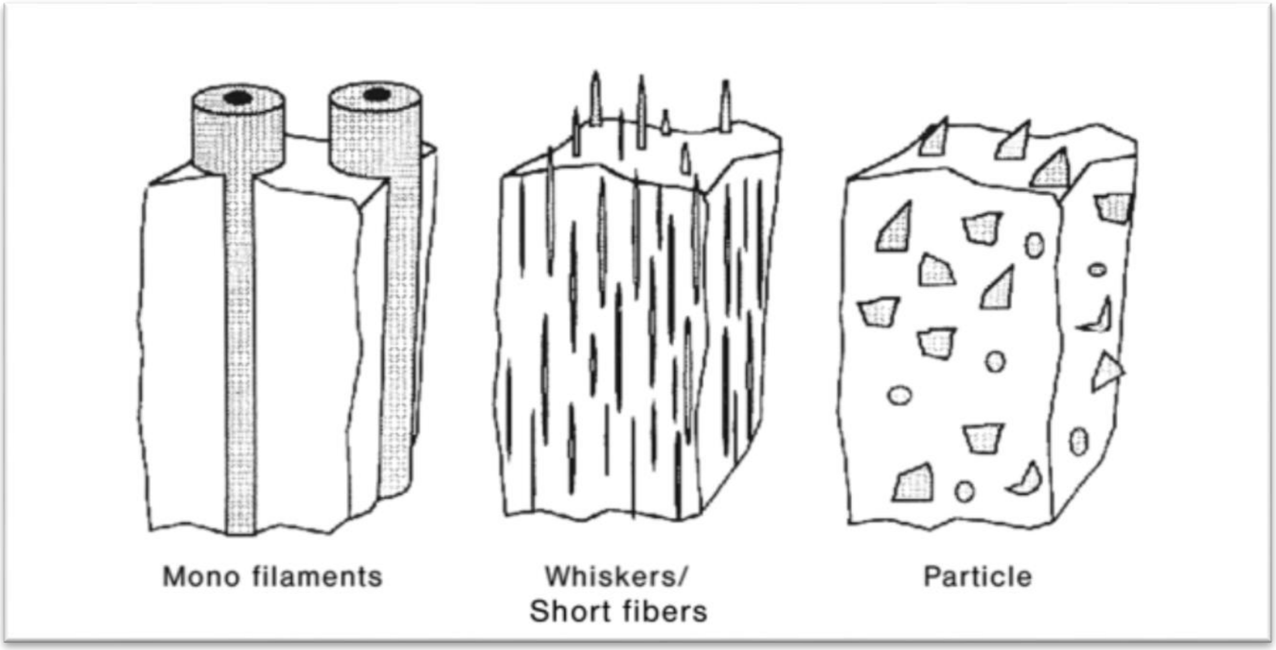


Fig.1.2 Different types of reinforcements

1.6 Fabrication of Metal Matrix Composites

A number of composite fabrication techniques have been developed that can be placed into four broad categories. These are: (i) liquid metallurgy, (ii) powder metallurgical techniques, (iii) diffusion bonding of filaments and foils, and (iv) vapour phase infiltration [26]. Among the various fabrication routes practiced for MMCs, liquid metallurgy i.e. the casting or solidification route has an edge over the others, being the simplest and most economical. It offers different moulding techniques for making intricate as well as near net-shaped components. The liquid metallurgy as well as the semi-solid casting/ stir casting/compocasting techniques are widely used for MMC synthesis under the banner, 'casting route' [10]. There are large no of factors that are responsible for the properties of the composites during its synthesis. Extensive research has been taken place and still going on in relation to these factors, especially for the production of aluminium MMCs. After commercialization of aluminium MMCs in automotive and aerospace sectors, the research in these areas has got a different pace.

1.6.1 Factors affecting Properties of MMCs:

Factors are such as (each factor is studied independently while keeping all other factors constant):

A. The critical distance of separation between dispersoids at rejection: [10]The energy required to keep the particles in suspension depends upon the distance between the surfaces of any two particles. This potential is represented by $(l - 2r_p)$ where l is the distance between the centers of any two particles and r_p is their radius. If E is the total energy input into the system, it is utilized to keep the particles in suspension and to overcome the buoyancy forces. Hence, it follows that:

$$E \geq \varphi(l - 2r_p) + B_1 r_p^4 \quad \text{...(1)}$$

Where $B_1 r_p^4$ is the energy required to overcome the buoyancy forces

The constant B_1 in above Equation is proportional to the difference between the densities of the particle and the liquid melt.

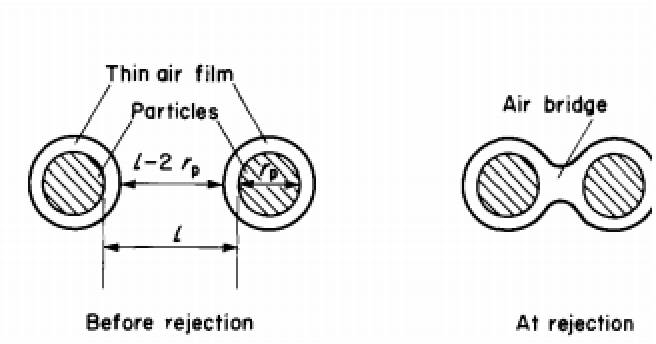


Fig. 1.3: Schematic showing the formation of air bridges

Authors have postulated that:

$$\varphi(l - 2r_p) = \frac{A}{(l-2r_p)^m} \text{...(2)}$$

Where $'A'$ and $'m'$ are constants. Where $m \geq 1$

Hence, it is clear that as the inter-particle distance decreases, the energy require to prevent the rejection goes on increasing. So there is a critical value for each combination of parameters, where the rejection of despersoids starts.

B. **Volume fraction of dispersoids:** [10] During MMC synthesis, segregation of dispersoids out of the melt is observed when their volume fraction exceeds a critical value for a given matrix -dispersoid combination and a given set of mixing conditions. The authors [11, 12] state that segregation of the particles is driven either by surface energy or by coalescence of adsorbed gases rather than by gravity. It is well known that the non-wetting dispersoids in suspension in the melt are surrounded by gas films [27]. When the concentration of the dispersoids in the melt increases, the interparticle distance, $(l-2r_p)$, decreases and the attractive forces between the dispersoids become more effective. This tends to thin down the liquid interlayer. When $(l-2r_p)$reaches a critical value, this liquid film between the dispersoids ruptures, leading to the formation of gas bridges between dispersoids as shown in Fig. above.

C. **Effect of density differences among reinforcements and Matrix:** When the density difference between the matrix and the dispersoid is small, B_1 is small, and hence the energy required to overcome buoyancy forces is negligible.

D. **Size of the Particles:** The smaller the size of the dispersoid, the smaller is the contribution due to buoyancy, hence lesser the rejection.

E. **Speed of rotation of the stirrer:** The experimental test conducted by[10],reveal that the critical volume fraction of dispersoid increases with increasing stirrer speed i.e., increasing energy input into the system.

F. **Effects of Interfaces:** [3]The interface between the matrix and reinforcement plays a crucial role in determining the properties of MMCs. Surface treatments and coating of the reinforcement are some of the important techniques by which the interfacial properties can be improved. The interface between the matrix and the reinforcement is the critical region that is affected during the fabrication. If this interface is not tailored properly, it can lead to the degradation of the properties of the composites. The problems associated with the interfaces are the interfacial chemical reaction, degradation of the reinforcement, lack of wettability with the matrix, etc. These interfacial problems are system-specific. Hence, it is a difficult exercise to design optimized interfaces common and suitable for all systems. Some of the methods to obtain desired interfaces with better properties are the modification of the matrix composition, coating of the reinforcement, specific treatments to the reinforcement and control of process parameters.

   a. **Wetting:** Wetting of reinforcement by molten metal, an important aspect in MMC synthesis, is favoured by the formation of strong chemical bonds at the interface. The presence of oxide films on the surface of molten metal and the adsorbed contaminant on the reinforcement surface generally leads to non-wetting of the reinforcement with

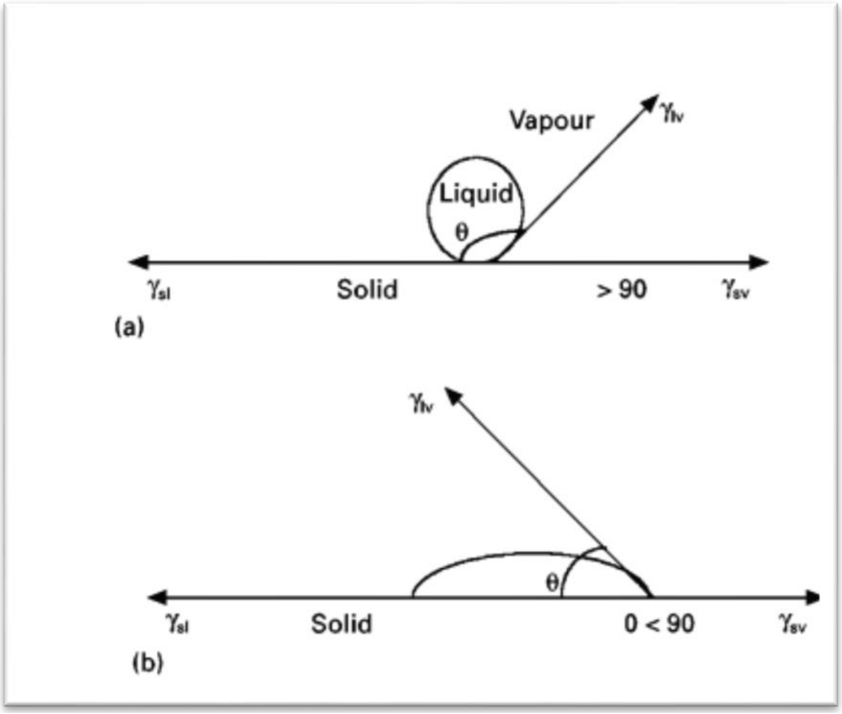


Fig. 1.4 Wettability Characteristics

molten metal The wettability of a solid by a liquid is indicated by the contact angle, as shown in Fig. 4. The contact angle, $'h'$, between solid, liquid and gas/vapour is related by the Young Dupre's equation,

$$\gamma_{1v} \cos\theta = \gamma_{sv} - \gamma_{sl} \quad \text{……………………………………} (3)$$

where, γ_{1v} is the surface tension of the liquid metal, γ_{sv} is the surface energy of the solid, and γ_{sl} is the solid/liquid interfacial energy. Based on the above equation, the contact angle$'\theta'$ can be decreased by increasing the surface energy of the solid, decreasing the solid/liquid interfacial energy, or by decreasing the surface tension of the liquid. The liquid is said to wet the solid when $\theta<90^0$, that is, when$\gamma_{sv} > \gamma_{sl}$.

b. **Nature of interface:** The nature of interface has a strong influence over the properties of the MMCs. Strengthening in the composites by the reinforcements is dependent on the strength of the interfacial bond between the matrix and the reinforcement. A strong interfacial bonding permits transfer and distribution of the load from the matrix to the reinforcement. The properties such as stiffness, fracture toughness, fatigue, coefficient of thermal expansion, thermal conductivity and creep are also affected by the nature of the interface.

   A mechanical bonding arises from mechanical interlocking between the matrix and reinforcements in the absence of all chemical sources of bonding.

   Chemical bonding occurs when the atoms of matrix and reinforcement are in direct contact and is accomplished by exchange or sharing of electrons.

   An interface with a metallic bond is more ductile than other bonds, and is desirable in MMCs.

c. **Interfacial chemical reaction:**

   During processing of MMCs, a chemical reaction occurs at the interface between the matrix and the reinforcement in some systems. In such cases, it leads to the formation of an interface reaction product layer with properties differing from those of either the matrix or the reinforcement. The extent of chemical reaction and the type of reaction products formed are dependent on the processing temperature, pressure and atmosphere, matrix composition and surface chemistry of reinforcements. Interfacial reaction can decrease the interfacial energy of the metal/reinforcement interface and improve adhesion through chemical bonding. The extent of the chemical reaction has a strong influence over the physical and mechanical properties of the composites.

The following interfacial reaction is observed during the synthesis of carbon-reinforced aluminium MMCs wherein the carbon can be either in the form of particulate or fiber:

$4Al_{(l)} + 3C_{(s)} \rightarrow Al_4C_{3(s)}$..(4)

The reaction tendency of carbon fibre with molten aluminium is observed to be severe when the melt temperature exceeds about 900K. Aluminium carbide formation occurring by the degradation of fibres decreases their strength.

In silicon carbide-reinforced aluminium MMCs, SiC is thermodynamically unstable in molten aluminium at around temperatures exceeding 1000 K**.** The SiC reacts with molten aluminium to form Al_4C_3rejecting metallic silicon according to the reaction.

$4Al_{(l)} + 3SiC_{(s)} \rightarrow Al_4C_{3(s)} + 3Si_{(s)}$..(5)

However, the above reaction can be suppressed by having a matrix alloy containing a higher silicon content.

Alumina (Al_2O_3) is considered as an ideal dispersoid because of its good interfacial compatibility and non-degrading surface with liquid aluminium. However, in most of the aluminium alloys of interest containing magnesium as an alloying element, magnesium reacts with alumina according to:

$3Mg + Al_2O_{3(s)} \rightarrow MgO + 2Al_{(l)}$..(6)

$3Mg + 4Al_2O_{3(s)} \rightarrow MgAl_2O_{4(s)} + 2Al_{(l)}$..(7)

MgO may form at high magnesium levels ($>$ 1.5 wt% Mg) and low processing temperatures, while spinel forms at low magnesium levels ($<$ 1.5 wt% Mg)

d. **Coating of reinforcement:** Coating of a reinforcement is one of the successful (though little bit costlier in some cases) techniques adopted to prevent the interfacial reaction and enhance the wetting of the reinforcement. Coating also prevents the diffusion of liquid metal into the reinforcement. Different types of coatings given to reinforcements are metallic, ceramic, bilayer and multilayer coatings containing metals and/or ceramics and are system-specific. The various coating techniques adopted aim at attaining a better, uniform and thin layer coating without degradation of the reinforcement properties. Some of the important coating techniques are chemical vapour deposition (CVD), physical vapour deposition (PVD), thermal spraying, sol-gel process, electrolytic, electroless and cementation methods.

1.7 What is Fly Ash?

Fly ash is one of the residues generated in the combustion of coal. It is an industrial by product recovered from the flue gas of coal burning electric power plants. Depending upon the source and makeup of the coal being burned, the components of the fly ash produced vary considerably, but all fly ash includes substantial amounts of silica (silicon dioxide, SiO_2) (both amorphous and crystalline) and lime (calcium oxide, CaO). In general, fly ash consists of SiO_2, Al_2O_3, and Fe_2O_3 as major constituents and oxides of Mg, Ca, Na, K etc. as minor constituent. Fly ash particles are mostly spherical in shape and range from less than 1 μm to 100 μm. The specific gravity of fly ash vary in the range of 0.6-2.8. Coal fly ash has many uses including as a cement additive, in masonry blocks, as a concrete admixture, as a material in lightweight alloys, as a concrete aggregate, in flow able fill materials, in roadway/runway construction, in structural fill materials, as roofing granules, and in grouting. The largest application of fly ash is in the cement and concrete industry, though, creative new uses for fly ash are being actively sought like use of fly ash for the fabrication of MMCs.

