



ADDIS ABABA UNIVERSITY
Addis Ababa Institute of Technology
School of Mechanical and Industrial Engineering

**Development and characterization of Al6061/SiC/Bagasse Fly ash/Aloe
Vera ash hybrid composite as an alternative material for drum break
Application**

A Thesis Submitted to the Graduate School of Addis Ababa University in Partial
fulfillment of the Requirement for the Degree of Masters of Science in Mechanical
Engineering (Manufacturing Engineering)

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SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

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Submitted in accordance with the requirements for the degree of
MASTER OF SCIENCE (MSc.)

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Author's declaration

I hereby declare that the work which is being presented in this thesis is entitled "**Development and Characterization of Al6061/SiC/Bagasse ash/Aloe Vera ash hybrid composite as an alternative material for drum Application.**" This authentic record of my own work, which was done under the supervision of **Getasew Ashagrie (Ph.D)**, and has not been submitted for a degree by any other universities, on one of the issues the automotive industry is currently facing, fulfills a portion of the requirements for the award of the degree of Masters of Science in Mechanical Engineering (Manufacturing Engineering).

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I hereby certify that the above declaration by the Candidate is correct to the best of my knowledge and belief. The results of this research may be submitted for review with my consent.

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Acknowledgment

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Abstract

Composite materials, which have low densities, are used for automotive body parts and structural functions, leading to high strength-to-weight ratios and high stiffness-to-weight ratios compared to other conventional materials. Most engineering applications nowadays in industry, such as, aerospace, automotive body parts, propellers, and manufacturing turbine blades, require better mechanical properties of material. To meet these requirements, metal matrix composite offers certain top mechanical properties such as higher transverse strength and stiffness, superior shear strength, wear resistance and compressive strength, and superior high temperature performance than other polymer and ceramic composites characteristics. This work aims to develop and evaluate Al matrix composites with better performance using low-cost reinforcements from industrial wastes and agricultural products. Fabrication and experimental study of mechanical properties of aluminum matrix (Al6061/SiC) composites the weight % of reinforcement was evaluated and compared. Al6061 matrix hybrid composites were prepared by stir casting at 700 °C and at 600 rpm of stir rotation.

The parameters were used to develop the Al6061/SiC bagasse fly-ash and aloe-vera ash hybrid composite are chemical composition of reinforcements, weighted requirements for matrix and reinforcements, powder mixing, and stirring the slurry at 600 rpm for 10 minutes. Compression strength testing (ASTM Standard E9), wear resistance of samples using (ASTM G99 standards, and impact strength testing (ASTM E-23) had been conducted to characterize the developed composite. The results showed that the compression strength slightly increased with bagasse ash and aloe vera ash content. The maximum compression strength achieved in sample 6 (Al6061-10% SiC, 9% bagasse ash, and 11% Aloe vera ash) is 376.3 MP, and the average value is 376.3 MP. A low average value of wear (in microns) has been found in sample 6 (Al6061-10 %SiC-9% bagasse ash - 11 % Aloe vera ash), and the value is gained at 64.8 microns, this shows more wear resistance in the composite sample as compared to other samples. The impact test result shows that samples gives better energy absorbed which is 4.79J.

Therefore, industrial waste, bagasse ash and agricultural product like alovera can enhance mechanical properties which mean hybrid composites had better properties than single-reinforced composites. Therefore, Al 6061/SiC with bagasse and alovera ash composite is suitable for

applications where less density with high yield strength and hardness are predominantly required for drum brake application.

Keywords: Aluminum matrix, metal matrix composite, bagasse ash, alovera ash, mechanical characterization, microstructure

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Abbreviations and Nomenclatures

Al	Aluminum
Al/SiC	Aluminum Silicon Carbide
Al/SiC-fly ash	Aluminum Silicon Carbide Fly ash
ASTM	American Society for Testing of Materials
BFA	Bagasse fly-ash
AV	Aloe vera ash
CMC	Ceramic matrix composite
GCI	Grey cast iron
HMMC	Hybrid metal matrix composite
MgO	Magnesium oxide
mm	Millimeter
MMC	Metal Matrix composites
MMHCs	Metal Matrix Hybrid Composites
nm	Nano meter
PMC	Polymer matrix composite
RH	Rockwell Hardness
RPM	Revolution per minute
SEM	Scanning Electron Microscope
SiC	Silicon Carbide
Wt. %	weight percentage
FSP	Friction stirs processing
μ	Coefficient of friction
T1	Trial 1
T2	Trial 2
T3	Trial 3
Avg	Average

Chapter one

Introduction

1.1. Background of the study

A composite material is a material consisting of a well-arranged mixture or combination of two, three, or more micro- or macro-elements separated by interfaces that differ in shape and chemical composition, and whose heterogeneous by nature they are essentially insoluble in each other. The discrete component is called reinforcement and the continuous phase is called matrix. Based on the shape of the reinforcement, composites are divided into particle reinforced composites, short fiber composites (whiskers) and continuous fiber composites. Composites are classified as the metal matrix (MMC), polymer matrix (PMC), and ceramic matrix composites (CMC) based on the basic chemical nature of the matrix phase. (Czerwinski, 2021) stated that the replacement of ordinary materials, such as steel, aluminum, and other compound materials, with composite materials, has essentially met all needs in the aviation, automobile, maritime, and general development fields. The essential point of developing new materials for car applications is to enhance vehicle proficiency and efficiency by diminishing the weight of the vehicle.

According to a study by (Himanshu, et al., 2014), metal matrix composites (MMCs) are engineering materials that incorporate powerful ceramic reinforcements in a metal matrix to enhance their properties. Metal matrix composites combine the metallic properties of the matrix (ductility and toughness properties) with the ceramic properties of the reinforcement (higher strength and higher modulus) to provide higher shear and compressive strength and higher service temperature capability. (M.KoK, 2005). For example, metal matrix composites containing copper were one of the first continuous fiber-reinforced composites studied as a model system. Initial work in the late 1960s was prompted by the high-performance requirements of the aerospace industry. Performance, not cost, was the primary driver for this development effort. The extensive use of aluminum alloys in the manufacture of aerospace and automotive structures has become well-known in recent years. However, aluminum alloys cannot meet all technical requirements in advanced fields of engineering and technology. Their main weaknesses are their poor behavior at high temperatures and their low wear resistance.

To overcome these problems, new engineering materials have been developed by reinforcing

aluminum alloys with ceramic particles/whiskers. These are known as metal matrix composites (MMCs) (Kailun, et al., 2018). Generally, the materials utilized in the development of vehicle bodies have different properties than steel and aluminum. Aluminum matrix composites have important properties in terms of high strength-to-weight ratio compared to other metal matrix composites. Particles such as SiC, TiC, TiB₂ and fly ash have been used to strengthen Al alloys to improve their mechanical properties and wear resistance (Manisha, et al., 2018). The literature reviewed shows that, among all reinforcements, SiC is chemically compatible with aluminum, forms suitable bonds with the matrix without developing intermetallic phases, has excellent thermal conductivity and it has been shown to have other advantages such as machinability and low cost (James, et al., 2014).

A major factor limiting the application of Al6061/SiC is the high cost of SiC materials and manufacturing, which can be minimized by using locally available fillers such as bagasse fly ash, aloe vera ash and natural minerals. Fly ash is cheaper compared to other reinforcements such as SiC, Al₂O₃, B₄C, TiC, etc. Due to its low cost, the use of fly ash as reinforcement material in aluminum alloys has been reported to be desirable in recent years from both an environmental and economic standpoint. The high cost of current MMCs compared to aluminum alloys inhibited production on a large industrial scale, for example, in the automotive industry (Yashpal, et al., 2017).

Investigation of the mechanical behavior of aluminum alloys strengthened with Nano- and micro-hard particles such as Al₂O₃ and SiC is an interesting research area (Mohd.Bilal, et al., 2018). This study focuses on aluminum hybrid matrix composites containing reinforcements such as silicon carbide particles, sugarcane bagasse fly ash waste and aloe vera ash particles. Al/SiC bagasse fly ash composite achieves wear resistance, high coefficient of thermal expansion, and high strength by increasing the bonding strength of the composite through hybridization and preventing dislocation. Silicon Carbide (SiC) is a hard, wear-resistant, and heat-resistant ceramic material. One of the most important properties of ceramics is that they are very good insulators. This means that ceramics can hold very high temperatures without interference. Bagasse fly ash is one of the cheapest, low-density reinforcements available in large quantities as a solid waste by-product of coal combustion in thermal power plants. Bagasse fly ash is readily available and inexpensive compared to other reinforcements such as SiC, TiC. Therefore the light and a better composite material can be developed for drum brake.

1.2. Problem Statement

The modern development in the field of material technology gave rise to hybrid materials such as composites that paved the way for engineers to explore the possibility of substitute material which can perform efficiently and effectively than conventional materials. For the Engineering applications such as Automotive and Aerospace are at first appearance in such applications. The present work is concentrated on the development of a particulate reinforced composite material for an automobile brake drum in place of conventional material such as cast iron and aluminum alloys are heavier and can be replaced by lightweight aluminum hybrid composites (Simon George, et al., 2013). Using these waste ash particles in aluminum alloys can effectively improve various mechanical properties of aluminum alloys (Arum, 2021). Increasing the volume percentage of SiC reinforcement (Aigbodion, 2010) may increase the weight of the composite. However, using some percentage of silicon carbide as reinforcement for developing Al/SiC/Fly-ash and aloe-vera-ash composites for internal automotive body applications reduces the density of the composites. Therefore, the aim of this study is to develop Al6061/SiC/bagasse-ash-aloe-vera-ash composites not only for reducing fuel consumption but also as an alternative material for drum applications in automobile interior parts (drum brakes). Develop and characterize of the composite material as well as protect the environment from harmful emissions.

1.3. Objective of the study

1.3.1. General Objective

The general objective of the research is to develop and characterize mechanical properties of Al6061/SiC with Bagasse fly-ash and aloe-vera ash hybrid composite material for drum brake

1.3.2. Specific Objectives:

- To develop composite materials by varying wt.% of SiC/ bagasse fly ash and Aloe vera ash for testing
- To conduct mechanical characterizations such as wear, impact and compression tests for prepared samples with varying wt. % of combinations
- To perform microstructural analysis of the developed composite.

1.4. Scope of the study

The scope of this study is to develop and characterize Al6061/SiC/Bagasse fly ash and aloe-vera ash hybrid composite as alternative material for internal automotive (drum brake) application. In addition, the effect of varying the volume percentages of bagasse fly ash and aloe vera ash on the mechanical properties of the engineered composites has been evaluated. Hardness, Compression, impact and Wear test had been conducted at different combinations with three trials of each of the experiments. 7.5-10%, 7.5-12%, 6.5-11% had been taken as the minimum and maximum wt.% of SiC(reinforcement), Bagasse fly ash (filler material) and Aloe vera ash(filler material) respectively.

1.5. Motivational statements

Due to the significant advancements in industrial processes today, new global materials with unique combination properties have been developed. On the other hand, the conventional design is unable to meet this requirement for such a rare combination of characteristics, as high paired with low density. To achieve desired material properties, composite materials are suggested as a material option. The drum brake, together with the wheel and axle on which it revolves, is normally made of a specific type of heat-conducting, wear-resistant cast iron. The lining is forced radially outward against the inner surface of the drum when the brakes are applied, delaying or stopping the rotation of the wheel and axle and ultimately the movement of the vehicle.(Shubhendra, et al., 2021). It has been determined that using fly ash, aluminum, and copper as reinforcements, the matrix is successfully able to distribute the reinforcements, increasing the hardness and wear resistance. The study for wear, hardness, compression and impact analysis drum brake and liner has become a strong need for this work. The automotive industry is focusing on manufacturing lighter vehicles using low-cost composite materials instead of steel, gray cast iron and aluminum alloys.

Aluminum matrix composites (AMCs) are the competent material in the industrial world. Due to its excellent mechanical properties, AMCs is widely used in aerospace, automobiles, marine etc. (J hashim. et al. 1999).Researchers, especially in the defense application is continuously striving hard to find the materials that suit their specific requirements. Improvement in production methods and finding the alternate materials are a few options to meet the above requirement. While their current usage is relatively limited apparently due to their high production cost among the various discontinuous reinforcements used, fly ash (FA) is one of the cheapest available reinforcement. The advantages of using FA as the reinforcement due to its low density paves way for the development of effective and low-cost AMCs. Most of the effort to develop Aluminum based composites from waste materials are centered on the use of FA. In addition to lowering the cost of production, incorporation of FA into aluminum has been proved to decrease the composite density, increase the hardness, abrasion resistance and stiffness (David, et al., 2013).

1.6. Significance of the study

The automotive industry is now focused on using cheaper composite materials to replace steel and aluminum alloys to build lighter vehicles. A good cross-section of cheap reinforcement lowers the vehicle's cost barrier. This research means reducing vehicle fuel consumption by making vehicle components lighter. Land use of bagasse waste and aloe vera ash minimizes or reduces pollution at sugar and agricultural sites, respectively.

. Generally, this study signifies the following

- It substitutes the metals which are used in automotive body parts with compared properties and cost effectiveness
- Minimizing pollution and give safe environment while using wastes as reinforcement
- Reducing fossil fuel consumption
- Using agriculture product as alternative material
- It also minimizes cost during processing material.

1.7. Research questions

- What is the effect of different wt% of reinforcement on the mechanical properties (wear, impact, hardness and compression) when reinforced with Al6061 alloy?
- Which composition of Al6061/SiC/Bagasse ash, aloe vera ash composite from tested compositions has maximum mechanical property for the application of drum brake?
- Is it possible to improve aluminum alloy's mechanical and tribological properties by reinforcing it with silicon, bagasse ash and aloe vera ash?

1.8. Limitation of the Research

The lack of an agitated (stirring) cast setup calls into question the uniform distribution of the reinforcing particles in the matrix material. This means that the uniformity of the reinforcement and filler distribution is only an approximation. In addition, sample brittleness due to hard ceramic particles such as SiC makes the task more difficult when machining standard-size samples in lathe operations.

1.9. Thesis organization

This research is divided into five chapters. The **first chapter** contains an introduction that includes the research background, problem statement, objectives, importance of the research, research question, motivational statement, scope and limitations of the overall research work, and structure of the research. The **second chapter** describes a review of some journal articles, conference papers that consulted during the research. What was done in this study is also described in relation to and comparison with previous studies. Existing gaps in this research are addressed. **Chapter 3** contains the methods and a material used both reinforcement and Al6061 matrix material. This chapter includes weight percent calculations, mold preparation, and manufacturing. Experimental tests such as compression, hardness and wear tests were performed. **Chapter 4** describes the results obtained and a discussion of the results. Finally, **chapter five** contains conclusions from the results presented in chapter 4 and recommendations for future work.

Chapter two

Literature review

In this chapter, the methods utilized to explore the mechanical properties of aluminum alloys reinforced with hard ceramic and agro-waste ash particles, among other materials, are discussed in detail. Several of them are thought to be crucial for these theses are explored further below.

2.1 composite materials

Composites are categorized according on how their own matrix behaves. Depending on the physical and chemical characteristics of the matrix and reinforcing particle, several fabrication techniques are also used. High-performance racing vehicles, automobiles, and constructions are the main applications for composite materials. Composite materials, also known as matrix and reinforcement materials, are frequently a combination of two or more dissimilar materials with distinct qualities that are utilized together to build and attain the best or new set of material properties (Nudvi, et al., 2020). As a form of fiber, whiskers, or particles employed in metal matrices, ceramics, metals, ashes, etc., are among the best often used reinforcements. Al, Ti, Mg, Cu, and other common matrices are only a few examples (Rebba, et al., 2014). SiC, Al₂O₃, BC, SiO₂, and others are reinforcements that are widely employed. Ash reinforcement is one of the discontinuously dispersed substances utilized and is mostly inexpensive and low-density reinforcement that is available in large quantities as a solid waste by product. Additionally, the qualities of a composite should be superior to those of the individual constituents that make it up, such as having a low specific gravity, superior strength, and a high modulus (kaw2006).

2.2 Classifications of composites

A matrix is used as one classification method for composite. Matrix serves the purpose of securing the components of the reinforcement together and shielding the reinforcement from corrosive and structural damage (Daniel , et al., 2003)

Based on matrix composite can be categorized in the following groups:

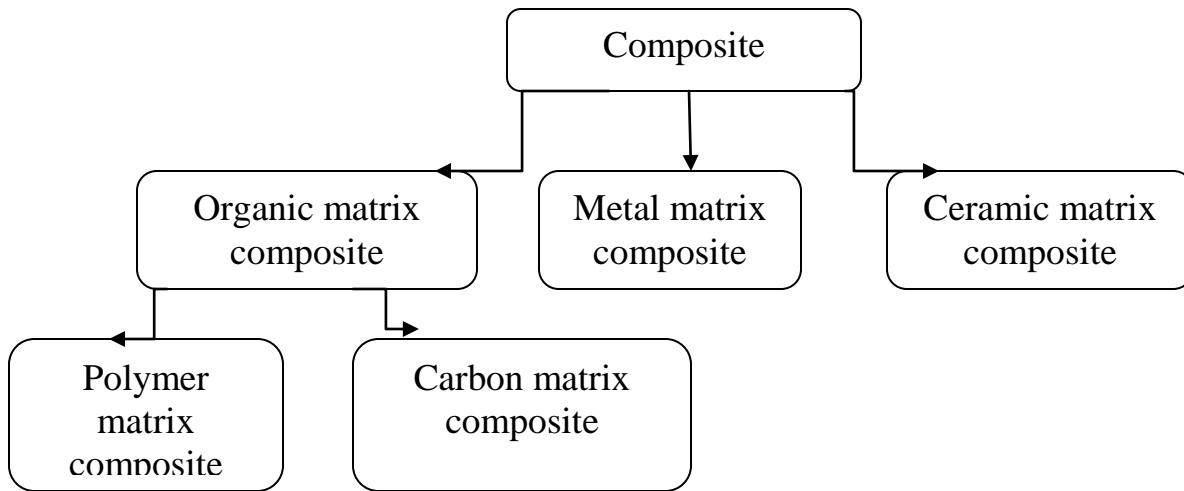


Figure 2.1 Composite materials classification based on matrix (Daniel , et al., 2003)

2.2.1 Metal Matrix Composite

One sort of composite, known as a "metal matrix composite," uses a ductile metal or metal alloy as the matrix phase, which serves as a bonding element to transfer and distribute the load to the reinforcing components. MMCs offer a desirable blend of outstanding high strength; improved raised temperature characteristics, wear resistance, high stiffness, and high electrical and thermal conductivity are some examples of these features. When compared to the basic material in terms of corrosion, oxidation, and wear resistance (Hung, et al. 1996).

Zn, Fe, Al, Cu, Ni, Mg, Ti, and Pb are the most often used metal matrix materials, but Al, Mg, and Ti are the most widely used. The lightest materials for use as a matrix phase in MMCs, which are about 35% lower in weight, are magnesium and its alloys. Unlike Aluminum, Mg alloys, however, are not strong enough to compete with aluminum alloys on an absolute level. Aluminum's superiority against magnesium is mostly attributable to its design flexibility, good wettability, and strong surface binding (Shuvendu Tripathy, 2009)

The most popular non-ferrous material used in engineering applications as a matrix is aluminum alloy because it has a high strength-to-weight ratio, a regulated coefficient of thermal expansion, and increased fatigue resistance.

