MECHANICAL BEHAVIOUR ASSESSMENT OF ALUMINIUM 2024 WITH SILICON CARBIDE AND FLY ASH REINFORCEMENTS USING THE RSM APPROACH

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CERTIFICATE

Certified that **Ankit Gupta** (Enrollment no. 04001160540) has carried out the research work presented in this thesis entitled **"*MECHANICAL BEHAVIOUR ASSESSMENT OF ALUMINIUM 2024 WITH SILICON CARBIDE AND FLY ASH REINFORCEMENTS USING THE RSM APPROACH*"** for the award of **Master of Technology** from Integral University, Lucknow under my supervision. The project / thesis embodies results of original work, and studies are carried out by the student himself and the contents of the thesis do not form the basis for the award of any other degree to the candidate or to anybody else from this or any other University/Institution.

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ABSTRACT

The market for advanced materials is growing every day with the development of materials with much improved characteristics. In different engineering applications such as shipbuilding, aircraft production, the construction industry, etc. Aluminium alloys are increasingly being used for favourable mechanical properties. In the manufacture of composites of the aluminium hybrid metal matrix, significant research in the area of materials science has been carried out. The current research was undertaken for the manufacture of aluminium 2024 metal matrix composite reinforced with silicon carbide and fly ash through optimisation using response surface methodology (RSM) to obtain enhanced properties. By experimental work, the mechanical behaviour of the composite formed through such as density and strength have been analyzed by response surface methodology technique. The density is found to be reduced to 2.09 g/cm^3 when the Al 2024 is reinforced with SiC 10 % + FA 10 % and the strength is found to be enhanced to 290 N/mm2 when the Al 2024 sample is reinforced SiC 10 % + FA 10 %. Overall, the results inferred that the Al2024/SiC/FA composites reinforced with SiC 10% + FA 10% exhibited superior mechanical properties with lower densities and greater strength. The hardness, as the reinforcement of Silicon carbide and Fly ash in Al 2024 alloy was varied, the results revealed that, the hardness will increase in composite as compares to non-reinforces sample. In Al/SiC 10% + FA 5% the hardness was found to be 94.9 BHN, in Al/SiC 10% + FA 10% the hardness was found to be 96.6 BHN and Al/SiC 5% + FA 10% the hardness was found to be 91.8 BHN. This study can be further increased for the evaluation of other properties of the other engineering material and aluminium alloys at more wide ranges of reinforcement values, utilizing various other scientific techniques.

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- Ankit Gupta

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CHAPTER 1

INTRODUCTION

1.1 Background

There is been tremendous growth in the automotive and engineering industries, and while material design is an important criterion in the selection of materials for which composite materials are considered to be superior to their parent materials (Hassan et al., 2009). This is because they inherit the properties of the parent material as well as the properties of the mixtures contained in that material. Thus the properties they inherit are incredibly better and thus more suitable (Zhang et al., 2019). These composite materials also have improved mechanical as well as physical properties which are more suited for industrial along with manufacturing operations. There will be a strong demand for composite materials in the building industry, the aircraft sector, electrical and electronic devices, as well as consumer goods, as these composite materials are very quickly on the market in these different sectors (Chandra et al., 2019). Not only in consumer products but also the industrial field, such as the aerospace industry, composites are commonly used in aircraft, for example, because of their ultra-fine qualities, a lot of materials which are made of composites are inherited from parent materials (Prasad Reddy et al., 2017). Not only because of its superior efficiency but also because of its more economical production, it is becoming the driving force and commodity of concern for applications in the aerospace, electronics, and construction industries (Kurapati et al., 2018). These composite materials tend to possess strong tensile strength, elastic modulus, and enhanced metallurgical properties and are the foundations of various structural structures. A lot of studies have been conducted, for example, by numerous researchers from England and the United States, who have found that composites can achieve a hundred times greater ductile strength with fewer defects relative to existing materials (Wang et al., 2016).

When current materials and metals are modified, they are placed on various types of materials such as bamboo fibers, fly ash, silicon carbide, boron carbide, plastics, etc. These materials may appear to increase material costs, but it is generally found that when waste materials are used, they tend to minimize total costs and may also have better properties, and may also improve material costs (Kurapati et al., 2018). To develop the properties of materials to make them commercially competitive, validated research should be carried out to create a metal Matrix composite, which has been successfully carried out in recent years, thereby allowing the industry to move towards composite materials due to their improved resilience. These properties are altered by modifying the compositions for enhanced properties.

1.2 Composite

The preparation of composite material means that two or more materials have to combine; sometimes the material properties are different, which makes it very difficult to combine them (Yang et al., 2001). The main aim of combining materials is to create a composite material that has completely different properties and can be used in a variety of places. In general, one can tell that different materials have been mixed for the preparation of the composite because many materials are don't dissolves and are also difficult to blend.

In 1972, Van Suchetclan explained composite material, which as heterogeneous substance comprising of two or more solid phases, which has been in close connection with each other on the microscopic scale, which can be deliberated as a homogeneous substance on a microscopic scale, it is only when the portion have identical physical properties.

1.2.1 Need for composites

Composite can be made by combining two different materials or even more than two materials can be mixed in different proportions (Prabu et al., 2006). As different materials have different properties so they interact with the properties of the metal on the material in which they are rain posts and alter the properties to form a unique and modified better property (Akbar et al., 2020).

The main reason is that composite materials are used for components that are relatively stable and high strength-to-weight ratio. E.g. carbon-fiber-reinforced composites can be five times stronger than 1020 grade steel and weigh just one quarter.

1.2.2 Composites over conventional materials

Modern industries identified that the composite material is more used in commercial applications like the aerospace industry; a very small amount of business opportunity is given by the domestic sector (Kiran et al., 2014). Recently the composite market has changed from the aircraft sector to the other sectors in recent years and it is a very big market and the opportunity is too much to move forward.

There are numerous reasons why composite material should be used, such as:

- ✓ A rise in stiffness, strength, and dimensional stability
- ✓ A rise in toughness and impact strength

- ✓ Heat deflection temperature amplifies
- ✓ Mechanical damping rises
- ✓ Minimize the cost
- ✓ Reduces the thermal expansion
- ✓ A rise in corrosion resistance and chemical wear

There has been a demand for the composite material, which is used as a lighter construction material, and more seismic-resistant in a structure leads to the increase in demand for new and advanced materials, which can also absorb shocks, as well as vibrations through tailored microstructures (Srinivasan et al., 2020). Nowadays, the composite has increased much more than before, in places where the rehabilitation and strengthening of pre-existing structures take place, especially in places where the structures have been damaged from shocks, etc for that they have to be seismic resistant moreover these materials are used to repair the cracks (Kalaiselvan et al., 2011).

1.2.3 Components of a composite material

The composite material combines two or else more elements to develop a new material that has properties that are different from the existing material which is combined. Generally, the composite consists of bulk material also called matrix and the materials that are inserted as reinforcement are intended to enhance strength and other desired mechanical properties of the matrix.

1.2.4 Role of the matrix in composite

Several materials display much better strength characteristics when they are in fibrous form, these properties are achieved only when the matrix combines the fibers, some of the matrices are mentioned in Table 1.1 below. Matrix works as a bridge that is used to grasp the fibers in their place. Fine Matrix possesses the ability to distort easily beneath applied load, transfer the load onto the fibers, and even distribute stress concentration (Kiran et al., 2014).

Table 1.1 Matrix used in composites along with its properties

Matrix Material (Metal Alloy)	Ultimate tensile strength σ_{UTM} (N/mm^2)	Elastic modulus, E (N/mm^2)× 10^3	Density, ρ (Kg/m^3)× 10^3
Steel	400-2200	180-210	7.8-7.85
Aluminium	140-700	69-72	2.7-2.85
Titanium	420-1200	110	4.5
Magnesium	220-320	40	1.8
Beryllium	620	320	1.85
Nickel	400-500	200	8.9

A matrix is usually a continuous and soft phase of composite material. There are some of the properties of the matrix phase which are displayed below.

- ✓ To manage the transverse characteristics, interlaminar strength, and elevated temperature strength.
- ✓ Reinforcement materials are to be kept in proper position with proper orientation.
- ✓ To shift load to the reinforcement and to defend them from the environment.
- ✓ To combine the reinforcements under its cohesive and adhesive properties.

1.3 Hybrid composite

Aluminum hybrid composite for which two types of reinforcement materials have been used, which are fly ash and silicon carbide. These composites have all the features that can satisfy the demand for today's modern-day applications. Hybrid aluminum matrix composites in which ingredient is an aluminum matrix and along with one or more reinforcement material but in this study, but this study two reinforcement materials have been used. Aluminum matrix composites in which reinforcement material is used in different quantities and is samples are developed as per the tests.

1.3.1 Fly ash as reinforcement

Fly Ash which is a by-product exists in a fine powder that comes after burning pulverized coal in an electric creation power plant (Sharma 2019). FA, which is a pozzolan material, implies that the substance contains aluminous and siliceous material thus will in general become cement when comes in contact with water (Jo et al. 2015). This makes it a significant material with regards to forming blended cement, mosaic tiles, and hollow blocks, among other structure materials (Bucher et al. 2017). Fly ash is cheap and low-density reinforcement material that exists in enormous amounts in the climate. It is available as a powder, which additionally turns into the reason behind the contamination of the environment (Sharma and Akhai 2019).

Figure 1.1: Fly ash

It exists as a powder through the way of air it enters the human body while breathing and increases the chances of suffering from dangerous diseases (Parveen et al. 2018). In the US, around 118 million tons of items are framed in one year by Coal ignition (Thareja and Akhai 2017). Fly ash is utilized in numerous nations, for example, India utilized just 3% by 1990 however as awareness of it grew in people, and this will ultimately increase the demand for fly ash (Criado, Jiménez, and Palomo 2010). The requirement will increase because of its use from various perspectives to improve properties, for example, concrete, mine filling, blocks and tiles, street, horticulture, concrete, and so on.

