Fabrication, characterization and machining of novel brake pad material

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CERTIFICATE

I hereby certify that the work being presented in the dissertation entitled "**Fabrication, characterization and machining of novel brake pad material**" in partial fulfillment of the requirement of the award of the Degree of master of technology and submitted to the Department of Mechanical Engineering of Lovely Professional University, Phagwara, is an authentic record of my own work carried out under the supervision of **Sayantan Bhattacharya**, Assistant professor, Department of Mechanical Engineering, Lovely Professional University. The matter embodied in this dissertation has not been submitted in part or full to any other University or Institute for the award of any degree.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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Abbreviations

MMC: Metal matrix composite

AMCs: Aluminium matrix composites

NAO: Non asbestos organic

Cf: Carbon fiber

SiC: Silicon carbide

Al6061/SiC/Cf: Carbon fiber and silicon carbide reinforced Aluminium matrix composite

CNC: Computer numeric control machine

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Abstract

This Paper lead us towards the future research and development which can be done in the automotive application of brake pads. Wear characteristics and Machinability of Al/SiC/Carbon fiber MMCs has been taking in to the consideration in this study. The route of stir casting is selected to manufacture the brake pads because of stir cast process is simplicity, applicability of large volume production and low cost. By the utilization of MMCs automobile organization can avail the environment and economic benefits. As we know by the mixing of SiC strength, wear resistance and toughness increases but the machinability decreases. The machinability is an important parameter. We can increase the machinability of the material by adding some % of Cf into the material. The friction coefficient and wear can be affective by the carbon fiber addition due to its lubrication property.

Keywords: aluminium, metal matrix composites, silicon carbide, carbon fiber, wear, machinability

Chapter 1

1.1 Introduction

The brake pads playing vital role in the field of automotive industries. Vehicles are made up of various parts and brake pads are one of them. Brake pads are made by verity of materials. In past automotive industries uses asbestos as a brake pad material. The asbestos fiber embedded in the polymer matrix with other ingredients to make material for brake pad [1]. Nowadays researcher try to find new material for brake pads which are free from the asbestos. To tackle challenge of present materials for variety of applications the advent of technological (tech.) era has bought the requirement of new material. To find or create the new material various material system has been invented by the researches. MMCs (metal matrix composites) is the one of the most prominent system in the past few decades, where new material is fabricate by the mixing of two or more constituents. MMCs help us to use the unique properties of the constituents in a manner to suppress the limitation of the other constituent. As we know in engineering application the MMCs plays an important role due to its mechanical and physical properties [3]. In automotive industries we use MMCs because they have high strength to weight ratio, good behavior and low cost. The wear rate and frictional coefficient is lower in case of Aluminium (Al) matrix composites as compare to the brake pads which consist resin as matrix [13]. The main motive of this research is to develop hybrid of Al, SiC and carbon fiber reinforced by the use of stir casting fabrication process for the brake pad application [2]. In this research we practice to enhance the properties of the present brake pads which are made up of Al/SiC MMCs by the use of the powder metallurgy manufacturing process because of its low cost, high production suitability, ease of operation and attractiveness [4, 10].

Al/SiC/Carbon fiber metal matrix composite is an alternative material for the brake pads which provide good machinability and significant wear properties as compare to the Al/SiC metal matrix composite [6].

When we mix the carbon fiber in Al then carbon reacts with the Al and generate Al4C3 (brittle and water soluble compound) on the surface of fiber. To prevent this we coated the carbon fiber with Nickel or Titanium-Boride [20] but when we do the coating to the carbon fiber and use it as a reinforcement then it does not decreases the wear [14].

At an elevated temperature MMCs are fabricated on which diffusion bounding of fiber/matrix take place and after that MMCs are cooled down to ambient temperature residual stresses generated due to mismatch between the coefficient of fiber and matrix.