Improved dimensional stability at high temperatures (K, 2006) and resistivity AMMCs are becoming more and more popular in the automotive, industrial, and aerospace industries due to their appealing qualities.

2.2.2 Ceramic matrices composite (CMCs)

Alumina, aluminum silicate, and calcium form the ceramic matrix of CMCs, which is reinforced by SiC, a great capacity temperature limit for ceramic, high strength, hardness, and less density are all advantages of ceramic matrices (V. V. K. Lakshmi, et al., 2018). Ceramic materials naturally withstand heat and have a tendency to fragile and nearly fracture-prone. There are four different kinds of ceramic matrices: cement, concreted carbon substituent, regular ceramic, and glass.

2.2.3 Polymer matrix composites (PMCs)

PMCs are the most innovative composites, which are made of thermosetting or thermoplastic polymers reinforced with fiber. They offer great strength, rigidity, and corrosion resistance. The PMCs usually confirm excellent particular characteristics because of the low component density (N. Saba, et al., 2018).

2.3 Metal and Ceramic Matrix Composites

Metal matrix composites (MMCs) have many benefits over base metals, including better specific strengths and modules, higher resistance to high temperatures, and lower coefficients of thermal expansion. CMCs have an extremely low breakage stiffness, which limits their structural applications (M. Sambathkumar, et al., 2017).

Due to their high price, commercial applications for MMCs are sparse. However, since they are counted as a capable material for future hypersonic aircraft vehicles, MMCs and CMCs remain essential materials. Ceramics hold numerous wanted properties, like great compression strengths, high moduli, high-temperature capability, & excessive hardness, high wear resistance, and low thermal conductivity Due to their very low breakage stiffness; CMCs are limited in structural uses (P. M. Composite, et al., 2016).

Table 2.1 Relative Comparisons of Material Groups Material (P. M. Composite, et al., 2016)

Material class	Tension strength	Compression strength	stiffness	Ductility	Temperature capability	Density
Metals	High	High	Medium	High	High	High
ceramics	Low	High	Very high	Nil	Very high	Medium
polymers	Very low	Very low	Very low	High	Low	Low
PMC	Very High	High	Very high	Low	Medium	Low
MMC	High	High	Very high	Low	High	Medium
CMC	Medium	High	Very high	low	Very high	medium

2.4 Ceramic reinforcements

When a ceramic reinforcement is incorporated into a metal matrix to create a composite material, the appropriate combination of mechanical & physical properties is produced, which is impossible with unreinforced alloys (P. D. Srivyas, et al., 2021).

2.5 Aluminum Alloys for composites

The aluminum 6XXX alloy series' AA 6061 alloy is the most adaptable of them all, and stir-casting is mostly used to create AA 6061 composites. To the best of the authors' knowledge, there is no thorough evaluation of AA 6061 stir-cast composites, despite the fact that many researchers have investigated a variety of AA 6061 composites and their manufacturing. Reviewing potential MMCs made using stir casting with AA 6061 as the matrix material is the main goal of this paper. The influence of various reinforcements in the AA 6061 matrix and the viability of the stir-casting technique for these materials are the subjects of the authors' discussion. Various types of aluminum alloys are currently commercially accessible, and each one has a special benefit and use. The aluminum alloys AA 6061 that can be heat treated, may be noticeably strengthened, and are utilized in a variety of applications where strength, weld ability, and corrosion resistance are necessary are the subject of this paper (L.P. Troeger, et al., 2000).

2.5.1 Theoretical background of Al6061/SiC with Bagasse and Alovera AShes

Al6061 with bagasse ashe

Al6061 Metal Matrix Composite was strengthened with aluminum oxide and researchers discovered that wear resistance, density, and ultimate tensile strengths exhibited no discernible differences, but ultimate yield strength and hardness improved when compared to the original aluminum-based Metal Matrix Composite((Hima Gireesh, et al., 2018).

Fly ash is one of the most promising inexpensive and low density reinforcement available in large quantities among other reinforcement. Even though it is a solid waste by-product obtained from thermal power plants. Fly ash has been used as filler in aluminum, polyester, epoxy, polyurethane and various rubbers. This development is largely due to the advantages of fly ash such as low density, strong filling ability, excellent fluidity and good process ability of the filled materials. Three sets of composite samples were prepared with 5, 10 and 15 weight percentage of fly ash with particle sizes in the ranges of 5-20, 25-30 and 50-60 μ m in each set. Mechanical properties like ultimate tensile strength (UTS), ultimate compression strength (UCS) and hardness were found to increase with the increase in weight percent of fly ash particles and decrease with the increase in the particle size of the reinforcement (Niranjan Nanjayyanamath, et al.2018).

(Rao CRP, et al., 2014) prepared Al 6061 composites reinforced with varying amounts of fly ash and conducted experimental investigation to know its mechanical characterization and machining behavior the outcome of their experimental study showed that the increased fly ash content in the composite of Al6061 increases the hardness of the composite with the increment of fly ash content

Al6061/SiC bagasse ash

(David Raja Selvam. J, et al., 2013) investigated the mechanical characteristics of a hybrid stir cast (SiC + Fly Ash) aluminum 6061 composite. According to the author, the composite's macro hardness and tensile strength increased as the weight percentage of SiC particles increased.

Al6061 with aloe vera ash

Manufacturers are focusing towards the use of metal matrix composite materials instead of monolithic aluminum alloys in automotive, marine and aerospace applications as they have good power to heaviness proportion, elevated firmness, wear confrontation, ease of manufacture etc. However, despite considerable improvement in the growth of metal matrix compounds, it is still required to develop metal matrix composites with cost effective eco-friendly reinforcement materials. The powder form of a Aloe vera is a light weight material and low cost, non-harmful to environment. In the present work metal matrix composites are prepared with Al6061 as matrix material and Aloe vera gunpowder as strengthening fabric. Stir casting technique have been working in the present work to prepare the specimens of proposed complex (Rao CRP, et al., 2014).

From the studies in overall it can be concluded that the Al6061-AV composite is exhibit good mechanical properties and it is suitable for the applications where requires low density, high yield strength, high hardness and high impact strength (Rao CRP, et al., 2014).

2.6 Reinforcements

2.6.1 Particulate reinforcements

Particle-reinforced composites are materials with microstructures made of metal and ceramic that show particles of one phase scattered in the other (Cooke, 2020).

The reinforcement was found to be triangular, spherical, and square, but all of its sides' sizes were found to be equal. The dispersion is distinct from distribution-hardened materials in terms of volume and size absorption. Particulate reinforced composites use the hydrostatic pressure exerted on fillers in the matrix and the particles' relative hardness to the matrix to reinforce the system. Due to the three systematic orthogonal planes, three-dimensional strengthening particles in composite materials give the material isotropic qualities. However, they are not identical; the material attributes show consideration for the basic characteristics, as well as the geometrical shapes and bonding qualities of the array. The inter-particle arrangement, volume fraction, and particle size were commonly used to determine the composite strength (T. Satish Kumar, et al., 2018)

2.6.2 Bagasse ash

Fly ash is one of the many discontinuously dispersed materials that are employed; it is the least expensive and least dense form of reinforcement that can be produced by the burning of waste by-products in thermal power plants. It is known the constituents of the fly ash produced differ extensively, but all fly ash covers SiO₂, Al₂O₃, and Fe₂O₃ as major constituents and oxides of Mg, Ca, Na, K, etc. as minor constituents. Fly ash reinforcing particles are mostly spherical ranging from less than 1 μm to 100 μm and a specific gravity of vary in the range of 0.6-2.8 gm/cm³ (Kumarasamy, et al., 2017). Since a large portion of the solid waste produced by thermal power plants is currently landfilled, there is a tendency to use fly ash as reinforcement in metal matrix composites. Due to the expensive expense of the reinforcing particles, MMC is only used in certain situations nowadays. Fly ash can therefore be added to the matrixes to drastically lower the cost of composites. Additionally, using fly ash in place of aluminum can reduce the requirement for energy-intensive aluminum, saving energy (Rohatgi, et al., 1997).

When used as a reinforcing particle in AMMCs, fly ash raises the hardness and stiffness while lowering the density. The primary criteria required in the automotive sectors, such as maintainability, damping capacity, and coefficient of friction, can also be improved (Hashim, 1999). The consumption of fly ash reinforcing particles can condense the fabrication of aluminum, which can reduce the formation of greenhouse gases that are produced during the bauxite processing and alumina reduction. Due to the presence of lightweight, porous, fibrous carbon particles, the specific surface area (145 m²/kg) and specific gravity (1.91) of raw bagasse ash are relatively low (Bahurudeen A, et al., 2015)

2.6.3 Alovera ash

Aloe vera is a perennial, drought-resisting, succulent plant belonging to the Asphodelaceae family (Karkala Manvitha, et al., 2014). The name Aloe vera derived from the Arabic word *Alloeh* and Latin word *vera* means shining bitter substance and true respectively (E.Tayal, et al., 2014). Aloe vera (*Aloe barbadensis miller*) is a tropical or sub-tropical plant which has lance-shaped leaves with jagged edges and sharp points. This plant is being used extensively in medicinal purposes and cosmetic industry. It was originated in tropical Africa and it is now cultivated in warm climatic areas of Asia, Europe and America. In India, Rajasthan, Andhra Pradesh, Chhattisgarh, Gujarat, Tamil Nadu, Maharashtra and Kerala are the major producers of this crop.

The cultivation of aloe vera plants is economically very attractive. The plantation of aloe vera does not require much water and it requires 150ml of water monthly for yield of good quality leaf weighing approximately 1 kg. In India, the average yield for organically grown aloe is about 12 tons per hectare (N.Das, et al., 2004). As aloe vera is largely available, easily cultivable, less dense eco-friendly material with considerable wettability, it is suitable for reinforcement of AMCs. It is observed from the literature that no work has been reported on the use of aloe vera as reinforced material in AMCs. In this paper an attempt is made to prepare aloe Vera (AV) reinforced aluminum metal matrix composite and to examine its mechanical characterization. A comparative study between AV reinforced aluminum metal matrix composite and fly ash reinforced aluminum metal matrix composite is also addressed in this paper.

The preparation of separate specimens of AMC with fly ash reinforcement and AV reinforcement, experimentation and mechanical characterization are discussed in the following sections. The hardness result of the composite revealed that the increase in ash content increases hardness (RAJU. K, et al., 2018), (Hima Gireesh, et al., 2018).

2.6.4 Silicon carbide

SiC is used as reinforcement in MMCs, greatly improving the materials' diverse thermal, wear, and mechanical properties. Tetrahedral carbon and silicon atoms combine to form the strong connection that makes up silicon carbide in crystal lattices. This results in a material that is exceedingly hard and powerful. SiC's physical characteristics, namely its high strength and high great thermal shock resistance, hardness, low density, high elastic modulus, and low thermal expansion (S. C. prasanna, et al., 2018). Silicon carbide is a sharper and harder abrasive grain than aluminum oxide. Silicon carbide and aluminum oxide are two ceramic materials used as abrasives. Silicon carbide grains are sharper and harder than aluminum oxide grains. Silicon carbide is best for non-metallic or low-tensile strength materials, while aluminum oxide works best on materials with high tensile strength. Both can be combined to produce a finer, smoother abrasive cut without wearing down the abrasives. (<https://www.preciseceramic.com/>).

2.7 Stir Casting Processes for Composite Fabrication

To increase the usage of composites, a quick and affordable technique of manufacturing them is required. A simple and widely used stir casting technique can be used to incorporate reinforcements like particle SiC, Al₂O₃, Bagasse ash, graphite, fly ash, etc. easily into the melt. The particle reinforcement is typically dispersed into the aluminum melts during mechanical stirring in a stir casting process. The behaviors of composite materials can be influenced by process factors (K. K. . M, et al., 2015).

In the stir casting process, stirring speed is crucial. This parameter affects how the particle reinforcement is properly mixed during the matrix phase. The outcome of motion could be revealed by the composite materials' microstructure. The regularity of particle distribution rises with increasing stirring speed, which reduces the average inclination of corroboration next to the admission path. Time to Stir The stirring step is crucial in the mixing forming process because it promotes evenly spreading of partials and boundary pledge among the background and strengthening. A composite made of aluminum alloy (A384) is created by them. After swirling for 10 minutes at a speed of 600 rpm, the composite material with a variety of weight percentages of SiC particle reinforcement powder measuring on average 60 mm determined to have good hardness (T. Satish Kumar, et al., 2018). The viscosity of the setting phase affects the distribution of reinforced particles in the matrix as well. The operating temperature and stirring hold duration affect the mixture's viscosity. As the stirring holding time increases, the viscosity of the aluminum

matrix decreases. A reduction in as literature revealed encouraging results and wettability between mixture & reinforced particles by maintaining the temperature of 800 °C, viscosity will lead to an increase in the pace of the chemical response between matrix and reinforced particles. It was necessary to pre-heat the reinforced particle in order to create good wettability between it and the matrix. To get rid of the moisture and gases inside the particle, which can have an impact on the property, pre-heating is also necessary (V. Mohanavel, et al., 2018). The most compelling material alternatives for developing lightweight components for many types of contemporary industrial equipment are AMCs due to their environmental resilience, low density, and good physical and mechanical qualities (K. Almadhoni, et al., 2015). Manufacture of aluminum & its alloys-based casting compound constituents through stir casting is the noticeable and inexpensive technique for improving and processing MMCs materials. The main trials of this method are to accomplish adequate wetting of particles by molten metal, get a uniform combination of ceramic particles, and decrease porosity in the cast MMCs (J. J. Moses, et al., 2016). This article analyzes the stir casting for the manufacture of AMCs. Diverse progression factors of the stir casting route, like reinforcement feed rate, stirring temperature, stirrer speed, stirring time, preheat temperature of reinforcement and mold, wettability-promoting agent, and pouring of melt, and problems faced in the effective production of AMMC's by stir casting method.

2.8 Drum brake

It is the first brakes used on cars were drum brakes. Drum brakes are still typically employed on a vehicle's rear wheels even 100 years after they were first deployed. In many cars, especially Light Motor Vehicles (LMV), drum brakes are employed as the rear brake. On passenger cars, light pickup trucks, and other vehicles in general, the leading-trailing shoe design or internally expanding drum brake is frequently employed as the rear brake. Rear leading-trailing shoe brakes are used by the majority of front-wheel-drive cars. With this design, torque generation is stable and low susceptibility to lining friction variations is given (Simon George, et al., 2013).

A motorcycle's brake drum is essentially a cylinder wedged between the wheel rim and the wheel hub and is typically composed of cast aluminum or cast iron. Brake shoes lined with friction material are inside the drum. A cam or actuators inside the wheel cylinders force the braking shoes against the surface of the inner drum. The brake shoe linings have an impact on the interior surface of the drum. In order to stop or slow the rotation of the wheel, the brake shoes must be forced to make contact with the interior surface of the brake drum when the brakes are applied (Simon

George, et al., 2013). The research is concentrated on the development of a particulate reinforced composite material for an automobile brake drum in place of conventional material such as cast iron and aluminum alloys are heavier and can be replaced by lightweight aluminum hybrid composites. Al6061 with 9% SiC and 15% fly ash is used to develop the composite by vortex casting. It is observed that this composition has enhanced mechanical and physical properties and FEA analysis shows the projected improvement which enables it to be used in practical application such as drum brakes (Simon George, et al., 2013).

2.9 Single- reinforced metal matrix composite

Al/bagasse ash composite is made using the two fold stir-casting method, according to (Aigbodion et al. 2010). To explore mechanical characteristics and microstructure using SEM and XRD techniques, they added 2–10wt% of bagasse ash. They found that adding up to 8 percent bagasse ash increased the yield strength and tensile strength by 49.76 percent and 34.25 percent, respectively. The distribution of hard and brittle ceramic phases within the ductile metal matrix has been thought to be responsible for the increased strength and hardness levels. The black ceramic and white metallic phases visible in the structure led to increased dislocation densities at the grain-matrix interfaces. The outcomes demonstrated that superior characteristics may be obtained by mixing bagasse ash with Al-Cu-Mg alloy.

The ultimate tensile strength and yield strength of the stir cast Al (6061) matrix composite were found to be superior to pure alloy, according to (Himanshu, et al., 2014). Investigation into the mechanical characteristics of the composite. The author found that as the amount of Al-N in the alloy matrix increased, so did the composite's micro hardness and macro hardness.

Al-Si-Fe alloy matrix composite reinforced with breadfruit seed hull ash was created by (Atuanya, et al., 2012) utilizing the stir casting technique. The impact strength of the composite reduced compared to the matrix alloy, while the tensile strength and hardness values increased, according to the author.

They developed Al/SiC metal matrix composites by varying the volume fraction of silicon carbide using a centrifugal caster (Karvanis, et al. 2016). The ideal silicon carbide content of metal matrix composites was determined by studying the mechanical properties and macrostructure of the composites. They concluded that increasing the silicon carbide content increased the tensile,

compressive, and hardness properties of the composite. SEM microscopy showed that the silicon carbide particles were fragmented.

The tensile strength and hardness of Al6061/SiC composites were studied by (Nelson, et al., 2016) by changing the weight percentage of SiC reinforcement from 3 to 18%. Composites were prepared by stirring casting at a speed of 600 rpm, stirring time and duration of 5 minutes. The ultimate tensile strength and Rockwell hardness results showed that the tensile strength and hardness of the metal matrix produced increased as the weight percent of silicon carbide increased.

Aluminum alloy composites with different particle sizes of 10 and 20 weight percent SiC particles were designed by (Y., 2003) using the squeeze casting method and molten metal mixing under argon gas. With a graphite impeller, the particle addition process was stirred. After the liquid had finished stirring, it was placed into a die, where pressure was then applied to create metal matrix composites. Hardness, density, and porosity measurements were made while using an optical microscope.

(Lim, et al., 2009) Friction stir processing is used to produce an aluminium alloy reinforced with multi-walled carbon nanotubes. Synthesis Multilayer aluminum alloys reinforced with carbon nanotubes are prepared by the friction stir method. According to SEM and TEM microscopy, the nanotubes are embedded in the Al alloy matrix produced in the stir zone and their multilayer microstructure withstands thermomechanical conditions during processing. The homogeneity of the nanotubes in the Al alloy matrix was improved by increasing the tool rotation speed from 1500 to 2500 rpm and increasing the penetration depth of the tool shoulder. However, using regularly entangled nanotubes, we were unable to create a perfectly uniform distribution.

A rotating tool pin is inserted into the metal surface to be machined and moved across the metal surface in a technique known as friction stir machining (FSP). It is used to bind solids together to change their microstructure. Friction and plastic deformation by the tool heats and softens the work piece, and the tool pin promotes local material mixing. Reinforcing particles are dispersed throughout the stir zone when placed in holes or grooves in the material surface in the path of the tool. FSP does not require numerous processing steps, does not rely on precursor metal powders, and does not require smelting like other techniques for producing CNT composites.

(Al khaqani, et al., 2020) investigated the creation of an alloy composite for use in engineering. The wear behavior of Al Alloy-SiC composite, including sliding wear, abrasive wear, erosion, corrosion, etc., was discussed in the paper. Al-SiC composites have been used to try to create prototype brake

drum, cylinder block, reflex apex insert, and other parts for the automotive and mineral processing sectors. Results from the performance assessment of the prototype components under real-world field conditions were favorable.