1.7 .1 Classification of Fly-ash

a. **Classification on the basis of Chemical Composition:** Fly ash can be classified into three classes, N, F and C, based on the chemical composition. According to ASTM C618, the chemical requirements to classify any fly ash are shown:

Properties	**Class N**	**Class F**	**Class C**
Silicon dioxide (SiO2) plus aluminum oxide (Al_2O_3) plus iron oxide (Fe_2O_3), min, %	70.0	70	50
Sulfur trioxide (SO_3), max, %	4	5	5
Moisture Content, max, %	3	3	3
Loss on ignition, max, %	10	6	6

b. **Classification on basis of size, shape and structure:**

- **Precipitator fly ash:** It is spherical in nature, the spheres are solid and the density is in the range of 2.0–2.5 gcm^{-3}
- **Cenosphere fly ash:** It is also spherical in shape but these spheres are hollow, so the density of this kind of fly ash is very less as compared to the precipitator fly ash. Here density is less than 1 gm cm-3 (0.3-0.6gm/cc).

1.7 .2 Why Fly-ash and Aluminum?

Aluminum alloys possess a number of characteristics that make them attractive for automotive and aerospace applications: low density, good resistance to corrosion, low thermal expansion, and established casting techniques for mass production [1].Advances in the science of MMCs present us an opportunity to design light-weight aluminum based materials with precise balances of mechanical and physical properties [2].Besides, the energy consumption of aluminum industry is about 25% of the total energy consumed by metals industry in the United States. In view of increasing cost of primary metals including aluminum, and of energy in recent times, incorporation of low cost and lower energy consuming reinforcements and fillers in metals has become increasingly attractive. If even 1% of aluminum could be replaced by fillers, the total energy saving could be of the order of 5×1011 kWh, making aluminum foundries more competitive [5]. Fly ash, a waste by-product generated by combustion of coal in thermal power plants, has been successfully dispersed into cast and wrought aluminum alloys to make aluminum alloy – fly ash (ALFA) composites, which have low density and adequate properties for several automotive applications.

Over 90 million tons of fly ash is produced each year in thermal power plants and most of it is land filled. Therefore, it is readily available at no cost and requires only the energy needed for beneficiation and transportation [7].

Thus, using fly ash as filler in Al casting reduces cost, decreases density and increase hardness, stiffness, wear and abrasion resistance. It also improves the maintainability, damping capacity, coefficient of friction etc. which are needed in various industries like automotive etc. Besides, as the production of Al is reduced by the utilization of fly ash. This reduces the generation of greenhouse gases as they are produced during the bauxite processing and alumina reduction.

1.7 .3 Stir Casting

Stir Casting is a liquid state method of composite materials fabrication, in which dispersed phase is mixed with a molten metal-matrix by means of mechanical stirring. The liquid composite material is then cast by conventional casting methods. This involves incorporation of ceramic particulate into liquid aluminum melt and allowing the mixture to solidify.

Fig. 1.5 Stir Casting Setup

1.8 The Taguchi Method for Experimental Design:

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan who maintained that variation. Therefore, poor quality in a process affects not only the manufacturer but also society. He developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied; it allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. Analysis of variance on the collected data from the Taguchi design of experiments can be used to select new parameter values to optimize the performance characteristic.

1.8.1 Summary of Taguchi Method

The general steps involved in the Taguchi Method are as follows:

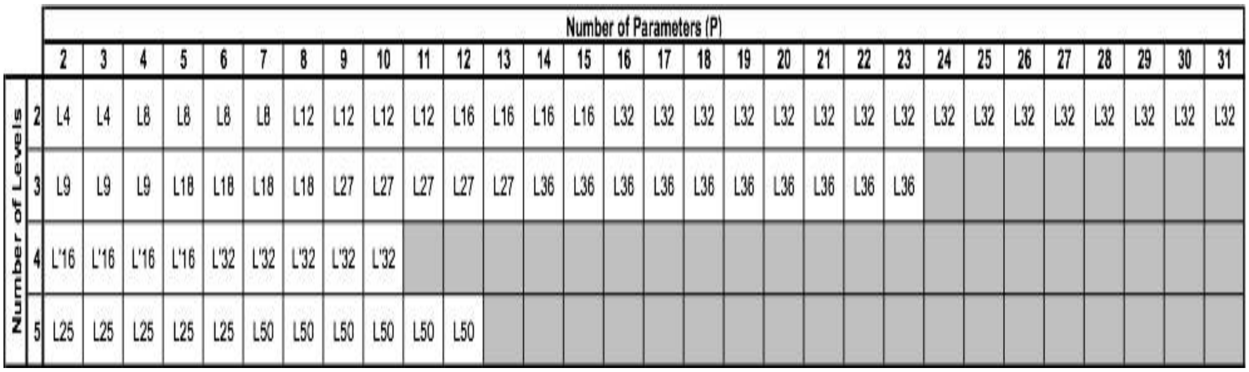
1. Define the experiment objective.
2. Determine the controlling factors affecting the process. Controllable factors are variables within the process that affect the performance measure that can be easily controlled. The number of levels that the factors should be varied at must be specified. Increasing the number of levels to vary a parameter increases the number of experiments to be conducted, but results become more precise. Thus a consensus is required to be made while selecting number of levels depending upon cost and criticality.

3. Create orthogonal arrays with selected factors and their levels, indicating the number of and conditions for each experiment. The selection of orthogonal arrays is done on the basis of array selector.
4. Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.
5. Complete data analysis to determine the effect of the different factors on the performance measures.

1.8.2 Determining Parameter Design Orthogonal Array

The effect of many different parameters on the performance characteristic in a condensed set of experiments can be examined by using the orthogonal array experimental design proposed by Taguchi. Once the parameters affecting a process that can be controlled have been determined, the levels at which these parameters should be varied must be determined. Typically, the number of levels for all parameters in the experimental design is chosen to be the same to aid in the selection of the proper orthogonal array.

Knowing the number of parameters and the number of levels, the proper orthogonal array can be selected. Using the array selector table shown below, the name of the appropriate array can be found by looking at the column and row corresponding to the number of parameters and number of levels. Once the name has been determined (the subscript represents the number of experiments that must be completed), the predefined array can be looked up.



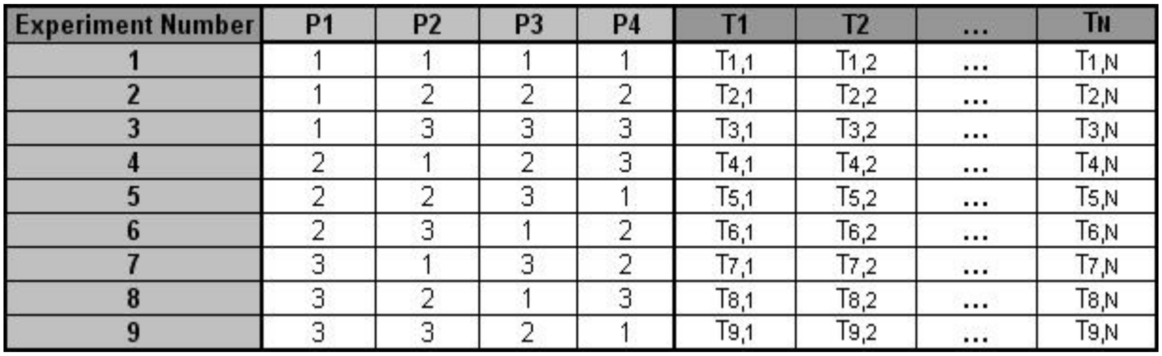
Number of Levels	Number of Parameters (P)																													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32
3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L27	L36	L36	L36	L36	L36	L36	L36	L36	L36	L36								
4	L'16	L'16	L'16	L'16	L'32	L'32	L'32	L'32	L'32																					
5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50																			

Fig. 1.6 Array Selector Tool

1.8.3 Analyzing Experimental Data

Once the experimental design has been determined and the trials have been carried out, the measured performance characteristic from each trial can be used to analyze the relative effect of the different parameters. To demonstrate the data analysis procedure, the following L9 array will be used, but the principles can be transferred to any type of array.

In this array, it can be seen that any number of repeated observations (trials) may be used. $T_{i,j}$ represents the different trials with i = experiment number and j = trial number.



Experiment Number	P1	P2	P3	P4	T1	T2	...	T_N
1	1	1	1	1	$T_{1,1}$	$T_{1,2}$	...	$T_{1,N}$
2	1	2	2	2	$T_{2,1}$	$T_{2,2}$	...	$T_{2,N}$
3	1	3	3	3	$T_{3,1}$	$T_{3,2}$	...	$T_{3,N}$
4	2	1	2	3	$T_{4,1}$	$T_{4,2}$	...	$T_{4,N}$
5	2	2	3	1	$T_{5,1}$	$T_{5,2}$	...	$T_{5,N}$
6	2	3	1	2	$T_{6,1}$	$T_{6,2}$	...	$T_{6,N}$
7	3	1	3	2	$T_{7,1}$	$T_{7,2}$	...	$T_{7,N}$
8	3	2	1	3	$T_{8,1}$	$T_{8,2}$	...	$T_{8,N}$
9	3	3	2	1	$T_{9,1}$	$T_{9,2}$	...	$T_{9,N}$

Figure 1.8 Factors and Level arrangement

To determine the effect each variable has on the output, the signal-to-noise ratio, or the SN number, needs to be calculated for each experiment conducted. The calculation of the SN for the first experiment in the array above is shown below for the case of a specific target value of the performance characteristic. In the equations below, $\overline{y_l}$ is the mean value and s_i is the variance. y_i is the value of the performance characteristic for a given experiment.

$SN_i = 10log\frac{\bar{y}_i^2}{s_i^2}$..(8)

Where

$\bar{y}_i = \frac{1}{N}\sum_{u=1}^{N_i} y_{u,i}$..(9)

$s_i^2 = \frac{1}{N}\sum_{u=1}^{N_i}(y_{i,u} - \bar{y}_i)$..(10)

i = Experiment No.

u = Trial No

N_i = No. of experiments for trial i

For the case of minimizing the performance characteristic, the following definition of the SN ratio should be calculated:

$SN_i = -10log\sum_{u=1}^{N_i}\frac{y_u^2}{N_i}$..(11)

For the case of maximizing the performance characteristic, the following definition of the SN ratio should be calculated:

$$SN_i = -10log\frac{1}{N_i}[\sum_{u=1}^{N_i}\frac{1}{y_u^2}]\text{...}(12)$$

After calculating the SN ratio for each experiment, the average SN value is calculated for each factor and level. This is done as shown below for Parameter 3 (P3) in the array:

Experiment Number	P1	P2	P3	P4	SN
1	1	1	1	1	SN1
2	1	2	2	2	SN2
3	1	3	3	3	SN3
4	2	1	2	3	SN4
5	2	2	3	1	SN5
6	2	3	1	2	SN6
7	3	1	3	2	SN7
8	3	2	1	3	SN8
9	3	3	2	1	SN9

$$SN_{P3,1} = \frac{(S_{N1}+S_{N6}+S_{N8})}{3}\text{...}(13)$$

$$SN_{P3,2} = \frac{(S_{N2}+S_{N4}+S_{N9})}{3}\text{...}(14)$$

$$SN_{P3,3} = \frac{(S_{N3}+S_{N5}+S_{N7})}{3}\text{...}(15)$$

Once these SN ratio values are calculated for each factor and level, they are tabulated as shown below and the range R (R = high SN - low SN) of the SN for each parameter is calculated and entered into the table. The larger the R value for a parameter, the larger the effect the variable has on the process. This is because the same change in signal causes a larger effect on the output variable being measured.

1.9 Wear behavior

Wear behavior is the surface damage or removal of material from one or both of two solid surfaces in a sliding, rolling, or impact motions relative to one another. So it is surface phenomenon that occurs by displacements and detachments of materials. Wear problems generally differ from those entailing outright breakage, as wear usually a progressive loss of weight and alterations of dimensions over a periods of time.

Wear is undesirable products in almost all machine applications such as bearings seals gears, and cams etc. Wear of those components may range forms mild polishing type attrition to rapid and severe removal of material accommodating with surface roughing. W heather or not wear constitutes failure of these components depends upon whether the wear deleteriously affects the ability of the components to function. Even mild polishing type ear of a close fitting pool in a hydraulic vale may cause excessive leakage and thus constitute failure, even though the surface of the pool is smooth and apparently undamaged .On the other hand, a hammer in rock crusher can continue to function satisfactorily in spite of serve detecting, gouging and removal of as much as several inches of surface metal.

1.9.1 Type of Wear:

Abrasive wear

Abrasive wear occurs when asperities of rough, hard surface or hard particles slide on a softer surface and damage the interface by plastic deformation or fracture. In case of ductile materials with high fracture toughness, hard asperities or hard particles result in the plastic flow of the softer material. Most metallic and ceramic surfaces during sliding show clear evidence of plastic flow, even some ceramic brittle materials. In one way abrasive wear is classified as gouging abrasion, high stress (grinding) abrasion. In` gouging, abrasion large particles are removed from surface, leaving dip groves and/or pits .High stress or grinding abrasion is accompanied by fracture of the abrasive particles. Low stress or scratching abrasion occurs when the loads is low enough that the abrasive particles are not fracture. Another way of classification divides abrasion into two bodies or three body abrasion. In the first case the hard surface is the harder of two rubbing surface (two body abrasion), for example, in mechanical operations such as grinding, cutting and machining. In three body abrasion; the hard surface is a third body generally a small particle of abrasive, caught between the two surfaces and sufficiently harder that is able to abrade either one or both mating surfaces, for examples, in free-abrasive lapping and polishing.

Adhesive wear

Adhesive wear occurs when two nominally flat bodies are in sliding contact, whether lubricated or not. Adhesion (or bonding) occurs at the asperity contacts at the interface, and these contacts are shared by sliding which may result in detachment of a fragment from one surface and attachment to the other surface. As the sliding continues the transferred fragment may come off the surface on which they are transferred and be transferred back to original surface,or else from loses wear particles. Some are fractured by fatigue process during repeated loading and unloading action resulting in the form of loses particles.

Corrosive wear

Wear where contribution to the wear rate by the chemical reaction with the environment. In certain cases chemical reaction is followed by removal of the corrosion product by mechanical action that is abrasion. It may be occurring that the mechanical action precedes the chemical action and results in the formation of very small particles of debris, which subsequently react with environment.

Erosive wear

Erosive wear is caused by particles that impinge on a component surface or edge and remove material from that surface due to momentum effects. This type of wear is especially noticed in components with high velocity flows such as servo and proportional valves. Particles repeatedly striking the surface may also cause denting and eventual fatigue of the surface.

Fatigue Wear

Bearing surfaces are subjected to fatigue failures as a result of repeated stressing caused by clearance size particles trapped by the two moving surfaces. At first, the surfaces are dented and cracking is initiated. These cracks spread after repeated stressing by the bearing load, even without additional particulate damage. Eventually the surface fails, producing a spall. Contamination reduces bearing life significantly through fatigue, abrasion and roughening of operating surfaces.