1.3.2 Silicon carbide as reinforcement

SiC is a compound that consists of silicon and carbon, it is otherwise called carborundum and its chemical formula is SiC (Choyke, Matsunami, and Pensl 2004). An electrochemical reaction is performed to create Silicon carbide in which the sand and carbon are treated at high temperatures (Spitzer, Kleinman, and Walsh 1959). It is an element that up to 800 °C any sort of acid, antacids, and Malton salt can't attack silicon carbide (Yang et al. 2001). In the air, SiC builds up a defensive layer of silicon oxide that protects it up to 1200°C to 1600°C (Nozawa et al. 2009). The purpose behind calling it carborundum is that it is utilized as a semiconductor and ceramic. Pure SiC which is obtained from a rare mineral is named moissanite (Divecha, Fishman, and Karmarkar 1981).

Figure 1.2: Silicon Carbide

The primary concern is that pure silicon carbide which colorless and transparent crystals until impurities, for example, nitrogen, aluminum isn't added in silicon carbide crystals, at that point its color is green and blue depending upon what level of impurities have been embedded (Shin et al. 1999). Silicon carbide is utilized in places where the temperatures are exceptionally high and are utilized to wear resistances application.

1.6 Scope of Present Study and Methodology

The main focus of this study is on the utilization of SiC and FA reinforcing in the aluminum-2024 to develop a hybrid metal matrix composite. For this, the reinforcing material has been mixed in different weight fractions. However, various processing methods can be used to prepare the matrix, such as pressure die casting, powder metallurgy, stir casting, etc. However in this research, the stir casting method was utilized to develop specimens, the reason for using this technique is its low cost as well as its commercial viability. The scope of this study is emphasizing on developing models for Al-2024 metal matrix composite by incorporating material that can improvise engineering properties for obtaining optimized parameters using the RSM technique.

1.7 Organization of Thesis

This investigation work has been organized into five chapters:

Chapter 1: The general preamble on aluminium alloys, composite materials, metal matrix composites (MMC), the scope of aluminium MMC, and the scope of current research is presented.

Chapter 2: This chapter presents a review of existing developments and researches relating to aluminium alloy composites for utilization in engineering applications, and especially concentrates on studies pertaining to the incorporation of fly ash (FA) and silicon carbide (SiC) to enhance mechanical properties of aluminium.

Chapter 3: This chapter details the material, design procedure, laboratory testing methodologies, equipment, and scientific technique (RSM) utilized in the current research work for modeling and optimization.

Chapter 4: This chapter covers the test findings, the RSM data investigation, and the impact of reinforcement particulates on the mechanical characteristics of aluminum hybrid composites reinforced by variable volume fractions of FA and SiC.

Chapter 5: This chapter comprehends the conclusion followed by recommendations based on the experimental results. Also, a recommendation for future study and further improvements are endorsed herein.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This part of the thesis briefs the work performed so far by researchers on various composites that have been prepared by different manufacturing operations, considering different conditions for the different various parameters for different compositions prepared. Following are focussed and discussed in this chapter:

- A variety of metal matrix composites (MMC) in conjunction with their applications, and the outcome of reinforcements.
- Various Aluminium MMC have been developed through the casting technique of processing.
- Various characteristics of MMC, such as mechanical, corrosion, and welding behavior.

This literature review consists specifically of previous studies done by various researchers on Aluminium alloy by incorporating FA and SiC in various proportions. The ongoing research is for the betterment of the properties of aluminum 2024 alloy. Much research is underway to improve mechanical characteristics such as strength to weight ratio by adding more compounds such as fly ash, silicon carbide, boron carbide, etc.

2.2 Literature on aluminum alloys reinforced with fly ash

In this part the literature review is based on the studies performed by researches on various aluminum alloy reinforced with FA:

(Rao et al., 2012) the paper presented that FA has been used as reinforcement to control all the costs from aluminum-related applications like automotive etc. In the study, aluminum alloy 2024 has been used 2 to 10 wt% fly ash composite through stir casting technique. The studies of X-ray diffraction have been utilized for the phase identification and structural properties of FA. Scanning electron microscope and optical microscopy have been utilized for the analysis of microstructure. By SEM (Scanning Electron Microscope) analysis on the sample, it has been reported that the fly ash particle, which has been used is evenly distributed in the matrix phase, which has led to much better bonding among the matrix and reinforcement. In the composite, as the quantity of the FA increases, as result, the density will move in a downward trend and the hardness follows an upward trend and because of the enhancement in the quantity of fly ash, the compression strength has been seen to be increased. FA particles become a reason for betterment in pitting corrosion of the aluminum–fly ash (ALFA) composites in contrast with unreinforced matrix (AA 2024 alloy).

(David Raja Selvam et al., 2013) the paper presented that composite has been developed by compocasting method by mixing the FA particle in 0, 4, 8, and 12 wt percent inside the Aluminum alloy AA6061. The developed AMCs revealed the occurrence of FA particles without the creation of any other intermetallic compounds this comes out with the help of X-ray diffraction patterns. The fly ash has been incorporated in the solid aluminum melt. The scanning electron microscopy is utilized for analyzing the microstructure of aluminum matrix composites. The FA particles have a clear interface as well as improved bonding from having homogeneous dispersion. Finally, it proves that adding FA particles in aluminum matrix composites improves microhardness and ultimate tensile strength.

(Kountouras et al., 2015) in their study using optical and scanning electron microscopes along with x-ray diffraction technology to analyze the microstructure and chemical composition of the FA and composite materials that have been prepared. The properties of composites have been tested in this study: macro-hardness, wear, thermal expansion, and corrosion behavior was analyzed. To evaluate the corrosion behavior of composite material potentiodynamic corrosion experiments have been used in 3.5 wt. % of sodium chloride solution. The results of this analysis have comes in such a way that composite specimens which include fly ash particles reflect Homogeneous distribution and hardness values are also seen to be better than matrix material. The presence of FA reinforcement (>40%) in the composite in a high volume fraction becomes a reason for the rise in wear rates ascribed to the disintegration of the FA particles. The incidence of FA particles in the aluminum alloy matrix has led to a reduction in co-efficiency of thermal expansion as results in an transformed corrosion mechanism of the composite material for the matrix alloy.

(Dinaharan et al., 2016) the paper studied FA particles reinforced in AA6061 aluminum matrix composites (AMCs) through the friction stir processing. The volume fraction of FA is in the range of 0 to 18 in 6 steps. The optical microscope, scanning electron microscopy and electron backscattered diagram these techniques are used to prepare aluminum matrix composites. Pin on discs wear equipment are used to obtain the approximate value of wear rate. Fly ash particles were examined and see that they are dispersed homogeneously in the aluminum matrix composites regardless of the position amongst the stir zone. After examining the micrographs through an electron backscattered diagram, shows that the aluminum matrix composites have shown excellent grain refinement and because of adding fly ash, the microhardness and wear resistance of aluminum matrix composites has improved much better.

(Razzaq et al., 2017) in their study used FA is utilized as a reinforcement material in an aluminum alloy (AA) 6063 for the development of the composite material to form AA6063-FA utilized in the various engineering field, automotive and aerospace, etc. The utilization in various fields is because of their low density and excellent mechanical characteristics. The compocasting technique has been used in this study by which the composite was prepared. In the range, 0 - 12 wt % of the fly ash is added with rising increments of 2%. Fly ash particles are inserted into aluminum alloy 6063 when it is in the molten form and inserted until it gets fully blended and cold down until it becomes slurry which is in a semi-solid state. Molten Aluminum Alloy (AA6063-FA) is then left to become solid in a mold of the cast iron which was previously prepared. These are the technique such as Bulk density and apparent porosity measurements, Charpy impact testing, Vickers microhardness measurements, Field Emission Scanning Electron Microscope, Variable Pressure Scanning Electron Microscope, and Energy Dispersive X-ray spectroscope elemental mapping to collect information about this composite and to arrive at a conclusion. The result of this study proved that as fly ash content rises, it results in rising in the microhardness and porosity of the composite, and on the other hand, bulk density and Charpy impact energy decrease with rise in fly ash content in the composite.

(Razzaq et al., 2018) developed composite through comop-casting technique in which fly ash which acts as reinforcement material in AA6063 alloy in various percentages 0, 2, 4 and 6 wt%. The main purpose of doing this study is to find out the impact the fly ash and sliding speed will have on the wear behavior of the aluminum alloy 6063 fly ash (AA6063-FA). The pin-on-disc equipment beside rough steel counterface has been used to measure wear. The wear tests are conducted on the composite by various loads such as 24.5 49 and 73.5 N respectively with the steady sliding speed which is 150 rpm and sliding time is 10 minutes. The result comes out as the addition of FA particles increases the wear resistance of the composite AA6063-FA. The wear rate decreases as the amount of the fly ash particles increase whereas the wear rate rises with the rise of the applied load.

(Ali & Lavanya, 2019) in their paper presented that fly ash which is an industrial waste can be used as an industrial wealth for the production of composite. There may be trouble associated with fly ash such as eliminating and storage of fly ash. Stir casting technique has been utilized for adding fly ash in Aluminium but only up to 20% by weight. The hardness of the Aluminium FA composite rises as the amount of fly ash increases.

(Razzaq et al., 2020) the paper investigated that AA6063 which includes a reinforcement of the FA fragments through the compocasting technique. The main motive of the study is to assess the effect of FA content, load, sliding speed, and tribological performance of the AA6063 –FA. Dry sliding wear tests are conducted on the composite by applying various loads such as 24.5 49 and 73.5 N with various speeds such as 150,200 and 250 rpm respectively these are performed at room temperature. The process parameter on the tribological behavior has been studied by the response surface methodology. The surface plot in the study displays that the wear rate is rising with a rise in load, time, and sliding velocity, and on the other hand, friction co-efficient decreases with increasing these parameters.