The main causes of the components' severe wear include sliding action, abrasion, erosion, and erosion-corrosion. Numerous tests have been conducted to evaluate the wear resistance of aluminum composites in a variety of environment and tribe conditions. Hard ceramic particles that emerge from the composite surface during sliding prevent material wear. The test parameters 9–12 10 affect how well composite materials withstand sliding wear compared to alloy materials. As a function of load, Alpas and Zhang 10 identified three unique wear areas. Oxidative wear, in which the oxide layer of the aluminum surface is lost during the sliding process, is the type of wear that occurs under low stress conditions. The materials wear during the medium load regime in general, it is seen that composite materials wear less frequently than alloy materials. There have only been a few researches done on the erosion-corrosion behavior at various experimental parameters such rotational speed, slurry composition, angle of impingement, erodent size, etc. According to studies on the behavior of sand slurry erosion, aluminum composites showed greater erosion resistance than its matrix alloy at shallow angles of impact. However, reversal wear patterns were seen at normal impact angles. The Zn-Al alloy- Al_2O_3 composite's erosion-corrosion behavior demonstrated that the composite had greater wear resistance than the alloy.

(Karvanis, et al. 2016) Al-SiC composites of various carbide compositions were produced using a centrifugal casting machine. Composites made with an Al-SiC metal matrix and their mechanical characteristics. Al-SiC Metal Matrix Composites have seen a steady increase in use over the past few years because of their distinctive qualities, including light weight, high strength, high specific modulus, high fatigue strength, high hardness, and low density. A centrifugal casting machine was used to create Al-SiC composites with different carbide compositions. In order to identify the ideal carbide percent in the metal matrix composites, the mechanical characteristics, tensile and compression strength, hardness, and drop-weight impact strength were examined. To investigate the association between microstructure and property, scanning electron microscopy was used. It was found that when the quantity of silicon carbide in the composites rose, the tensile and compressive strengths of the composites also rose.

Aluminum Alloy-Based Metal Matrix Composites: A Potential Material for Wear Resistant Applications, (Dasgupta, 2012). This study examines the impact of dispersing SiC in various alloy matrices using the liquid metallurgy route on various wear modes typically encountered by engineering components in non-wear/mild environments, such as sliding and abrasion as well as combinations of the two, and the results as compared to the base alloy. The ensuing wear is discovered to have a number of contributing elements, many of which are not necessarily negative in character. The ranges of performance advantages the AMMCs can have over the base alloy have been discussed. Studies of the worn surface and subsurface have been conducted to comprehend the process of material removal and the function of the various contributing variables to material removal.

2.10 Hybrid metal matrix (HMM) composites with two reinforcements

The effects of SiC/Gr and SiC/Al₂O₃ on the wear characteristics of friction stir treated Al 6061-T6 hybrid composites have been studied by (Michael, et al., 2015). According to the authors, the hybrid's nugget zone's reinforcing elements were distributed uniformly. The scientists have published a similar report on hybrid AMCs composed of SiC and Al₂O₃. The hybrid composites outperformed the matrix material in terms of hardness and wear resistance. Furthermore, due to the combined pinning effect of SiC and Al₂O₃ and the higher hardness of Al₂O₃ compared to that of the Gr, the hardness of the composites comprising SiC and Al₂O₃ was higher than that of the composites including SiC and Gr. Despite its hardness, Al₂O₃-containing composites have worse wear resistance than other composites.

The mechanical characteristics of aluminum hybrid composites reinforced with Al₂O₃ and B₄C were assessed by (Gupta, et al., 2020). Due to its great strength, low density, exceptionally high hardness, excellent chemical stability, and neutron absorption properties, B₄C was taken into consideration despite its high cost. In comparison to the unreinforced alloy, the hybrid composites showed superior hardness and impact strength. The unreinforced alloy, however, outperformed its hybrid equivalents in terms of flexural strength and tensile strength. Poor stirring and an unequal distribution of the reinforcements in the matrix were the cause of this discovery, according to microstructural research.

The microstructure and mechanical characteristics of hybrid aluminum Nano composites with graphite as a solid lubricant were studied by (Rathika, et al., 2013). The composites contained up to 10% graphite and had a SiC concentration of 5 weight percent. Tensile strength, wear resistance, and hardness were reported to rise with increasing reinforcement. The hybrid composites outperformed the single-reinforced Al/5 wt. % SiC composite in terms of mechanical parameters, with Al/5 wt. % SiC/10 wt. % Gr having the maximum strength and wear resistance.

The wear and friction properties of an Al matrix composite augmented with fly ash particles were studied by (Ramachandra and Radha-krishna 2007). The wear resistance of the composite increased as the weight percent of fly ash grew, but it reduced when the normal load and sliding velocity increased, according to the authors' observations. The dry sliding wear and mechanical behavior of aluminum/fly ash/graphite hybrid metal matrix composites were studied by (K.Anand and R.Jeyapaul 2022) using the Taguchi method. They found that load had the greatest impact on the wear rate of the composites, followed by sliding speed and fly ash content, respectively. As the fly ash content rose, the hybrid composites' hardness rose as well. The interfacial response between the matrix and the reinforcing particle can be suppressed using FA.

(David, et al., 2013) used the stir casting technique to create and characterize aluminum hybrid composites reinforced with SiC and FA. Due to high dislocation caused by thermal mismatch between the reinforcement and matrix as well as significant surface area of the hard ceramic phase, which bears the load transferred by the matrix when subjected to loading conditions, the composites' tensile strength and hardness were increased. Microstructural analysis showed that SiC and FA were evenly distributed throughout the aluminum matrix, and that FA was particularly effective at preventing the formation of the Al_4C_3 phase because it contained SiO_2 . The corrosion performance of aluminum hybrid composites has been reported to be improved by FA that prevents the formation of the Al_4C_3 phase.

Al-Si-SiCp dry reciprocating wear behavior was statistically examined by (Rajeev, et al. 2013), who found that a composite with high silicon content has less wear loss than a composite with low silicon content. Following load, reciprocating velocity and silicon weight % as a proportion of the total weight, sliding distance has the greatest impact on the wear behavior of the composite. Additionally, there was a significant impact on wear behavior from the interplay between load and

sliding distance. The governing factor for friction behavior is load, followed by the silicon weight percentage.

(Y.Mazaheri, et al. 2013) conducted a comparative study of mechanical properties of Al-TiC, AlB₄C and AlTiC-B₄C hybrid composite. The author has revealed that Al/TiC/ B₄C composite possessed highest hardness. Highest yield strength and tensile strength had obtained by AlB₄C composite and Al-TiC showed maximum elongation.

Aluminum alloy (A356) composites containing 6 vol% and 12 vol% fly ash particles were studied by (Sudarshan & M.K., 2008). Using a pin-on disc machine, dry sliding of unreinforced alloys and composites under various loads of 10, 20, 50, 65 and 80 N at a constant sliding speed of 1 m/s. The wear behavior was investigated. The results show that the dry sliding wear resistance of Al-fly ash composites is almost the same as Al₂O₃ and SiC-reinforced Al alloys. Ingestion of 6 vol.% fly ash particles reduces the dry sliding wear rate at low loads (10–20 N) and 12 vol. The % fly ash reinforced alloy showed a lower wear rate compared to the unreinforced alloy in the load range of 20-80 N.

Using modified agitated casting and compound casting techniques (David, et al., 2013), different weight percentages of SiC particles and constant weight percentages of fly ash (7.5 weight percent fly ash and various weight percentages of 7.5 and 10 wt% SiC). Adding magnesium to the melt improved the wettability of SiC and fly ash particles in the matrix. The addition of fly ash correlated with a weight percent addition of SiC and a constant weight percent addition of FA particles, as shown by optical and scanning electron micrographs showing both uniform dispersion, and SiCp dissolution and It helped prevent the formation of Al₄C₃. SiC and fly ash particles in an aluminum matrix.

(A.Baradeswaran and Perumal, 2014).Examined the mechanical and wear characteristics of hybrid composites made of Al7075, Al₂O₃, and graphite. A hybrid composite of Al7075, Al₂O₃, and graphite was created by adding graphite particles at a rate of 5% and Al₂O₃ at 2, 4, 6, and 8 %. The weight percentage of ceramic phase was found to increase the hardness, tensile strength, flexural strength, and compression strength of the Al7075-Al₂O₃-graphite hybrid composites. The hybrid composites with graphite showed the best wear resistance characteristics in terms of wear properties.

(Muhammad, et al., 2016) using the stir casting method. Three instances were added as reinforcements. In the first situation, there is a constant 2 percent bagasse ash with changing graphite percentages of 1 percent, 3 percent, and 5 percent. In the second case, there is a constant 4 percent bagasse ash, and in the third case, there is a constant 6 percent with varying graphite percentage. Results showed that 6% bagasse ash with varied graphite achieved more enhanced mechanical properties than cases one and two of bagasse-ash combination by 1%, 3%, and 5%, respectively. With an increase in the weight percentage of reinforcement, the produced composites' hardness, ultimate tensile strength, and yielding strength gradually increased but their ductility declined.

(Karvanis, et al. 2016) production and mechanical properties of Al-SiC metal matrix composites., Preparation and Characterization of Physical and Mechanical Behavior of Al-Mg, Si Alloy Matrix Composites Reinforced with Alumina (0, 2.3, and 4 wt% Al₂O₃) and 10 wt% Rice Husk Ash (RHA, Agricultural Waste) Stirring casting method. Al7075-Al₂O₃ and A6061-SiCp composite tensile strength, hardness, and wear resistance properties were compared by (Devaraju, et al., 2013). The composites were made using the liquid metallurgy process. The incorporation of reinforcements, such as SiC and Al₂O₃, demonstrates the improved mechanical properties of the corresponding composites, such as resistance to wear, hardness, and strength.

Research was done by (RAJESH, et al. 2019) to determine the hardness and wear behavior of the A7075-SiC composite. The results demonstrate that the qualities of hardness and wear resistance were improved. The contribution of heat treatment and the creation of Al-Zn-Mg-Cu alloy composites by adding 15% by weight of SiC to the mixture is responsible for the results' improvement. Additionally, it has been discovered that the silicon carbide (SiC) particle size affects the enhanced qualities. Through the use of heat treatment, the composite material and base metal will both have increased hardness, which lowers the rate of wear. Because as-cast material has a larger estimated wear constant than heat-treated material, along with the wear process, the cracks will spread at the intersection of the matrix and reinforcement. Heat-treated materials exhibit wear resistance. Due to the aluminum matrix's increased ductility and strength, heat-treated alloys result in reduced effective stress on the material's surface and slower wear progression. Compared to the alloy as it was cast, this event resulted in a decrease in the material's surface's susceptibility to crack.

The morphology was not significantly altered by the heat treatment; rather, the matrix hardened due to age hardening, leading to increased strength & hardness. The SiC and Al₂O₃ components are added to the aluminum metal matrix as reinforcement, which boosts the material's hardness. Al7075's hardness is increased both without and with heat treatment by adding 10% more SiC and Al₂O₃ reinforcement. When SiC and Al₂O₃ are added to Al7075 at a rate of 10 percent each, there is a 22 percent increase in hardness with heat treatment as opposed to no heat treatment.

By using friction stir processing; (Tyagi, et al., 2020) studied the mechanical and tribological characteristics of AA7075-T6 metal matrix composite reinforced with ceramic particles and aloe vera ash. This study examines the mechanical and wear characteristics of AA7075-T6 made using friction stir processing (FSP) and reinforced with SiC and Aloe vera ash. Aloe vera ash is regarded as one of the reinforcements due to its lower density, ease of availability, and affordability. Using a square tool pin profile and various tool rotating rates, FSP is performed. On a high temperature rotary tribometer, a pin-on-disc test was performed with an applied load of 20 N, 30 N, and 40 N to examine wear behavior. Because of the production of an oxide tribo layer, processing an Al+SiC/Aloe Vera ash composite at 600 tool rpm under a 20N load produced the best results. Al + SiC composite processed at 900 tool rpm showed the least wear at 30N and 40N applied loads due to proper ceramic particle scattering caused by the high tool rotational speed. The coefficient of friction 16 rises as the applied load is increased, and all samples of composite materials that were manufactured exhibited a lower coefficient of friction than base metal. When reinforcement is added, the properties of micro hardness, ductility, and ultimate tensile strength all improve, and they are all directly related to tool rpm. With the help of a scanning electron microscope, wear morphology was examined (SEM). After wear, Energy Dispersive Spectroscopy (EDS) examination validates the creation of an oxide layer that reduces wear loss by demonstrating the presence of C, Fe, O, Mg, Zn, Si, and Al components. The fabrication of aluminum composite with suitable mechanical and tribological properties has been the subject of numerous studies in recent years.

Al₂O₃-SiO₂ composite Nano lubricant's influence on wear rate and coefficient of friction was discussed by (Zawawi, et al. 2017). They discovered that compared to composite Nano lubricant, pure lubricant had a greater coefficient of friction and wear rate.

(Hima Gireesh, et al., 2018).reinforced aluminum with fly ash and aloe vera separately and came to the conclusion that aloe vera-reinforced aluminum had greater wear resistance than fly ash-reinforced aluminum.

2.11 Summary of literatures

Author name	Title of the journal	Main findings
Himanshu, et al., 2014)	Mechanical and Tribological Behaviors of Stir Cast Aluminum Matrix Composites.	Investigation into the mechanical behavior of the composite, the author found that as the amount of Al-N in the alloy matrix increased, so did the composite's micro hardness and macro hardness
Karvanis, et al. 2016	Production and mechanical properties of Al-SiC metal matrix composites.	Using a centrifugal casting machine developed an Al/SiC metal matrix composite with varying silicon carbide volume fractions. They came to the conclusion that the increase in silicon carbide content caused the composite's tensile, compressive, and hardness to increase
Nelson, et al., 2016	Microstructure and wear characterization of aluminum matrix composites reinforced with industrial waste fly ash particulates synthesized by friction stir processing	The tensile strength and hardness of an Al6061/SiC composite were examined by altering the weight percentage of SiC reinforcements from 3 to 18%. The ultimate tensile strength and

		Rockwell hardness results demonstrated that the created metal matrix's tensile strength and hardness increased as the weight percentage of silicon carbide was increased.
(Al khaqani, et al., 2020)	Erosions- Corrosion Behavior of (Al-Y2O3) Composite Prepared by Powder Metallurgy	The wear behavior of Al Alloy-SiC composite, including sliding wear, abrasive wear, erosion, corrosion, etc., was discussed in the paper. Al-SiC composites have been used to try to create prototype brake drum, cylinder block, refax apex insert, and other parts for the automotive and mineral processing sectors
Dasgupta, 2012	Aluminium Alloy - Based Metal Matrix Composites: A potential Material for Wear Resistant Application	This study examines the impact of dispersing SiC in various alloy matrices using the liquid metallurgy route on various wear modes typically encountered by engineering components in non-wear/mild environments, such as sliding and abrasion as well as combinations of the two, and the results as compared to the base alloy

<p>David, et al., 2013</p>	<p>Synthesis and characterization of Al6061-Fly Ashp-SiCp composites by stir casting and compocasting methods</p>	<p>Used the stir casting technique to create and characterize aluminum hybrid composites reinforced with SiC and FA.</p> <p>Due to high dislocation caused by thermal mismatch between the reinforcement and matrix as well as significant surface area of the hard ceramic phase, which bears the load transferred by the matrix when subjected to loading conditions, the composites' tensile strength and hardness were increased.</p> <p>Microstructural analysis showed that SiC and FA were evenly distributed throughout the aluminum matrix, and that FA was particularly effective at preventing the formation of the Al₄C₃ phase because it contained SiO₂</p>
<p>Muhammad, et al., 2016</p>	<p>Manufacturing of Aluminum Composite Material Using Stir Casting Process</p>	<p>Using the stir casting method. Three instances were added as reinforcements.</p> <p>Results showed that 6% bagasse ash with varied graphite achieved more enhanced mechanical properties than cases one and two of bagasse-ash combination by 1%, 3%, and 5%, respectively.</p> <p>With an increase in the weight</p>

		percentage of reinforcement, the produced composites' hardness, ultimate tensile strength, and yielding strength gradually increased but their ductility declined.
RAJESH, et al. 2019	Development and characterization of hybrid aluminum metal matrix composites	Research was determining the hardness and wear behavior of the A7075-SiC composite. The results demonstrate that the qualities of hardness and wear resistance were improved.
Karvanis, et al. 2016	Production and mechanical properties of Al-SiC metal matrix composites	Fabrication and mechanical properties of Al-SiC metal matrix composites, Fabrication and characterization of Al-Mg, Si alloy matrix composites reinforced with alumina (0, 2,3, 4 wt% Al ₂ O ₃) and 10% rice Physical and Mechanical Behavior of Attachment Hull Ash (RHA, Agricultural Waste) using a two-stage agitation casting process.
Hima Gireesh, et al., 2018	Experimental Investigation on Mechanical Properties of an Al6061 Hybrid Metal Matrix Composite	Reinforced aluminum with fly ash and aloe vera separately and came to the conclusion that aloe vera-reinforced aluminum had greater wear resistance than fly ash reinforced aluminum.

2.12 Research gap

Previous researchers developed and studied different types of metal matrix composites for internal automotive body parts. But different internal body parts need different properties of a material. So, it is needed further investigation on mechanical properties of a product for specific application. This work has been focused on Mechanical property evaluation of Al6061/SiC composite using additional reinforcement's bagasse fly ash and aloe-vera ash for drum brake application. These bagasse and aloe Vera ashes lead to decrease the weight of the fabricated composite.

In addition, previous articles are limited to two or three constituents in developing the composite. In this work it is tried to combine more than three elements that are Al6061, SiC, bagasse fly ash and aloe vera ash. So, it was expected to increase the bond strength which makes the developed would be strong and achieved the required hardness as well as the required strength to weight ratio and wear resistance.

Majority of the researches are focused on natural existed minerals such as Silica, Alumina and used others costly materials such as silicon, Titanium, Copper, Aluminum these may limited the researcher and manufacturer to investigate new alternative materials.

Most studies focused on general mechanical properties but do not study on specific application with related application area. In addition, most studies focused on weight percentage of reinforcements limited up to 30% addition.

Several studies addressed the development of Al6061/bagasse ash and Al6061/SiC composites, but hybrid metal matrix composites (Al6061/SiC bagasse fly ash and aloe vera ash) were not further explored.

Literature studies show that majority of researcher investigate more on Al6061/SiC composite for general application. Therefor for replacement of some expensive materials with better performance and considering cost effective. Using industrial waste and agricultural product is recommended and also some mechanical properties designed based on the matrix and reinforcement material which is difficult to get with other materials.

In case of MMC's, aluminum matrix composite due their high strength to weight ratio, low cost and high wear resistance are widely manufactured and used in structural applications along with aerospace and automobile industry. Also a simple and cost effective method for manufacturing of the composites is very essential for expanding their application. Reinforcements like particulate alumina, silicon carbide, graphite, fly ash etc can easily be incorporated in the melt using cheap and widely available stir casting method (Himanshu, et al., 2014).