Fretting wear

Fretting wear is the repeated cyclical rubbing between two surfaces, which is known as fretting, over a period of time which will remove material from one or both surfaces in contact. It occurs typically in bearings, although most bearings have their surfaces hardened to resist the problem. Another problem occurs when cracks in either surface are created, known as fretting fatigue. It is the more serious of the two phenomena because it can lead to catastrophic failure of the bearing. An associated problem occurs when the small particles removed by wear are oxidized in air. The oxides are usually harder than the underlying metal, so wear accelerates as the harder particles abrade the metal surfaces further. Fretting corrosion acts in the same way, especially when water is present.

LITERATURE REVIEW

Ramaniet al. (1991) had reviewed various factors affecting the stability of the aluminium MMCs and conclusions drawn were: (i) Segregation of dispersoids out of the melt had been observed when their volume fraction exceeds a critical value for a given matrix dispersoid combination and a given set of mixing conditions. The authors [11, 12] state that segregation of the particles is driven either by surface energy or by coalescence of adsorbed gases rather than by gravity. (ii) The other parameters controlling the rejection rate were found to be: the speed of rotation of the stirrer, the critical distance of separation between dispersoids at rejection, the composition of the dispersing medium, the dispersoid size, the density difference between the matrix alloy and the dispersoid

Robi et al. (1991) had observed that the use of aluminium alloy for matrix is preferred on account of low cost and ease of handling. SiC has gained favour over other dispersoids (e.g. carbon fiber, Al_2O_3) as a result of its good thermal and chemical stability, both during synthesis and under severe service conditions, in addition to its strength, cost, and availability. However, the prime factor that dictates consistency in properties is the extent of uniformity of dispersion of the second phase in the matrix. The distribution, in turn, is controlled by solidification and later modified in processing. Similarly the wetting of the dispersoids is important in obtaining better strength properties in composites. These two factors are achieved by subjecting the dispersoids to surface treatments. In fact, during powder metallurgy processing of MMCs, SiC_p is given a surface treatment using K_2ZrF_6 in order to obtain uniform distribution of the SiC_p in the matrix [14] The increased UTS values noted with Mg added composites clearly reflect the improvement in bonding between SiC_p and Matrix.

Mykura and Mykura (1992) had found that the commercial availability of MMCswas increasing. A range of continuous filament reinforced aluminum alloy MMCs had become available and they had measured the coefficients of thermal expansion (CTE) of several of MMCs to gain adequate knowledge of the (usually anisotropic) thermal properties of these materials as it was necessary for the proper engineering design for many MMC applications. They concluded that in general the matrix CTE is much larger than that of the reinforcing fibre. Internal stresses therefore arise in the composite as the temperature changes. This causes anisotropic CTEs, particularly in unidirectional reinforced composites. Asymmetrically reinforced specimens bend under these thermal stresses and at higher temperatures creep relaxation of the matrix occurs. The authors had examined these effects in specimens asymmetrically reinforced with mono-filament carbon fiber and thus evaluated the stress distribution and interface stress by using bending beam theory.

Lloyd(1994) discussed the high cost involved in making continuous fiber reinforced MMCs and properties were also not very good. This led to the development of discontinuously reinforced composites, particularly short staple Al_2O_3 fibers and SiC whisker reinforced composites. Discontinuous fibers have found commercial application as selective reinforcement in the ring land area of diesel pistons, and whisker reinforcement is under development for aerospace applications. Particle reinforced light metals, with their potential as low cost, high modulus and strength, high wear resistance, and easily fabricated material, are just reaching the commercial production stage. Author studied various factors affecting aluminum MMC properties, taking into consideration the work of past 5 years. The objective of the present paper was to identify some of the key factors which need to be controlled for having the best combination of Properties.

Pai et al. (1995)observed that *w*etting between the dispersoid and the matrix alloy is the foremost requirement during the preparation of MMCs especially with the casting/liquid metal processing technique. The basic principles involved in improving wetting fall under three categories: (i) increasing the surface energies of the solids, (ii) decreasing the surface tension of the liquid matrix alloy, and (iii) decreasing the solid/liquid interfacial energy at the dispersoid matrix interface. The presence of magnesium, a powerful surfactant as well as a reactive element, in the aluminium alloy matrix seems to fulfill all the above three requirements. The role played by magnesium during the synthesis of aluminum alloy matrix composites with dispersoids such as zircon (ZrSiO4), zirconia (ZrO2), titania (TiO2), silica (SiO_2), graphite, aluminium oxide (Al_2O_3) and silicon carbide (SiC), had been analyzed. The important role played by the magnesium during the composite synthesis is the scavenging of the oxygen from the dispersoid surface, thus thinning the gas layer and improving wetting between dispersoids and metal matrix. Thus, the combinations of magnesium and aluminum seem to have some synergistic effect on wetting. The other treatments studied are such as coating of despersoids, chemical and ultrasound treatments, addition of reactive elements to the matrix etc.

Kainer (1996)reviewed that there are abundance of application that can involve the use of MMCs as a low cost replacement for their counterparts, i.e. alloy systems. Besides, there are ample of technological advances taking place in respect of MMCs to obtain the balance properties requirements in respect of different applications. Moreover the production processes allow the manufacturing of semi-finished products or near net shape parts.

Jeong et al. (1998)studied the effects of addition of magnesium on interface structure and high-strain-rate superplasticity in Si_3N_4-reinforced Al-alloy composites and conclusions drawn were:

(i) The Al-Cu alloy composites exhibit much lower elongations than the Al-Cu-Mg alloy composites and extensive development of cavities is found to be responsible for the much lower elongation. (ii) Existence of reaction phases was observed at the interfaces in the Al-Cu-Mg alloy composites, but no reaction phases in the Al-Cu alloy composites, mainly because of reaction at interface with addition of Mg between matrix and composites. (iii) Addition of Mg consequently reduced the melting point of the reaction phase at interface, thus partial melting at interface, that further relax the stress concentration and hence reduction in micro-cracks and cavities at the interfaces during super-plastic flow

Rajan et al. (1998)had discussed the state of art knowledge available on the surface treatments and coating work carried out on reinforcements such as carbon/graphite, silicon carbide (SiC) and alumina (Al_2O_3) and their effects on the interface, structure and properties of aluminium alloy matrix composites. The interface between the matrix and the reinforcement is the critical region that is affected during the fabrication. If this interface is not tailored properly, it can lead to the degradation of the properties of the composites. The problems associated with the interfaces are the interfacial chemical reaction, degradation of the reinforcement, lack of wettability with the matrix, etc. These interfacial problems are system-specific. Hence, it is a difficult exercise to design optimized interfaces common and suitable for all systems. Some of the methods to obtain desired interfaces with better properties are the modification of the matrix composition, coating of the reinforcement, specific treatments to the reinforcement and control of process parameters. Among these, the most important technique to improve interfacial properties is that of coating of the reinforcement. Different types of coatings have been discussed. However, appropriate techniques need to be developed for achieving controlled thickness coatings. Both multifunctional coatings and the effect of coating as hybridizing and alloying agents need detailed study.

Wu et al. (2000)Studies have been conducted on Composites of aluminum-silicon (Al – 12wt.%Si) alloy reinforced with potassium titanate whiskers were prepared by the squeeze casting process. The tensile behavior, thermal expansion and dimensional stability of such composites were investigated. Tensile tests are slightly inferior to that of as cast Al-12Si alloy. However, potassium titanium whiskers exert a beneficial effect in improving the tensile strength of Al-12Si alloy at higher temperatures. Also, Dilatometric measurements revealed that the coefficient of thermal expansion of Al-12Si alloy tends to decrease with increasing whisker content. Finally, the authors had concluded that the thermal strain response curves can be used to predict the thermal stability and failure of the structural materials on exposure to fluctuating temperature environments.

Bienias et al.(2003)had conducted the studies in regard to the corrosion behavior of aluminium MMCs with flyash as reinforced materials. The authors had come out with conclusions (i) Addition of fly ash particles as reinforcement in MMCs and synthesis of ALFA composites by squeeze casting technology is better than gravity casting for higher structural homogeneity with minimum possible porosity levels, good interfacial bonding and quite a uniform distribution of reinforcement. (ii) Fly ash particles lead to an enhanced pitting corrosion of the AK12/9.0% fly ash composite in comparison with unreinforced matrix (AK12 alloy) mainly due to introduction of nobler second phase of fly ash particles.

Prasad and Asthana (2004) evaluated friction and wear behavior of Aluminum MMCs produced with varying processes and variables. The friction and wear behavior of the materials is a critical aspect for use of these in automotive and other critical applications. The authors come up with conclusions: Aluminum matrix with reinforcing materials such as Al_2O_3 and SiC are found to have very superior properties. Considerable reduction in wear and friction is achieved by use of these particulates. Besides, increased cylinder pressures (and therefore, higher engine performance) are possible because Al MMCs can withstand high mechanical and thermal loads, and reduce heat losses by permitting closer fit that can be achieved because of lower thermal expansion coefficient of Al MMCs.

Rohatgi et al.(2006)had made attempts of incorporating fly ash into aluminum castings to decrease the energy content, material content, cost, and weight of selected industrial components, while also improving selected properties. It is shown that fly ash can be incorporated in aluminum alloy matrix using stir casting and pressure infiltration techniques. The sand and permanent mold castings, which included differential covers, intake manifolds, brake drums and outdoor equipment castings, including post caps demonstrate adequate castability of aluminum melts containing up to 10 vol.% fly ash particles. The potential cost, energy and pollution savings as a result of incorporation of fly ash in aluminum are also discussed.

Nam et al. (2008)investigated the thermal Expansion behaviour of aluminium matrix composites with densely packed SiC particles. The coefficient of thermal expansion (CTE) of Al-based MMCs containing 70 vol. % SiC particles (AlSiC) has been measured based on the length change from room temperature (RT) to 500 °C. In the work, this instantaneous CTE (T) of AlSiC is studied by thermo-elastic models and micromechanical simulation using finite element analysis. . The CTE (T) is modelled for heating and cooling cycles from 20 °C to 500 °C considering the effects of microscopic voids and phase connectivity. The thermal expansion behaviour is strongly influenced by the presence of voids and confirms qualitatively that they cause the experimentally observed decrease of the CTE (T) above 250 °C.

Candan et al. (2010)had investigated the wetting of SiC by aluminum–magnesium alloys with a sessile drop apparatus that strips the surface oxide from the molten alloy droplet so that, at least at the instant of initial contact, it is not interfering with the measurements. The measurements have been carried out at 750^0C for times up to 60 min and for alloys ranging in magnesium content from 2 to 14 wt%. Magnesium is found to play a key role in the adhesion, or otherwise, of the droplet to the substrate.

Jit et al. (2011)had conducted the studies for various sizes of the reinforcement particulates with aluminum alloy as matrix. Moreover the interfacial and density studies had also been done by the authors. The authors came out with results that a relatively greater degree of agglomeration of SiC, Al_2O_3, MgO particles based composites is noted as compare to un-reinforced Al alloys. The interface bonding between the matrix and reinforced particles are quite sharp indicating reasonably good bonding. As the density increases, the MMC becomes stiffer since the molecules do not have as much space to move around one another. It was observed that the value of porosity is found to increase with reinforcement. SiC with an average size of grain sizes of 0.220μm had considerably lower porosity contents, good strength and increased ductility in comparison with the other counterparts.

Dasgupta (2012) had found that aluminium alloy-based MMCs (AMMCs) have been by now established themselves as a suitable wear resistant material especially for sliding wear applications. However, in actual practice engineering components usually encounter combination of wear types. An attempt has been made in the present paper to highlight the effect of dispersing

SiC in 2014base alloy (composition Cu-4.5%, Fe-0.5%, Mg-0.5%, balance Al) adopting the liquid metallurgy route on different wear modes like sliding, abrasion, erosion, and combinations of wear modes like cavitation erosion, erosion abrasion, sliding abrasion, and the results obtained compared with the base alloy. Again making composites reduces the volume loss in all the cases as compared to their alloy counterparts. Ageing improves the wear rate in both the alloy and composite of the 2014 system, this can be attributed to the strengthening attained on ageing. This paper highlights the improvements in different types of wear normally encountered by engineering components during service and the improvements attained in them by making composites through the liquid metallurgy route and also ageing. Two alloy systems generally used by the engineering sector amongst the different aluminium based alloys have been reported in the present study.

RESEARCH PROBLEM AND METHODOLOGY

CHAPTER 3 RESEARCH PROBLEM AND METHODOLOGY

3.1 Gaps in Literature

From the literature study, it is found that for improvement of wettability of fly ash in aluminum matrix, magnesium as reactant has not been used so far. The research carried out earlier by other researchers is focused mainly on the varying the process parameters during manufacturing to improve the interfacial bonding. The proposed work is aimed to fulfill the gap.

3.2 Research Problem

The present study is aimed to improve the interfacial bonding between fly ash reinforcement in aluminum matrix composites made by stir casting method. Taguchi design of experiments is used for determining effects of addition of reactant and changes in process variables on interfacial bonding and mechanical properties.

3.3 Objectives of the present work

1. To uniformly disperse the fly ash particles in aluminum matrix.
2. To explore suitability of magnesium for enhancing the interfacial bonding between flyash and aluminum in composites.
3. Optimization of process parameters for improvement of wear resistance, hardness and tensile strength of composites.

3.4 Methodology

1. First of all, the fly ash is preheated for 2hrs at 100^0C..
2. Aluminium is melted into a crucible at about 670 ^{0}C.
3. While the melt is stirring, magnesium and then preheated fly ash particulates are be added into the crucible. During stirring process, the impeller is frequently moved vertically within the slurry by means of stirrer position control unit.
4. Finally the composite slurry is poured into the green sand mould and allowed to cool.
5. Hexachloroethane tablets along with Argon Gas are used during solidification to minimize the effect of high temperature oxidation problems of aluminum and magnesium.
6. Step 1-6 are repeated for analyzing the effect of concentration of magnesium, fly ash and stirrer speed.
7. Mechanical tests are performed on all the composites.
8. Taguchi's DOE (Design of Experiments) is applied for analyzing the results and finding the best combinations of parameter settings that give best results.

EXPERIMENTAL WORK

CHAPTER 4 EXPERIMENT WORK

4.1 METHODOLOGY

The full factorial design is referred as the technique of defining and investigating all possible conditions in an experiment involving multiple factors while the fractional factorial design investigates only a fraction of all the combinations. Although these approaches are widely used, they have certain limitations: they are inefficient in time and cost when the number of the variables is large; they require strict mathematical treatment in the design of the experiment and in the analysis of results; the same experiment may have different designs thus produce different results; further, determination of contribution of each factors is normally not permitted in this kind of design.

The Taguchi method has been proposed to overcome these limitations by simplifying and standardizing the fractional factorial design. The methodology involves identification of controllable and uncontrollable parameters and the establishment of a series of experiments to find out the optimum combination of the parameters which has greatest influence on the performance and the least variation from the target of the design. The effect of varying parameters (Fly Ash Content (wt.%), Magnesium Content (wt.%), and Stirrer Speed).

4.2ESTABLISHMENT OF OBJECTIVE FUNCTION

The objective of the study is to evaluate the main effects of Fly Ash content, Mg. content and Stirrer speed on Mechanical and physical properties such as Wear Rate, Hardness and Tensile Strength.