2.3 Literature on aluminum alloys reinforced with silicon carbide

Here in the literature review is based on the studies performed by researches on various AA reinforced with SiC:

(Alaneme & Aluko, 2012) in the paper investigated cast and age-hardened Al in which SiC particulate composites are present through borax additives and two-step stir casting methods are used to analyze the tension and fracture behavior. SiCp composite which consists of 3, 6, 9, and 12 volume percents of SiC sample representatives of every composition were subjected to age-hardening treatment at 18 00°C which is done for every composition for 3 hours. To determine tensile characteristics along with fracture toughness of the composite calculate through tension testing for that tensile and Circumferential Notched Tensile specimens were bring into play. The outcomes of the study through experimentations showcase that the improvised tensile strength of the composites can be witnessed through the aging treatment. For both the conditions whether it is as-cast or age-hardened the tensile and yield strength rises to approximately a similar magnitude with the rise in SiC volume percent. This rise was significant for the 9 and 12 volume percent for the reinforcement of silicon carbide.

(Dandekar & Shin, 2013) in their study performed laser assistant machining on particle-reinforced MMC, A359 aluminum matrix composites, within which 20% by volume fraction of SiC particles had been successfully utilized. Laser-assisted machining was evaluated by performing experiments for the betterment of machinability while minimizing the subsurface damage. Cutting forces, specific cutting energy, surface roughness, subsurface damage, and tool wear under different material removal temperatures all are utilized to estimate the actual effectiveness of laser assistant machining. The result is something like this material removal temperature which prevails as 300°C with laser-assisted machining in which surface roughness has decreased by 37% and somewhere specific cutting energy has diminished by 12% and tool life was improvised by 1.7-2.35 times if compared with conventional machining but it also depends on cutting speed.

(Rahman & Al Rashed, 2014) investigated aluminium matrix composites that use cast silicon carbide as a reinforcement. The main purpose of the study to analyze the microstructures, mechanical properties, and wear characteristics. Aluminum matrix composites have different quantities of silicon carbide for which the steel casting process has been used. Silicon carbide has been used in 0,5,10 and 20 wt%. The result is something like that the silicon carbide, which has been inserted into the aluminum matrix as reinforcement, has resulted in a rise in hardness and tensile strength. The maximum hardness and tensile strength have been seen at 20 wt. %. Analysing the microstructure has brought out clustering and non-homogeneous circulation of SiC in the Al matrix. Through microstructure, porosities have also been examined and rise with the rise in wt. % of silicon carbide reinforcement in aluminium matrix composites. Finally, through the pin-on-disc wear test, it has come out that the silicon carbide particles that have been reinforced into the aluminium matrix along with silicon carbide have resulted in a rise in wear resistance.

(Rajeswari et al., 2015) in the paper investigated mechanical characteristics of Al 7075 - SiC - alumina hybrid composite using Taguchi technique. The metal matrix composite utilizes in various areas from aerospace, automotive to biomedical industries the reason behind this is their natural characteristics such as high strength to weight ratio, low wear rate, etc. Here in this study design of the experiment through the Taguchi technique was used to investigate the metal matrix composite-based aluminum 7075 alloys. To attain casting with better quality and minimal defect for that control of processing characteristics is very essential. The samples have been developed in different wt. % of reinforcement moreover variation in stirring speed and processing temperature in stir casting technique. The influence on the parameters used during the process for that orthogonal array and analysis of variance was utilized to examine characteristics. Through the Taguchi technique, the optimum parameters are noted to obtain the maximum mechanical characteristics.

(Paidar, M., & Sarab, M. L. 2016) in the paper investigated friction stir spot welding of 2024-T3 aluminum alloy, with a thickness of 1.6 mm. The effect of the metallurgical and mechanical properties of silicon carbide particles has been discussed. This process has a constant rotational speed which is 1000 rpm. The outcomes of this study reveal that the increment of the Silicon Carbide nanoparticles during friction stir welding has major effects on mechanical characteristics. This means that the nanoparticles act as a barrier that prevents the rise in grain in the stir zone. On the other hand, the statistics obtained from the tensile-shear and wear test showcase that the addition of SiC nanoparticles ultimately rises the tensile-shear and wear resistance.

(Prasad Reddy et al., 2017) in their review concluded that Al metal matrix nanocomposite which is used in various industries such as automobile, aircraft, structural and many defense systems is because Al metal matrix nanocomposite is among the new generation of substance which has the potential to meet the demands for advanced engineering applications. This study makes it clear that the nano-sized SiCp particles reinforced in aluminium alloy matrix display better mechanical, physical, and interfacial characteristics. Scanning electron micrograph, which has been made of Aluminium metal matrix nanocomposites, after analyzing, it was clear that the particles of the Silicon Carbaid are equally distributed in the matrix alloy.

(Mohanavel et al., 2018) researched that the liquid metallurgy route is also known as the stir casting technique through this, the particles of silicon carbide can be added successfully to AA6351 matrix composites. Silicon Carbide, which is used as reinforcement, used in a range of weight fractions which was 0% to 20% in a stage of 4%. The composite has been analyzed by optical microscope and its density, hardness yield strength, and impact strength have also been examined. The optical microphotographs have revealed that the reinforcement, which is silicon carbide, is evenly spread in the matrix. Mechanical properties have also been better than ever, as the weight fraction of reinforcement rises, characteristics of Al matrix composites.

2.4 Literature on aluminum alloys reinforced with FA and SiC

In this part, the literature review is based on the studies performed by researches on various Al alloy reinforced with FA and SiC

(Ravesh, S. and Garg, 2012) mixed SiC & FA in Al metal matrix composites to analyze mechanical characteristics, which were hardness, toughness, and tensile strength. For this, stir casting technique has been used, silicon carbide and fly ash as reinforcement in aluminium 6061. To experiment, SiC has been utilized in different weight fractions which are 2.5%, 5% to 7.5%, and 10% and on the other hand, all other parameters have been kept constant. Finally, with the results of the study, this method comes out to be successful and the value of the tensile strength, hardness, and toughness rises as the weight percentage of the Silicon Carbaid rises.

(Mahendra Boopathi et al., 2013) in their work developed SiC, FA, and aluminum metal matrix composites. The study aimed at inserting the SiC, FA, and together in aluminium 2024 for analyzing its physical properties. The stir casting technique has been utilized to prepare aluminum metal matrix composites and the composition was added up to ultimately level. The structure of metal matrix composites was analyzed by x-ray diffraction and an optical microscope to study the microstructure. The study has used tests which are density, tensile strength, yield strength, elongation, and hardness tests to analyze the mechanical behavior of metal matrix composites performing carefully designed laboratory experiments that replicate the service conditions. The density of the samples of aluminum 2024 containing SiC 5% and fly ash 10% was reduced, but their hardness increased when the composition was altered to SiC 5% and fly ash 10%.

(Dwivedi et al., 2014) produced A356/SiC/FA hybrid composites through electromagnetic stir casting. The composite has been developed an aluminum matrix for which SiC and FA have been used in various weight percentages as a reinforcement material. Electromagnetic stir casting methodology was utilized to improve the allocation of SiC and FA particles in the matrix, the external argon gas has been supplied at the time of the electromagnetic steering process in the melt. A total of five samples of hybrid composite have been prepared electromagnetic stir casting technique in different combinations which consist of fly ash and silicon carbide (25 µm). Here mechanical properties in which tensile strength, hardness, toughness, and fatigue strength, as well as microstructure of all the five samples, were examined. After examining the microstructure, SiC particles and FA have been distributed evenly in the matrix. The outcome of all samples A356, SiC15%, and 5% of FA have become out to be the best among all samples.

(Gowda, 2017) their study presented that SiC and FA when utilized as a reinforcement material improves corrosion behavior, of aluminum 5083 alloys. Stir casting technique had been used, to prepare composite silicon carbide has incorporated, ranging from 3 to 9 wt% at an interval of 2% each for every addition. Some tests have been used to analyze the weight loss test, open circuit potential test, potentiodynamic test. The outcome comes out after the analyses are like corrosion current rises with the rise in the percentage of silicon carbide in the matrix. The electrolyte chosen for the potentiodynamic test is sodium hydroxide and hydrochloric acid. The concentrations of both the acid and alkaline solution in the present work are taken at 1.0 M.

(Reddy & Srinivas, 2018) fabricated SiC and FA Reinforced Al metal matrix hybrid composites to study 6082 Al matrix hybrid composite consisting of SiC and FA as reinforcement material. For this fabrication, stir casting technology had been used as reinforcement; SiC has been taken into different weight fraction, which is 2.5% 5 and 7.5%, and FA is used in the same proportion. The scanning electron microscope, which is called RSM, is used for analyzing the microstructure of the composite. For analysis, the dry sliding wear behavior of composites the pin-on-disc wear testing machine is utilized. The result reveals that improved ultimate tensile strength, hardness, and wear properties as the reinforcement which is SiC and FA rises in Al matrix hybrid composites.

2.5 Literature on aluminum 2024 alloys reinforced with FA and SiC

A lot of research is currently ongoing to improve the properties of aluminium 2024 alloy as these composites of the aluminium metal matrix with several reinforcements have immense ability to fulfill the current requirements of moodern engineering applications/pratices because of their mechanical characteristics such as hardness, ultimate tensile strength, and many more. Figure 2.2 reveals one such application of Al 2024 being used for the manufacture of the landing gear of aircraft. Al 2024 is also used in wing components of certain aircrafts due to its suitable mechanical properties. It is available in form of bars, sheets, tubes etc. Its fabrication is usually done through friction stir welding in structures.

Figure 2.2 Application of Aluminium 2024 in the landing gear of aircraft.

Copper is one of its constituents apart from various other alloying elements in it. Much research is underway to improve mechanical characteristics for example strength to weight ratio, hardness, etc. by adding more compounds such as FA, SiC, etc. In Table 1 below, some of the works in this regard are mentioned:

Table 2.1: Recent research contribution on various aluminum 2024 alloys reinforced with fly ash and silicon carbide

Author	Year	Admixtures	Outcomes/Inferences
Boopathi et al., 2014	2014	SiC + Fly Ash	Aluminum 2024 reinforced by 5% SiC + 5% fly ash, as compare with non-reinforced Aluminum 2024 reflected improvised wear resistance. The rate of wear also decreased with the increase in the weight ratio up to 10% SiC and 10% ash.
Singh & Chauhan, 2016	2016	SiC + Fly Ash	Compared to the samples of aluminium 2024 and FA or aluminium 2024 and silicon carbide, the hybrid composites which include both silicon carbide and fly ash exhibit better characteristics. Through the rise in reinforcement content, the hardness and strength of the composite aluminum 2024 improved further.
Kurapati & Kommineni, 2017	2017	SiC + Fly Ash	Wear decreases as the weight percentage of FA and SiC particles increases in the matrix. Simultaneously, wear also increases when load and sliding time increase. Thus, Al 2024 hybrid composites have higher wear resistance as compare to with Al 2024 matrix.