Aluminum matrix composites (AMCs) are the competent material in the industrial world. Due to its excellent mechanical properties, AMCs is widely used in aerospace, automobiles, marine etc. [13] Researchers, especially in the defense application, are continuously striving hard to find the materials that suit their specific requirements. Improvement in production methods and finding the alternate materials are a few options to meet the above requirement. While their current usage is relatively limited apparently due to their high production cost, among the various discontinuous reinforcements used, fly ash (FA) is one of the cheapest available reinforcement. The advantages of using FA as the reinforcement due to its low density paves way for the development of effective and low-cost AMCs. Most of the effort to develop Aluminum based composites from waste materials are centered on the use of FA. In addition to lowering the cost of production, incorporation of FA into aluminum has been proved to decrease the composite density, increase the hardness, abrasion resistance and stiffness.

Chapter Three

Materials and Methods

3.1 Matrix and reinforcement materials

3.1.1 Aluminum alloy (Al6061)

Mg and Si are the main alloys in the 6xxx series of aluminum alloys. (Davis J., 2001), (Som, et al., 2022) Series 6 aluminum alloys have excellent properties such as machinability, weld ability, and formability to form complex structures. Mg-Si aluminum alloys are also lightweight and have excellent thermal stability. Al6xxx alloys were chosen because of their widespread use in automotive components and building materials such as pistons, disc rotors, cylinder liners and decorative parts. 6061 Al alloy is a boundless general-purpose alloy, and is used in all kinds of applications ranging from electronics to welding assemblies. This is of its good formability, weld ability, fair corrosion resistance, and moderately high strength, which all make 6061Al highly versatile. 6061 aluminum is used primarily for its increased strength over other 6xxx alloys, which is a consequence of both its chemical makeup and its favorable response to precipitation-hardening. It is one of the most popular aluminum alloys and is a great general- purpose material for almost any job requiring a light weight tough metal.

3.1.2 Physical and Mechanical properties of Al6061

Type 6061 aluminum is of the 6xxx aluminum alloys, which entails those mixtures which use magnesium and silicon as the primary alloying elements. (M.S, et al., 2004),(Davis, 1998) the second digit indicates the degree of impurity control for the base aluminum. When this second digit is a “0”, it indicates that the bulk of the alloy is commercial aluminum containing its existing impurity levels, and no special care is needed to tighten controls. The third and fourth digits are simply designators for individual alloys (note that this is not the case with 1xxx aluminum alloys). The density of 6061 aluminum alloy is 2.7 g/cm³. 6061 aluminum alloy is heat treatable, easily formed, weld-able, and is good at resisting corrosion. The mechanical properties of 6061 aluminum alloy differ based on how it is heat treated, or made stronger using the tempering process. Its modulus of elasticity is 68.9 GPa (10,000 ksi) and its shear modulus is 26 GPa (3770 ksi). These values measure the alloy’s stiffness, or resistance to deformation (Christian Galvallo, 2007).

Table 3. 1 Chemical composition of Al 6061 Alloy (measured at Ethiopian Technical University)

Composition	Mg	Si	Fe	Cu	Mn	Cr	Zn	Ti	Al
	%	%	%	%	%	%	%	%	%
Wt. %	0.85	0.57	0.22	0.35	0.13	0.25	0.08	0.01	97.54

Table 3.1 implies that the aluminums differ in their chemical composition by using spectroscopy machine to identify Aluminum type based on their grade type so knowing chemical composition enables us to identify and to select the desired aluminums.

3.1.3 Silicon carbide (SiC)

Silicon carbide (carborundum) is a ceramic material composed of silicon and carbon atoms. It rarely occurs naturally as a mineral but is manufactured in powder form. Silicon carbide materials have been chosen as reinforcement materials because they are widely used in high-hardness and high-temperature applications such as car brakes, cylinders, clutches valves, bulletproof vests, semiconductor electronics, etc. It can also be applied to power cutters, cutting tools, grinding wheels, and nuclear reactors (Yutai, et al., 2019) where the particle size of silicon carbide varies from micro- to Nano-sized. One way to improve the mechanical properties of composites is to reduce the particle size of the reinforcement. This depends on the processing method. Very small SiC powder particles produce agglomerates (sludge) during poorly agitated casting. To overcome these problems, we used SiC powder with a particle size of 50µm, which can be adequately stirred for 10 minutes. Aluminum–matrix composites have attracted much attention and wide acceptance due to their high specific strength and superior wear resistance. Tribological behavior of Aluminum metal matrix composites has been investigated by several researchers due to their application as bearing material, brushes, contact strips etc. Wilson et al. (1996) investigated the high temperature dry sliding wear behavior of Al(A356)/SiC, Al(A356)/(SiC+ Graphite) and Al(6061)/Al₂O₃ composite. The authors observed that addition of ceramic particles improves the seizure resistance of the composite at higher temperature compared to pure alloy, SiC being more effective than Al₂O₃. The hybrid composite possessed better resistance to severe wear compared to other two composites at higher temperature regimes (Himanshu, et al., 2014).

The figure 3.1 shows the silicon carbide powder micron (50 microns) used as a ceramic reinforcement to produce an Al/SiC bagasse fly ash/aloe vera ash hybrid composite.



Figure 3. 1 Silicon carbide (A) powder (50µm), (B) morphology of SiC(conducted at ASTU)

Figure 3.1 A , shows a 50µm silicon carbide powder from supplier figure 3.1 B, the morphology of the SiC this show that the particle sizes involved during casting.

Robust crystal structure

Silicon carbide (SiC) is composed of light elements, silicon (Si) and carbon (C). (Somiya, 2012) justified that its basic building block is a crystal of four carbon atoms forming a tetrahedron, covalently bonded to a single silicon atom at the center. SiC also exhibits polymorphism as it exists in different phases and crystalline structures.

High hardness

(Stephen E., et al., 2004) studied that Silicon carbide has an Mohs hardness rating of 9, making it the hardest available material next to boron carbide (9.5) and diamond (10). This apparent property makes SiC an excellent material choice for development of different mechanical components.

Chemical stability

Silicon carbide is a stable and chemically inert substance with high corrosion resistance even when exposed or boiled in acids (hydrochloric, sulphuric, or hydrofluoric acid) or bases (concentrated sodium hydroxides). Based on the study (S. Somiya et al. (2012) it is found that to react in chlorine,

but only at a temperature of 900°C and above. Silicon carbide will start an oxidation reaction in the air when the temperature is at approximately 850°C to form SiO₂.

High-temperature resistance

Silicon carbide's resistance to high temperature and thermal shock is the property that allows SiC to be used in the manufacturing of fire bricks and other refractory materials. The decomposition of silicon carbide starts at 2000°C (Kawahara, 2013).

3.1.4 Bagasse fly ash (BFA)

Bagasse is made from sugar cane during the sugar production process. It is most abundant in the world's sugar industry. (Nikodinovic, 2013), (Nicoleta, et al., 2022) the bagasse is the main residue of the sugarcane industry representing, by weight, almost 30 % (hundreds of millions of tons per year in the world. Bagasse fly ash was produced by burning bagasse to generate steam power that was formerly used in the sugar industry to generate electricity. This ash powder poses a series of problems in terms of pollution, land use and health hazards. Bagasse fly ash is chosen for its light weight, high density. The main composition of bagasse ash consists of various weight percentages of SiO₂, Al₂O₃, Fe₂O₃, and MgO. In the current work, bagasse ash was collected from Wenjji Shewa Sugar Mill in Ethiopia. The ash was crushed by using miller machine with proper screened sieves 100 μm to make fine powder particles. (Dr.S, Dr C, & Binnu, 2022) The hardness value and the tensile property of fly ash reinforced aluminum composite rise as the volume % of fly ash rises and the addition of fly ash particles to the aluminum alloy also enhances its abrasive wear resistance. (Anilkumar, et al., 2011), The tensile strength and ductility of the composite diminish as the weight % of Fly ash increases, according to a study on mechanical characteristics of Fly ash reinforced aluminum alloy Al 6061.

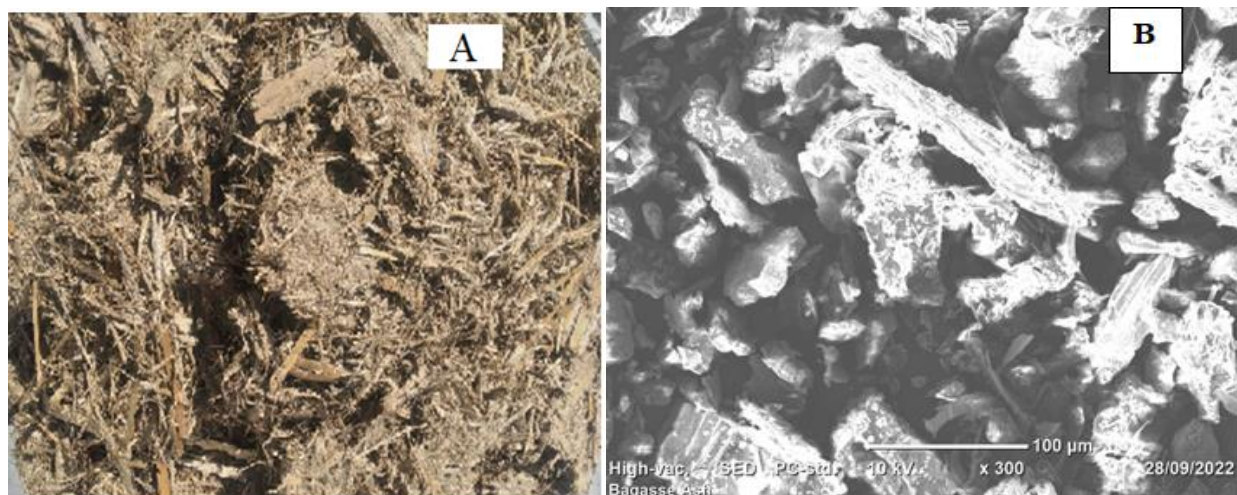


Figure 3. 2 Sugar cane (A) bagasse, (B) morphology of bagasse ash

Figure 3.2 A, shows sugar cane waste which is collected from wenji sugar factory and drying by sun light until completely removed the moisture and figure 3.2 B shows the powder form of the sugar cane after grounded by miller at 100μm.

Table 3. 2 Chemical composition of bagasse ash in weight (conducted at AAU 4 Kilo branch)

Composition	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	Mgo	TiO ₂	K ₂ O	others
	Wt. %	Wt. %	Wt. %	Wt. %	Wt. %	Wt.	Wt.	Wt.
Wt. %	57.95	28.15	4.75	3.74	1.73	0.93	0.62	2.13

3.1.5 Aloe-vera ash

Aloe-vera is agricultural product throughout the world and it is important highly in hair oil and face soap manufacturing. Industries also use it as an alternative material for composite material because of its ash has good mechanical properties such as highly wear resistance in composite material specially when used with aluminum. (Amare, et al., 2008), Aloe Vera is naturally occurring medicinal plant. It has high water content and is rich in nutrients, minerals and vitamins. It is easy to grow plant, which can easily be found through the world. As aloe vera is largely available, easily cultivable, less dense eco-friendly material with considerable wettability, it is suitable for reinforcement of AMCs. It is observed from the literature that only few works have been reported

on the use of aloe vera ash and as reinforced material in AMCs. In this work an attempt was made to prepare aloe vera (AV) as additional reinforcement in aluminum metal matrix composite and to examine its mechanical characterization. The powder form of aloe vera is a light weight material and low cost, non-harmful to environment. AV powder considered as reinforcement material for preparing the composite. While making powder, fresh leaves of aloe vera has been taken and chopped as slices of thickness 5mm and dried up at 250⁰c for a period of 4-hours to remove complete moisture content present in it, the outcome is then grounded in to the powder using miller machine with proper screened sieves 100 μ m to make fine powder particles. A comparative study between AV/bagasse ash reinforced aluminum metal matrix composite and Al6061/SiC had been investigated. (Sandeep, et al., 2014).the aloe vera essentially contains calcium, magnesium, sodium, potassium, phosphorous, iron, manganese copper and Zink. The aloe vera has higher water holding capacity and essentially contains calcium (3.58%), magnesium (1.22%), sodium (3.66%), potassium (4.06%), phosphorous (0.02%), iron (0.1%), copper (0.06%) and zinc (0.02%) and 87.28% SiO₂.



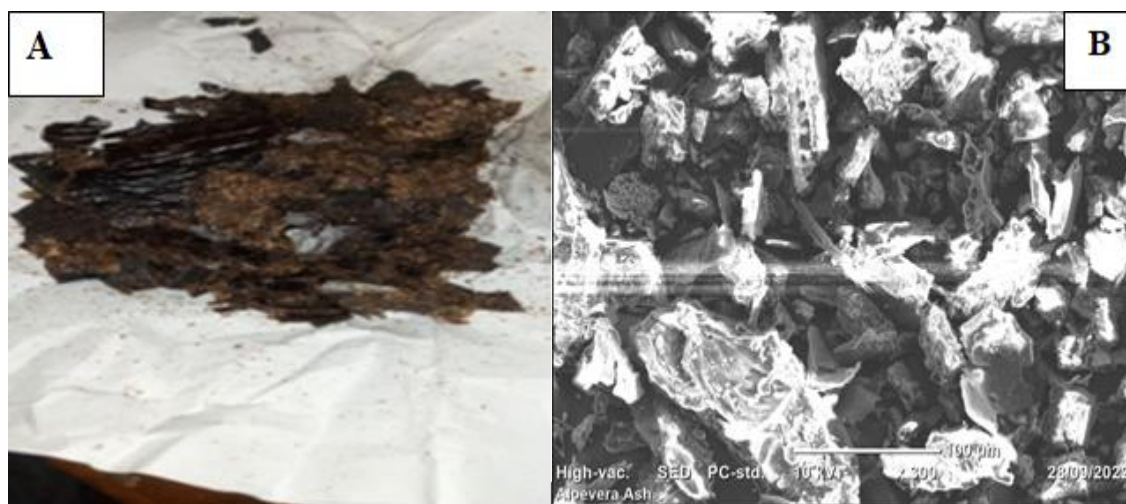
Figure 3. 3 Fresh aloe-vera

Figure 3.3 shows the fresh aloe-vera plant from market which ready to chopped into small pieces



Figure 3. 4 Aloe vera in electrical furnace to dry

Figure 3.4 shows drying the small pieces of the aloe-vera plant at 250°C in furnace until completely removed the moisture.



(A) Dried aloe vera

(B) morphology of aloe vera ash

Figure 3. 5 Aloe vera

Figure 3.5 A, shows dried aloe-vera which is collected from furnace and ready to ground through miller machine and figure 3.5 B shows scanning electron microscope of the powder form of the aloe-vera after grounded by miller at $100\mu\text{m}$.

Table 3. 3 Chemical composition of Aloe vera ash in weight % (conducted at AAU 4 Kilo branch

Composition	SiO ₂	CaO	Mgo	Na	K	P	Fe	Cu	Zn
Wt. %	87.28	3.58	1.22	3.66	4.06	0.02	0.1	0.06	0.02



Figure 3. 6 Miller machine

Figure 3.6 shows miller machine which is used to ground the reinforcements both aloe-vera and bagasse ash.

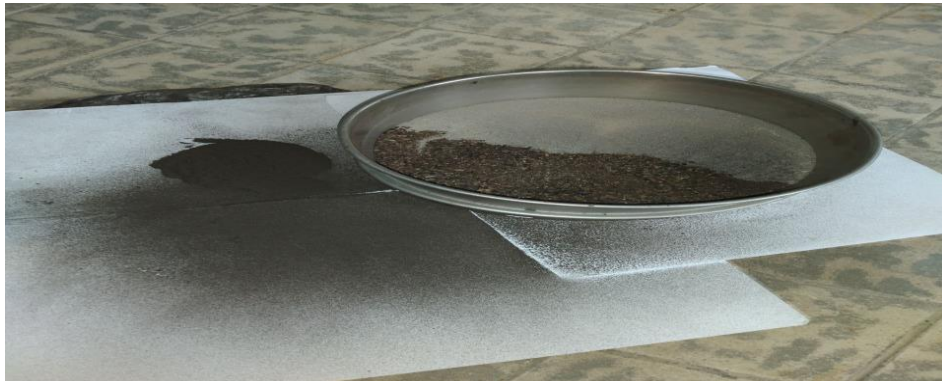


Figure 3. 7 Screening ashes using(100µm) sieve

Figure 3.7 shows screening the aloe-vera ash through 100µm sieve

3.2. Methods

3.2.1. Mold preparation

The size of the mold depends on the size of the sample used for testing. The required amount of reinforcements and matrix for each sample was weighed and placed in a crucible. The weight of powder added to the matrix depends on the sample size. Three samples were made in molds with the same reinforcement composition. This is due to the three trials of the experiment performed. Sand molds can be prepared for the production of Al6061/SiC/bagasse fly ash aloe vera ash hybrid composites based on the required sample size.

Mold preparation steps:

- Pattern making
- Sieving sand
- Moisturize the sand using water
- Preparing gating systems (sprue, risers, etc.)
- Ramming the sand and make drag and cop.

3.2.2. Sampling and sample method

The reinforcement composition ratios were taken from the literature showing the highest improvement in mechanical properties in relation to automotive interior parts (drum brake applications). The composition is 7.5, 10 wt. % of SiC, 7.5, 10, 9 wt. % of bagasse fly-ash and 6.5, 9, 11 wt. % Aloe vera ash

Samples were prepared with different percentage compositions of reinforcement, as shown below in Table 3.4 and 3.5.

Table 3. 4 Composite content in wt. % of all reinforcements

S/n	Wt. % of Al6061	Wt. % of Silicon carbide (SiC)	Wt. % of Bagasse fly-ash	Wt. % of Aloe vera ash	Al/SiC/ bagasse fly-ash/Aloe vera ash	Wt. % reinforcement
1	78.5	7.5	7.5	6.5	Al6061-7.5%SiC-7.5% bagasse ash- 6.5% Aloe vera ash	21.5%
2	73.5	7.5	10	9	Al6061-7.5%SiC-10% bagasse ash - 9 % Aloe vera ash	26.5%
3	72.5	7.5	9	11	Al6061-7.5%SiC-9% bagasse ash - 11 % Aloe vera ash	27.5%
4	76	10	7.5	6.5	Al6061-10 %SiC-7.5% bagasse ash - 6.5 % Aloe vera	24%

					ash	
5	71	10	10	9	Al6061-10 %SiC-10% bagasse ash - 9 % Aloe vera ash	29%
6	70	10	9	11	Al6061-10 %SiC-9% bagasse ash - 11 % Aloe vera ash	30%

Table 3. 5 Composite content in wt. % of silicon carbide only

S/n	Wt. % of Al 6061	Wt. % of SiC	Al/SiC
1	92.5	7.5	Al6061-7.5 % SiC
2	90	10	Al6061-10 % SiC

Therefore, the total number of experiments that can be performed in this work is eight (8) with three trials for each type of mechanical test.

10mm width, 10mm height, 60mm length, 20mm diameter, 60mm length, 20mm diameter, 120mm height, Sample sizes prepared for impact, compression, and wear testing.

3.2.3. Sample preparation technique

- ✓ The steps involved in composite manufacturing were;
 - Weight the required amount of aluminum alloy and place it in the crucible in the furnace.
 - Heat the crucible to a temperature higher than the liquid temperature of aluminum (710°C or higher).
 - After reaching the temperature, keep it at the same temperature for 10 minutes and check the molten state of the metal.
- The corresponding wt. % of reinforcement (SiC, fly-ash and Aloe vera ash) is weighted and preheats to 400°C to remove moisture. And also, pre heat the mold to minimize cast defects.