1.1.1 Historical background of brake pad materials:

1. **Wooden brake pads:** In initial stages the brake pads are made by wood. These brake pads are made by the sintered wood. These brake pads were used in the wagons. The manufacturing of these brake pads are quite easy and cheap but they have problem when they burnt by heat then they lose their contact with the tire surface.

Figure 1 wooden brake pads

2. **Copper brake pads:** In early 20th century the brake pads are made by copper. These brake pads has better properties then wooden brake pads but the manufacturing of these are tough.

Figure 2 copper brake pads

3. **Asbestos brake pads:** These brake pads are developed after the copper brake pads in 20th century. Asbestos used to manufacture brake pads because they have ability to dissipate heat. These brake pads has longer life then the copper brake pads. These are harmful for the human because when these fibers dust comes in to our body they causes chest pain, cough and lung cancer.

4. **Non asbestos organic (NAO) brake pads:** Non asbestos brake pads are of the material which consists of organic fiber such as glass fiber, carbon fiber, ceramic or other fibers as a reinforced material. Friction material of NAO consist 30% of steel by weight. These brake pads are invented to replace the harmful asbestos brake pads.

Composite:

It is a combination of two or two material which are mix together to create unique and superior material. By the use of composite we can create material as per requirement of the properties.

Metal matrix composite (MMC):

The composite which is made by combining more than two constituents together. In which one constituent always a metal other may be of different material. When the composite contains three or more constituents then it becomes a hybrid metal composite [9, 2]. In a composite matrix act as one constituent and other as reinforcement.

Thus we can say metal matrix composite is the combination of matrix and reinforcements [2].

Matrix:

It is the monolithic and continuous material in which the reinforcement are added. It is use to bind the reinforcement together.

Example: Aluminium

Reinforcement:

These are the material which we add in to the matrix. Reinforcement use to change the physical properties like thermal conductivity, wear resistance, strength and friction. Reinforcement either continuous or non-continuous [2].

Example: Carbon fiber, silicon carbide

I. Continuous reinforcement:

i. Monofilament wire or Long fiber

II. Non-continuous reinforcement:

i. Whiskers

ii. Short fiber

iii. Particulate

1.1.2 Fabrication process

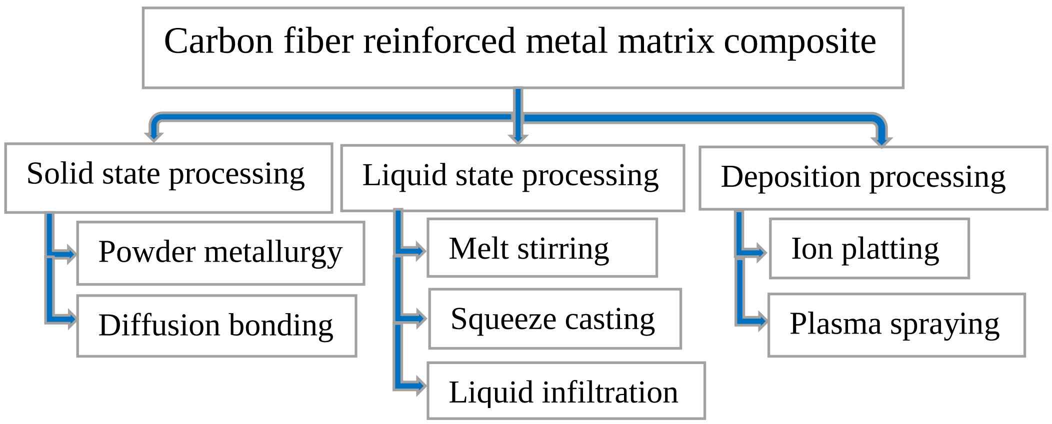


Figure 3 Flow diagram

1.1.2.1 Solid state method

i. **Powder metallurgy:** Metal particulates (powder) and non-continuous reinforcement are mixed and then bounded by a process of compaction, degassing or extrusion [2].