Wear Rate: Smaller the better

Hardness: Larger the better

4.3 DEGREE OF FREEDOM (dof)

The number of factors and their interactions and level for factors determine the total degree of freedom required for the entire experiment. The degree of freedom for each factor is given by the number of levels minus one.

dof for each factor : k-1

where k is the number of level for each factor

dof for interactions between factors : $(k_A-1) \times (k_B-1)$

where k_A and k_B are number of level for factor A and B

Table 4.2 Degree of Freedom

Factor	Fly Ash	Mg	Stirrer Speed	Residual Error	Total
Degree of Freedom	2	2	2	2	8

4.4 SELECTION OF FACTORS

The determination of which factors to investigate depends on the responses of interest. The factors affects the responses were identified using pilot experimentation. The lists of factors studied with their levels are shown in the Table 7.1.

Table 4.1 Factor and their level

Factor	Levels		
	Level 1	Level 2	Level 3
Fly Ash (wt. %)	5	10	15
Magnesium (wt. %)	0.5	1.5	3
Stirrer Speed (RPM)	600	900	1200

The minimum degree of freedom required in the experiment are the sum of all the degrees of freedom of factors and interaction. In the present experiment setup, there are three (Fly Ash content, Mg. content and stirrer speed) 3-level factors. The total DOF for the experiment is given in Table 4.2, as the degree of freedom for the experiment is 8, the orthogonal array (OA) to be used should have more than 9 dof. The most suitable orthogonal array that can be used for this experiment is L18 mixed, which have 9 dof assigned to its various columns. The additional 8 do fare used to measure the random error.

4.6 RAW MATERIALS SELECTED

The matrix material used in the experiment investigation are

- Commercially available aluminum of 6061 grade.
- 99.5% pure Magnesium
- Fly ash (Average particle size - (50-100μm))

  Chemical composition: SiO_2–48.50%, Al_2O_3-43.63%, Fe_2O_3 – 4.83%, CaO-0.47%, MgO-0.18%.

The fly ash was collected from Guru Nanak Dev Thermal Plant, Bathinda, India.

4.7 STEPS FOLLOWED FOR SAMPLES PREPARATION

1. First of all green sand for the mould preparation was made ready with proper moisture content, by removing any foreign particles and by removal of any coagulation of sand particles.
2. Green sand mould is prepared and allowed to dry for 2 hrs. so as to impart quality to the casting.
3. Aluminum 99.5% Pure(6061 GRADE) was charged into graphite crucible and the temperature of the furnace raised upto 700^0C so as to melt Aluminum piece completely. It took around 3hrs for complete melting of Aluminum.
4. In the meantime Fly ash was preheated at 100^0C for two hours to remove the moisture.
5. After complete melting, it was degassed by purging hexachloro ethane tablets to minimize the high temperature oxidation problems.
6. Thereafter preheated Fly ash and Mg is added. Stirring is then carried out for 10 minutes and the impeller is moved up and down to disperse the reinforcement thoroughly.
7. Stirrer speed was recorded with the help of digital tachometer.

8. Then the metal was poured into the mould prepared and allowed to cool for 45 minutes.
9. All these steps were followed for all the 9 samples prepared at different levels of the 3 factors mentioned.

   Sample prepared were **457.2mm** x **76.2mm** x **8mm**

4.1 Photograph of One Sample

4.9AVERAGE PARTICLE SIZE ANALYSIS:

A sieve analysis (or gradation test) is a practice or procedure used to assess the particle size distribution (also called gradation) of a granular material.

Particle size analysis for the fly ash particles was done using Sieve Shaker available at Sand Testing Lab at Thapar University in Sand Testing Lab.

Table 4.3 Sieve Shaker Specifications

Sieve capacity:	Upto 8 full size sieves for 50 mm height
Sieve mesh size:	53 microns
	75 micons
	106 microns
	150 microns
	250 microns
	360 microns
	720 microns
	1 mm
	2 mm
Sieve dimensions:	Diameter : 200 mm
	Height: 50 mm
Power level:	Programmable (Amplitude level 0.5 mm to 2 mm)

100g fly ash was taken for this analysis. This weighed sample of fly ash was poured into the top sieve which has the largest screen openings. Each lower sieve in the column has smaller openings than the one above. At the base is a round pan, called the receiver.

The column was placed in a mechanical shaker. Then the shaking was conducted for 15 minutes. After the shaking is complete the material on each sieve was weighed. The weight of the sample of each sieve is then divided by the total weight to give a percentage retained on each sieve. Following graph **Fig 4.1** and **Table 4.4** depicts the percentage distribution for various particle sizes.

Table 4.4 Particle Size Distribution

% Retained	Mesh size (microns)
27	<53
40	53
22	75
3.7	150
2	250

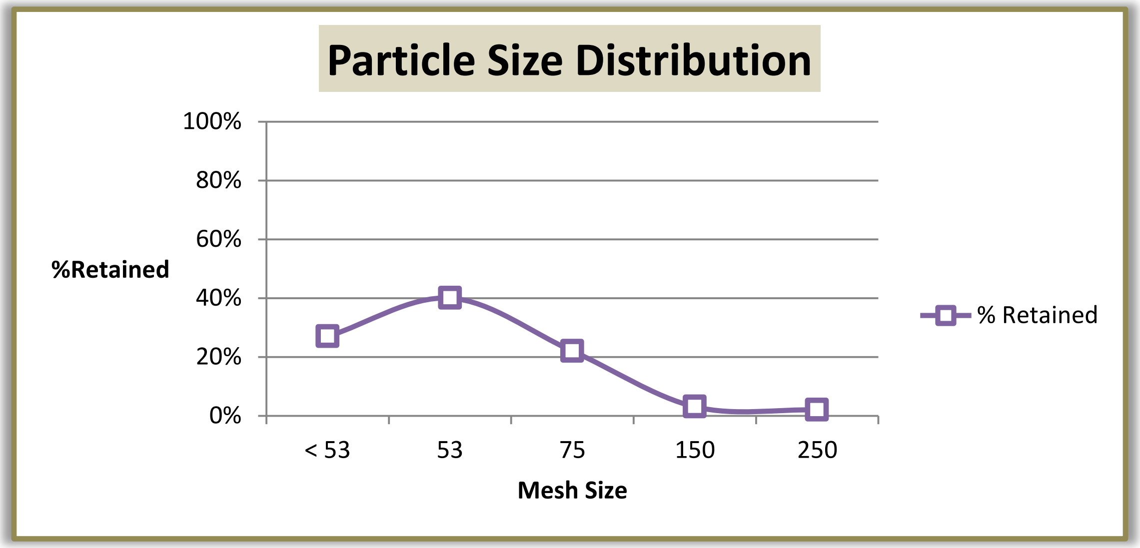


Figure 4.2

The average particle size is found out to be 53 microns. This experiment is conducted to get an insight that the properties obtained are based on which average particle size.

Figure 4.3 Sieve Shaker

4.10 PARTICLE SHAPE ANALYSIS (SEM) OF FLY ASH

SEM photographs were taken to analyze the particle shape of fly ash particles.