- After adding SiC, bagasse ash, and aloe vera ash to a fully liquid state, the melt was stirred and stirred for 10 minutes at 600rpm before removing the slag and pouring the melt into a permanent mold.
- Remove the composite from the mold after curing.

Specimen size and shape are prepared according to ASTM standards for each type of mechanical test. The composites produced are named based on the weight percentage of the reinforcing phase and the weight ratio of SiC, bagasse fly ash and aloe vera ash in the reinforcement.

The specimens prepared by the steps include:

- Weight percentage calculation
- Fabrication (Casting)
- Machining
- Conduct the experiment.

3.2.4. Estimate Wt. % percentage of reinforcements and matrix

Volume of reinforcement estimated by:

$V_f = m_f \times \rho_f$, where V_f , m_f and ρ_f represents volume fraction and mass fraction respectively.

The dimensions of the specimens to be manufactured depend on the type of test to be performed.

The input parameters for the sample dimensions are:

- Size of the test machine grip which hold the specimen (diameter of specimen).
- Minimum and maximum vertical movement of testing machine to hold the specimen (length of specimen).

Estimated mold volume used to weight the amount of matrix (Al6061) and reinforcements (SiC, bagasse fly ash, aloe vera ash) required to produce the sample. The sample size and shape depends on the type of test being performed, such as:

- Compression test specimen
- Wear test specimen
- Hardness test sample
- Impact test specimen preparation

3.2.5. Compression and hardness test specimen preparation

$$\text{Volume (area} \times \text{length) of the mold} = \pi \left(\frac{d^2}{4}\right) \times H = \pi \left(\frac{2^2}{4}\right) 6 = 18.84 \text{ cm}^3$$

The weight percentage (Wt. %) of matrix and reinforcements for each specimen obtained as follows:

- ✓ For addition of 7.5% of SiC, 7.5% of bagasse fly-ash and 6.5% of Aloe vera ash

$$\text{weight of Aluminium alloy} = \left(\frac{79.5}{100}\right) \times 18.84 \times 2.72 = 40.74 \text{ gram}$$

$$\text{Weight of SiC} = \left(\frac{7.5}{100}\right) \times 18.84 \times 3.21 = 4.53 \text{ gram}$$

$$\text{weight of Bagasse ash} = \left(\frac{7.5}{100}\right) \times 18.84 \times 1.96 = 2.77 \text{ gram}$$

$$\text{weight of Aloe vera ash} = \left(\frac{6.5}{100}\right) \times 18.84 \times 1.2 = 1.5 \text{ gram}$$

- ✓ For addition of 7.5% of SiC, 10% of bagasse fly-ash and 9% of Aloe vera ash

$$\text{weight of Aluminium alloy} = \left(\frac{73.5}{100}\right) \times 18.84 \times 2.72 = 37.67 \text{ gram}$$

$$\text{weight of SiC} = \left(\frac{7.5}{100}\right) \times 18.84 \times 3.21 = 4.53 \text{ gram}$$

$$\text{weight of Bagasse ash} = \left(\frac{10}{100}\right) \times 18.84 \times 1.96 = 3.69 \text{ gram}$$

$$\text{weight of Aloe vera ash} = \left(\frac{9}{100}\right) \times 18.84 \times 1.2 = 2.03 \text{ gram}$$

- ✓ For addition of 7.5% of SiC, 9% of bagasse fly-ash and 11 % of Aloe vera ash

$$\text{weight of Aluminium Alloy} = \left(\frac{72.5}{100}\right) \times 18.84 \times 2.72 = 37.15 \text{ gram}$$

$$\text{weight of SiC} = \left(\frac{7.5}{100}\right) \times 18.84 \times 3.21 = 4.53 \text{ gram}$$

$$\text{weight of Bagasse ash} = \left(\frac{9}{100}\right) \times 18.84 \times 1.96 = 3.32 \text{ gram}$$

$$\text{weight of Aloe vera ash} = \left(\frac{11}{100}\right) \times 18.84 \times 1.2 = 2.49 \text{ gram}$$

- ✓ For addition of 10% SiC, 7.5% bagasse fly-ash and 6.5 % of Aloe vera ash

$$\text{weight of Aluminium Alloy} = \left(\frac{76}{100}\right) \times 18.84 \times 2.72 = 38.95 \text{ gram}$$

$$\text{weight of SiC} = \left(\frac{10}{100}\right) \times 18.84 \times 3.21 = 6.05 \text{ gram}$$

$$\text{weight of Bagasse ash} = \left(\frac{7.5}{100}\right) \times 18.84 \times 1.96 = 2.77 \text{ gram}$$

$$\text{weight of Aloe vera ash} = \left(\frac{6.5}{100}\right) \times 18.84 \times 1.2 = 1.5 \text{ gram}$$

- ✓ For Addition of 10% SiC, 10% bagasse fly-ash and 9% of Aloe vera ash

$$\text{weight of Aluminium alloy} = \left(\frac{71}{100}\right) \times 18.84 \times 2.72 = 36.38 \text{ gram}$$

$$\text{weight of SiC} = \left(\frac{10}{100}\right) \times 18.84 \times 3.21 = 6.05 \text{ gram}$$

$$\text{weight of Bagasse ash} = \left(\frac{10}{100}\right) \times 18.84 \times 1.96 = 3.69 \text{ gram}$$

$$\text{weight of Aloe vera ash} = \left(\frac{9}{100}\right) \times 18.84 \times 1.2 = 2.03 \text{ gram}$$

- ✓ For Addition of 10% SiC, 9% bagasse fly-ash and 11 % of Aloe vera ash

$$\text{weight of Aluminium alloy} = \left(\frac{70}{100}\right) \times 18.84 \times 2.72 = 35.87 \text{ gram}$$

$$\text{weight of SiC} = \left(\frac{10}{100}\right) \times 18.84 \times 3.21 = 6.05 \text{ gram}$$

$$\text{weight of Bagasse ash} = \left(\frac{9}{100}\right) \times 18.84 \times 1.96 = 3.32 \text{ gram}$$

$$\text{weight of Aloe vera ash} = \left(\frac{11}{100}\right) \times 18.84 \times 1.2 = 2.49 \text{ gram}$$

- ✓ For addition of 7.5% of SiC only

$$\text{weight of Aluminium alloy} = \left(\frac{92.5}{100}\right) \times 18.84 \times 2.72 = 47.4 \text{ gram}$$

$$\text{weight of SiC} = \left(\frac{7.5}{100}\right) \times 18.84 \times 3.21 = 4.53 \text{ gram}$$

- ✓ For addition of 10 % of SiC only

$$\text{weight of Aluminium alloy} = \left(\frac{90}{100}\right) \times 18.84 \times 2.72 = 46.12 \text{ gram}$$

$$\text{weight of SiC} = \left(\frac{10}{100}\right) \times 18.84 \times 3.21 = 6.05 \text{ gram}$$

Total Al6061 required = 46.12+47.4+35.87+36.38+38.95+37.15+37.67+40.74 = 320.28 gram

Total SiC required = 6.05+4.53+6.05+6.05+6.05+4.53+4.53+4.53 = 42.43 gram

Total Bagasse ash required = 3.32+3.69+2.77+3.32+3.69+2.77 = 19.56 gram

Total Aloe vera ash required = 2.49+2.03+1.5+2.49+2.03+1.5 = 12.04 gram

3.2.6. Wear test specimen preparation

Volume (area \times length) of the mold = $\pi \left(\frac{d^2}{4}\right) \times H = \pi(2^2/4) \times 12 = 37.68$ cc

- ✓ For addition of 7.5% of SiC, 7.5% of bagasse fly-ash and 6.5% of Aloe vera ash

$$\text{weight of Aluminium alloy} = \left(\frac{79.5}{100}\right) \times 37.68 \times 2.72 = 80.97 \text{ gram}$$

$$\text{weight of SiC} = \left(\frac{7.5}{100}\right) \times 37.68 \times 3.21 = 9.1 \text{ gram}$$

$$\text{weight of Bagasse ash} = \left(\frac{7.5}{100}\right) \times 37.68 \times 1.96 = 5.54 \text{ gram}$$

$$\text{weight of Aloe vera ash} = \left(\frac{6.5}{100}\right) \times 37.68 \times 1.2 = 2.94 \text{ gram}$$

- ✓ For addition of 7.5% SiC, 10% of bagasse fly-ash and 9% of Aloe vera ash

$$\text{weight of Aluminium alloy} = \left(\frac{73.5}{100}\right) \times 37.68 \times 2.72 = 75.3 \text{ gram}$$

$$\text{weight of SiC} = \left(\frac{7.5}{100}\right) \times 37.68 \times 3.21 = 9.1 \text{ gram}$$

$$\text{weight of Bagasse ash} = \left(\frac{10}{100}\right) \times 37.68 \times 1.96 = 7.4 \text{ gram}$$

$$\text{weight of Aloe vera ash} = \left(\frac{9}{100}\right) \times 37.68 \times 1.2 = 4.5 \text{ gram}$$

- ✓ For addition of 7.5% of SiC, 9 % of bagasse fly-ash and 11% of Aloe vera ash

$$\text{weight of Aluminium alloy} = \left(\frac{72.5}{100}\right) \times 37.68 \times 2.72 = 74.305 \text{ gram}$$

$$\text{weight of SiC} = \left(\frac{7.5}{100}\right) \times 37.68 \times 3.21 = 9.1 \text{ gram}$$

$$\text{weight of Bagasse ash} = \left(\frac{9}{100}\right) \times 37.68 \times 1.96 = 6.64 \text{ gram}$$

$$\text{weight of Aloe vera ash} = \left(\frac{11}{100}\right) \times 37.68 \times 1.2 = 8.12 \text{ gram}$$

- ✓ For Addition of 10% SiC, 7.5% bagasse fly-ash and 6.5% of Aloe vera ash

$$\text{weight of Aluminium alloy} = \left(\frac{76}{100}\right) \times 37.68 \times 2.72 = 77.9 \text{ gram}$$

$$\text{weight of SiC} = \left(\frac{10}{100}\right) \times 37.68 \times 3.21 = 12.1 \text{ gram}$$

$$\text{weight of Bagasse ash} = \left(\frac{7.5}{100}\right) \times 37.68 \times 1.96 = 5.54 \text{ gram}$$

$$\text{weight of Aloe vera ash} = \left(\frac{6.5}{100}\right) \times 37.68 \times 1.2 = 2.94 \text{ gram}$$

- ✓ For Addition of 10% SiC, 10% bagasse fly-ash and 9% of Aloe vera ash

$$\text{weight of Aluminium alloy} = \left(\frac{71}{100}\right) \times 37.68 \times 2.72 = 72.77 \text{ gram}$$

$$\text{weight of SiC} = \left(\frac{10}{100}\right) \times 37.68 \times 3.21 = 12.1 \text{ gram}$$

$$\text{weight of Bagasse ash} = \left(\frac{10}{100}\right) \times 37.68 \times 1.96 = 7.4 \text{ gram}$$

$$\text{weight of Aloe vera ash} = \left(\frac{9}{100}\right) \times 37.68 \times 1.2 = 4.1 \text{ gram}$$

- ✓ For Addition of 10% SiC, 9% bagasse fly-ash and 11% of Aloe vera ash

$$\text{weight of Aluminium alloy} = \left(\frac{70}{100}\right) \times 37.68 \times 2.72 = 71.743 \text{ gram}$$

$$\text{weight of SiC} = \left(\frac{10}{100}\right) \times 37.6 \times 3.21 = 11.7 \text{ gram}$$

$$\text{weight of Bagasse ash} = \left(\frac{9}{100}\right) \times 37.68 \times 1.96 = 6.64 \text{ gram}$$

$$\text{weight of Aloe vera ash} = \left(\frac{11}{100}\right) \times 37.68 \times 1.2 = 4.97 \text{ gram}$$

- ✓ For addition of 7.5% of SiC only

$$\text{weight of Aluminium Alloy} = \left(\frac{92.5}{100}\right) \times 37.68 \times 2.72 = 94.8 \text{ gram}$$

$$\text{weight of SiC} = \left(\frac{7.5}{100}\right) \times 37.68 \times 3.21 = 9.1 \text{ gram}$$

- ✓ For addition of 10% of SiC only

$$\text{weight of Aluminium alloy} = \left(\frac{90}{100}\right) \times 37.68 \times 2.72 = 92.24 \text{ gram}$$

$$\text{weight of SiC} = \left(\frac{10}{100}\right) \times 37.68 \times 3.21 = 12.1 \text{ gram}$$

The total Aluminum alloy required for wear test sample preparation calculated as follows

$$92.24+94.8+71.43+72.77+77.9+74.305+75.3+80.97 = 639.76 \text{ gram}$$

$$\text{The total SiC required} = 12.1+9.1+11.7+11.7+12.1+12.1+9.1+9.1 = 87 \text{ gram}$$

$$\text{The total Bagasse required} = 6.64+7.4+5.54+6.64+7.4+5.54 = 39.16 \text{ gram}$$

$$\text{The total Aloe vera ash} = 4.97+4.1+2.94+8.12+4.5+2.94 = 27.03 \text{ gram}$$

Therefore, the total weight of the matrix and the reinforcement have been calculated as follows

$$\text{Total weight of Aluminum required} = 639.76 + 320.28 + 500 \text{ (for shrinkage allowance)} = 1460.04 \text{ gram} = 1.460 \text{ Kg.}$$

$$\text{The total weight of SiC} = 87+42.43+30 \text{ (for shrinkage allowance)} = 159 \text{ gram}$$

$$\text{The total weight of Bagasse ash} = 39.16+21.78+15 \text{ (for shrinkage allowance)} = 80.38 \text{ gram}$$

$$\text{The total weight Aloe vera ash required for all samples} = 27.03+12.04+10 \text{ (shrinkage allowance)} = 39.07 \text{ gram}$$

3.2.7. Impact test specimen preparation

$$\text{Volume (length} \times \text{width} \times \text{height)} = (6 \times 1 \times 1) \text{ cm} = 6 \text{ cm}^3$$

- ✓ For addition of 7.5% of SiC, 7.5% of bagasse fly-ash and 6.5% of Aloe vera ash

$$\text{Weight of Aluminum alloy} = (79.5/100) \times 6 \times 2.72 = 12.97 \text{ gram}$$

$$\text{Weight of SiC} = (7.5/100) \times 6 \times 3.21 = 1.44 \text{ gram}$$

$$\text{Weight of Bagasse ash} = (7.5/100) \times 6 \times 1.96 = 0.882 \text{ gram}$$

$$\text{Weight of aloe vera ash} = (6.5/100) \times 6 \times 1.2 = 0.47 \text{ gram}$$

- ✓ For addition of 7.5% SiC, 10% of bagasse fly-ash and 9% of Aloe vera ash

$$\text{Weight of aluminum alloy} = (73.5/100) \times 6 \times 2.72 = 12 \text{ gram}$$

$$\text{Weight of SiC} = (7.5/100) \times 6 \times 3.21 = 1.44 \text{ gram}$$

$$\text{Weight of Bagasse ash} = (10/100) \times 6 \times 1.96 = 1.18 \text{ gram}$$

$$\text{Weight of aloe vera ash} = (9/100) \times 6 \times 1.2 = 0.65 \text{ gram}$$

- ✓ For addition of 7.5% SiC, 9% of bagasse fly-ash and 11% of Aloe vera ash

$$\text{Weight of aluminum alloy} = (72.5/100) \times 6 \times 2.72 = 11.832 \text{ gram}$$

$$\text{Weight of SiC} = (7.5/100) \times 6 \times 3.21 = 1.44 \text{ gram}$$

$$\text{Weight of Bagasse ash} = (9/100) \times 6 \times 1.96 = 1.06 \text{ gram}$$

$$\text{Weight of aloe vera ash} = (11/100) \times 6 \times 1.2 = 0.8 \text{ gram}$$

- ✓ For addition of 10% SiC, 7.5% of bagasse fly-ash and 6.5% of Aloe vera ash

$$\text{Weight of aluminum alloy} = (76/100) \times 6 \times 2.72 = 12.4 \text{ gram}$$

$$\text{Weight of SiC} = (10/100) \times 6 \times 3.21 = 1.93 \text{ gram}$$

$$\text{Weight of Bagasse ash} = (7.5/100) \times 6 \times 1.96 = 0.882 \text{ gram}$$

$$\text{Weight of aloe vera ash} = (6.5/100) \times 6 \times 1.2 = 0.47 \text{ gram}$$

- ✓ For addition of 10% SiC, 10% of bagasse fly-ash and 9 % of Aloe vera ash

$$\text{Weight of aluminum alloy} = (71/100) \times 6 \times 2.72 = 11.6 \text{ gram}$$

$$\text{Weight of SiC} = (10/100) \times 6 \times 3.21 = 1.93 \text{ gram}$$

$$\text{Weight of Bagasse ash} = (10/100) \times 6 \times 1.96 = 1.18 \text{ gram}$$

$$\text{Weight of aloe vera ash} = (9/100) \times 6 \times 1.2 = 0.65 \text{ gram}$$

- ✓ For addition of 10% SiC, 9% of bagasse fly-ash and 11 % of Aloe vera ash

$$\text{Weight of aluminum alloy} = (70/100) \times 6 \times 2.72 = 11.72 \text{ gram}$$

$$\text{Weight of SiC} = (10/100) \times 6 \times 3.21 = 1.93 \text{ gram}$$

$$\text{Weight of Bagasse ash} = (9/100) \times 6 \times 1.96 = 1.06 \text{ gram}$$

$$\text{Weight of aloe vera ash} = (11/100) \times 6 \times 1.2 = 0.8 \text{ gram}$$

- ✓ For addition of 7.5% SiC only

$$\text{Weight of aluminum alloy} = (92.5/100) \times 6 \times 2.72 = 15.1 \text{ gram}$$

$$\text{Weight of SiC} = (7.5/100) \times 6 \times 3.21 = 1.44 \text{ gram}$$

- ✓ For addition of 10% SiC only

$$\text{Weight of aluminum alloy} = (90/100) \times 6 \times 2.72 = 14.7 \text{ gram}$$

$$\text{Weight of SiC} = (10/100) \times 6 \times 3.21 = 1.93 \text{ gram}$$

The total Aluminum alloy and others required for impact test samples preparation calculated as follows

$$14.7+15.1+11.832+11.6+12.4+11.72+12+12.97 = 102.322 \text{ gram}$$

$$\text{The total SiC required} = 1.93+1.44+1.93+1.93+1.93+1.44+1.44+1.44 = 13.48 \text{ gram}$$

$$\text{The total Bagasse ash required} = 0.882+1.18+1.06+0.882+1.18+1.06 = 6.244 \text{ gram}$$

$$\text{The total Aloe vera ash required} = 0.8+0.65+0.47+0.8+0.65+0.47 = 3.84 \text{ gram}$$

Therefore, the total weight of the matrix and the reinforcement have been calculated as follows

$$\text{Total weight of Aluminum required} = 639.76+320.28+102.322 + 500 \text{ (for shrinkage allowance)} = 1562.362 \text{ gram} = 1.562 \text{ kg.}$$

3.3. Fabrication

The work used the most cost-effective and flexible manufacturing process. Agitation casting technology for producing hybrid composite Al6061/SiC-Bagasse-Fly Ash/Aloe-Vera-Ash. A matrix aluminum alloy was melted in a crucible placed in a furnace. This was melted at 700° C., a reinforcing material was added, and the melt was stirred for 10 minutes. A stirrer attached to a hand drill. The process parameters considered during the composite casting process are:

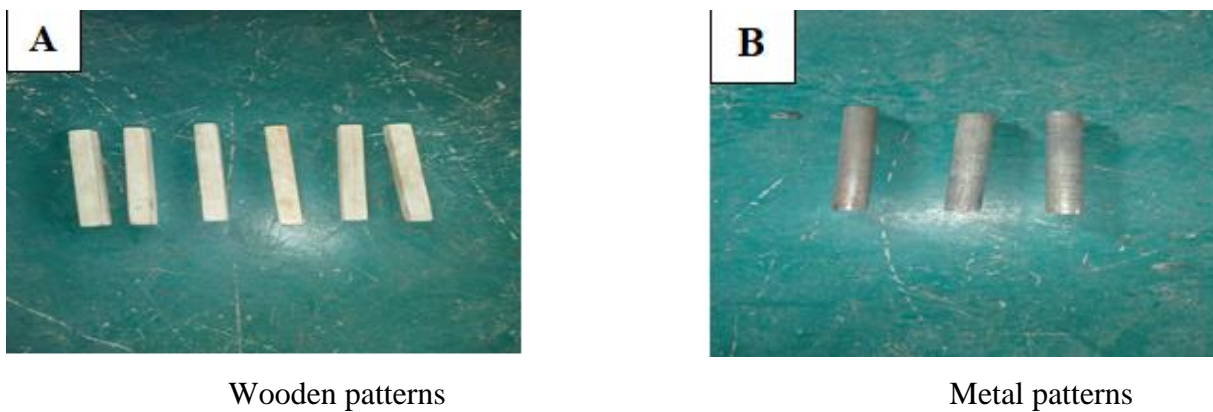
- 1) Melting temperature
- 2) Stirring speed and stirring time
- 3) Percentage composition of reinforcements

✚ The steps involved in composite preparation were;

- 1) Weight the required amount of matrix and reinforcement and place it near the crucible
- 2) Eight different molds were prepared for different weight samples. % reinforcement and two additional molds without adding bagasse fly and aloe vera ash for base metal (Al6061) and SiC.
- 3) Heated the crucible above the liquid's temperature of aluminum (above 710°C).
- 4) After reaching the temperature, maintain the same temperature for 10 minutes and check the molten state of the metal.
- 5) Preheat an appropriate weight percent of reinforcement (SiC, fly ash, aloe vera ash) to 400°C to remove moisture. Also, the mold should be preheated to minimize casting errors.