Kurapati et al., 2018	2018	SiC + Fly Ash	In this study, experiments are formed as per Taguchi L_{27} orthogonal array. The addition of fly ash and silicon carbide particles to the aluminium 2024 leads to a decrease in the wear of the composite. The methodology of Taguchi and Analysis of Variance was used to assess the wear and relationship with reinforcements by MINITAB 18 software.
Kumar et al., 2020	2020	SiC + Fly Ash	The hardness measurements; wear rate testing and microstructural analysis have been carried for Aluminium 2024 metal matrix composite in this work. SEM results indicate that SiC is evenly dispersed, and those FA particles in the Al 2024 matrix are rather irregularly distributed. The increase in the weight fraction increases the hardness and decreases the wear rate. In automobiles and aviation systems the outcomes can be helpful.

* **AA: Aluminium Alloy**

This section thus highlights various research works carried on AA 2024 composite reinforced with SiC, and FA. It was found that Al-2024 hybrid metal composite with different volume% of FA and SiC was manufactured successfully using the stir casting process. The mechanical characteristics of Al-2024 hybrid metal composite reinforced with SiC, and fly ash are outlined which reflect that the addition of FA and SiC particles to the metal matrix of the aluminium 2024 alloy leads to improved strength, hardness, wear resistance, and density. Al-2024 alloys with SiC and fly ash incorporated above 5 % each showed improvised wear resistance in contrast to the unreinforced Aluminum-2024 alloy. The hybrid composites which include silicon carbide and fly ash showcase better mechanical and physical characteristics in contrast to the composite which includes only Fly ash or SiC as a reinforced material or an unreinforced alloy. Hence, we can conclude that the mechanical characterstics of hybrid composites are improvised with enhance in reinforcement's contents up to certain proportions.

2.6 Gaps in the literature

Following are the gaps which are observed in from the current literature review conducted:

1. While a vast amount of research on the mechanical characteristics of aluminium alloys has been carried out a limited amount of research in the for aluminium 2024 alloy when reinforced with fly ash and silicon carbide at varying compositions.
2. No research analyses the percentage contribution of different factors such as FA composition and SiC on mechanical characteristics of Al-2024 MMC.
3. There is no research in Literature in which optimization of mechanical characteristics such as strength, hardness, and density of aluminum 2024 is conducted using an RSM technique.

2.7 Objectives of the research

The main objectives of current study are:

1. To develop in minimum 2024 metal matrix composite reinforced with fly ash and silicon carbide for studying the effects on mechanical characteristics such as hardness, strength, and density, to modulate the relationship between strength and density.
2. To develop mathematical models for the prediction of Mechanical characteristics for various formulations of SiC and FA reinforced and Aluminium 2024 MMC by RSM through optimization technique.
3. To obtain percentage contribution of both SiC as well as fly ash in modifying the mechanical characteristics when reinforced and Al 2024 metal Matrix composite.

2.8 Title of the thesis

The following is the proposed title of the study is based on these literature gaps and the goals/objectives of the current work

–*Development of Aluminium Alloy 2024 Metal Matrix Hybrid Composite Reinforced with Silicon Carbide and Fly Ash for enhanced mechanical properties by RSM approach*

CHAPTER 3

EXPERIMENTATION

3.1 Mechanical Testing and Techniques

Methods and machinery for the conduct of the experiments are described in this chapter. The manufactured aluminum metal matrix was produced through stir casting and the specimen was tested to measure the value of mechanical characteristics such as strength. The sample strength on the universal test machine (UTM) has been tested in order to know the sample hardness they are tested on the Brinell hardness test. The density was achieved with the Archimedes principle. The description of these devices used for testing is mentioned in this part. The measuring machines have been briefed which were used to obtain the mechanical property values of the samples prepared by the Al 2024+FA+SiC MMC in various proportions. In this chapter, the following are discussed

3.2 Stir Casting Fabrication Method

The reason behind the formation of a hybrid metal matrix composite in which SiC and FA are utilized. For this, Al-2024 has been utilized, as a matrix material, for the development of Al-SiC-fly ash as a hybrid composite material. The casting route is mostly used as it is economical and amenable to mass production. Stir casting is the main technique utilized for commercial production for the large quantity. The stir casting process includes a mechanical stirrer is incorporated so that it can form a vortex so that the reinforcement can be mixed well in a matrix material (Prem Kumar et al. 2019). The stir casting method is a method that is utilized for the manufacturing of hybrid composite material (Mozammil et al. 2020). The method is very excellent for the creation of MMC because of its effectiveness, applicability to mass production, simplicity, and especially for the easier control of the composite structure. Thus there are numerous reasons to utilize this method as its simplicity, flexibility, and development of the large size of components easily. This investigation focused on the utilization of SiC and FA which exists in huge amount. The main focus is to utilize the waste material in a useful manner by dispersing it into aluminum 2024 to fabricate composites by stir casting method.

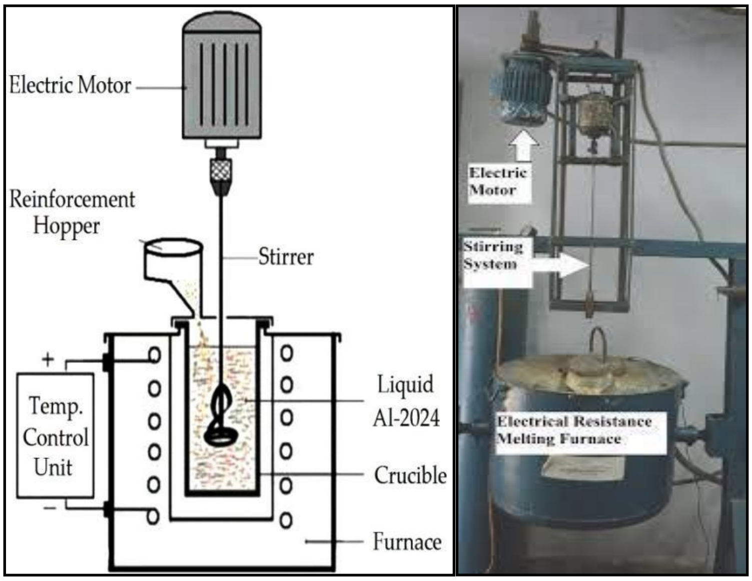

Figure 3.1: Stir casting machine.

In this procedure, the liquid state fabrication of MMC includes the incorporation of the dispersed phase into a molten matrix metal, followed by its solidification. Stir casting is a liquid state method of composite materials fabrication, in which dispersed phase particles are mixed with a molten matrix metal by methods for mechanical stirring. The liquid composite material is then cast by conventional casting methods and may likewise be prepared through conventional metal forming technologies. Stirring is carried out vigorously to form a vortex where the reinforcing particles are introduced through the side of the vortex. The formation of the vortex will drag not only the reinforcement particles into the melt but also all impurities which are developed on the surface of the melt. The vortex will also entrap air into the mold which is extremely difficult to eliminate as the viscosity of the slurry rises.

Finally, it has been concluded that the stir casting technique can be utilized in this study for making a metal matrix composite of Al 2024 in which fly ash and silicon carbide has been utilized. In this investigation metal matrix, a hybrid composite of Al 2024 by stir casting technique was thus prepared.

3.3 Strength Testing

A universal testing machine (UTM) has been utilized in this investigation, which is according to ASTM E-8 standards, as shown in Figure 3.2. The capacity of the UTM is up to 20 tons. The sample rate was 9.103 pts/sec plus crosshead speed of 5.0 mm/min. A standard specimen with 36 mm gauge length was utilized to assess strength. The arm has the ability for full return at the above-mentioned speed. The machine had an interface that functioned properly at room temperature. The machine was designed as per ASTME4, ASTM E 74, and ASTM E83. The rectangular smooth specimens for testing in the universal testing machine were prepared for judging the strength properties of the samples prepared by Stir casting. The machine used was the ultimate tensile strength testing machine. Samples were prepared by casting operation and then tested in UTM to check the fracture reading of the different test samples prepared.

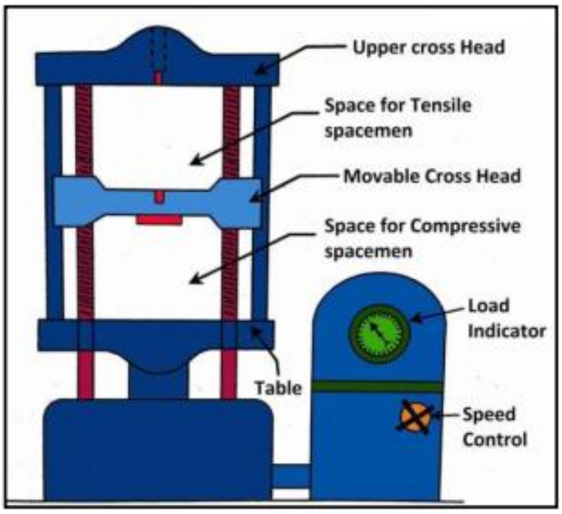

Figure 3.2: Universal Testing Machine.


(a) **(b)**

Figure 3.3 (a) Depicts specimens for tensile testing (b) Depicts specimens for hardness testing

The samples to be readied were first cleaned of soil, oil, and other remote materials and sized into the required measurements by a mechanical power saw. Nine numbers of specimens were developed from the Stir casting process and the sample was examined in a tensile test machine to record the interpretation of different tensile test samples, which were produced in a setup investigated by the design of the experiment.