Figure 4.4 SEM Machine

Figure 4.5 Sample Prepared for SEM

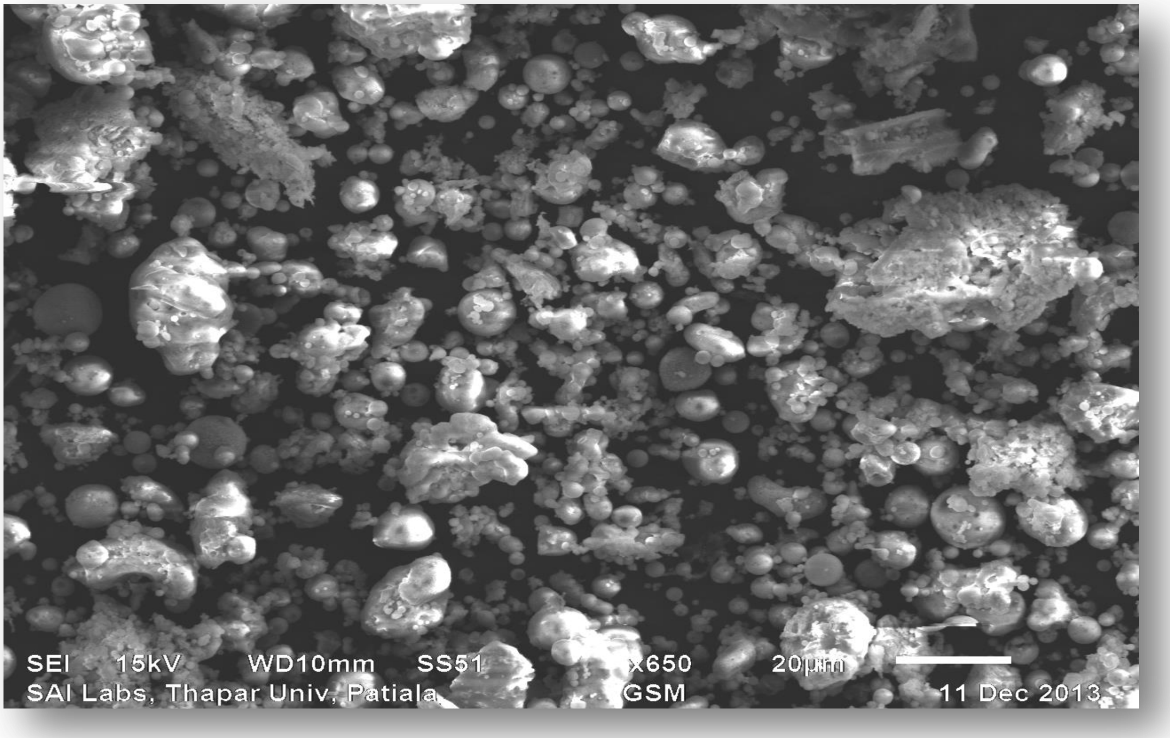


Figure 4.6 SEM Micrograph at 650X

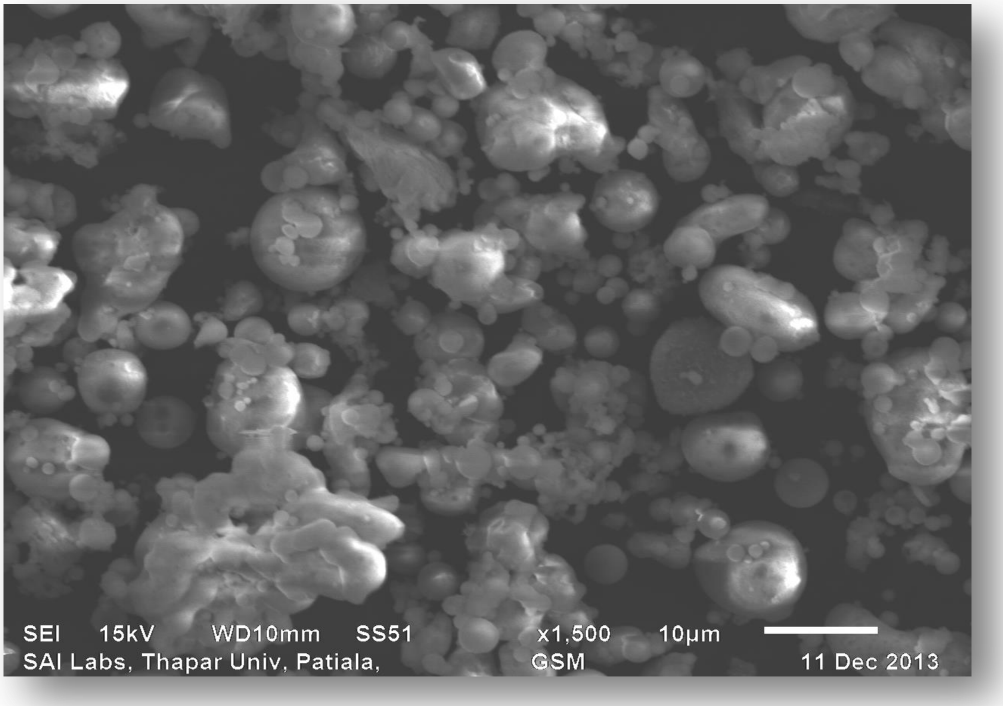


Figure 4.7 SEM Micrograph at 1500X

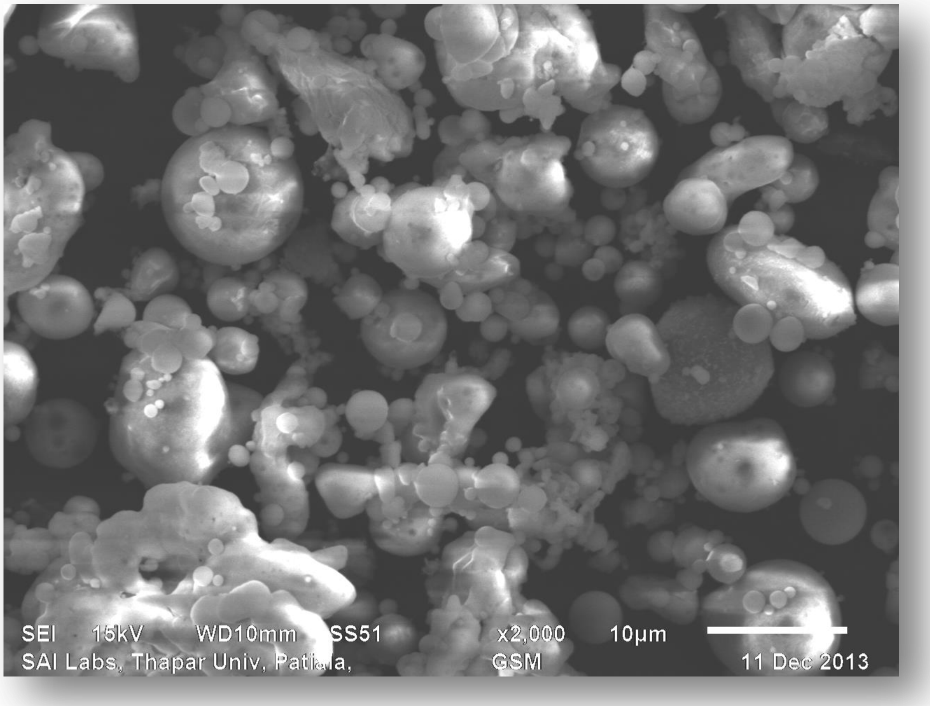


Figure 4.8 SEM Micrograph at 2000X

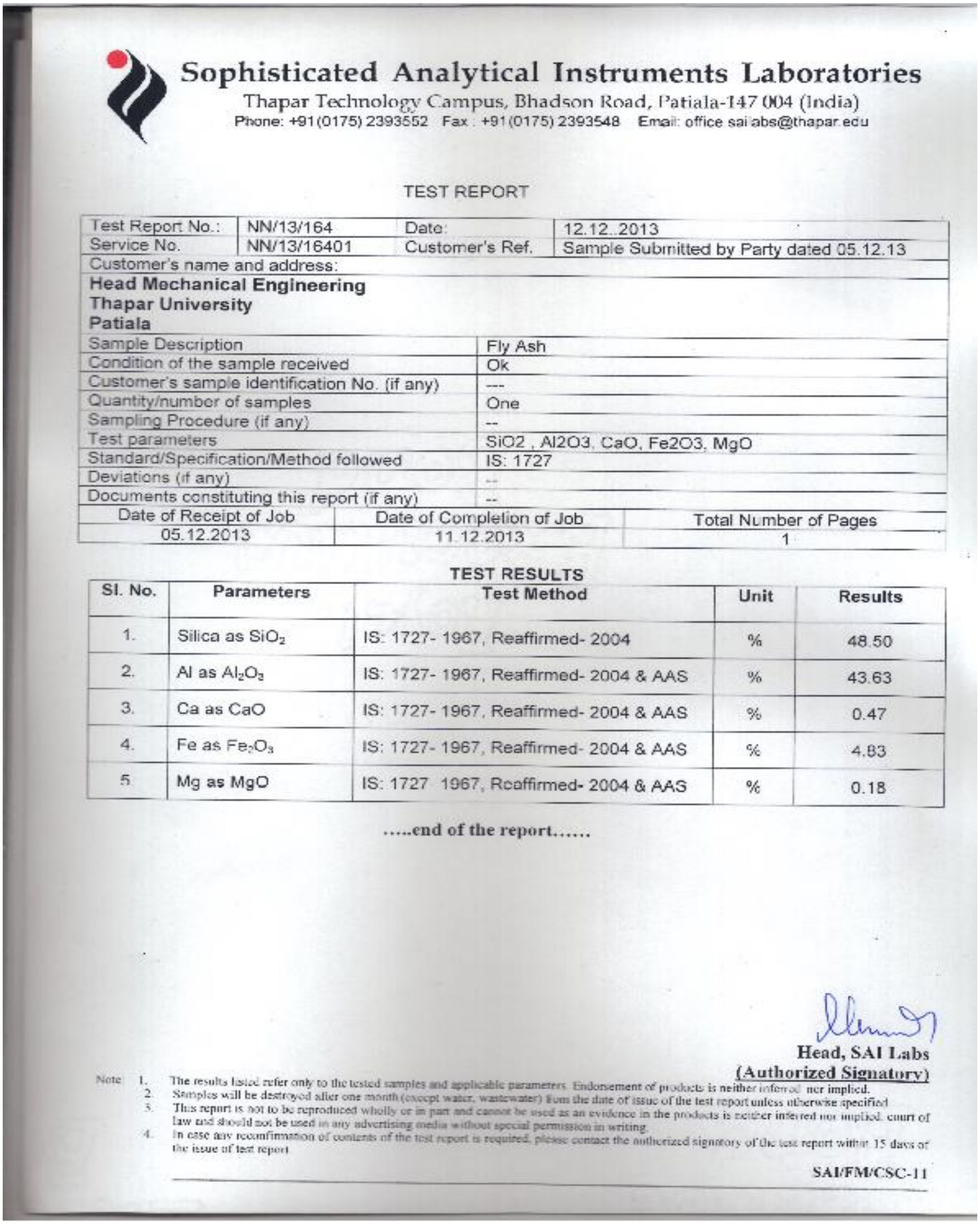
From the micrographs of Fly-Ash particles, it is clear that the particle shape is almost rounded. As discussed in section

4.11 CHEMICAL ANALYSIS OF FLY ASH

Chemical analysis of the fly ash was done and as per analysis, chemical composition of the fly as used is as under:

Table 4.5 Chemical Composition of Fly Ash

COMPOUNDS	PERCENTAGE (%)
SiO_2	48.50
Al_2O_3	43.63
Fe_2O_3	0.47
CaO	4.83
MgO	0.18



Sophisticated Analytical Instruments Laboratories

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TEST REPORT

Test Report No.:	NN/13/164	Date:	12.12..2013
Service No.	NN/13/16401	Customer's Ref.	Sample Submitted by Party dated 05.12.13

Customer's name and address:

Head Mechanical Engineering
Thapar University
Patiala

Sample Description	Fly Ash
Condition of the sample received	Ok
Customer's sample identification No. (if any)	---
Quantity/number of samples	One
Sampling Procedure (if any)	--
Test parameters	SiO2 , Al2O3, CaO, Fe2O3, MgO
Standard/Specification/Method followed	IS: 1727
Deviations (if any)	--
Documents constituting this report (if any)	--

Date of Receipt of Job	Date of Completion of Job	Total Number of Pages
05.12.2013	11.12.2013	1

TEST RESULTS

Sl. No.	Parameters	Test Method	Unit	Results
1.	Silica as SiO_2	IS: 1727- 1967, Reaffirmed- 2004	%	48.50
2.	Al as Al_2O_3	IS: 1727- 1967, Reaffirmed- 2004 & AAS	%	43.63
3.	Ca as CaO	IS: 1727- 1967, Reaffirmed- 2004 & AAS	%	0.47
4.	Fe as Fe_2O_3	IS: 1727- 1967, Reaffirmed- 2004 & AAS	%	4.83
5.	Mg as MgO	IS: 1727 1967, Reaffirmed- 2004 & AAS	%	0.18

.....end of the report......

Head, SAI Labs
(Authorized Signatory)

Note
1. The results listed refer only to the tested samples and applicable parameters. Endorsement of products is neither inferred nor implied.
2. Samples will be destroyed after one month (except water, wastewater) from the date of issue of the test report unless otherwise specified
3. This report is not to be reproduced wholly or in part and cannot be used as an evidence in the products is neither inferred nor implied. court of law and should not be used in any advertising media without special permission in writing.
4. In case any reconfirmation of contents of the test report is required, please contact the authorized signatory of the test report within 15 days of the issue of test report

SAI/FM/CSC-11

4.12 TESTS CONDUCTED

1. **Wear Test:**

   A pin on disc test apparatus isused to perform the sliding wear test on the prepared composite. Specimens of size 10 mm diameter and 50 mm length were cut from the cast samples, turned and faced at 90^0 so as to attain the complete contact with the sliding disc. During the test, the pin is held pressed against a rotating EN32 steel disc (hardness of 65HRC) by applying load that acts as counterweight and balances the pin. The track diameter was kept constant 80mm for all experiments. Standard load of 50N was also kept constant for each set of experiments. A LVDT (load cell) on the lever arm helps in monitoring the movement of the arm. Once the surface in contact wears out, the load pushes the arm to remain in contact with the disc.Weight loss of each specimen was obtained by weighing the specimen before and after the experiment by a single pan electronic weighing machine with an accuracy of 0.001g (least count) after thorough cleaning with acetone solution.Three readings were taken on each specimen to eliminate possibility of error and mean value was taken wear rate of the composites.

2. **Rockwell Hardness Test (B-Scale)**

   The Rockwell scale is a hardness scale based on indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload.

Scales and values[28]

There are several alternative scales, the most commonly used being the "B" and "C" scales.

Various Rockwell scales

Scale	**Abbreviation**	**Load**	**Indenter**	**Use**
A	HRA	50 kgf	120° diamond cone†	Tungsten carbide
B	HRB	100 kgf	$^{1}/_{16}$-inch-diameter (1.588 mm) steel sphere	Aluminium, brass, and soft steels
C	HRC	150 kgf	120° diamond cone	Harder steels >B100
D	HRD	100 kgf	120° diamond cone	
E	HRE	100 kgf	$^{1}/_{8}$-inch-diameter (3.175 mm) steel sphere	
F	HRF	60 kgf	$^{1}/_{16}$-inch-diameter (1.588 mm)	

			steel sphere	
G	HRG	150 kgf	$^{1}/_{16}$-inch-diameter (1.588 mm) steel sphere	

As per above specification, for Al and related materials Rockwell HRB test was conducted with steel ball (diameter: 1.588mm) at load of 980N.

3. **Tensile Test:**

Tensile strength tests were carried out on Al MMCs using a computerized UTM testing machine as per the ASTM E-8 standards.

RESULTS AND DISCUSSIONS

CHAPTER 5 RESULTS AND DISCUSSIONS

5.1 Result and Analysis of Wear Behavior

The effects of control parameters i.e. fly ash content, magnesium content and stirrer speedon wear rate are evaluated using ANOVA. A confidence interval of 95% has been used for the analysis. Threerepetitions for each of 10runswere completed to measure the Signal to Noise ratio(S/N Ratio).The control parameter with the strongest influence was determined by the difference between the maximum and minimum value of the mean of S/N ratios. Higher the difference between the mean of S/N ratios, the more influential will be the control parameter.

The wear rates of the specimens are evaluated based on initial weight and final weight after subjecting the samples to sliding wear by keeping the following parameters constant

Load – 50N, Frictional Force – 156N, at 2.5 m/s sliding speed, Track diameter – 80mm

Table 5.2 Result of Wear rates for all 10 samples with 3 trials each

Sample No.	Fly Ash (wt%)	Mg. (wt.%)	RPM	Initial Wt (g)	Final Wt (g)	Wear Rate (g/min)	Initial Wt (g)	Final Wt (g)	Wear Rate (g/min)	Initial Wt (g)	Final Wt (g)	Wear Rate (g/min)
1	5	0.5	600	9.235	9.104	0.0142	9.104	8.976	0.0141	8.976	8.850	0.014
2	5	1.5	900	8.970	8.853	0.013	8.853	8.736	0.0132	8.736	8.620	0.0133
3	5	3	1200	8.777	8.656	0.0137	8.656	8.537	0.0138	8.537	8.420	0.0137
4	10	0.5	900	8.389	8.295	0.0112	8.295	8.203	0.0111	8.203	8.110	0.0113
5	10	1.5	1200	8.278	8.193	0.0103	8.193	8.109	0.0102	8.109	8.028	0.01
6	10	3	600	9.133	9.033	0.011	9.033	8.934	0.0109	8.934	8.838	0.0108
7	15	0.5	1200	8.670	8.559	0.0128	8.559	8.448	0.013	8.448	8.339	0.0129
8	15	1.5	600	7.878	7.784	0.012	7.784	7.693	0.0117	7.693	7.601	0.0119
9	15	3	900	9.995	9.871	0.0124	9.871	9.750	0.0123	9.750	9.628	0.0125
10	Pure Aluminum			8.42	8.29	0.0149	8.29	8.17	0.0151	8.170	8.05	0.0152

5.1.1 S/N Ratio and Mean Response Analysis

The experiments were conducted based on the run order generated by Taguchi model and the results were obtained. This analysis includes the ranks based on the delta statistics, which compares the relative value of the effects. S/N ratio is a response which consolidates repetitions and the effect of noise levels into one data point. Analysis of variance of the S/N ratio is performed to identify the statistically significant parameters. The analyses of the experimental data were carried out using MINITAB 14 software, which is specially used for DOE applications.

The experimental results were transformed into signal-to-noise (S/N) ratios. S/N ratio is defined as the ratio of the mean of the signal to the standard deviation of the noise. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors. The S/N ratio for wear rate using “smaller the better characteristic”, which can be calculated as logarithmic transformation of the loss function, is given as:

$S/N = -10 \log [(\Sigma y^2)*1/n]$ where y is the observed data (wear) and n is the number of observations.

Table 5.3 Response Table for SN Ratios – Smaller the Better

Level	FA	Mg	RPM
1	37.29	37.94	38.26
2	39.37	38.66	38.25
3	38.14	38.21	38.3
Delta	2.08	0.72	0.04
Rank	**1**	**2**	**3**

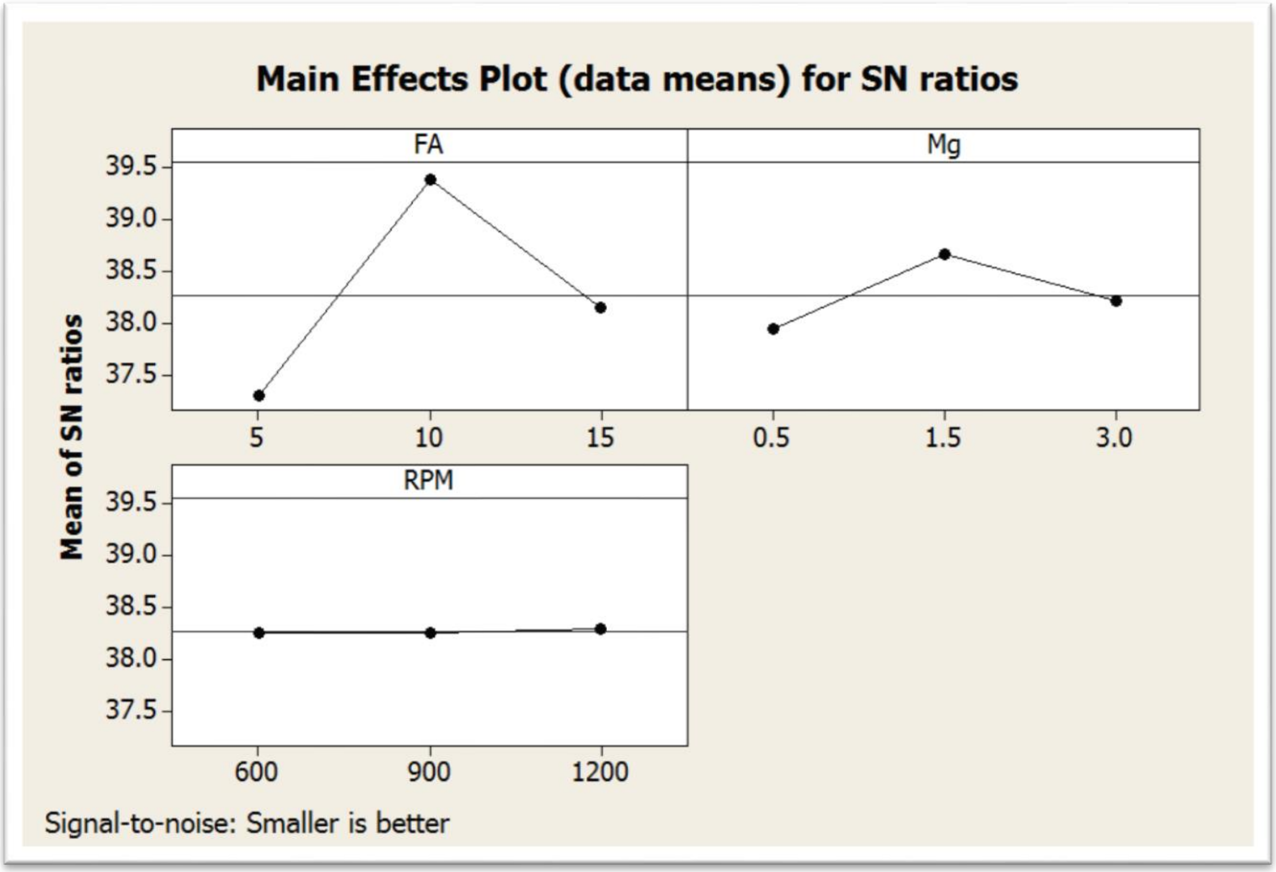

Figure 5.1 Main effect plot for S/N ratio

The above S/N ratio transformation is suitable for minimization of wear rate.