- 6) After adding SiC, bagasse ash and aloe vera ash to a fully liquid state, the melt was stirred and stirred for 10 minutes before removing the slag and pouring the melt into the prepared mold.
- 7) Removal of composite from mold after solidification.
- 8) Samples are prepared to ASTM standards and ready for testing.

Agitation of the slurry during preparation is accomplished by attaching an agitator to a drill press capable of agitating the stiffener with the molten metal in the crucible, as shown in Figure 3.8 below.



Wooden patterns

Metal patterns

Figure 3. 8 Patterns

- ✓ A pattern is a physical model of the casting used to make the required mold. As shown in figure 3.8 a pattern is a shaped form of wood or metal around which sand is packed in the mold. Wood is a common pattern material because it is easily shaped but it has disadvantages of it tends to distort, and it is abraded/wear off by the sand being compacted around it, thus limiting the number of times it can be reused. Metal patterns are employed where large number of castings has to be produced from the same patterns. Patterns are more expensive to make, but they last much longer. For the present work metal pattern is used except for impact samples which are prepared from wood.



Figure 3. 9 sand mixing and moisturizing machine

Sand mixing machines are the key piece of foundry equipment for mixing sand with binding agents.



A



B

Figure 3. 10 Molding A) empty drag

B) Mold with casting sand and pattern

Figure 3.10 A shows the empty drag that means without sand and pattern whereas Figure 3.10 B shows the drag and cope with compacted sand and the prepared pattern.



Figure 3. 11 Mold ready for pouring

As shown in figure 3.11 the pattern is properly removed from the compacted sand without damaging the hole so that casting quality would be increased and ready for pouring of the molten.



Drilling machine



stirring

Figure 3. 12 Stirrer set up

Figure 3.12 A, shows universal drilling machine with stirrer mounted on it and figure 3.12 B, shows stirring the melted Aluminum with the reinforcements.



Figure 3. 13 Taking the molten material for pouring
As shown in figure 3.13 the molten hybrid material ready to pouring in to the prepared mold



Figure 3. 14 Solidified products
Figure 3.14 shows the solidified products after pouring the molten in the desired cavity



Casting impact specimen after solidify prepared based on ASTM E23
10mmx10mmx55mm.



Figure 3. 15 Manufactured samples removed from mold

Figure 3.15 shows that the manufactured samples for wear, compression and impact test removed from the mold solidified.

3.4. Machining of samples for testing

Al6061/SiC/Bagasse ash-Aloe Vera Ash composite specimens machined on lath for each type of mechanical testes shown below in figure 3.16



Figure 3. 16 Machining of sample

Figure 3.16 shows machining of the samples before goes to testing

3.4.1. Compression test specimen

Compression specimens of metal matrix composites are prepared according to ASTM E9. Flat and round configurations of metal matrix samples are employed. If the composite material is made by diffusion bonding, a flattened shape of the sample is obtained. In other cases, metal matrix composites produced by various liquid infiltration and other methods of producing bulk materials are better suited for circular cross-sectional geometries with sample heights and diameters.

Height of specimen =20mm, diameter of specimen =15mm

For the present work the diameter of specimen used 15mm and height of the specimen is 20 mm used Based on ASTM E9.



Figure 3. 17 Compression test specimens

Figure3.17 shows that prepared specimen for compression test based on ASTM E9 15mm diameter and 20mm height.

3.4.2. Wear test specimen

The samples could be subjected to tribological testing performed on the samples to investigate the wear properties and to suggest a material which have more wear resistance from different wt.% combinations. There are several set ups which can be used for conducting wear tests some of them are dry sand rubber wheel, pin on drum, linear tribo machine, block on ring, block on disc and pin on disc. For this work the pin on disc set up was used. ASTM G99 is the standard for pin on disc wear testing if the base material is metals and its alloys. The samples were prepared with 6 cm in diameter and 12 cm in length based on ASTM G99.



Figure 3. 18 Wear test specimens

3.4.3. Impact test specimen

An impact test is a technique for determining the behavior of material subjected to shock loading in:

- Bending
- Tension
- Torsion

This test had been designed to determine how a specimen of a known material will respond to a suddenly applied stress. The test ascertains whether the material is tough or brittle. It is mostly used to test the toughness of metals, but similar tests are used for polymers, ceramics and composites. The impact test is a method for evaluating the toughness, impact strength and notch sensitivity of engineering materials. Engineers test the ability of a material to withstand impact to predict its behavior under actual conditions. The most common impact tests use a swinging pendulum to strike a notched bar; heights before and after impact are used to compute the energy required to fracture the bar. The samples could be subjected to impact performed on the samples to investigate the the impact properties and to suggest a material which have more impact resistance from different wt.% combinations. The Charpy type of impact test was used to measure the energy absorbed by a standard notched specimen while breaking under an impact load the samples were prepared with 55 mm in length and 10 mm width and 10mm height based on ASTM E-23.



Figure 3. 19 Impact test specimens

3.5. Mechanical characterization

3.5.1. Compression test

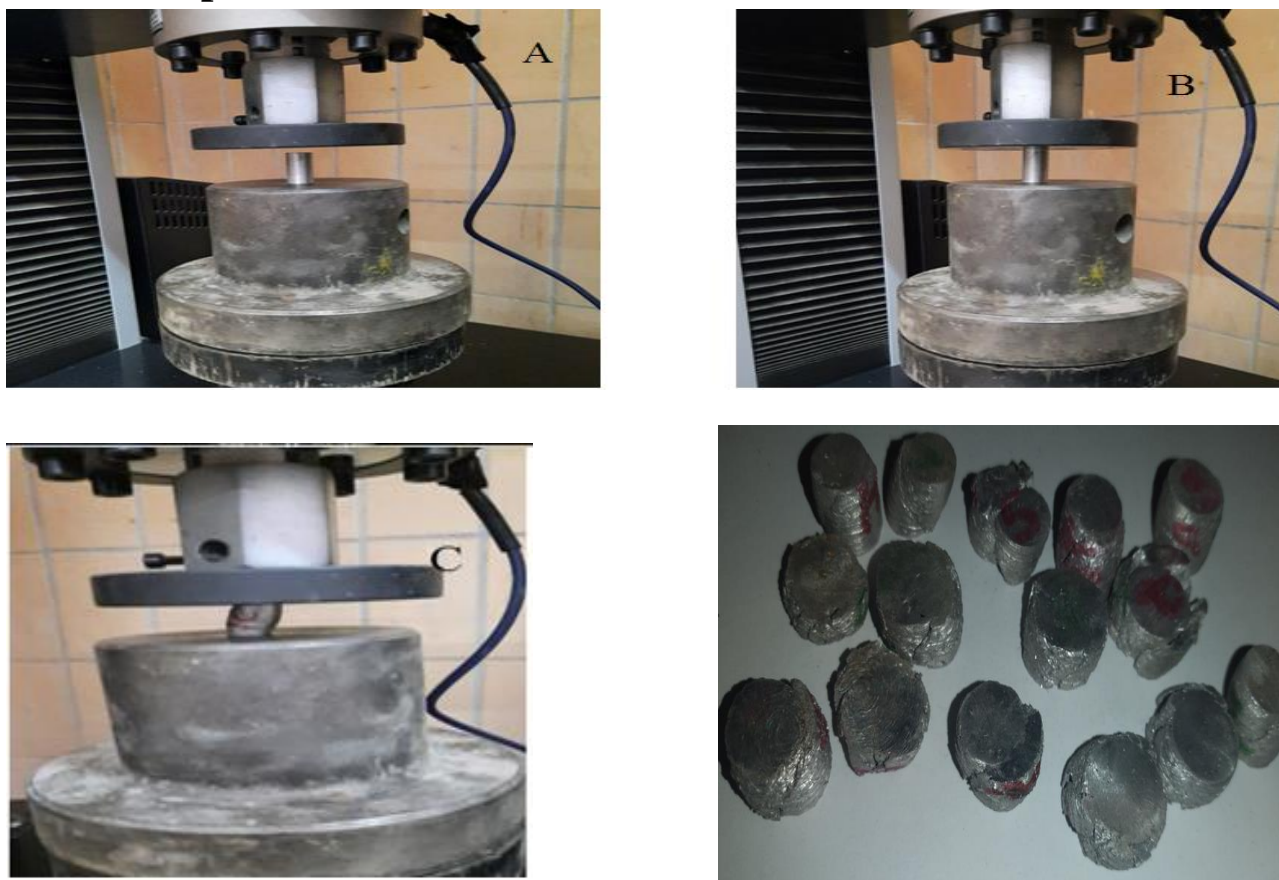


Figure 3. 20 Compression test process A) before compression, B) During compression, C) During failing, D) Failed compression test samples

Development and characterization of Al6061/SiC/Bagasse ash/aloevera ash hybrid composite

Compression tests of Al/SiC composites with and without the addition of bagasse fly ash and aloe vera ash were performed using sample dimensions of 20 mm height and 15 mm diameter. The test was performed on his 3 trials of the same composition. Compressive strengths of singly reinforced Al/SiC composites and Al/SiC hybrid bagasse ash/aloe vera ash were compared as follows.

Table 3. 6 Compression strength of Al/SiC/bagasse ash, and aloe vera ash composite with different Wt. % of reinforcements

S.N	Al/SiC/fly-ash/Aloe vera ash composite	Compression strength (MP)			Average Compression strength (MP)
		Trial 1	Trial 2	Trial 3	
1	Al6061-7.5%SiC-7.5% bagasse ash-6.5% Aloe vera ash	291.8	315.74	285.74	297.76
2	Al6061-7.5%SiC-10% bagasse ash - 9 % Aloe vera ash	298.0	309.4	294.8	300.73
3	Al6061-7.5%SiC-9% bagasse ash - 11 % Aloe vera ash	302.8	324.52	299.31	308.87
4	Al6061-10 %SiC-7.5% bagasse ash - 6.5 % Aloe vera ash	334.2	357.5	315.8	335.83
5	Al6061-10 %SiC-10% bagasse ash - 9 % Aloe vera ash	348.4	351.9	339.6	358.63
6	Al6061-10 %SiC-9% bagasse ash - 11 % Aloe vera ash	374.0	367.5	387.3	376.3

Table 3. 7 Compression strength

S.N	Al/SiC composite	Compression strength (MP)			Average compression strength
		Trial 1	Trial 2	Trial 3	
1	Al6061-7.5%SiC	166.2	180.74	174.91	173.95
2	Al6061-10%SiC	191.9	214.13	223.85	209.96

3.5.3. Wear test

Wear is a process of removal of material from one or both of two solid surfaces in solid state contact. The samples were subjected to tribological testing performed on the samples to investigate the wear properties and to suggest a material which have more wear resistance from different wt. % combinations. There are several set ups which can be used for conducting wear tests, some of them are dry sand rubber wheel, pin on drum, linear tribo machine, block on ring, block on disc and pin on disc. For this work the pin on disc set up is used. ASTM G99 is the standard for pin on disc wear testing since the base material is metal alloy. The sample is 6 mm in diameter and 12 mm in length. The pin (sample) was held against the counter face of a rotating disc with wear track diameter 25 mm. The contact with the counter face continuously erodes the material and the wear and the frictional force acting is continuously measured with the help of sensors fitted on the set up.

The tests were conducted at the speed of 600 RPM and at a total sliding distance of approximately 281 m and maximum sliding velocity of 0.78m/se (Appendix F) under similar conditions while keeping the normal load constant. The experiment was conducted at normal load of 30N while the maximum load is 60N. Care was taken while applying and removing the loads was done carefully to avoid errors incurred due to possible fluctuations in the load.

3.5.4. Specifications of Pin on Disc Wear Test Setup (koehler, 2010)

- ASTM G99 standard test method
- ✓ **Specifications of: ASTM G99**
- Sliding Speed Range: 0.26-10 m/sec
- Disc Rotation Speed: 100-2000 rpm
- Maximum Normal Load: 200 N
- Frictional Force: 0-200 N
- Wear Measurement Range: 4 mm
- Pin Size: 3-12 mm diagonal/diameter
- Disc Size: 160 mm x 8 mm thick
- Wear Track Diameter: 10-140 mm

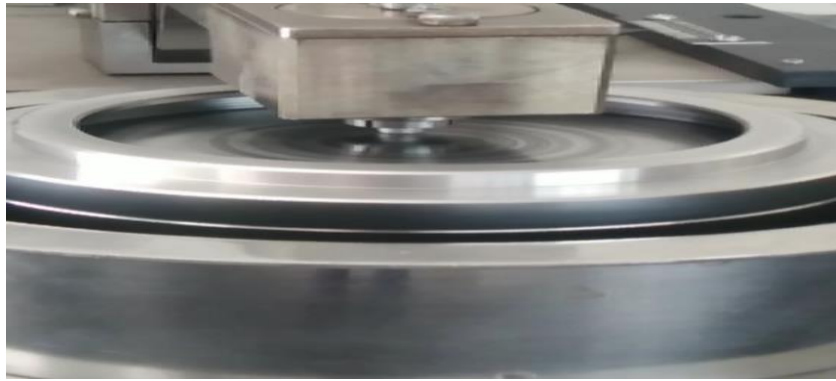


Figure 3. 21 Wear test set up

3.5.5. Wear loss

Each sample was weighed using a digital balance having an accuracy of ± 0.1 mg (wear testing measurement teaching material chapter 6, page 87). After that, the sample was mounted on the pin holder of the tribometer ready for wear test. For all experiments, the sliding speeds and sliding distances were adjusted to 0.78m/s and 281m respectively.

Table 3. 8 Weight loss of the prepared composite

Weight loss of the composite				
S.N	Specimens	Sliding speed(m/s)		
		Initial weight(gm.)	Final weight(gm.)	Weight loss(gm.)
1	Sample 1	0.8402	0.836	0.0042
2	Sample 2	0.8438	0.839	0.0048
3	Sample 3	0.7672	0.7491	0.0181
4	Sample 4	0.6490	0.647	0.002
5	Sample 5	0.7169	0.715	0.0019
6	Sample 6	0.6831	0.6813	0.0018
7	Sample 7	0.8633	0.800	0.0633
8	Sample 8	0.8895	0.711	0.1785

Wear rate = weight loss/sliding distance

Wear resistance = 1/ wear rate

Table 3. 9 Wear rate and wear resistance of the prepared samples

Weight loss of the composite						
S.N	Specimens	Sliding speed(m/s)				
		Initial weight(gm.)	Final weight(gm.)	Weight loss(gm.)	Wear rate (g/m)	Wear resistance (mm ³)
1	Sample 1	0.8402	0.836	0.0042	0.0000149	67114
2	Sample 2	0.8438	0.839	0.0048	0.0000170	58823.5
3	Sample 3	0.7672	0.7491	0.0181	0.0000644	15527.9
4	Sample 4	0.6490	0.647	0.002	0.00000711	140646.98
5	Sample 5	0.7169	0.715	0.0019	0.000000676	147928.99
6	Sample 6	0.6831	0.6813	0.0018	0.0000064	156250
7	Sample 7	0.8633	0.800	0.0633	0.000225	4444.4
8	Sample 8	0.8895	0.711	0.1785	0.000635	1574.8

In the above table 3.9, the wear rate and wear resistance were calculated and filled by using the above equations.

As it is explained in the above table the hybrid composite sample 5(Al6061-10 %SiC-10% bagasse ash - 9 % Aloe vera ash) and sample 6(Al6061-10 %SiC-12% bagasse ash - 11 % Aloe vera ash) achieved higher wear resistance as compared to another hybrid and single reinforced composite samples. The result also tells us the composite of single reinforced composite is less wear resistance than the hybrid composite materials.

3.5.6. Impact test

The impact test was conducted using 25c⁰ on impact testing machine with model of JWT-406 that has power and voltage values of 1.5kw and 380v respectively.



Figure 3. 22 impact testing equipment

Figure 3.22 shows the Charpy impact test machine which testing the desired sample



Figure 3. 23 Impact test samples

.Figure 3.23 shows the sample prepared based on ASTM E-23

3.6. Microstructure of the developed composite

Using a scanning electron microscope (SEM), the microstructure of a prepared composite material (Al606/SiC, bagasse ash, aloe vera ash) had been studied. Al606/SiC, bagasse ash, and aloe vera ash had a microstructure that is shown in figure. Examination of the microstructure demonstrates that the matrix and the correct link were formed. Particles of the substance are aloe vera powder, bagasse ash, and silicon carbide. The SEM examination was tested at Adama Science and Technology University, with the samples prepared for microstructure measuring 1 cm by 1 cm and the morphology of the reinforcements being in powder form, and then the test was done after all preparation and all required procedures, like etching the samples.