3.4 Hardness Testing

Brinell hardness can be measured through the Brinell hardness test method and it is mentioned in detail in the ASTM E10. Casting and forgings are other methods that are used to test certain materials but the Brinell hardness method is utilized to evaluate materials that have a structure that has a rough surface so that it cannot be tested by any other method easily. In this testing, a very high test load is used and an indenter of 10 mm in diameter.

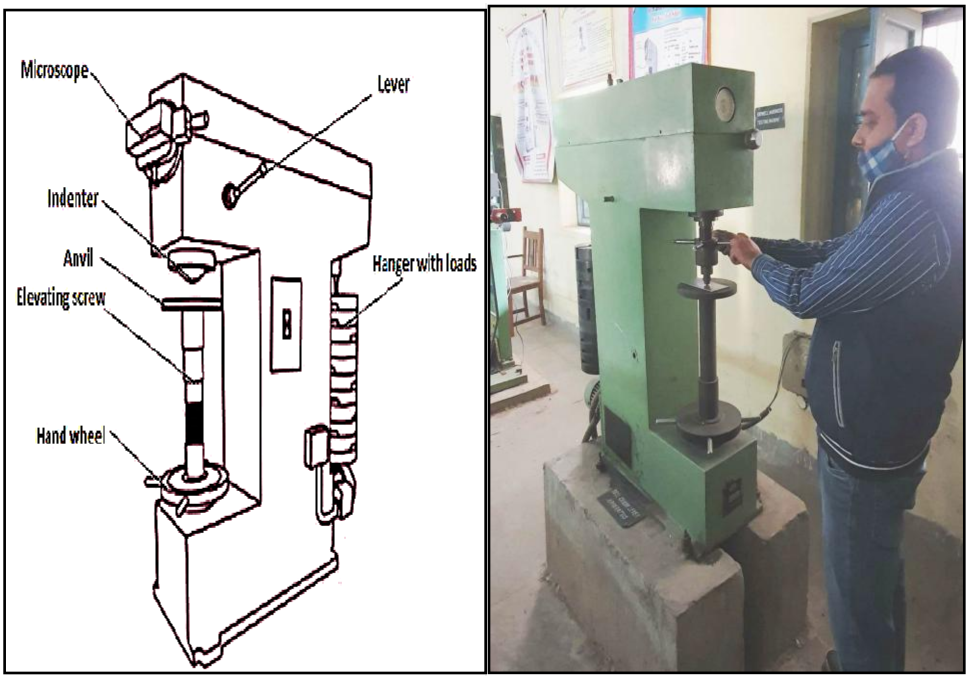

Figure 3.4: The Brinell hardness test

This is done to reduce the indention to get a surface and sub-surface devoid of consistencies. Material is subjected to a load of 500-3000 kg for 10-30 seconds and an indenter with a 10 mm diameter carbide ball or hardened steel. In the case of softer materials, less load is applied. By dividing the applied load with the surface area of indention one can calculate the Brinell hardness number.

3.5 Density testing

Archimedes Principle is a law of physics. It is related to the subject of fluid mechanics. This principle was formulated by Archimedes. This principle permits the buoyancy of any floating object partially or fully emerged in a liquid to be calculated. An upward force is exerted when a body is submerged in a liquid and this upward force is equal to the liquid displaced by the body.

Figure 3.5: Archimedes Principle

Two forces are acting on a body submerged fully or partially in a fluid. The upward force is exerted by the body which displaces the fluid. The second force is exerted by the weight of its own body. This principle, however, ignores the surface tension of the body, and also it is seen that it does not work in complex liquids.

3.6 Design of Experiments using RSM

For this, aluminum 2024 alloy has been utilized, which is 100 grams. Other side SiC which is the SiC and FA are utilized as admixtures in various percentages of 0, 5, and 10 percent. Table 3.2 showcases the two parameters which are A: silicon carbide (SiC) and B: Fly ash (FA) and three levels L (0), L (5), and L (10). Total 9 samples have been prepared in different percentages of aggregated by keeping aluminum constant. Further R.S.M that is Response surface methodology is utilized for examination; the experimental matrix is mention in Table 3.3. Response surface methodology commonly referred to as RSM is used for mathematical modeling and examination. The aim of utilizing this methodology is to obtain streamlined response replications that are affected by different variables.

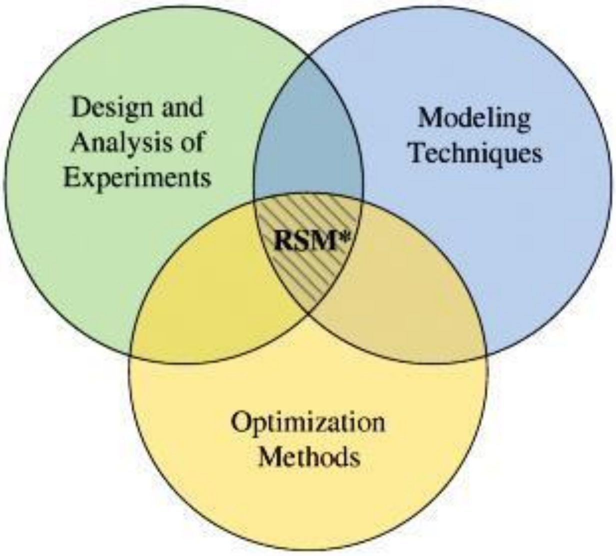

Figure 3.6: RSM for modeling and analysis.

In RSM, the most congruous relationship is established by investigating the input of the yield factors. This technique is utilized here to associate the operating requisites through the exploration of the factor for satisfying or demonstrating the working conditions. Figure 3.7 chooses the flowchart that shows the steps followed for optimizing the process parameters through RSM in the current study. Fly ash, silicon carbide, and its blend are to be preheated at a temperature of 300°C for 3 hours so that if moisture exists can be removed. Pure aluminum has been melted by the resistance furnace. It is important to raise the melt temperature to 720°C once pure aluminum is melted; it was stirred with the help of a mild steel turbine stirrer. It is important to take special care of the speed which should be 200 rpm and the steering time is to be between 5 to 7 minutes.

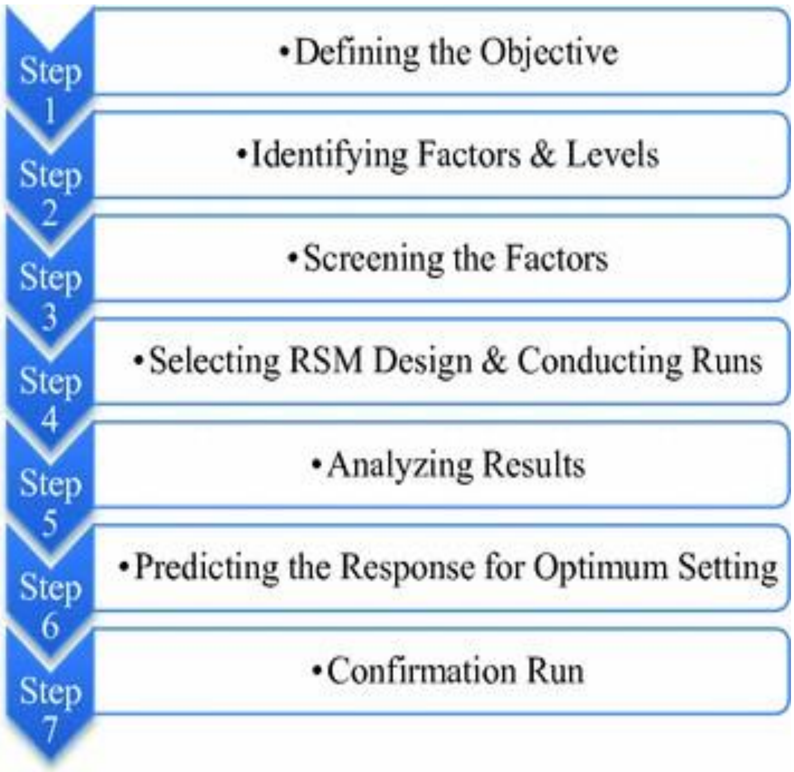

Figure 3.6: RSM steps

If the wettability needs to be increased then 1.5% of pure magnesium (Mg) must be added to this composite (Arora and Akhai 2015). It is important to keep up the melt temperature at 700^0 C during the addition of Mg, fly ash, and silicon carbide. At that point, the preheated permanent metallic mold in which the melt and the reinforced particulates are poured and the poring temperature, which is 680°C, is needed to be maintained. Finally, the mold to be naturally solidified at room temperature.

Table 3.2: Parameters and their levels for RSM.

Sr.No	Symbols	Parameters	Units	Levels		
				I	II	III
1	A	Silicon Carbide	%	0	5	10
2	B	Fly ash	%	0	5	10

Table 3.3: Experimental values.

Samples	Factor 1	Factor 2
	A: Silicon Carbide (SiC)	B: Fly ash(FA)
	%	%
1	0	0
2	5	5
3	0	10
4	0	5
5	10	5
6	5	10
7	5	0
8	10	0
9	10	10

CHAPTER 4

RESULTS & DISCUSSIONS

4.1 Strength Behaviour

The outcomes of the mechanical characteristics of the hybrid metal matrix composites obtained are mentioned in this section. Table 4.1, shows an experimental matrix that consists of nine samples that are prepared in this study along with their outcomes which are referred to as Response 1 for Strength (N/mm^2), Response 2 for hardness (BHN), and Response 3 for density (g/cm^3) in Table 4.2 and Table 4.3. In this study, 100 gm of aluminum and 1.5% of Magnesium (Mg) is used and will remain constant throughout the study. In Sample 2 SiC (5%) and Fly ash (5%) shows the density of 2.3 g/cm^3 and 280 N/mm^2 of strength. Sample 3 SiC (0%) and FA (10%) shows the density of 2.32 g/cm^3 and 265 N/mm^2 of strength. Where sample 4 and sample 5 is consists of SiC (0%) and FA (5%) and SiC (10%) and FA (5%) respectively and showcase density 2.55 and 2.21 g/cm^3 and strength comes out to be 253 and 288 N/mm^2 respectively. Where in Sample 1 SiC (0%) and FA (0%) shows the density of 2.71 g/cm^3 and 240 N/mm^2 of strength and in Sample 9 SiC (10%) and FA (10%) shows the density of 2.09 g/cm^3 and 290 N/mm^2 of strength.