Table 5.4 Response Table for Means (Wear Rate)

Level	FA	Mg	RPM
1	0.01367	0.01273	0.01229
2	0.01076	0.01173	0.01226
3	0.01239	0.01234	0.01227
Delta	0.00291	0.001	0.00003
Rank	**1**	**2**	**3**

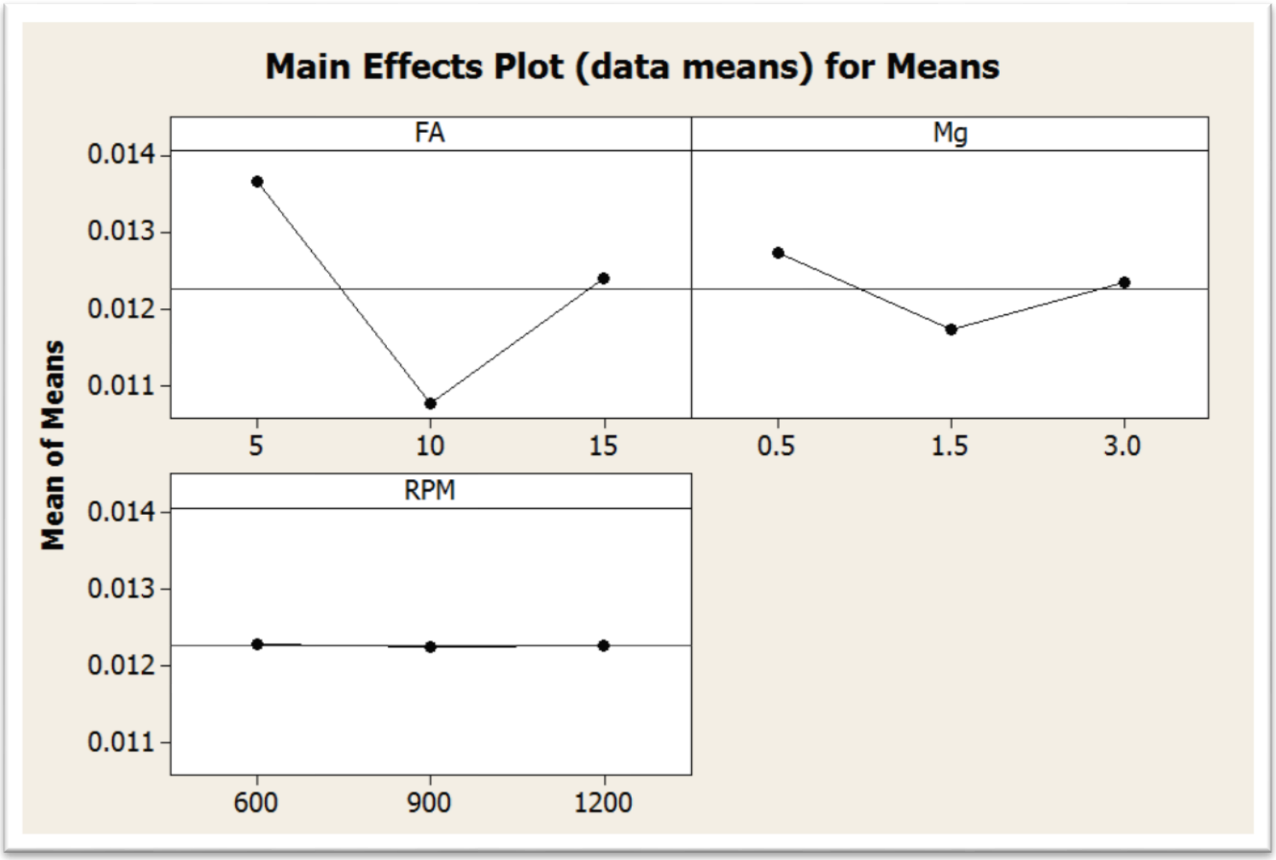

Figure 5.2 Main effect plot for mean

5.1.2 Analysis of Variances

The experiments were conducted as per orthogonal array and the wear rate results obtained in terms of S/N ratios for various combinations of parameters are shown in **Table 5.5**. The experimental values were transformed into S/N ratios for measuring the quality characteristics using MINITAB 14.

Table 5.5 S/N ratio and Mean

Expt. No.	Fly Ash (wt%)	Mg. (wt.%)	RPM	S/N Ratio	Mean
1	5	0.5	600	36.9507	0.014148
2	5	1.5	900	37.6631	0.013115
3	5	3	1200	37.2563	0.013737
4	10	0.5	900	39.0272	0.011204
5	10	1.5	1200	39.791	0.010215
6	10	3	600	39.3042	0.010848
7	15	0.5	1200	37.841	0.012848
8	15	1.5	600	38.5248	0.01187
9	15	3	900	38.0666	0.012448

Table 5.6 Analysis of Variance for SN ratio

Source	DF	Seq SS	Adj SS	Adj MS	F	P	SS	% Contribution
FA	2	6.5861	6.5861	3.29305	307.34	0.003	6.58586	89.20
Mg	2	0.79395	0.79395	0.39697	37.05	0.026	0.794017	10.75
RPM	2	0.00328	0.00328	0.00164	0.15	0.867	0.003287	0.04
ResidualError	2	0.02143	0.02143	0.01071				
Total	8	7.40476						

Table 5.7 Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
FA	2	0.000013	0.000013	0.000006	848.18	0.001
Mg	2	0.000002	0.000002	0.000001	101.23	0.01
RPM	2	0	0	0	0.11	0.897
ResidualError	2	0	0	0		
Total	8	0.000014				

ANOVA was used to determine the design parameters significantly influencing the wear rate (response). **Table 5.7** shows the results of ANOVA for wear rate. This analysis was evaluated for a confidence level of 95%, that is for significance level of α=0.05. The last column of Table 5.5 shows the percentage ofcontribution (P %) of each parameter on the response, indicating the degree of influence on the result. It can be observed from the results obtained that Fly Ash Content [89.20%], Magnesium [10.75%] and RPM[0.044%] which are influencing wear rate of Al6061 MMC.

Table 5.8 Best Combination of Factor Levels

Factor	Affecting Mean		Affecting Variation	
	Contribution	Best Level	Contribution	Best Level
Fly Ash Content	Significant	Level-2 (10%)	Significant	Level-2 (10%)
Mg. Content	Significant	Level-2 (1.5%)	Significant	Level-2 (1.5%)
Stirrer Speed (RPM)	Insignificant	---	Insignificant	---

5.2 Result and Analysis of Hardness

The effects of control parameters i.e. Fly ash content, Magnesium content and Stirrer Speed on Hardness were evaluated using ANOVA. A confidence interval of 95% has been used for the analysis. Three repetitions for each of 10 runs were completed to measure the Signal to Noise ratio (S/N Ratio). The control parameter with the strongest influence was determined by the difference between the maximum and minimum value of the mean of S/N ratios. Higher the difference between the mean of S/N ratios, the more influential will be the control parameter.

The hardness of each of the 10 samples were evaluated with following parameters constant

Test – HRB (Rockwell B-Scale for soft materials)

Indenter – Steel Ball (diameter:1.588mm), Load – 100Kgf

Table 5.9 Rockwell Test Readings for 10 samples

Sample No.	Fly Ash (wt%)	Mg. (wt.%)	RPM	Trial 1 (HRB)	Trial 2 (HRB)	Trial 3 (HRB)
1	5	0.5	600	60	61	62
2	5	1.5	900	70	69	69.5
3	5	3	1200	66	66.5	65
4	10	0.5	900	73.5	74	75.5
5	10	1.5	1200	85	84	83
6	10	3	600	78	77	77.5
7	15	0.5	1200	66	67	66.5
8	15	1.5	600	70	71	69.5
9	15	3	900	64	63	65
10	PURE Aluminum			58	57	56

5.2.1 SN Ratio and Mean Response Analysis

The experimental results were transformed into signal-to-noise (S/N) ratios. S/N ratio is defined as the ratio of the mean of the signal to the standard deviation of the noise. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors. The S/N ratio for Hardness using "larger the better characteristic", which can be calculated as logarithmic transformation of the loss function, is given as:

$S/N = -10 \log [(1/\Sigma y^2)*1/n]$ where y is the observed data (hardness) and n is the number of observations.

Table 5.11 Response Table for S/N ratio– Larger the Better

Level	Fly Ash	Mg	Stirrer Speed (RPM)
1	36.3	36.53	36.8
2	37.9	37.42	36.79
3	36.5	36.76	37.1
Delta	**1.59**	**0.89**	**0.31**
Rank	**1**	**2**	**3**

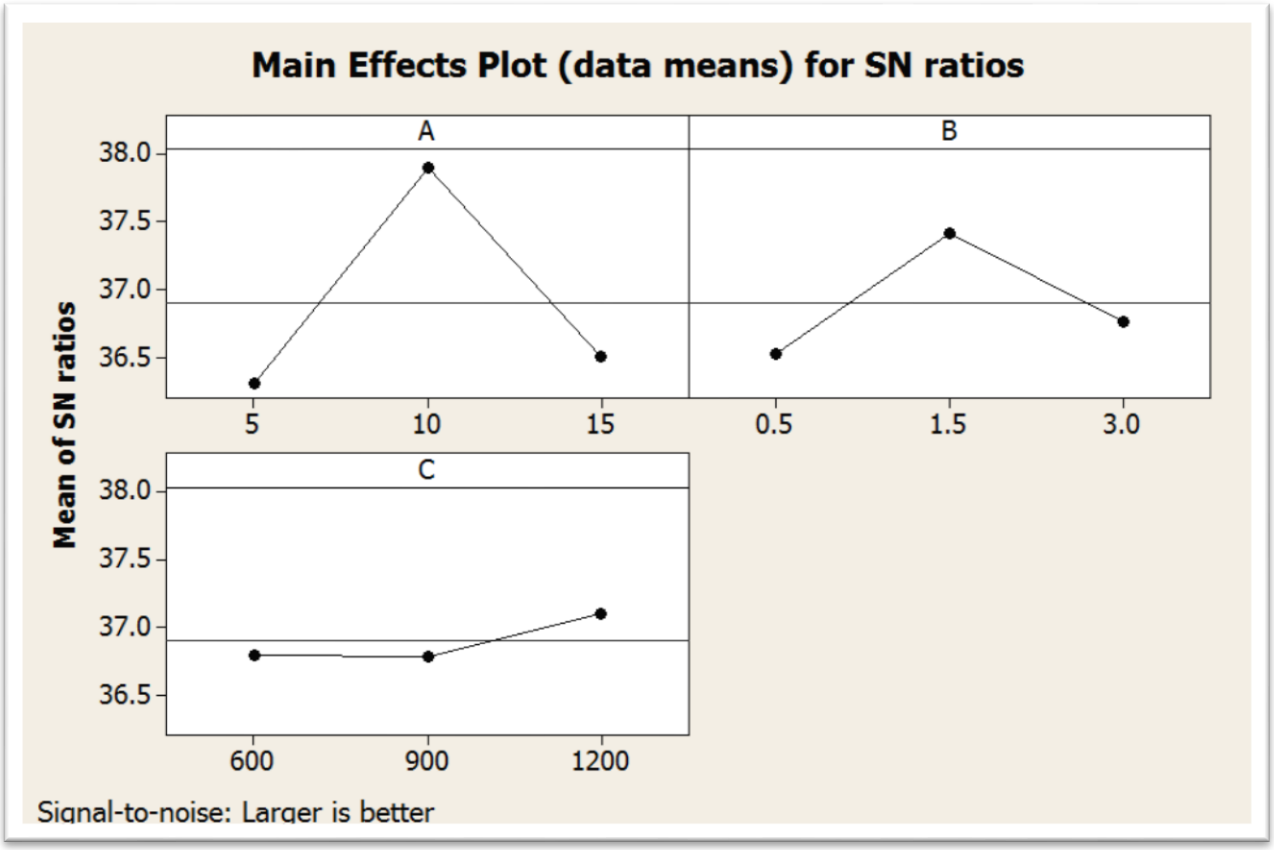

Figure 5.4

Table 5.12 Response Table for Mean – Larger the Better

Level	Fly Ash	Mg	Stirrer Speed (RPM)
1	65.44	67.28	69.56
2	78.61	74.56	69.28
3	66.89	69.11	72.11
Delta	**13.17**	**7.28**	**2.83**
Rank	**1**	**2**	**3**

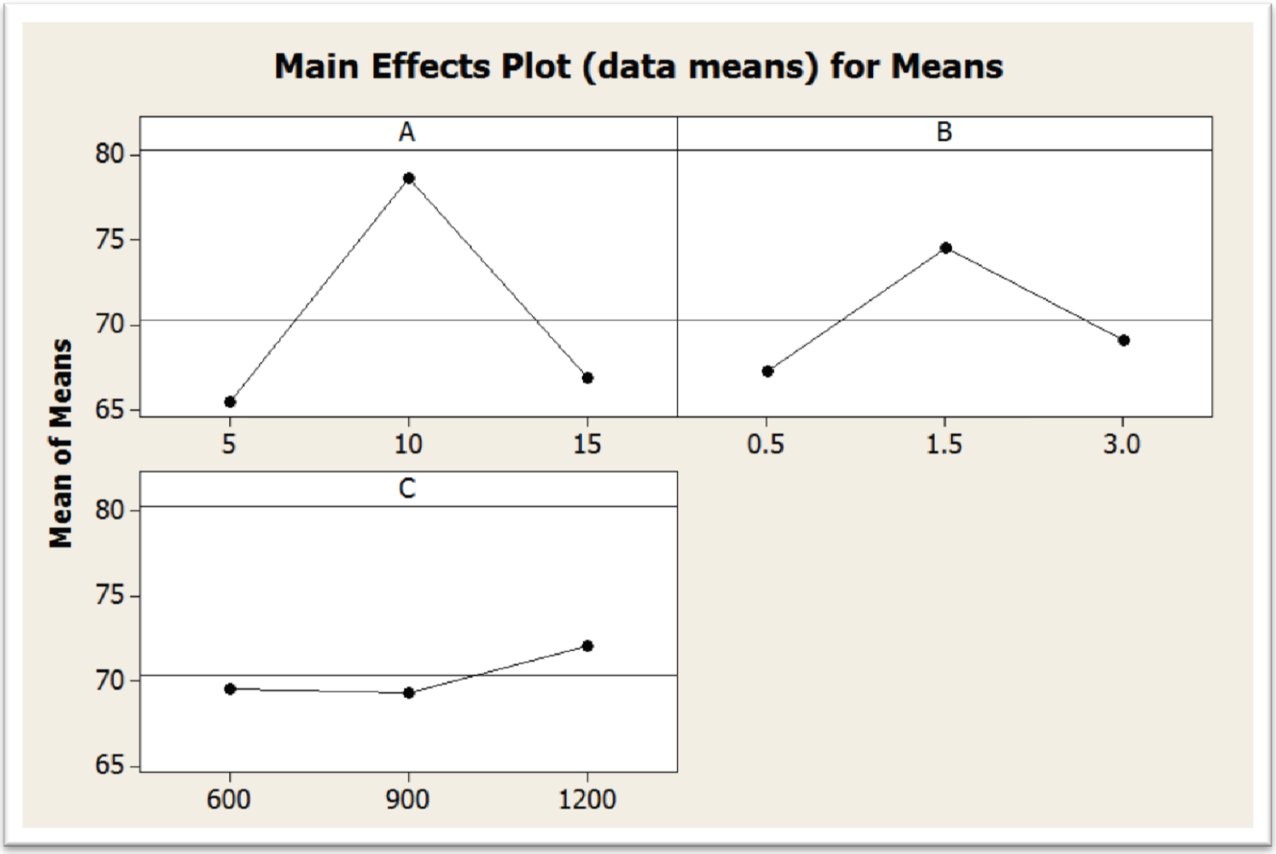

Figure 5.5

5.2.2 Analysis of Variances

The experiments were conducted as per orthogonal array and the hardness results also obtained in terms of S/N ratios for various combinations of parameters are shown in **Table 5.10**. The experimental values were transformed into S/N ratios for measuring the quality characteristics using MINITAB 14.