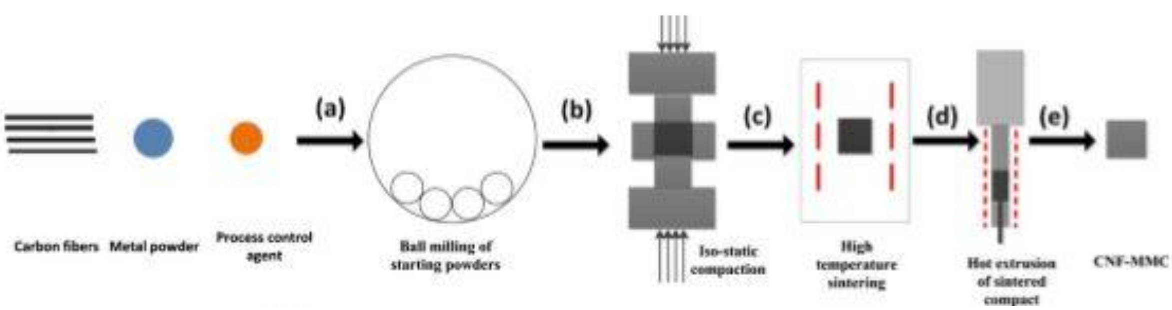


Figure 4 Powder metallurgy process [2]

ii. **Diffusion bonding:** It is the tech by which we can join similar or different metals. It works on solid state diffusion principle. For fabrication by this process we user specific tool such as dies and rams.

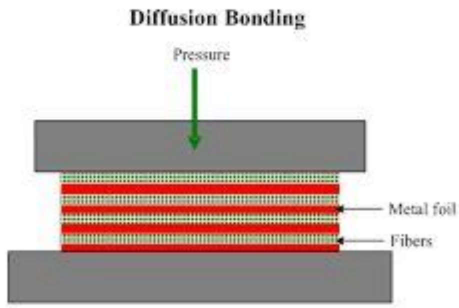


Figure 5 Diffusion bonding [2]

1.1.2.2 Liquid state method

i. **Stir casting:** In this discontinuous reinforcement stirred into the molten, which is allow to solidify [2]. It is cost effective, simple and use for large volume production.

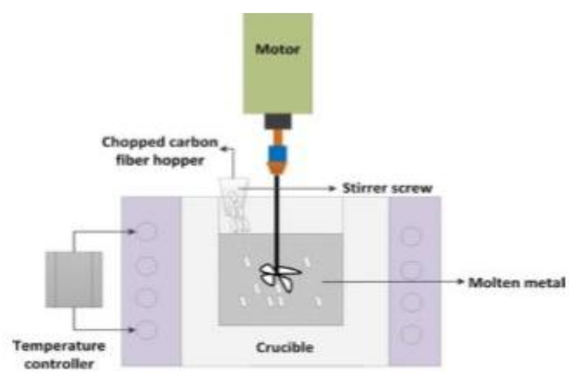


Figure 6 Stir casting process [2]

ii. **Squeeze casting:** The combine formation of casting and forging is known as squeeze casting process. In this the preheated bottom part of the die is filled with the molten metal. When the metal start solidifying then we close the part of the die and apply pressure on the metal.

iii. **Liquid infiltration**: In this process the molten matrix of the metal passes through the fiber under high pressure. The infiltration carried out within seconds.

1.2 Aim and objective

a) To enhance the (Al/SiC) existing material of brake pad in order to improve ease for machinability.

b) To enhance the tribological properties of the material.

c) To optimize the machinability and mechanical characteristics of Al/SiC/Carbon fiber.

Chapter 2

2.1 Literature review

Rathod Abhik (2016) [1] attempted to create a hybrid material of Al/SiC/Cf by the powder metrology process and then perform serval test like harness test, porosity test and wear analysis to evaluate the properties. It is observed that strength improved by increasing fiber content. The wear rate also found to be improved. The wear reduce due to better bonding between matrix and other reinforced. By improving the interface and reducing the porosity we can achieve high performance.