Strength = 242.083 + 3.08333 × Silicon Carbide (SiC) + 2.51667 × Fly ash (FA) - 0.03 × Silicon Carbide (SiC) ×Fly ash (FA**)** **(1)**

A universal testing machine (UTM) has been utilized in this investigation, which is according to ASTM E-8 standards. The sample rate was 9.103 pts/sec and crosshead speed 5.0 mm/min. A standard specimen with 36 mm gauge length was utilized to assess the strength.

Table 4.1 a: Experimental results for strength values.

Samples	Factor 1	Factor 2	Response 1
	A: Silicon Carbide (SiC)	**B: Fly ash (FA)**	**Strength**
	%	%	N/mm^2
1	0	0	240
2	5	5	280
3	0	10	265
4	0	5	253
5	10	5	288
6	5	10	282
7	5	0	258
8	10	0	268
9	10	10	290

Results show that the maximum strength which is 290 N/mm^2 exhibits in the reinforced alloy which is sample 9 in the SiC which 10% and the FA which is also 10%. Sample 1 which is an unreinforced alloy (SiC 0% and FA 0%) shows the minimum strength which is 240 N/mm^2. As the percentage of the admixture increases it ultimately affect the strength of the specimen as when there is Al/SiC 10% which is sample 8 showcases the strength 268 N/mm^2. This is far better as compared to sample 1. When Al/FA 10% then the strength which is obtained is 265 N/mm^2 in sample 3.

Table 4.1 b: ANOVA table for the strength

Source	Sum of Squares	df	Mean Square	F-value	p-value	Contribution %
Model	2133.08	3	711.03	18.43	0.0039	---
A	1290.67	1	1290.67	33.45	0.0022	55.41
B	840.17	1	840.17	21.78	0.0055	36.14
AB	2.25	1	2.25	0.0583	0.8188	.09
Residual	192.92	5	38.58			8.36
Total	2326.00	8				

Table 4.1 b is an ANOVA table for strength showcase that the major role is of silicon carbide which is 33.45 and then Fly ash which is 21.78. There is some residual which to be 38.58. From **Table 4.1 (a)** it is visible that as the percentage of the reinforcing material which is SiC and FA increased in the sample the strength of the composite increases. ANOVA analysis it is clear that silicon carbide as well as fly ash both play important role in improving the strength of the selected aluminium alloy. In contrast to the other studies carried out in which only silicon carbide or only fly ash was added in aluminium alloys it can be seen that both fly ash and silicon carbide, when combined, play a significant role in improving the strength of the hybrid metal Matrix composite does instead of using only metal Matrix composite having a single reinforcement like fly ash or silicon carbide we can also use hybrid metal Matrix composite containing more than one reinforcements like in the current experimentation to obtain successful results in terms of strength enhancement

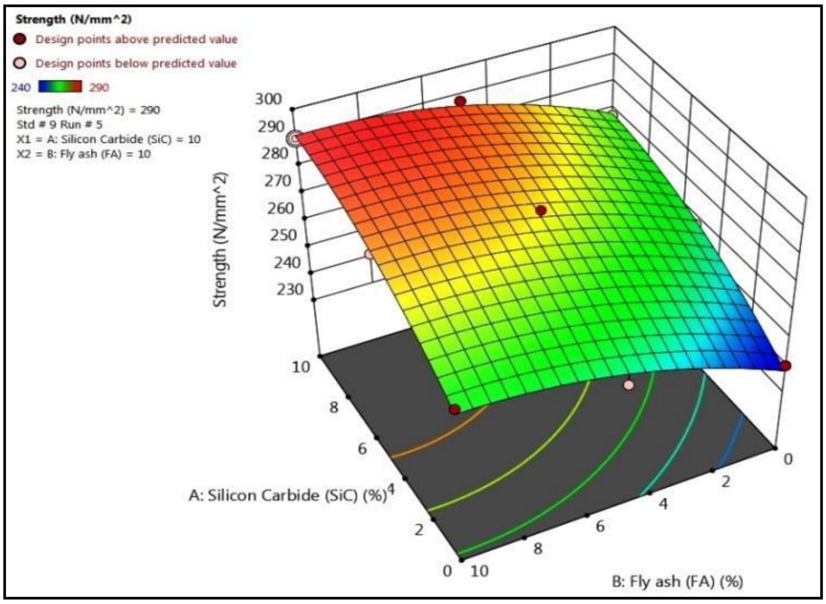

Figure 4.1 (a): 3D surface graph for the obtained strength.

Figure 4.1 (a) is a 3D surface graph and Contour Plot respectively created from design expert software through the experimental obtained in this study there are two factors A: silicon carbide and B: fly ash.

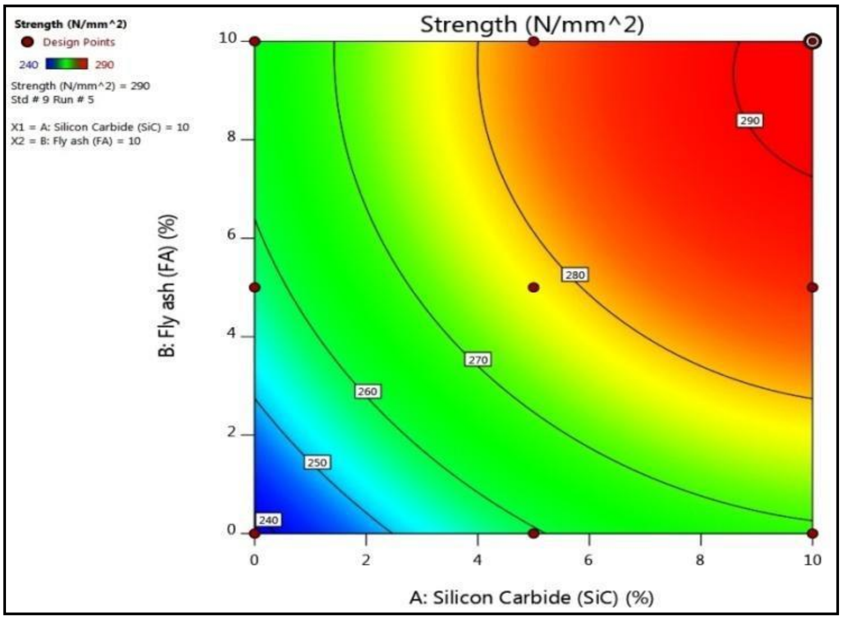

Figure 4.1 (b): Contour Plot for the obtained strength.

Figure 4.1 (b) is a Contour Plot created from design expert software through the experimental obtained in this study there are two factors A: SiC and B: FA and also in Contour Plot.

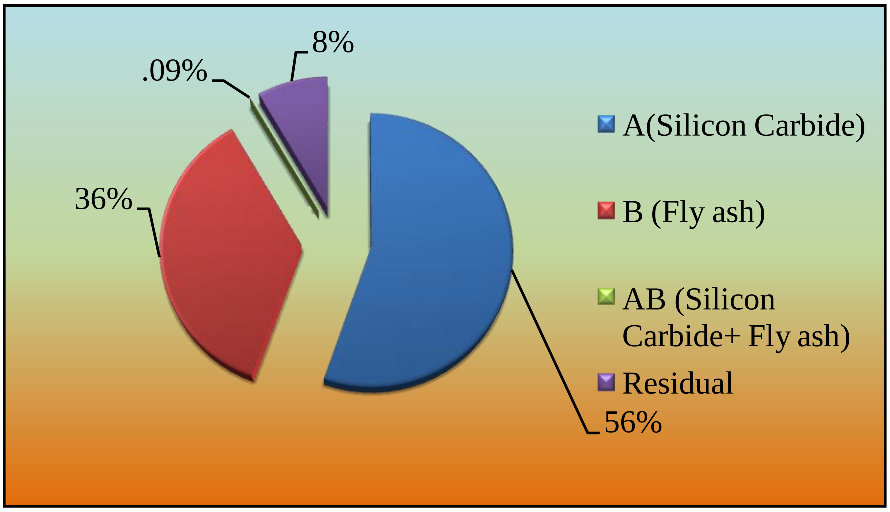

Figure 4.1 (c): Percentage contribution for the obtained strength.

Figure 4.1 (c) shows the percentage contribution of the two factors A: silicon carbide and B: fly ash towards the achievement of obtained strengths.

Through the investigation of the plots shown in figure 4 and Table 4.1, it can be seen that with the rise in the percentage of the admixture added in the Al 2024, the value of strength moves in an upward direction.

4.2 Hardness Behaviour

In this study, a Brinell hardness test machine was utilized to determine the hardness of base metal and composite metal. Brinell hardness number came into existence in early 1900 and now is used as a standard for measurement of hardness for different materials under metallurgical considerations. Thus this device - Brinell hardness test machine has been used to find out the hardness of the composite in which silicon carbide and fly ash have been inserted into aluminium 2024 as reinforcement in this current experimentation. Here in this experimentation, a load of 10 kg was applied through a machine and a square base diamond pyramid indenter has been used.

Table 4.2 a: Experimental results for the Brinell hardness test.