The following chart shows generalized procedure of research work clearly summarized way

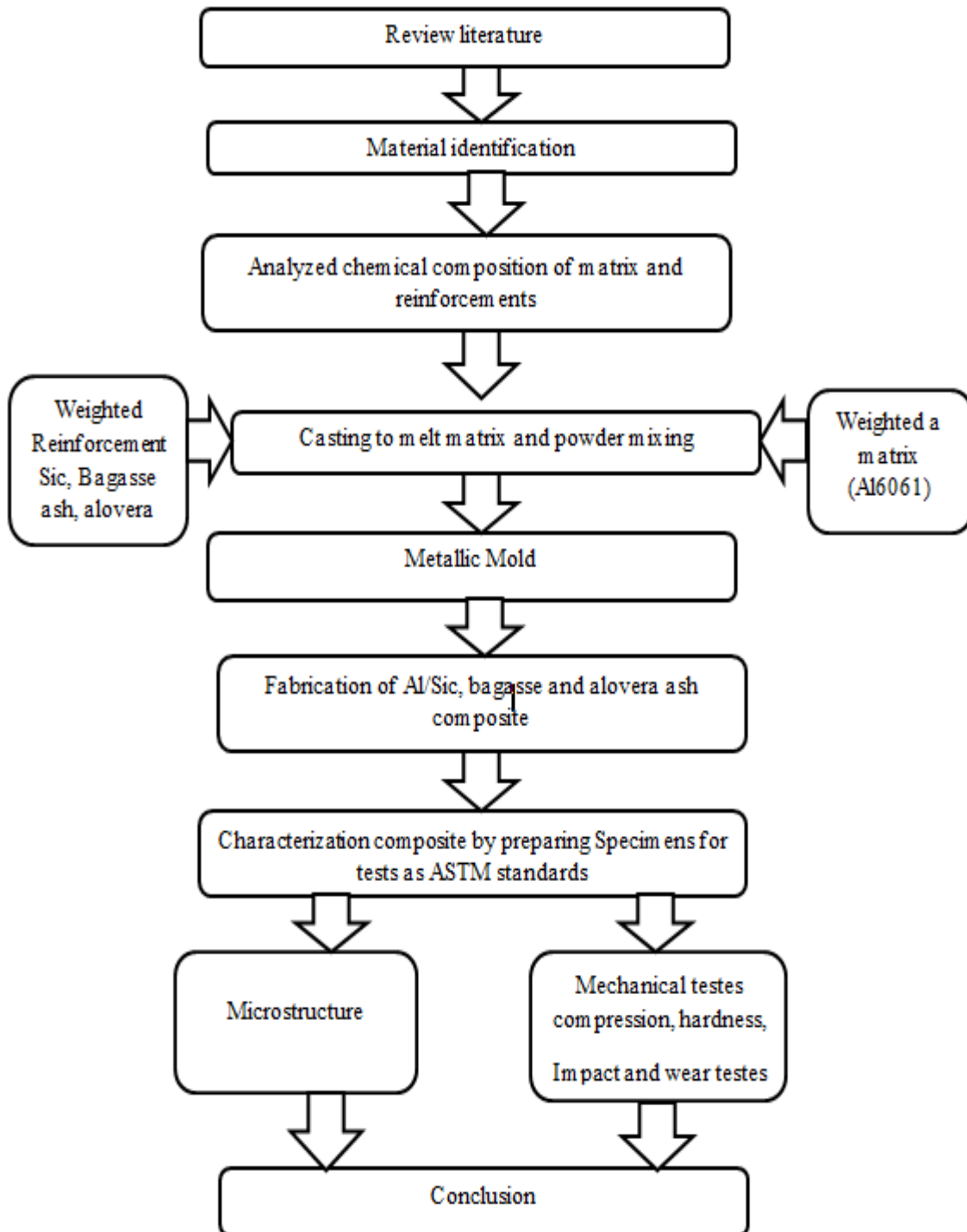


Figure 3. 24 General Procedure of the research

Chapter four

Result and Discussion

This chapter presents the experimental results and discussion of the desired properties it also deals with comparison of the experimental results of compression, hardness, wear and impact also microstructure of manufactured material.

4.1 Compression test results

The experimental results in figure 4.1 and figure 4.2 shows that the average compressive strength of hybrid composites is increased compared to single reinforced composites. As a result, that compressive strength increased slightly with an increasing composition of SiC, bagasse fly ash, and aloe vera ash. In sample 6 (Al6061-10% SiC-9-gase-11% aloe vera ash) compositions showed increasing in compression value compared to single and hybrid composites. This is due to the increased dislocation density of bagasse fly ash and aloe vera ash in the matrix material.

Figure 4.1 shows as SiC is constant and varying the fillers result also vary when the fillers wt. %. Increase compression result increase so the maximum compressive strength was found at combination 6 and the value is 376.3 MP. Results shows as the contribution of the reinforced material clearly increasing the reinforcement increase the compressive values.

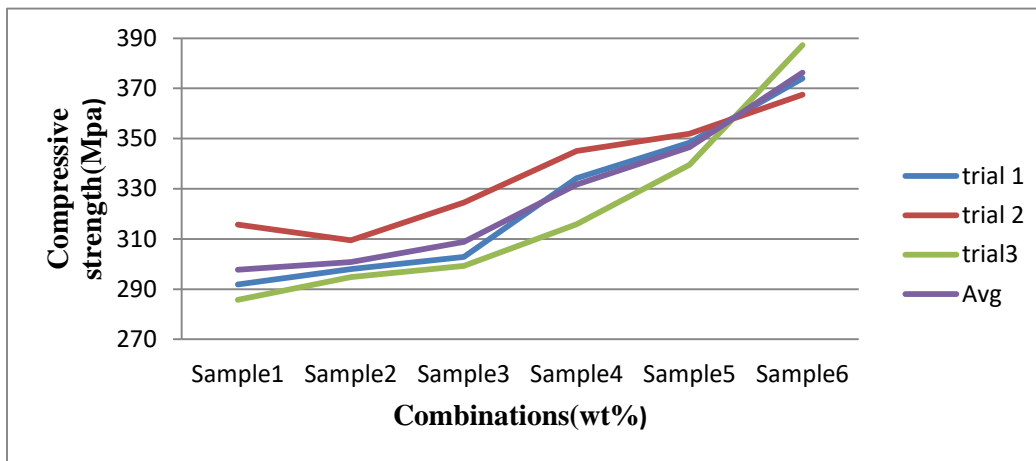


Figure 4. 1 Compressive strength vs. wt. % combinations

4.2 Compressive test result of manufactured single reinforced composite (Al6061/SiC)

Figure 4.2 shows that Al alloy reinforced by SiC Only wt% of silicon carbide increase the compressive value increase and also less than reinforced with bagasse and aloe vera ash this implies that the ashes has a contribution on the value of compressive which is increased from 173.95mpa to 209.96mpa.

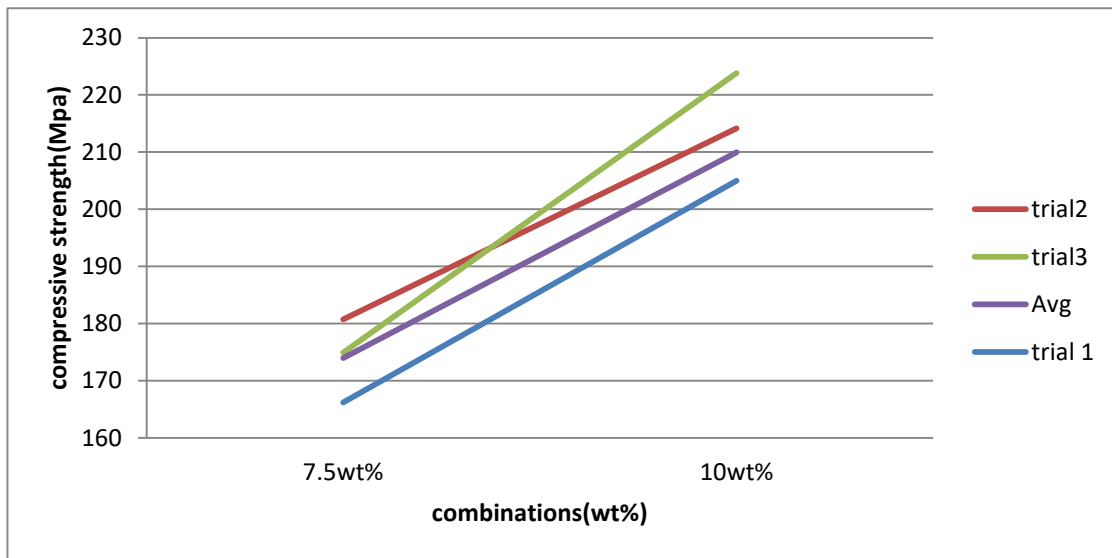


Figure 4. 2 Compressive strength vs. wt. % combinations for single reinforced composite

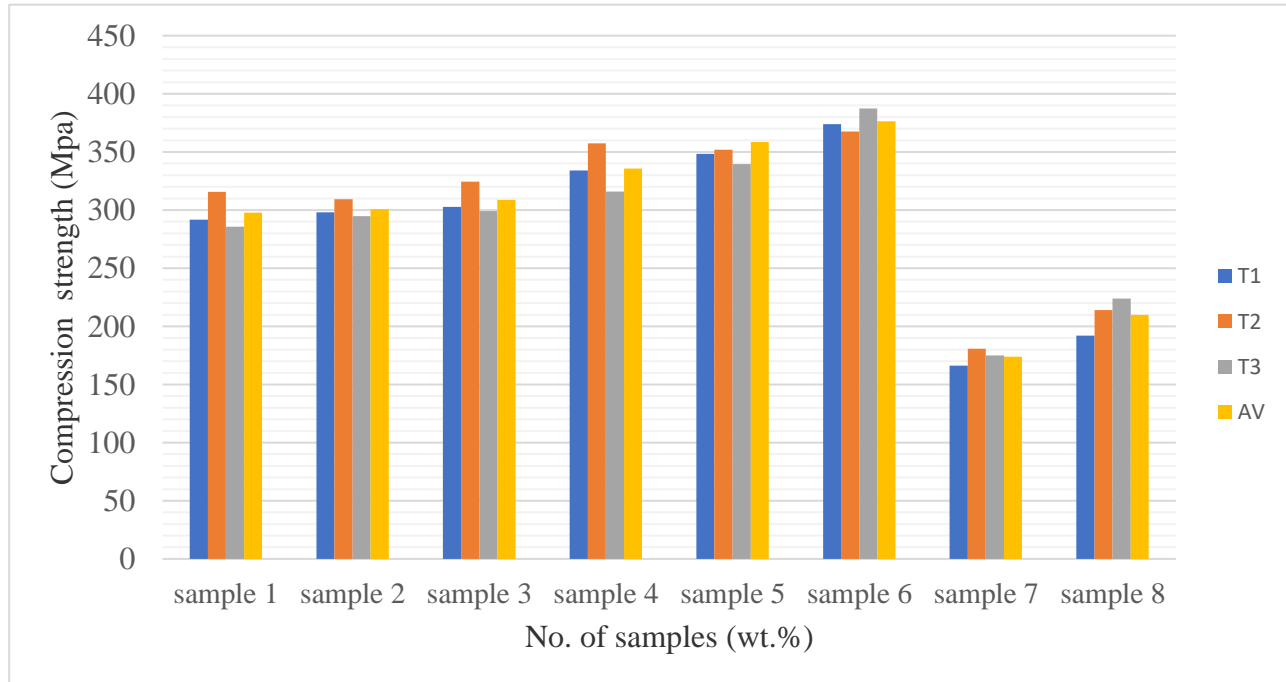


Figure 4. 3 Influence of wt. % reinforcements on compression strength

Figure 4.3 shows that the compression results increasing as the reinforcements increase also it tell as the ashes have significant change on the value. The composite with Silicon carbide less than that of reinforced with ashes.

4.3Wear Test result

The samples were subjected to tribological testing performed on the samples to investigate the wear properties and to suggest a material which wt. % combinations have better wear resistance. Results of wear test showed that with increasing reinforcement concentration the wear decreased.

The result of wear is explained as follows in terms of coefficient of friction, frictional force, and direct wear reading on pin on disc set up and wear loss.

4.3.1 Coefficient of friction

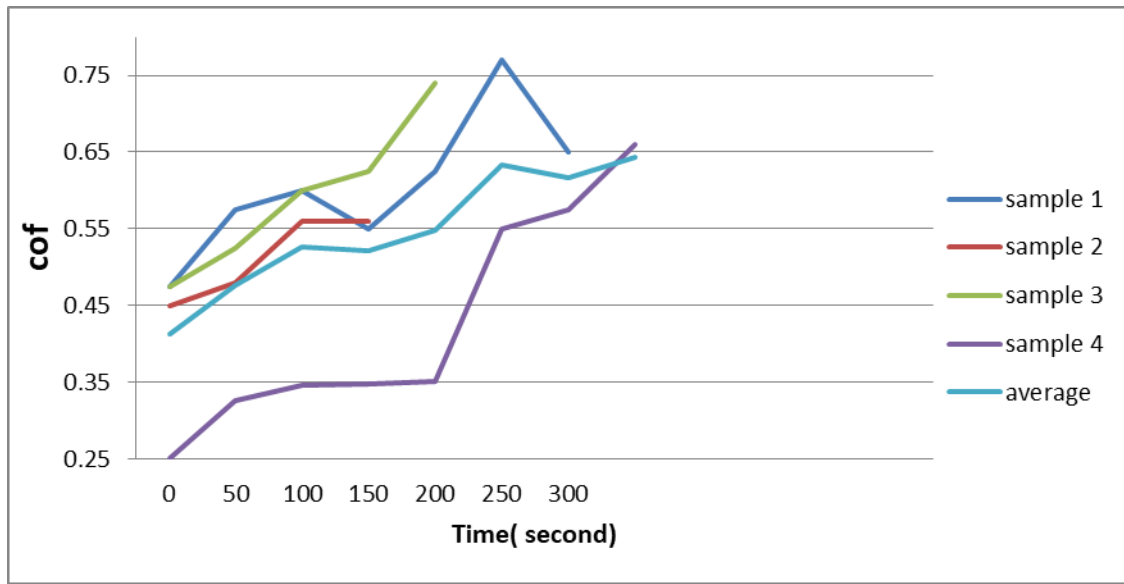


Figure 4. 4 result of coefficient of friction vs. time for the first four wt. % combinations

The symbols ED(sample) indicates the wt.% combinations which means sample 1 (Al6061-7.5%SiC-7.5% bagasse ash- 6.5% Aloe Vera ash, sample 2 = Al6061-7.5%SiC-10% bagasse ash - 9 % Aloe Vera ash and so on.). This figure shows the maximum coefficient of friction is recorded in the first combination and the value is 0.77 at around 225 sec or 3.75 min. The lowest coefficient of friction is observed in the fourth combination (sample 4) and the value is 0.32. If we take the highest values and compare the four combinations of wt.% in increasing order in terms of coefficient of friction, the result is sample 2 < sample 4 < sample 3 < sample 1 and the values are 0.56, 0.66, 0.74 and 0.77 respectively.

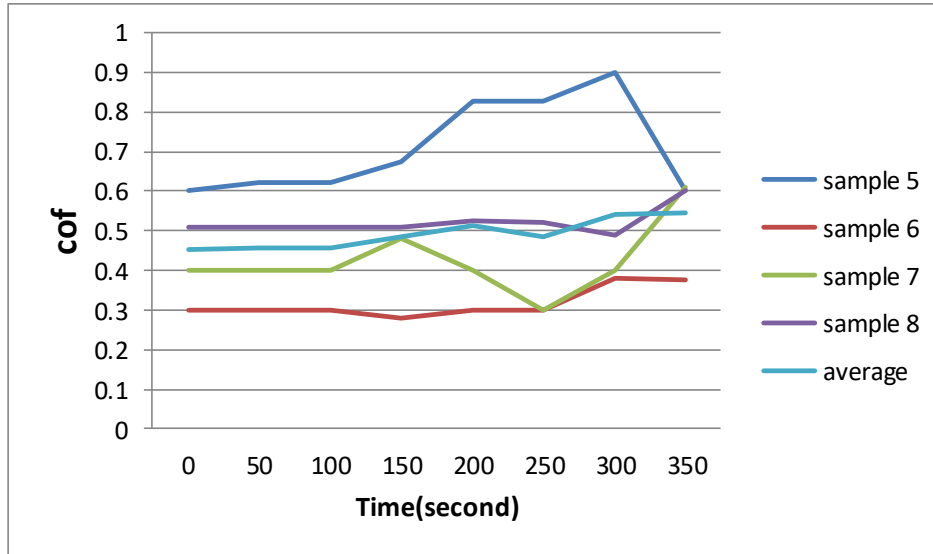


Figure 4. 5 result of coefficient of friction vs. time for the next four wt. % combinations

Figure 4.5 shows the maximum coefficient of friction is recorded in the fifth combination (sample 5 = Al6061-10 %SiC-10% bagasse ash - 9 % Aloe Vera ash) and the value is obtained as 0.9. If we take the maximum coefficient of friction values for the four wt. % combinations the values are 0.9, 0.61, 0.6 and 0.39 for sample 5, sample 7, sample 8 and sample 6 respectively. Hence it is possible to compare the total eight combinations in terms of coefficient of friction with the maximum values in increasing order as follows

sample6<sample2<sample8<sample7<sample4<sample3<sample1<sample5 and the values are 0.39, 0.56, 0.6, 0.61, 0.66, 0.74, 0.77 and 0.9 respectively which means the sample 6(Al6061-10 %SiC-9% bagasse ash - 11 % Aloe Vera ash) has better wear resistance as compared to others. This result is much related with the work that was don on friction coefficient values for drum brake application and the value was found that in the range of 0.35-0.42 (Sourav Das et al. 2013).

4.3.2 Frictional force

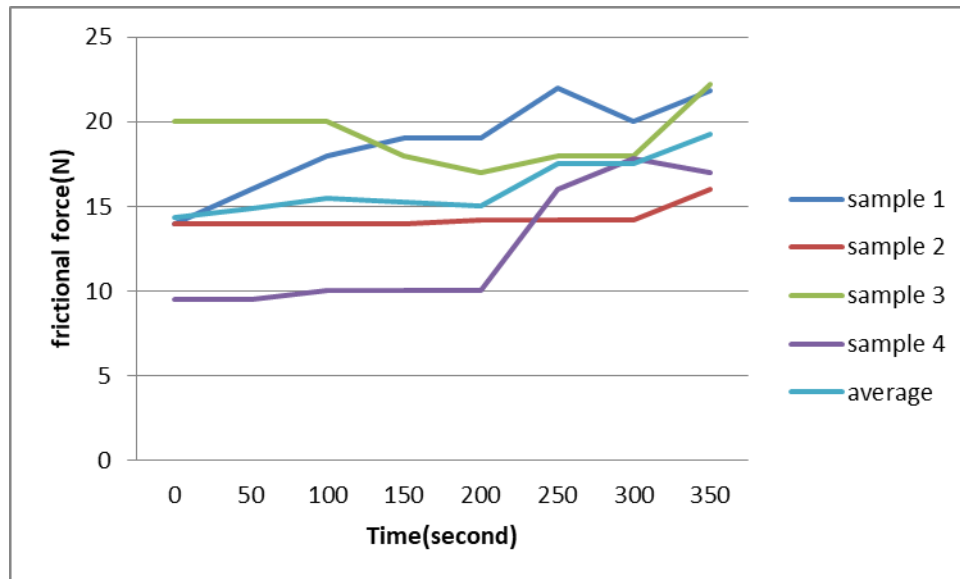


Figure 4. 6 result of frictional force vs. time for the first four wt. % combinations

As it is clearly shown in the figure 4.6 the maximum frictional force recorded is in sample 1 and the value is 23.5 N at around 225 seconds. The minimum frictional force is obtained in combination sample 4 and the value is 9 N. If we take all the maximum values of frictional force for these four wt.% combinations and compare the values we get 23.5N, 22.2N,19.5N and 16.8N for sample 1, sample 3, sample 4 and sample 2 respectively. The minimum frictional force of the four wt.% combination is 9N, 12.5N, 14.1N and 16.3 for sample 4, sample 2, sample 1 and sample 3 respectively.