Kamyar Shirvanimoghaddam (2016) [2] in this document research and development over past few years on carbon fiber reinforced MMCs was conducted. The structure of carbon fiber, composition and its bonding to matrix affecting its properties. Poor dispersion of carbon filler in metal matrix will lead to the deterioration of composite material. The effect of carbon fiber on structural, physical characteristics and mechanical properties. Various fabrication method to produce the CFR-MMC such as powder metrology and stir casting etc.

Sijo M T et al. (2015) [3] proposed multiple advantages of stir casting over the other fabrication processes. Stir casting mechanical properties are depend on the various factors like fabrication techniques, shape, reinforcement particulate size and properties of constituents and distribution.

By the addition of reinforcement mechanical properties increase but fracture toughness is decreased. To enhance fracture toughness reinforcements homogenous distribution is required. The motive of this work was to help the researchers to identify strategies for experimentation.

A. Tony Thomas et al. (2014) [4] investigate on the stir cast fabrication process for Al (LM6) /SiC metal matrix composites. The methodology for stir casting and its benefits. The focus of this research on the design, fabrication and testing of different stirrers and feeder. Their specification by testing on specimen.

Mohamed Zakaulla (2015) [5] in this document, the hybrid MMC is made with Al6061/Cu-SiC/Cu-Gr to evaluate the wear of this composite with different loading (10, 20, 40N), sliding speed (0.42, 0.84, 1.64m/s) and different distance (750, 1500, 3000m) by the taquchi method. Thus from this research we get to know that taquchi method is best suited method to find the specific wear rate and regression equation for the coefficient of friction.

Duanjie Li (2014) [6] in this, mechanical and tribological attributes of Cf composite discussed. Carbon fiber plays a critical role in enhancement of properties like wear and friction.

P. Suresh et al. (2014) [7] the study was proposed that MMCs with reinforced graphite particles provide better tribological and mechanical attributes. The study attempts to find optimal level of machining parameter for multi – perfect characteristics in turning of Al/SiC/Gr using Gray fuzz algorithm composing of 5%, 7.5% and 10%. Al with 10% (SiC-Gr) provide better machinability as compare to the 5% and 7.5%. Gray fuzz analyses used to find result. The recommended level of turning is done to decrease flank-wear and surface roughness. To generate more accurate and effective result number of process and experiment should be increase.

Rachit warwaha et al. (2013) [8] in this analysis and experimental analysis has been done to find the parameter of wear on Al/SiC/Gr hybrid (fabricated through Stir casting with the composition of 5% Gr and 10% SiC) by the help of taguchi method. Sliding wear test is performed on the Pin-on-disk wear test machine. ANOVA technique is use to find out the frictional coefficient and from this it was observed that by sliding speed and load has influence on the track diameter.

Guo (2013) [9] the study was to develop the hybrid composite of Al/SiC/Gr by the powder metallurgy process. In matrix of Al 6061 series (general purpose alloy) different composition of SiC (10%) and (2/5/87) Gr powder (in volume percentage) is used to check the tribological characteristics. The frictional coefficient decreases when the Gr is up to 5%.

Jayashree P .K (2013) [10] was observed that wear characteristics and mechanical aspects of aluminum MMCs with reinforced SiC particles in both precipitation toughened and untreated condition. The effect of SiC over stir cast Al MMCs was observed.

S. Mahdari (2013) [11] in this research, the hybrid of Al6061/SiC/Gr fabricated through situ powder metallurgy by varying the size of SiC particulates (19, 93,146µm) and taking 20% volume of SiC constant for the samples. According to this study when the size of SiC particulates decreases then the hybrid hardness increases. From this study we know that by increase the SiC particulates size, the wear rate decreases. The hybrid which contains SiC particulates of medium sized has minimum wear loss.