Samples	**Factor 1**	**Factor 2**	**Response 2**
	A: Silicon Carbide (SiC)	**B: Fly ash (FA)**	**Hardness**
	%	%	BHN
1	0	0	82.8
2	5	5	88.8
3	0	10	83.1
4	0	5	83.5
5	10	5	94.9
6	5	10	91.8
7	5	0	84.4
8	10	0	86.3
9	10	10	96.6

***BHN: Brinell Hardness Number**

Hardness = 82.7889 + 0.446667 * Silicon Carbide (SiC) + 0.1 * Fly ash (FA) + 0.1 * Silicon Carbide (SiC) * Fly ash (FA)

The highest hardness id 96.6 BHN is obtained, which is seen in sample 9, where the percentage of SiC and FA is 10% in the sample and the lowest hardness which was obtained 82.8 BHN, has been observed in sample 1 where the percentage of the SiC and FA is 0%. When there is Al/SiC 10% + FA 5% which is sample 5 showcases

94.9 BHN. To find out the hardness in the study, a small circular piece of the sample has been developed.

Table 4.2 b: ANOVA table for the hardness

Source	Sum of Squares	df	Mean Square	F-value	p-value	% Contribution
Model	213.43	3	71.14	34.31	0.0009	
A	134.43	1	134.43	64.82	0.0005	60.03
B	54.00	1	54.00	26.04	0.0038	24.12
AB	25.00	1	25.00	12.06	0.0178	11.27
Residual	10.37	5	2.07			4.58
Total	223.80	8				

Table 4.2 (b) which is an ANOVA table for hardness showcase that the major role is of silicon carbide which is 64.82 and then fly ash which is 26.04. There is some residual which to be 2.07. From **Table 4.2 (a)** it is shown that the mixture of SiC with fly ash FA particles shown higher hardness than aluminum.

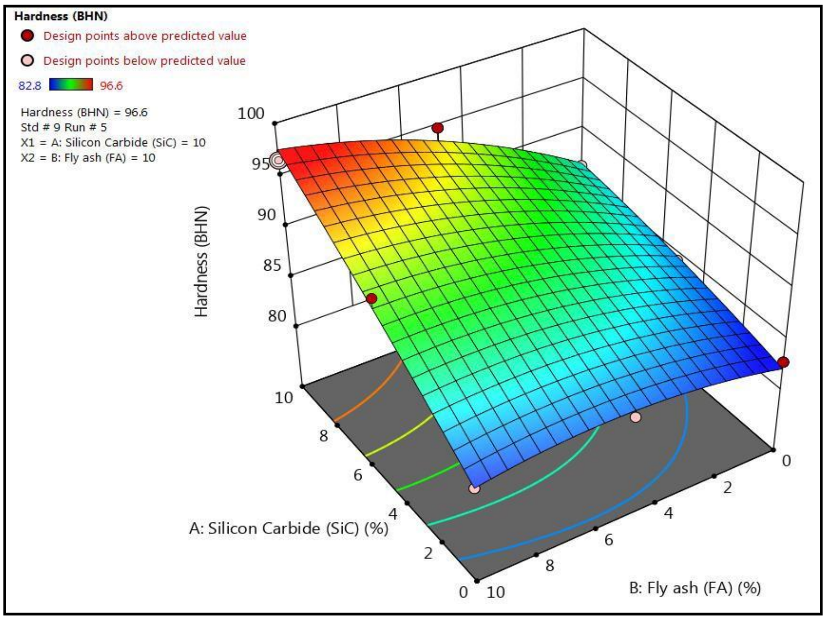

Figure 4.2 (a): 3D surface graph for the values of hardness.

Figure 4.2 (a) is a 3D surface graph and Contour Plot respectively created from design expert software through the experimental obtained in this study there are two factors A: silicon carbide and B: fly ash.

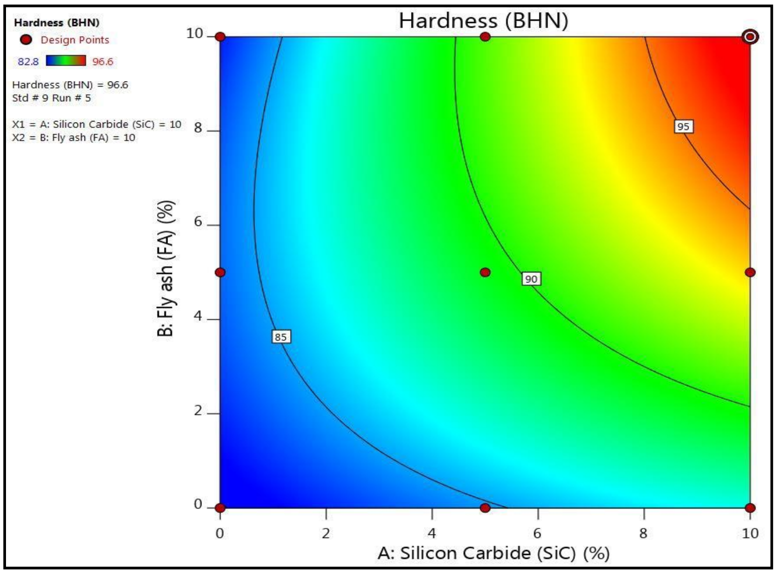

Figure 4.2 (b): Contour Plot for the values of hardness

Figure 4.2 (b) is a Contour Plot created from design expert software through the experimental obtained in this study there are two factors A: SiC and B: FA and also in Contour Plot.

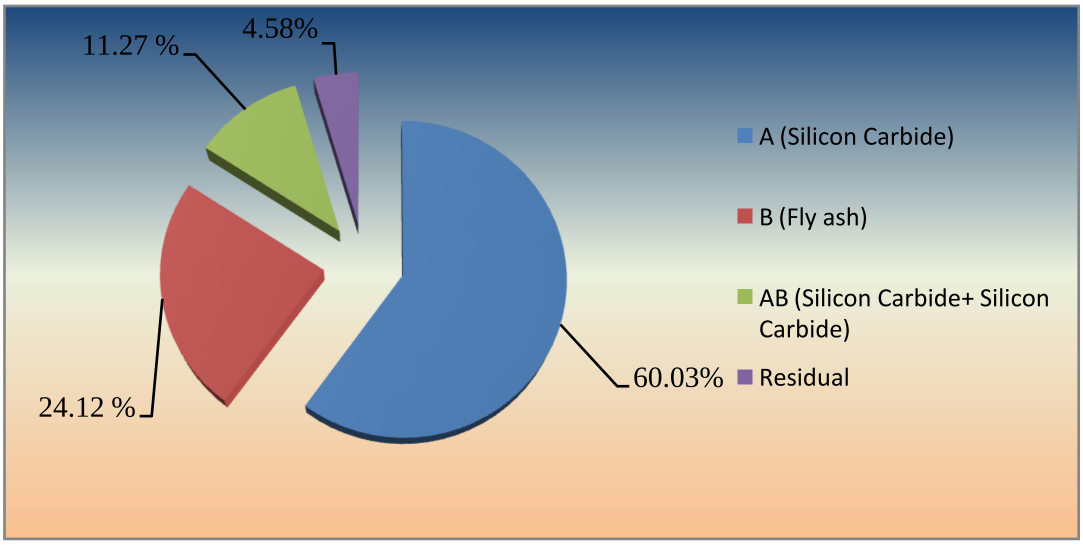

Figure 4.2 (c): Percentage contribution for the hardness.

Figure 4.2 (c) is a 3D surface graph and Contour Plot respectively generated from design expert software through the experimental values obtained in this study there are two factors A: SiC and B: FA and similarly in Contour Plot.

Through the analysis of the plot and also it is seen in **Table 4**. It proves that the percentage of the admixture added in the Al 2024, the value of hardness moves in the upward direction.

4.3 Density Behaviour

The density was obtained by the test performed by Archimedes standard, and then again, the theoretical density was determined by applying the standard of combinations as indicated by the weight fraction of reinforcement. SiC and FA particles display very less density as compared to aluminum. Here in this study, 9 samples have been prepared.

Table 4.3 (a): Experimental results for density values.

Samples	Factor 1	Factor 2	Response 3
	A: Silicon Carbide (SiC)	**B: Fly ash (FA)**	**Density**
	%	%	g/cm^3
1	0	0	2.71
2	5	5	2.3
3	0	10	2.32
4	0	5	2.55
5	10	5	2.21
6	5	10	2.12

7	5	0	2.56
8	10	0	2.4
9	10	10	2.09

Density = 2.71889 + -0.0333333 * Silicon Carbide (SiC) + -0.042 * Fly ash (FA) + 0.0008 * Silicon Carbide (SiC) * Fly ash (FA)

The highest density 2.71 g/cm^3 is obtained, which is seen in sample 1, where the percentage of SiC and FA is 0% in the sample and the lowest density which was obtained 2.09 g/cm^3, has been observed in sample 9 where the percentage of the SiC and FA is 10%. When there is Al/SiC 10% which is sample 8 showcases 2.4 g/cm^3 density. When the Al/FA 10% then the density which is obtained is 2.32 g/cm^3 in sample 3. To find out the density in the study, a small piece of the sample has been cut and weighed first in the air and then in water.

Table 4.3 (b): ANOVA table for the Density

Source	Sum of Squares	df	Mean Square	F-value	p-value	% Contribution
Model	0.3473	3	0.1158	52.19	0.0003	
A	0.1291	1	0.1291	58.20	0.0006	36.02
B	0.21663	1	0.2166	97.67	0.0002	60.43
AB	0.0016	1	0.0016	0.7214	0.4344	.44
Residual	0.0111	5	0.0022			3.11
Total	0.3584	8				

Table 4.3 (b) which is an ANOVA table for density showcase that the major role is of fly ash which is 97.67 and then silicon carbide which is 58.20. There is some residual which to be 0.0022. From **Table 4** it is visible that as the percentage of the reinforcing material which is SiC and FA increased in the sample the density of the composite decrease.

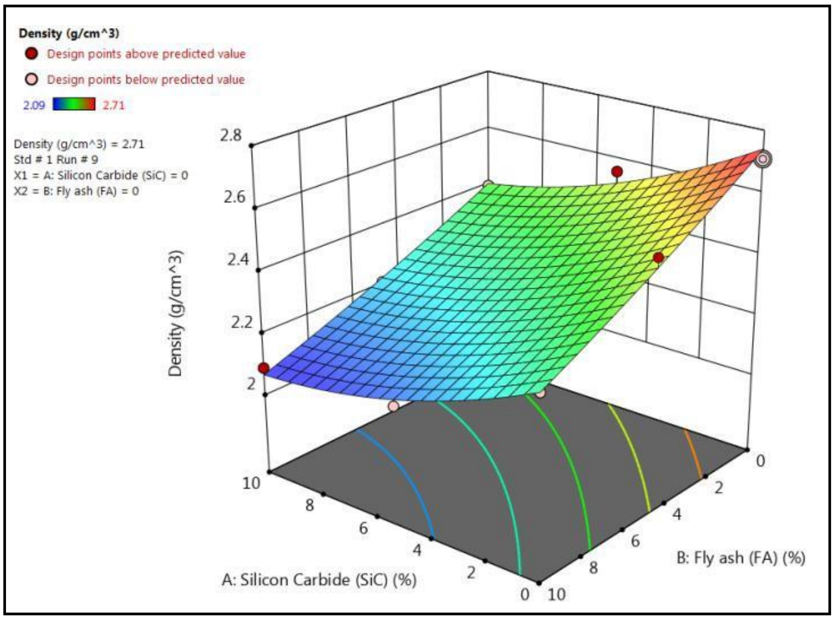

Figure 4.3 (a): 3D surface graph for the values of density.