Table 5.10 S/N ratio and Mean

Expt. No.	Fly Ash (wt. %)	Mg. (Wt. %)	RPM	S/N Ratio	Mean
1	5	0.5	600	35.8345	61.6481
2	5	1.5	900	36.7125	68.6481
3	5	3	1200	36.3642	66.037
4	10	0.5	900	37.4185	74.537
5	10	1.5	1200	38.6146	84.6481
6	10	3	600	37.659	76.6481
7	15	0.5	1200	36.3292	65.6481
8	15	1.5	600	36.9181	70.3704
9	15	3	900	36.2517	64.6481

Table 5.11 Analysis of Variance for S/N ratio

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**SS**	**% Contribution**
Fly Ash Content	2	4.53137	4.53137	2.26569	45.74	0.021	4.531622	75.669
Mg content	2	1.27261	1.27261	0.63631	12.85	0.072	1.272609	21.250
Stirrer Speed (RPM)	2	0.18453	0.18453	0.09227	1.86	0.349	0.184505	3.081
Residual Error	2	0.09907	0.09907	0.04953				
Total	**8**	**6.08759**						

Table 5.12 Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Fly Ash Content	2	312.858	312.858	156.429	87.84	0.011
Mg content	2	85.969	85.969	42.985	24.14	0.04
Stirrer Speed (RPM)	2	14.636	14.636	7.318	4.11	0.196
Residual Error	2	3.562	3.562	1.781		
Total	**8**	**417.025**				

ANOVA was again used to determine the design parameters significantly influencing the Hardness (response). **Table 5.11** shows the results of ANOVA for Hardness. This analysis was evaluated for a confidence level of 95%, that is for significance level of α=0.05. The last column of Table 5.11 shows the percentage ofcontribution (P %) of each parameter on the response, indicating the degree of influence on the result. It can be observed from the results obtained that Fly Ash Content [75.67%], Magnesium [21.25%] and RPM[3.08%] which are influencing Hardness of Al6061 MMC.

Table 5.13 Best Combination of Factor Levels

Factor	**Affecting Mean**		**Affecting Variation**	
	Contribution	Best Level	Contribution	Best Level
Fly Ash Content	Significant	Level-2 (10%)	Significant	Level-2 (10%)
Mg. Content	Significant	Level-2 (1.5%)	Significant	Level-2 (1.5%)
Stirrer Speed (RPM)	Insignificant	Level-3 (1200 RPM)	Insignificant	Level-3 (1200 RPM)

5.3 Results and Analysis of Tensile Strength

All the samples casted were subjected to tensile loading using a computerized UTM testing machine as per the ASTM E-8 standards. Tensile strength was evaluated for breaking point with load speed ratio of 15kN/min. Specimens with **457.2mm** x **76.2mm** x **8mm**dimensions were used to evaluate ultimate tensile strength. The comparison of the properties of the composite material was made with the commercially pure Al.

Figure 5.5 – 5.15 depicts the tensile loading characteristics of factors at all levels

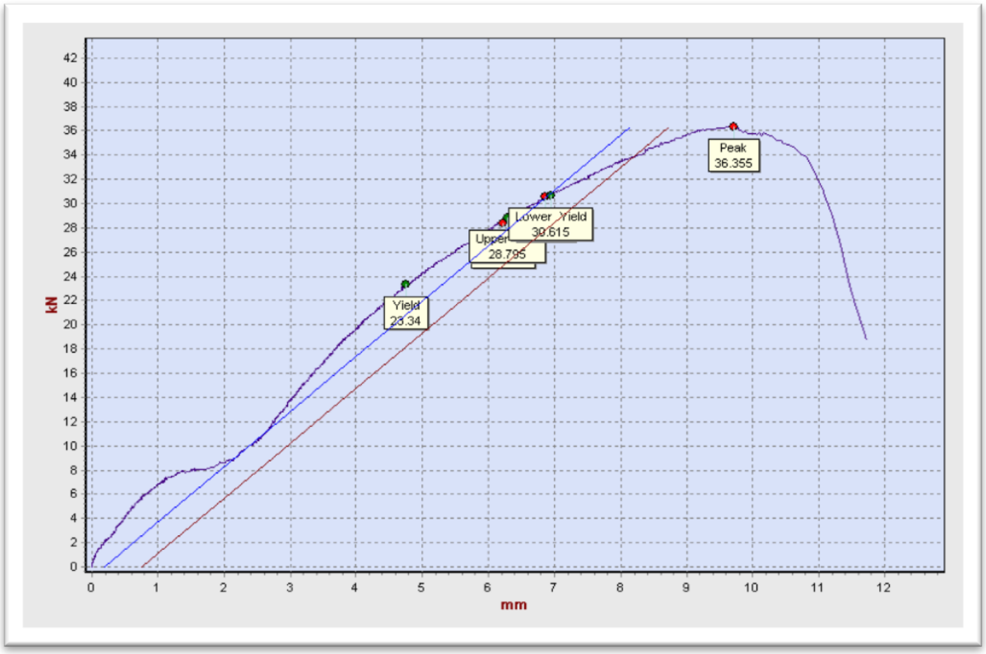

Figure 5.6 (Load vs elongation for Sample 1)

Figure 5.6 shows the percent elongation and load characteristics of 6061 Aluminum with factors at (5%FA, 0.5%Mg, 600RPM)levels. In relation to pure aluminum there is slight increase in tensile strength (i.e. 36.355 kN vs 35.97kN) and %age elongation reduced from 29mm to 9.5mm at breakage point.

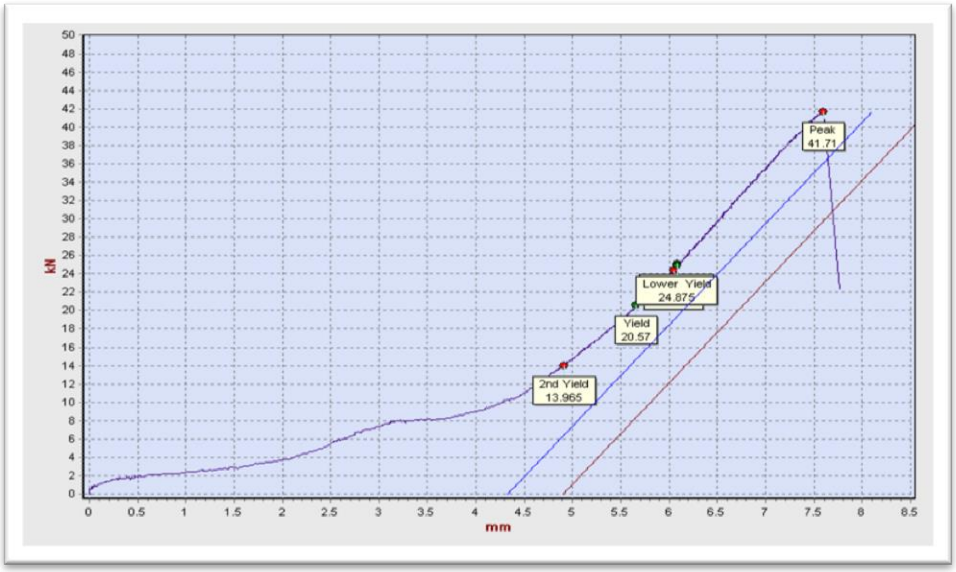

Figure 5.7(Load vs elongation for Sample 2)

Figure 5.7 shows the percent elongation and load characteristics of 6061 Aluminum with factors at (5%FA, 1.5%Mg, 900RPM) levels. In relation to factors at (5%FA, 0.5%Mg, 600RPM) there is slight increase in tensile strength (i.e. 41.71kN vs 36.355 kN) and %age elongation reduced from 9.5mm to 7.6 mm at breakage point.

Figure 5.8 (Load vs elongation for Sample 3)

Figure 5.8 shows the percent elongation and load characteristics of 6061 Aluminum with factors at (5%FA, 3%Mg, 1200RPM) levels. In relation to factors at (5%FA, 1.5%Mg, 900RPM) there is slight reduction in tensile strength (i.e. 39.8kN vs 41.71 kN) and %age elongation reduced from 7.6mm to 6.6 mm at breakage point.

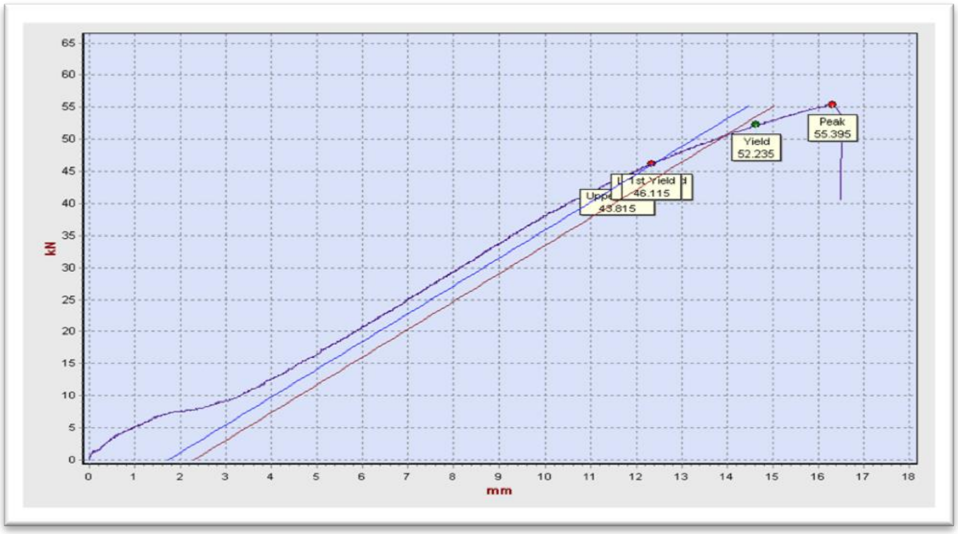

Figure 5.9 (Load vs elongation for Sample 4)

Figure 5.9 shows the percent elongation and load characteristics of 6061 Aluminum with factors at (10%FA, 0.5%Mg, 900RPM) levels. In relation to factors at (5%FA, 3%Mg, 1200RPM) there is great increase in tensile strength (i.e. 55.395kN vs 39.8 kN) and %age elongation also increased from 6.6 mm 16.3mm at breakage point, i.e. this combination of factors lead to good tensile strength and good ductility.

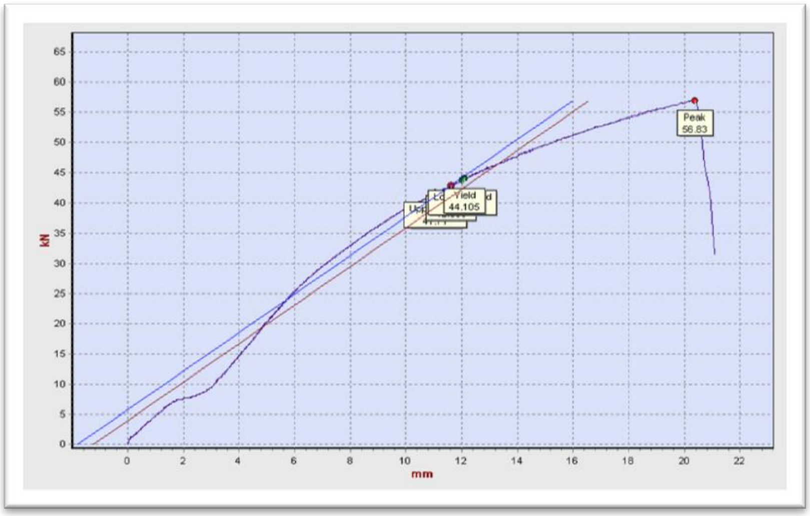

Figure 5.10 (Load vs elongation for Sample 5)

Figure 5.10 shows the percent elongation and load characteristics of 6061 Aluminum with factors at (10%FA, 1.5%Mg, 1200RPM) levels. In relation to factors at (10%FA, 0.5%Mg, 900RPM) there is a further improvement in tensile strength (i.e. 56.83kN vs 55.395kN) and %age elongation also further increased from 16.3 mm to 20.5mm at breakage point. Thus this combination of factors is a further improvement in relation to both aspects i.e. tensile strength and ductility.

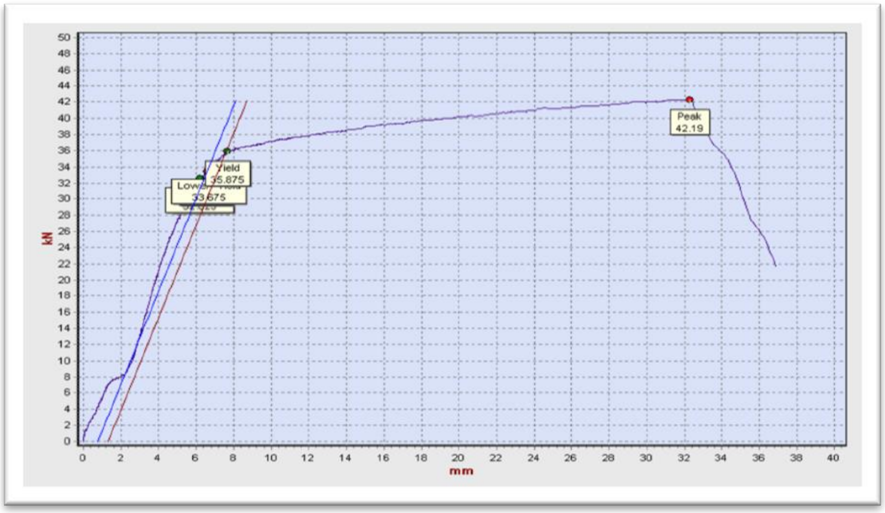

Figure 5.11 (Load vs elongation for Sample 6)

Figure 5.11 shows the percent elongation and load characteristics of 6061 Aluminum with factors at (10%FA, 3%Mg, 600RPM) levels. In relation to factors at (10%FA, 1.5%Mg, 1200RPM) there is a reduction in tensile strength (i.e.42.19 kN vs 56.83kN) and %age elongation behavior is inconclusive because of some slipperiness at the interface b/w the sample and UTM jaws. This combination of factors is leading to reduction in tensile strength.