RupaDasgupta (2012) [12] it proves that Al alloy based MMCs are act as a wear resistance material for the application of sliding wear. However, in actual practice different wear combination encounter in engineering components. Different modes for the wear like abrasion, sliding, erosion. The combination of wear modes are like cavitation erosion, erosion abrasion, sliding abrasion and the obtained result compared with base alloy.

Mohammad. Asif (2012) [13] proposed to fabricate brake pad by Al-MMC against the cast iron. It was observed that the Al based brake pads possess less wear rate at same order of friction coefficient as in resin bounded brake pad. Temperature rise, judder and vibration of Al based brake pad slightly higher as compare to the brake pad of resin based material. Al based brake pad has lower wear loss than the brake pad of resin. Coefficient of friction lower in Al based brake pad as compare to the brake pad of resin based material. Temperature risen in developed Al based composite three time lower then resin based material. Fluctuation in Al based is slightly higher as compare to resin based.

Guo (2012) [14] in this article, the wear behavior of A6061/SiC/Nickel-Coated graphite is discussed. They made the samples with 5 vol. % and 8 vol. % of nickel coated graphite composition. As per this study we get to know that the hybrid which contains Gr-Ni has higher wear rate as compare to normal Al/SiC composite. Thus the composite which contains Gr-Ni does not works for the wear reduction. It may result very small benefit in friction reduction as compare to the loss in mechanical properties.

Soheil Mahdari (2011) [15] in this study the effect SiC content in Al6061/SiC/Gr hybrid are discussed. According to this study the wear impending of the hybrid composite which contains 20% volume of SiC and 9% Gr is higher as compare to the other hybrids. When the SiC volume is increase to 20% then after a distance of 1000m, there's a decline in wear rate and volume loss about 88% and when we increasing the SiC content from 20% to 40 % the wear rate and volume loss is increase by 76%.

Telang .A K et al. (2010) [16] was observed the attributes of AMCs which would affect serval major advantages. Al MMCs frictional coefficient is 25-30 % time the cast-iron and the wear attributes are also far better than the cast iron. Thermic conductivity of Al matrix composite is higher than the cast-iron. It was found that when SiC particulate introduced to the Al matrix it increases the flexural strength, hardness and fatigue resistance.

L.H. Hihara A. (2010) [17] was studied over the Corrosion of MMCs. The fiber and particulates added to the MMCs to tailor or improve the properties (stiffness, friction, strength, and wear resistance) but they may interact chemically, electrochemically or physically with the matrix which lead to distinct degradation problem. In comparison of massive matrix alloy MMCs are generally more supine to corrosion. The effect of corrosion on various MMCs also discussed.

Liu Lei et al. (2008) [18] was studied about the wear and frictional attributes of short carbon fibers (SCFs) in Al MMC. Wear behavior and friction of SCFs/Al and Al alloy were investigated in this. The wear mechanism, load applied, fiber volume fraction were also discussed. They found the result which indicates that SCFs/Al composite has higher properties then Al alloy. By the increase of fiber volume fraction the wear loss and frictional coefficient decreased. SCFS enhance the wear resistance of Al alloy. The wear loss increased by increasing the load and rotating speed. In all the range of load a liner evolution displayed by wear.

M.L Ted Guo et al. (2002) [19] investigating over the tribological demeanor of Al/SiC/nickel-coated graphite hybrid composite. The investigation recommends that the SiC and Gr-Ni particle distributed uniformly. Thermal expansion decreased significantly with the addition of Gr-Ni. By increasing the amount of Gr-Ni rupture energy decrease and wear detritus become smaller. Seizure occur for massive Al alloy but not for the Al/SiC and Al/SiC/Carbon fiber. The wear rate of both the composite and the counter-part increase as the mount of the Gr-Ni added up to 5% and then drop for 8%.

H.Chen et al. (1995) [20] was studied over the A356 series Al alloy reinforced with Cf-Ni. Wear test carried out at constant load level with the range of 5 to 300N using constant velocity of 0.5ms^-1. Increment loading in wear rate was also studied. Wear rate of Cf reinforced composite were tantamount or less than the Silicon carbide (SiC) particulate reinforced material. The wear resistance of A356-4%Cf compared with A356-20%SiC, due to the iron oxide transfer layer on the contact surface.