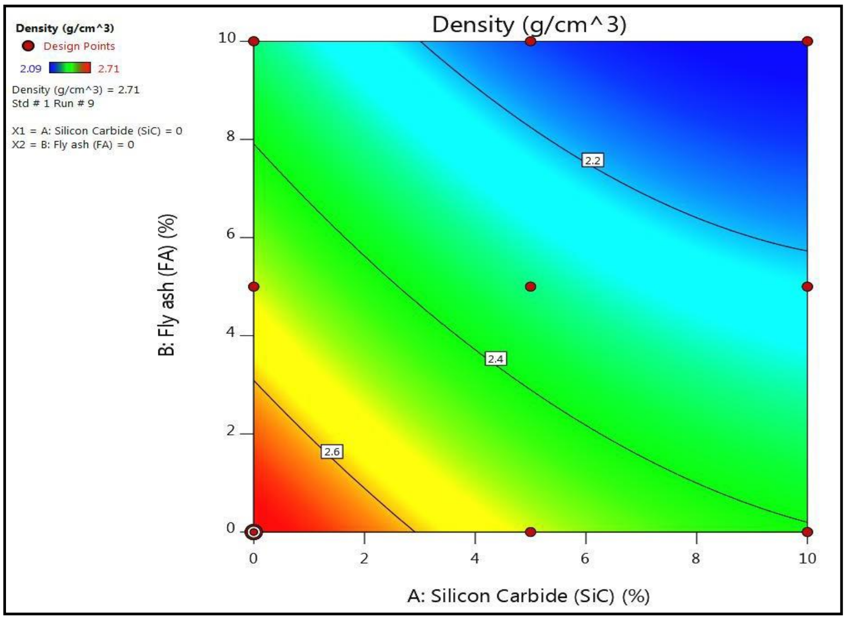

Figure 4.3 (b): Contour Plot for the values of density.

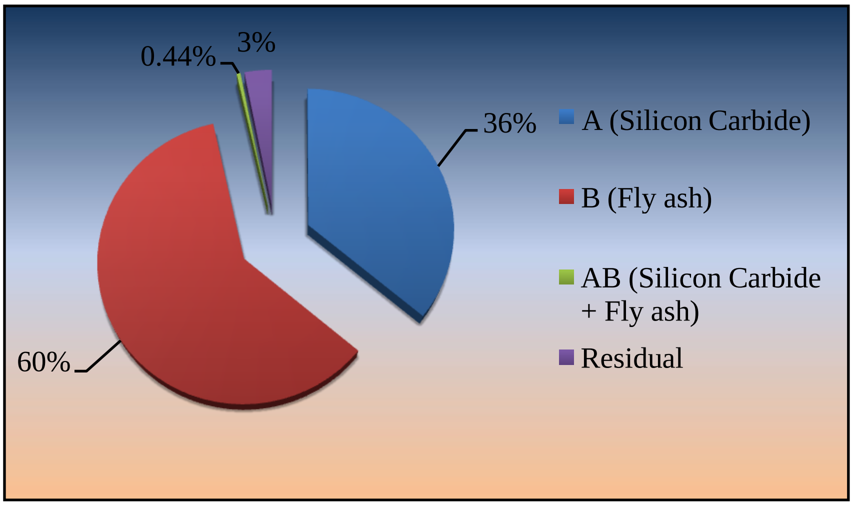

Figure 4.3 (c): Percentage contribution for the obtained density.

Figure 4.3 (c) is a 3D surface graph and Contour Plot respectively generated from design expert software through the experimental values obtained in this study there are two factors A: SiC and B: FA and similarly in Contour Plot. Through the analysis of the plot and also it is seen in **Table 4**. It proves that the percentage of the admixture added in the Al 2024, the value of density moves in a downwards direction.

4.4 Validation

In the analysis above, we saw how the mechanical properties of aluminium 2024 were modified after they had been incorporated with fly ash and silicon carbide by experiments performed and modeled graphically with regression equations. Through this model, we can obtain the output of at any input value within the set ranges, such as strength, density, and hardness.

In this confirmation experiment, we evaluate the composite for maximum strength, minimum density so that the strength to the weight ratio could get the maximum to use. This composite can be accordingly utilized in the application such as the airplane, structures, etc. From these parameters when we evaluate the value of the density, hardness, and strength the value that comes out from the model within ± 10% variation in the specified ranges.

Table 4.4: Predicted values and actual values obtained from RSM.

Validation Experiment	Parameters (Input Variables)		Strength (N/mm^2)		Hardness (BHN)		Density (g/cm^3)	
	FA	SiC	Actual value	240	Actual Value	82.80	Actual Value	2.71
	10	10	Predicted value	242	Predicted Value	82.79	Predicted Value	2.72

The results of a sample validation test and RSM model results are shown in Table 4.4. The result of this validation is on the parameters when FA and SiC both are used in 10 % then the actual and predicted strength come out to be 240 and 242.08 N/mm^2 respectively, in case of hardness the actual and predicted value is 82.80 and 82.79 BHN respectively and in case of density the actual and predicted value is 2.71 and 2.72 g/cm^3 respectively. This indicates that with ± 10% variance with the test findings, this model is reliable.

CHAPTER 5

CONCLUSIONS & FUTURE SCOPE

5.1 Conclusions

This thesis addressed the use of the RSM technique to optimize the parameters of reinforcement i.e. SiC and fly ash in Al-2024. The purpose of this work was to develop a reinforced metal matrix of Al-SiC-FA with improved mechanical properties, which was successfully prepared and optimized particulate compositions obtained through a successful RSM analysis. From an experimental study of Al-SiC-FA MMC, it was concluded that:

1. When it comes to density, as the reinforcement of SiC and FA in Al 2024 alloy, the result has been come out to be that as the percentage of reinforced material increase in the sample the density will decrease. In Al/SiC 10% the density comes out to be 2.4 g/cm^3, in Al/FA 10% the density comes out to be 2.32 g/cm^{3,} and when the Al/ SiC 10% + FA 10% then the density comes out to be 2.09 g/cm^3.

2. The strength, as the reinforcement of SiC and FA in Al 2024 alloy, the result has been come out to be that as the percentage of reinforced material increase in the sample the strength will increase. In Al/SiC 10% the strength comes out to be 268 N/mm^2, in Al/FA 10% the density comes out to be 265 N/mm^2, and when the Al/ SiC 10% + FA 10% then the strength comes out to be 290 N/mm^2.

3. The hardness, as the reinforcement of Silicon carbide and Fly ash in Al 2024 alloy, the result has been come out to be that as the percentage of reinforced materials increase in the sample the hardness will increase. In Al/SiC 10% + FA

5% the hardness comes out to be 94.9 BHN, in Al/SiC 10% + FA 10% the hardness comes out to be 96.6 BHN and Al/SiC 5% + FA 10% the hardness comes out to be 91.8 BHN. The contribution of SiC was about 60 % towards increased hardness followed by FA contribution of approximate 24 % as reflected from ANNOVA analysis.

4. From the ANOVA table made for strength and density values, it was observed that the strength characteristic is more affected by silicon carbide as well as fly ash addition. The percentage contribution of silica carbide towards an increase in the strength was 55.41% and the contribution of fly ash was 36.14%. Similarly, improvement in the density characteristic towards desired values was observed in which the contribution of silicon carbide was 36.02 % and the contribution of fly ash was 60.43%.

5. Overall the results revealed that the Al2024/SiC/FA composites reinforced with SiC 10 % + FA % reveal superior mechanical properties with lower densities and higher strength.

In the various applications such as automotive and aerospace, the findings assessed in this work may be valuable. Furthermore, the findings of this work will serve as the basis for the utilization of industrial waste including FA which can be turned into industrial resources in hybrid composites production.

5.2 Scope for Future Work

1. This thesis can be used in connection with several works, which can be performed in the same manner based on this analysis. The suggestions for further work are as follows:

2. Subsequently, this study can be applied to other aluminum alloys such as alloy 3003, alloy 5052, alloy 6061, alloy 6063, etc. This current research work concentrates on Al-2024 alloy.
3. More admixtures may be applied to the Al 2024, such as rice husk, sugarcane husk, boron carbide, carbon fibers, and others to enhance the strength of the Al 2024 alloy.
4. The present work can be expanded by the selection of parameters other than what had been considered for the current research work. More parameters can be taken into account.
5. The analysis and development can be extended utilizing various techniques such as Genetic algorithms, artificial neural networks, and particle swarm optimization for further studies. Techniques such as Taguchi, RSM, etc. can be used for mathematical simulation and enhancement of the results obtained by incorporating SiC and fly ash in 2024 aluminum alloys.

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LIST OF PUBLICATIONS

S.No.	Title with page Nos. and Date ofPublication	Journal	ISSN	Name of authors / Co-authors
1	Advancements in aluminium 2024 hybrid composites- A review	Journal of Advanced Research in Aeronautics and Space Science	eISSN: 2454-8669	Ankit Gupta & Mohd. Faizan Hasan
2	Strength behaviour assessment of Aluminium 2024 with Silicon Carbide and Fly Ash reinforcements using the RSM approach	Journal of Advanced Research in Aeronautics and Space Science	eISSN: 2454-8669	Ankit Gupta & Mohd. Faizan Hasan