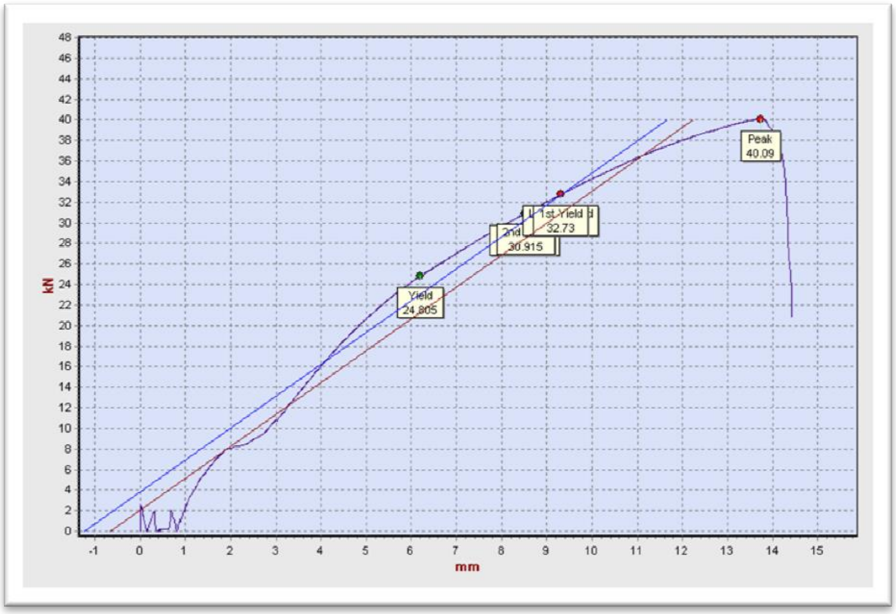

Figure 5.12 (Load vs elongation for Sample 7)

Figure 5.12 shows the percent elongation and load characteristics of 6061 Aluminum with factors at (15%FA, 0.5%Mg, 1200RPM) levels. In relation to factors at (10%FA, 3%Mg, 600RPM) there is a reduction in tensile strength (i.e.40.09kN vs 42.19kN) and %age elongation is approx. 13.7mm. This combination of factors is leading to reduction in tensile strength as well as ductility.

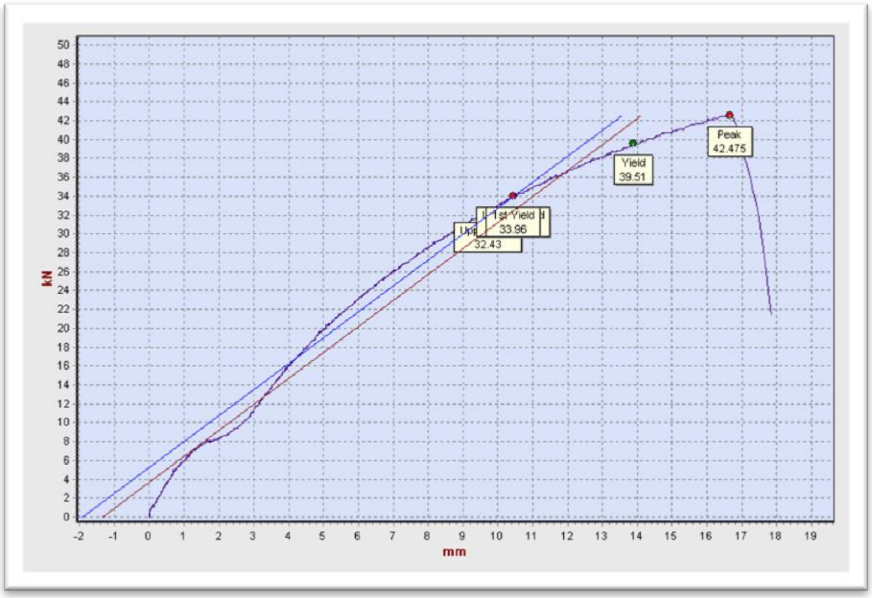

Figure 5.13(**Load vs elongation for Sample 8**)

Figure 5.13 shows the percent elongation and load characteristics of 6061 Aluminum with factors at (15%FA, 1.5%Mg., 600RPM) levels. In relation to factors at (15%FA, 0.5%Mg, 1200RPM) there is a reduction in tensile strength (i.e.42.47kN vs 40.09kN) and %age elongation is approx. 16.5mm. This combination of factors is giving a slight increase in tensile strength as well as ductility in comparison to previous one.

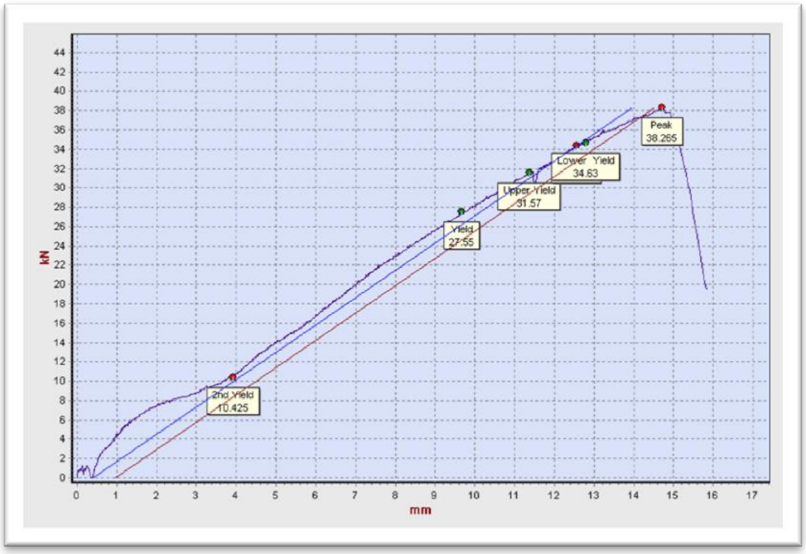

Figure 5.14(**Load vs elongation for Sample 9**)

Figure 5.14 shows the percent elongation and load characteristics of 6061 Aluminum with factors at (15%FA, 1.5%Mg., 600RPM) levels. In relation to factors at (15%FA, 1.5%Mg., 600RPM) there is a reduction in tensile strength (i.e.38.265kN vs 42.47kN) and %age elongation is approx. 14.5mm. This combination of factors is giving a reduction in tensile strength as well as ductility in comparison to previous one.

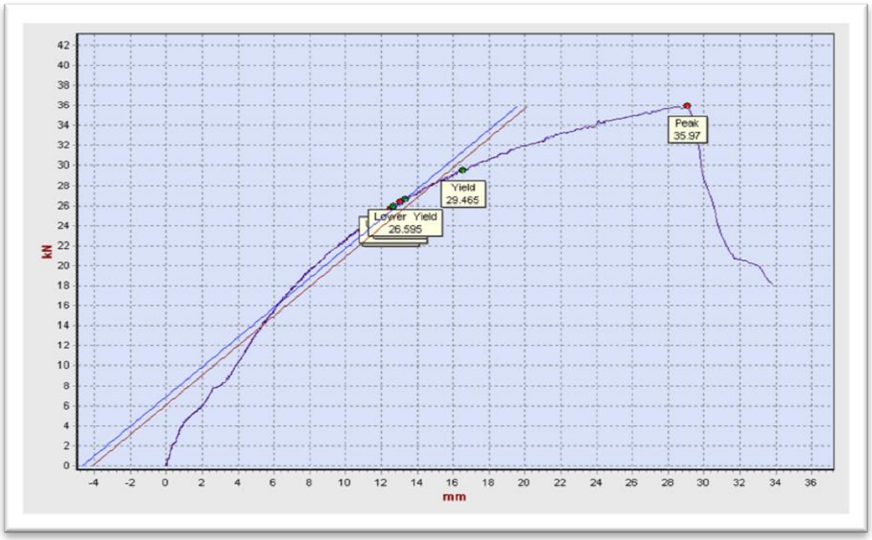

Figure 5.15 Pure aluminum (Load vs elongation for Sample 10)

Figure 5.14 Tensile Strengths of all composites

Expt. No.	Fly Ash (wt%)	Mg. (wt.%)	RPM	UTS (kN)
1	5	0.5	600	**36.355**
2	5	1.5	900	**41.71**
3	5	3	1200	**39.8**
4	10	0.5	900	**55.39**
5	10	1.5	1200	**56.83**
6	10	3	600	**42.19**
7	15	0.5	1200	**40.09**
8	15	1.5	600	**42.475**
9	15	3	900	**38.265**
10	PURE Aluminum			**35.97**

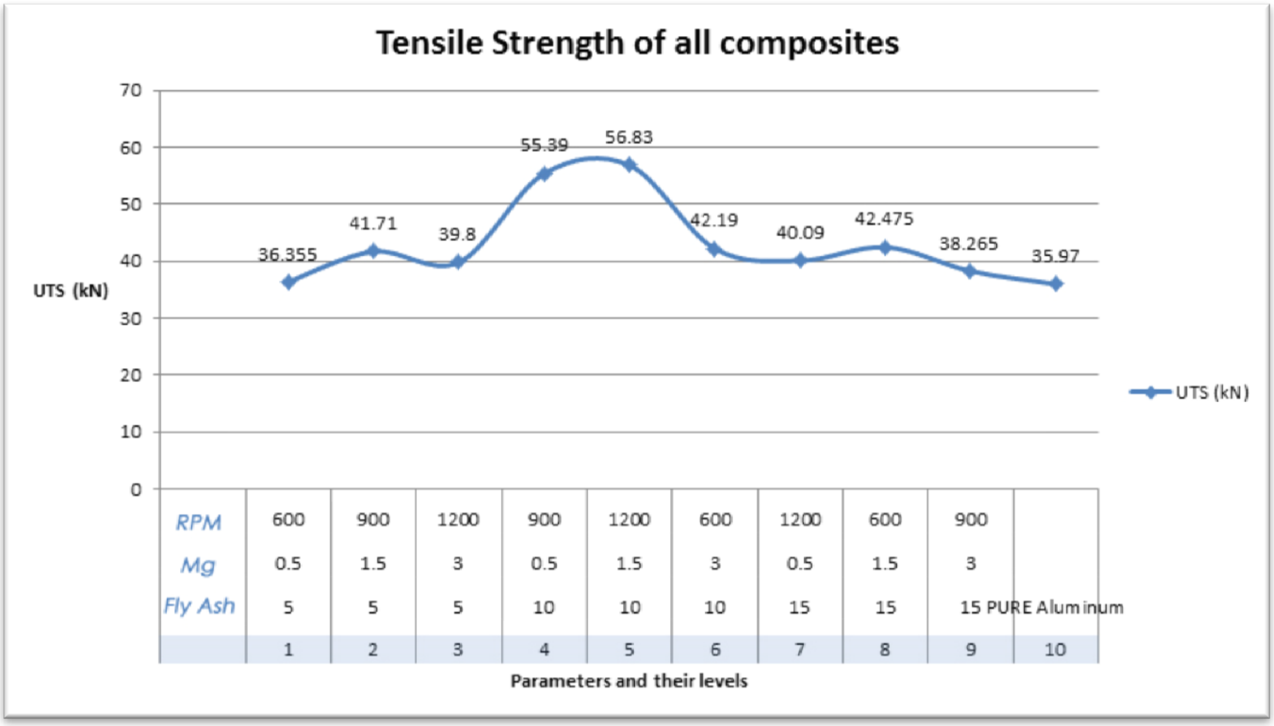

Figure 5.16

Figure 5.15 depicts that the best levels for the 3 factors considered are at (10% fly ash, 1.5%Mg and 1200RPM) from both aspects i.e. Tensile strength as well as for ductility.

Figure 5.17 UTM Experiment running on sample

Figure 5.18 Broken sample after UTM Experimentation

5.4 Discussions

Fly ash (the most significant factor for wear rate) content as per ANOVA results is found to be optimum at 10% level. There are evidences from previous research [10, 11, 12] also which conclude that there is a critical volume fraction of the dispersoid (in our case, it is Fly ash particles) below which the mechanical and physical properties tends to improve and above which the properties shows reverse trend. And similar observation was seen in our case also. Our results are supported by the theory proposed by the authors which explain the rejection behavior when volume fraction exceeds the critical value.

Second significant factor i.e. Mg content was found to be optimum at 1.5wt. %.The most important consideration in the production of metal matrix composites by stir casting route is the difficulty of wettability between the reinforcement and the matrix material. Since the surface tension of Mg (0.599N/m) is lower than Al (0.760 N/m), the addition of Mg reduces the surface tension of the molten Al. Moreover, addition of Mg facilitates the formation of solid solution reaction elements and increases the dynamic viscosity of composite slurry which reduces the floating velocity of fly ash particles. It also reduces the solid–liquid interfacial energy by aiding the chemical reaction at the interface surface between the Al and fly ash particles and form various solid solution reaction elements as shown in equations (18 – 22).

$3Mg + 4Al_2O_3 \leftrightarrow 2Al + 3MgAl_2O_4$……………………………………(18)

$SiO_2 + 2Mg \leftrightarrow 2MgO + Si$ ……………………………………(19)

$2SiO_2 + 2Al + Mg \leftrightarrow MgAl_2O_4 + 2Si$ ……………………………………(20)

$2Mg + Si \leftrightarrow Mg_2Si$ ……………………………………(21)

$4Al\ (l)\ +3C(s)\ \rightarrow\ Al_4C_3(s)$...(22)

Several researchers have reported that the strength of the Al matrix ceramic reinforcement composite is dependent on the magnesium-silicide precipitates. Depending on the existing processing conditions, the excess Si would react with Mg to forms Mg_2Si as shown in Equation (21). It was reported that Mg_2Si precipitates when 5wt. % Mg is added to Aluminium [29]. It was observed that Mg_2Siprecipitates in AMCs containing more than 2 wt. % Mg [30]. It was concluded that the Al_2O_3 particles are unstable in Al- Mg alloys and reacts with the Mg to form spinel $MgAl_2O_4$ on the surfaces of oxidized particles, resulting in the increase of interfacial bonding strength [16].

It was reported that the bonding was achieved for an Al-Mg alloy based composite through the formation of $MgAl_2O_4$ layer by reaction at the solid-liquid interface. It was reported that the optimum addition of Mg for obtaining good distribution and maximum mechanical properties to be around 1wt. %. The addition of Mg lower than the optimum value results in the formation of agglomerates of reinforcement particles [31]. Hence the presence of Mg in Al matrix during composite production strengthens the matrix and scavenges the oxygen from the surface of the dispersoid, leading to an increase in the surface energy of the dispersoid.

It may be noted that the diffusion of Mg and its subsequent incorporation into the reinforcement at the Al- fly ash interface could also result in Mg depletion from the matrix, accounting for the reduction of the Mg_2Si particle sizes which lead to a decrease in solid solution strengthening. Hence results in declining the mechanical properties of the composites as well as an increase in porosity.

On the other hand, when the content of Mg is higher than 6%, above 650˚C, fly ash particles tend to react with aluminium forms brittle compounds like Al_3Mg_2 and Al_4C_3 which deteriorates the mechanical properties of composite and also the fly ash particles agglomerate in the Al matrix again. Moreover, higher Mg content (more than 3 wt.%) composites would reduce the corrosion resistance when it is subjected to high temperature service in corrosive environments [32] and leads to the large gas enclosures in the composite due to higher viscosity of the composite slurry. Hence, it is proved that the proper Mg addition (1.5 wt. %) is beneficial to homogeneous distribution of fly ash particles in the Al matrix which enhances the mechanical properties of composites.

CHAPTER 6 CONCLUSIONS

The results of ANOVA reveal that factors responsible for improvement in mechanical properties of flyash aluminium 6061 composite are fly ash content and Mg content. It is found that the optimum levels of these parameters are 10 wt% of fly ash and 1.5 wt% of magnesium for achieving best results in relation to wear resistance, hardness and tensile strength of composite materials.

The results indicate that the addition of fly ash result in increase in tensile strength , hardness and hence wear resistance of the composites in comparison to pure aluminium. Further, an addition of Mg up to 1.5% by weight into the composite improved the wettability of reinforcement. This results into strong interfacial bonding of fly ash particles leading to improvement in mechanical properties. The best results have been obtained for the factors at the mentioned levels.

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