Scope of the study

Nowadays the requirement of new material is required in each sector which can replace the old one. The new material should have better properties as compare to the monolithic material. These properties can vary with the application. For example if we talk about the automotive industries application of brake pad. Generally the brake pads are manufacture by Al/SIC MMCs but the era is changed now there is need of new material which can replace the Al/SiC MMCs by proposing the higher properties like low wear, high machinability, light weight, good coefficient of friction, high strength, and good thermal properties. These attributes can be archived by the Al/SiC/Carbon fiber hybrid MMCs.

Chapter 3

3.1 Materials

3.1.1 Aluminium (Al)

It is a slivery-white metal.it is placed on 13 position in periodic table. It is the third most common chemical element on our planet after oxygen and silicon. The unforeseen fact about the Al is that it is the most widespread metal on earth. It can easily bind with the other materials. Pure Al doesn't occur in nature. Light, durable and functional these quality make aluminum the key engineering material of our time.

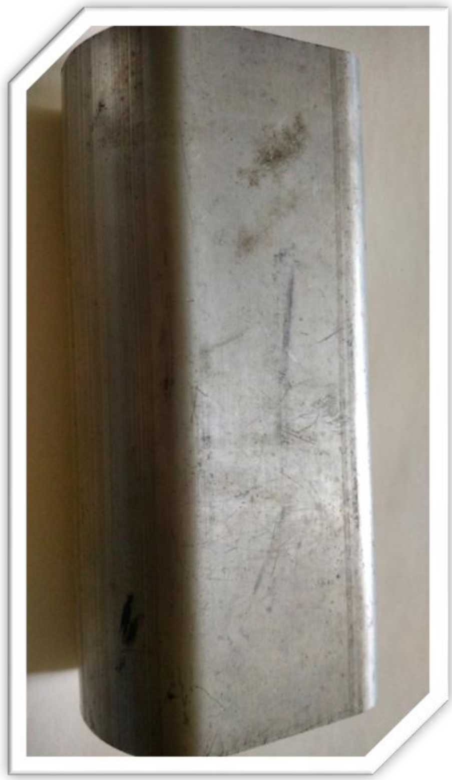


Figure 7 Al 6061 block

Al properties:

1- Light weight

2- High corrosion resistant – because of AL_2O_3 layer

3- High strength to weight ratio

4- Easy to shape

5- Al foil

6- Easy to recycle

7- Al cryogenic properties

Series of Al:

1000- Pure Al (99% Al content)

2000- Alloys with Cu (common aerospace alloy)

3000- Alloyed with manganese

4000- Alloyed with silicon (silumin)

5000- Alloyed with magnesium

6000- Alloyed with magnesium and silicon (easy to machine, wieldable and general purpose alloy)

7000- Alloyed with zinc (ultimate tensile strength up to 700Mpa for 7068 alloy)

8000- Alloyed with other element which isn't covered by other series

It is introduced by the upper research paper that Al 6xxx series is suitable for making brake pads. And most commonly brake pads are made up of Al 6082 series [1].

3.1.2 Carbon fiber (Cf)

In this long chain is formed by the bounded carbon atoms. The fibers are light, strong and stiff. Different order of carbon fiber waves result in different properties for composite parts. Cf are 5-10 micrometer in dia. Cf is the strongest and light weight material. It is five time stronger then the steel and one third of the weight of the steel. Mostly CNC used for machining of carbon fiber parts.

Carbon fiber (Cf) properties:

1- Fatigue resistance
2- Admirable tensile strength
3- Fire resistance
4- Low thermal enlargement
5- Self-lubricating
6- High thermal conductivity

Figure 8 Carbon fiber (chopped)

3.1.3 Silicon carbide (SiC)

It is the amalgamation (mixture) of silicon and carbon. It does naturally occur as mineral moissanite but it is extremely rare. It is produced in mass quantity to use as an abrasive since 1893. In past it has been used grinding wheels. Due to its property of high strength and endurance it is used in applications like automotive brakes and clutches. Its physical property make this material useful for the high temperature applications.

Silicon carbide (SiC) properties:

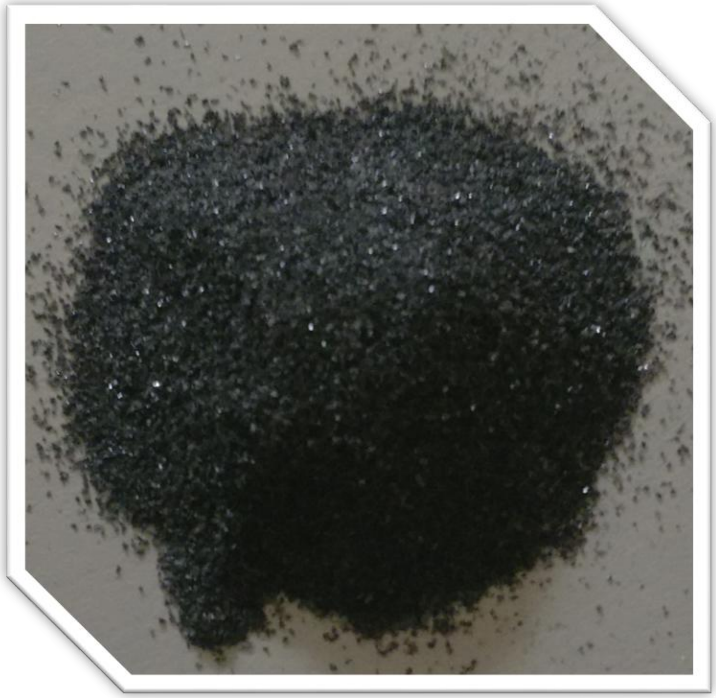


Figure 9 Silicon carbide

1- Extreme melting point
2- Effective thermal conductivity
3- Low thermal enlargement
4- Good thermal shock resistance
5- Wear resistance
6- Corrosion resistance
7- High hardness

3.1.4 Composition of materials for the sample preparation:

Materials	Sample 1	Sample 2	Sample 3	Sample 4
Al 6061	79.5%	79.3%	79.1%	79%
SiC	20%	20%	20%	20%
Carbon Fiber	0.5%	0.7%	0.9%	1%
Total	100%	100%	100%	100%

Table 1 Composition of materials for various samples

3.1.5 Calculation

- Density of Al =2.7 g/cm3
- Density of SiC = 3.21 g/cm3
- Density of Carbon fiber = 1.60 g/cm3

3.1.6 Dimensions of sample

Diameter (d) - 30mm

Height (h) - 100mm

Volume of the die -

V=3.14*(r^2)*h

=3.14*2.25*10

=70.65cm3

As we know density is equal to mass upon volume (p=m/v)

There for

Mass = density * volume

= 2.7 * 70.65

= 190.755 gm.

Weight of materials as per the percentages

Weight	Sample 1	Sample 2	Sample 3	Sample 4
Al 6061	151.65 gm.	150.27 gm.	150.88 gm.	150.69 gm.
SiC	38.15 gm.	38.15 gm.	38.15 gm.	38.15 gm.
Carbon fiber	0.9537 gm.	1.33 gm.	1.78 gm.	1.90 gm.

Table 2 weight of materials for the sample as per the percentages

Chapter 4

4.1 Test and methodology

4.1.1 Test

i. Tribological and mechanical test:

a- Hardness test –

Vickers micro hardness test (ASTM E-384)

b- Microstructure analysis –

SEM microscopic test

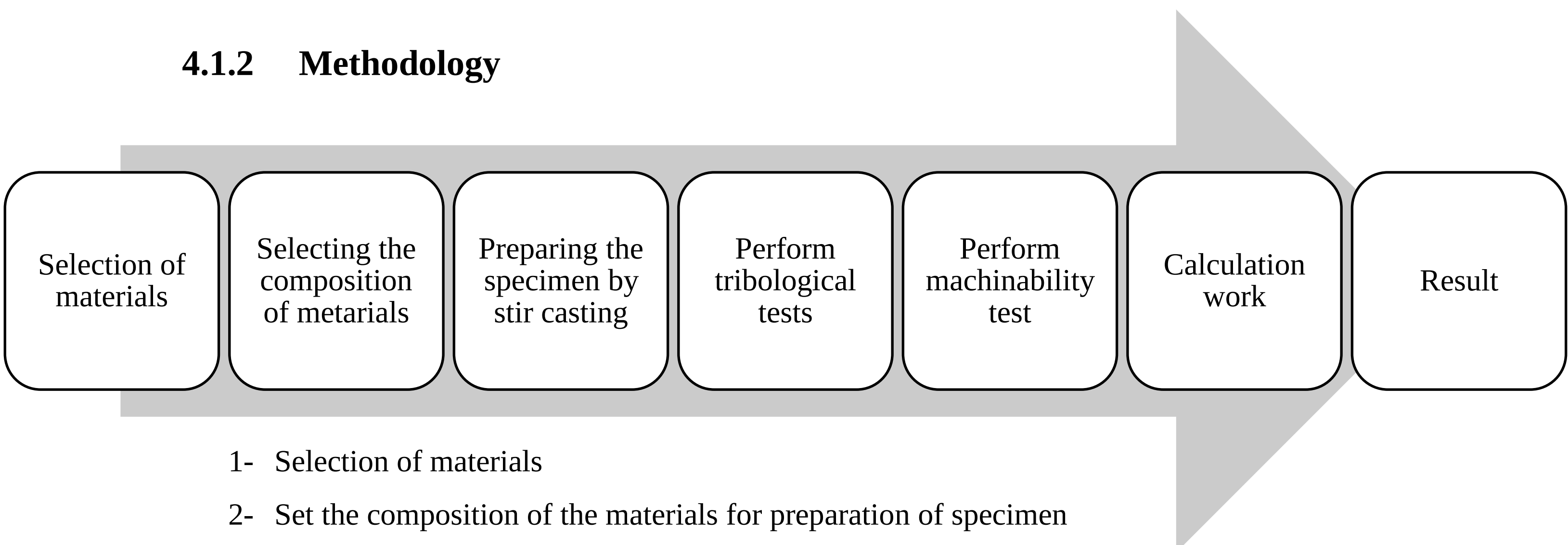
c- Wear test –

Pin-on-disk wear testing (ASTM G99)

ii. Machinability test:

Performing turning operation by varying speed, feed and depth of cut and evaluating the tool wear and surface roughness as output parameter.

4.1.2 Methodology



1- Selection of materials
2- Set the composition of the materials for preparation of specimen
3- Prepare the specimen of the material by the use of stir cast fabrication
4- Perform tribological test over the specimen
5- Then perform machinability test
6- Optimization using ANOVA and Taguchi analysis
7- Calculation work
8- Result

Chapter 5

5.1 Gantt chart

Chapter 6

6.1 Expected outcome

By observing the outcomes and the preeminent finding from these research papers and articles it can be deduced that manufacturing of Al/SiC/carbon fiber hybrid composite is possible by the Stir Casting process. It is proved that covet (desired) outcome can be achieve by the following processes which is further used in research papers. According to the paper the wear rate is decreased by carbon fiber addition by virtue of lubricating property. SiC provides wear resistance, strength and toughness to the composite but it reduces the machinability. So, by the addition of some carbon fiber percentage in to the material good machinability can be achieved. After mixing carbon fiber frictional coefficient is decreases slightly, relatively so far machinability increases.

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