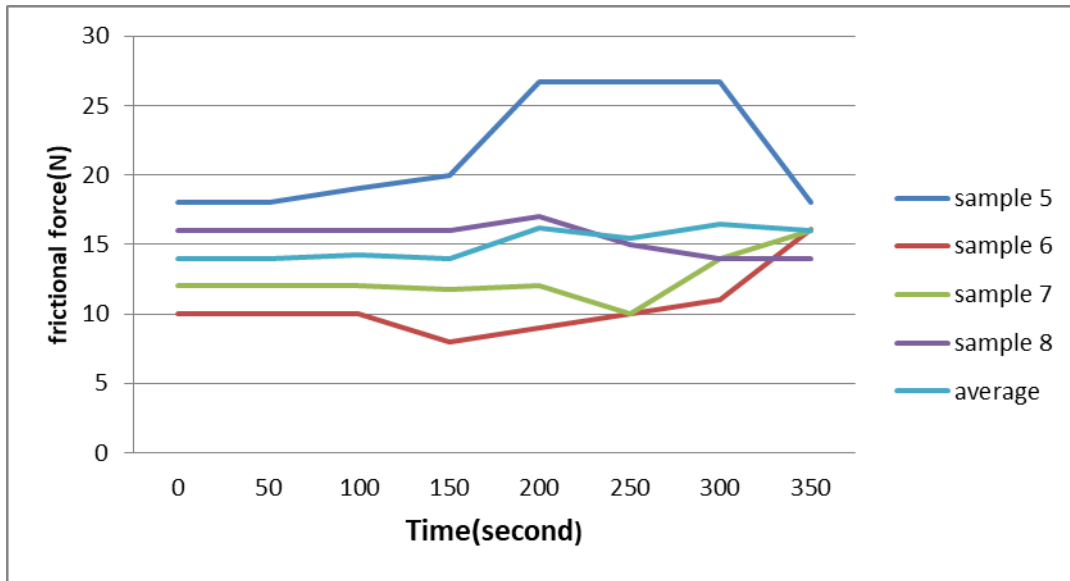


Figure 4. 7 result of frictional force vs. time for the next four wt. % combinations

Figure 4.7 tells us the maximum frictional force recorded in combination sample 5 and the value obtained is 26.7N around 302 sec or 5.03min. The minimum frictional force is obtained in sample 6 and the value is 8N around 170 sec. If we take all the maximum values of frictional forces for these four wt.% combinations and compare the values we get 26.7N, 16.1N, 16N and 11.9N for sample 5, sample 7, sample 8 and sample 6 respectively. Hence these results showed that the frictional force and coefficient of friction is less at sample 6 (Al6061-10 %SiC-9% bagasse ash - 11 % Aloe Vera ash).

As it is already explained in the figure 4.8 the samples 5 and 6 or combination 5 and 6 in wt. % have better wear resistance than the other combinations. The wt.% combination influences on wear resistance of the prepared sample is discussed in the figure 4.8.

It is better performance comparatively such as a study by Gireesh et al. (2019) who studied the mechanical belongings of a complex Al6061-AV and a composite with pure aluminum as matrix material and aloe Vera powder as reinforcement were 85 microns.

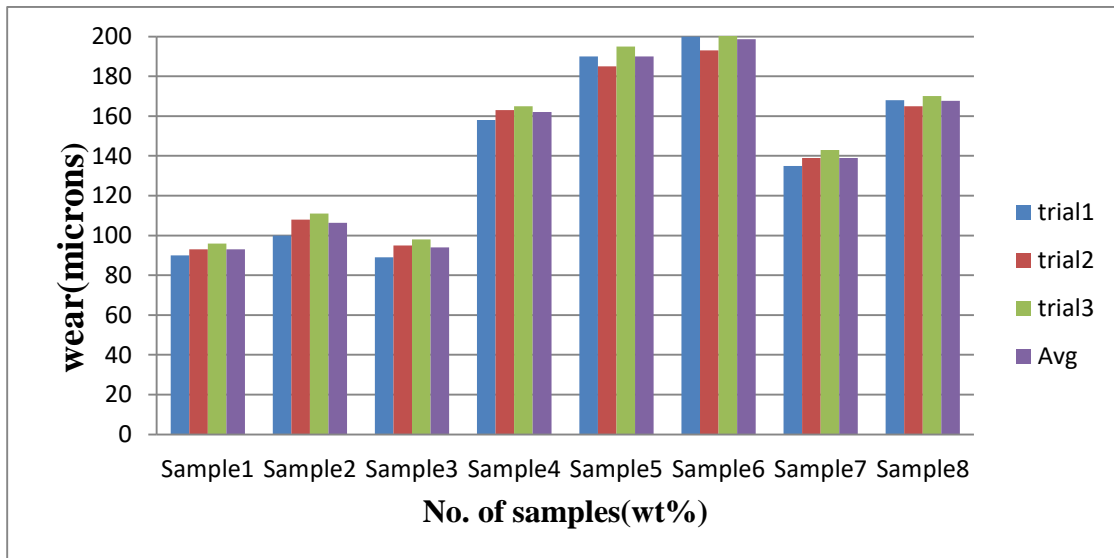


Figure 4. 8 Influence of wt. % reinforcements on wear resistance

Figure 4.8 showed that the samples 5(71%Al6061-10 %SiC-10% bagasse ash - 9 % Aloe vera ash) and 6(Al6061-10 %SiC-9% bagasse ash - 11 % Aloe Vera ash) had more wear resistance property as compared to other samples. As the wt. % of reinforcements increased it is shown that wear resistance also increased least percentage of the base metal. In sample 4 the base metal is 76 % since Aluminum content's high and the reinforcements are also low which makes sample4 highly wear from others samples.

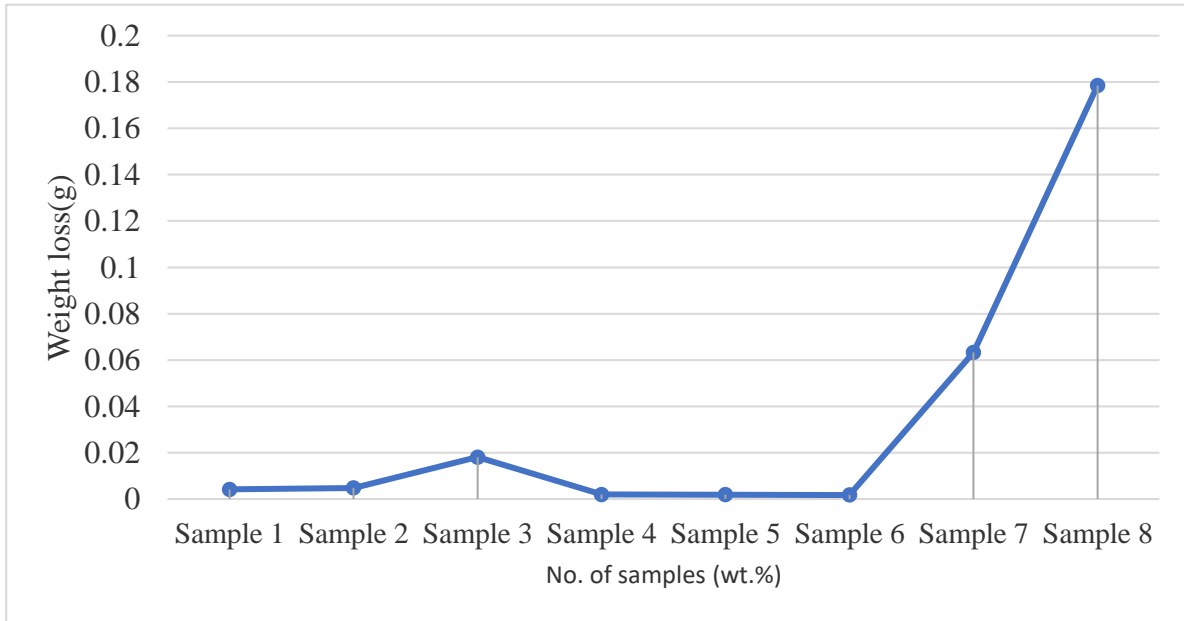


Figure 4. 4 weight loss of the tested samples (Recorded values in Appendix G)

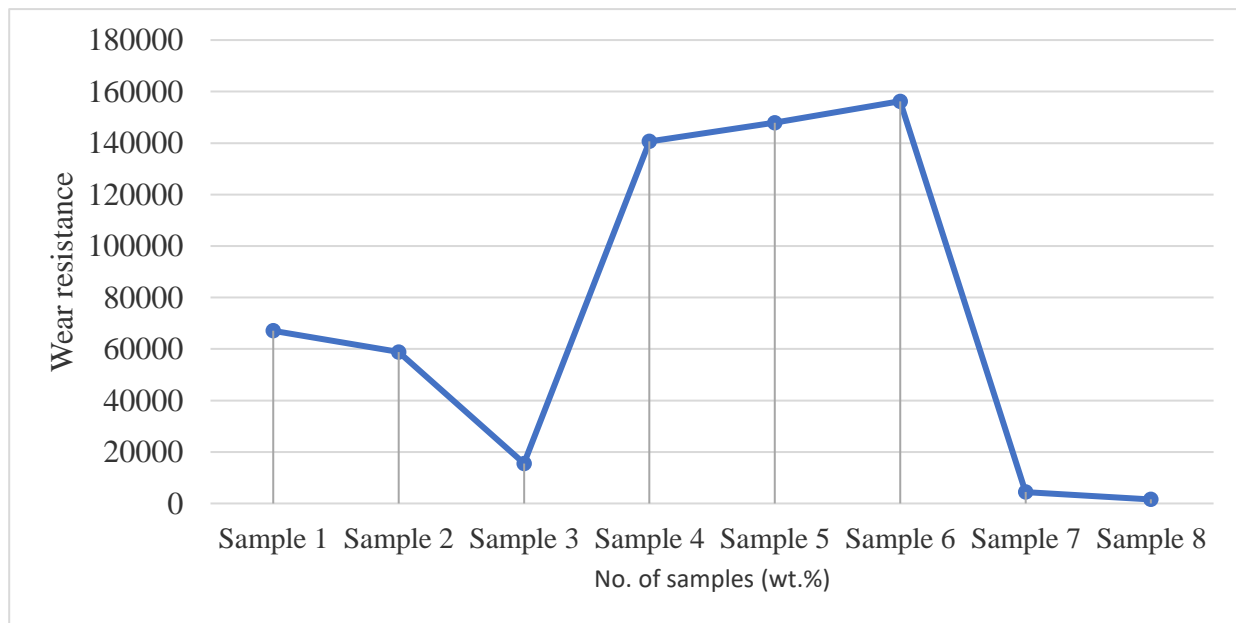


Figure 4. 5 Wear resistance of tested samples (Recorded values in Appendix G)

4.4 Impact test result

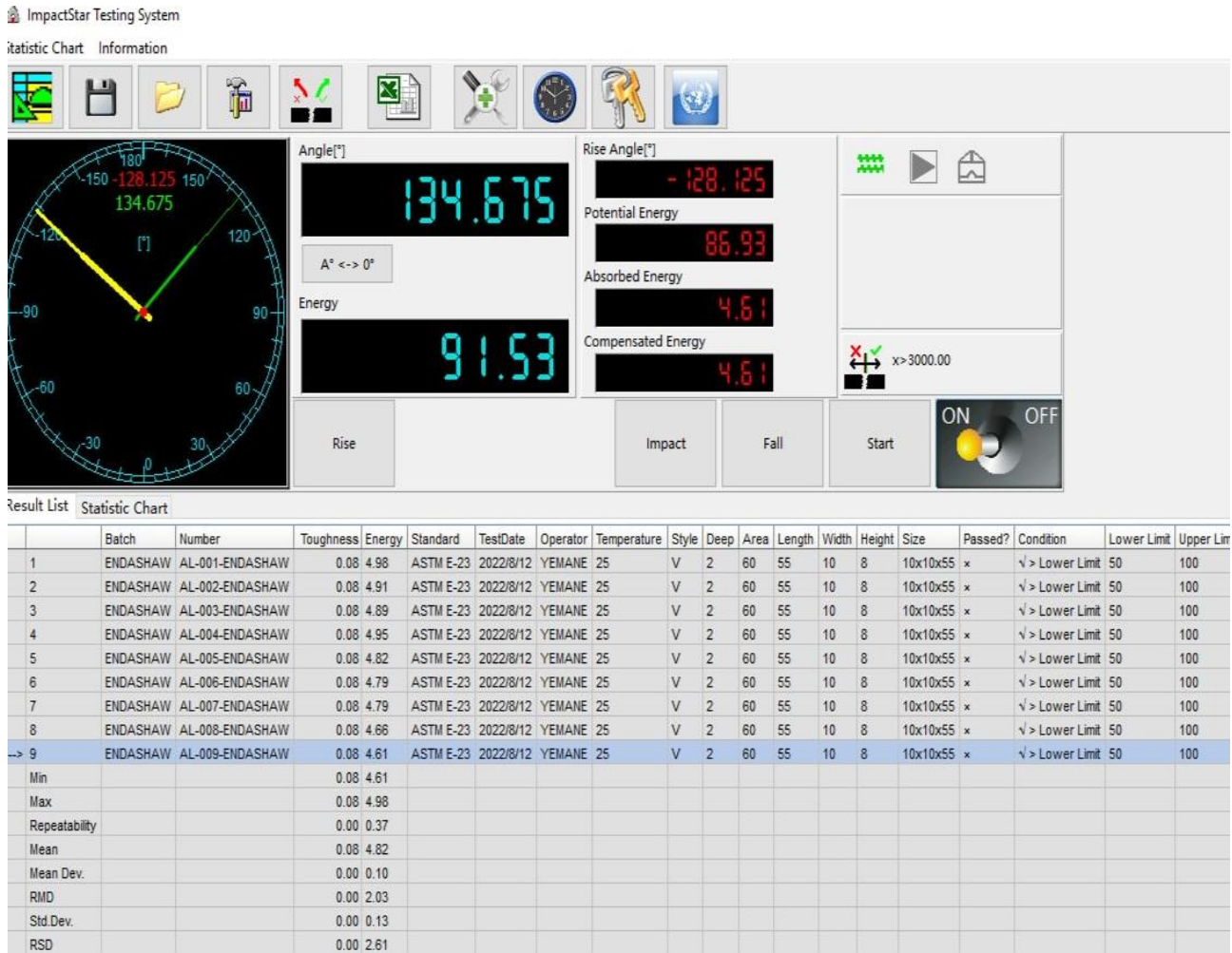


Figure 4. 6 Results of Impact test

As shown in figure 4.11 the minimum and maximum energy observed was 4.61 and 4.98J respectively. There is only small variation of energy that is 0.37J between the maximum and minimum value. This shows increasing SiC content makes the composite brittle. A brittle material will absorb a small amount of energy when impact tested, and a ductile material absorbs a large amount of energy. It is better performance comparatively others research, Gireesh et.al. (2019) who studied the mechanical belongings of a complex Al6061-AV and a composite with pure aluminum as matrix material and aloe vera powder as reinforcement were 1.85 J/mm².

4.5 Microstructural analysis

Scanning Electron microscopy was employed to obtain some qualitative evidences on the particle distribution in the matrix and bonding quality between the particulate and the matrix. Besides, the fracture surface of the composite was analyzed by using SEM to show the detail of chemically reacted interfaces. Thus, in order to increase the potential application of MMCs, it is necessary to concentrate on the major aspects, like particle size of SiC, bagasse ash, aloe vera ash and also SiC, bagasse ash, aloe vera ash distribution concentration.

The micro structure of fabricated composite material (Al606/SiC, bagasse ash, aloe vera ash) was examined by using Scanning Electron Microscope (SEM). The microstructure of Al606/SiC, bagasse ash, aloe vera ash is depicted in the Figure 4.12 and figure 4.13 below. The examination of Micro structure reveals that a proper bond was formed between matrix material, reinforcements and filler materials.

The orientation of each particle has significance on the material properties. The main advantages of Stir casting are to distribute the particles (reinforcements) in to the base metal so stir casting enables uniform distribution throughout the base metal.

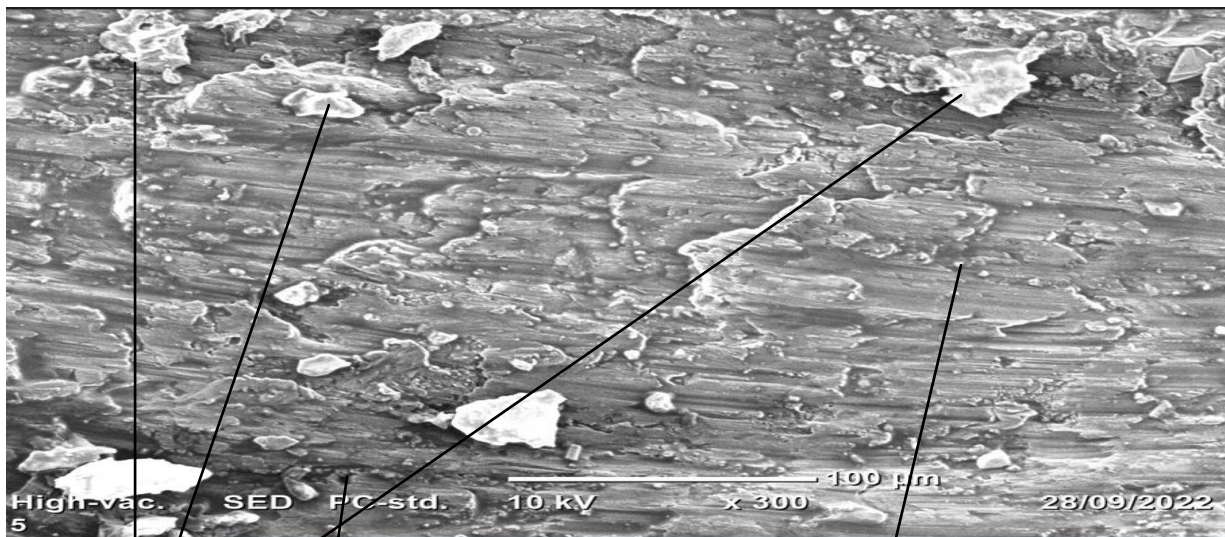


Figure 4.12 Al-10% SiC-10% Bagasse ash-9% Aloe Vera ashes

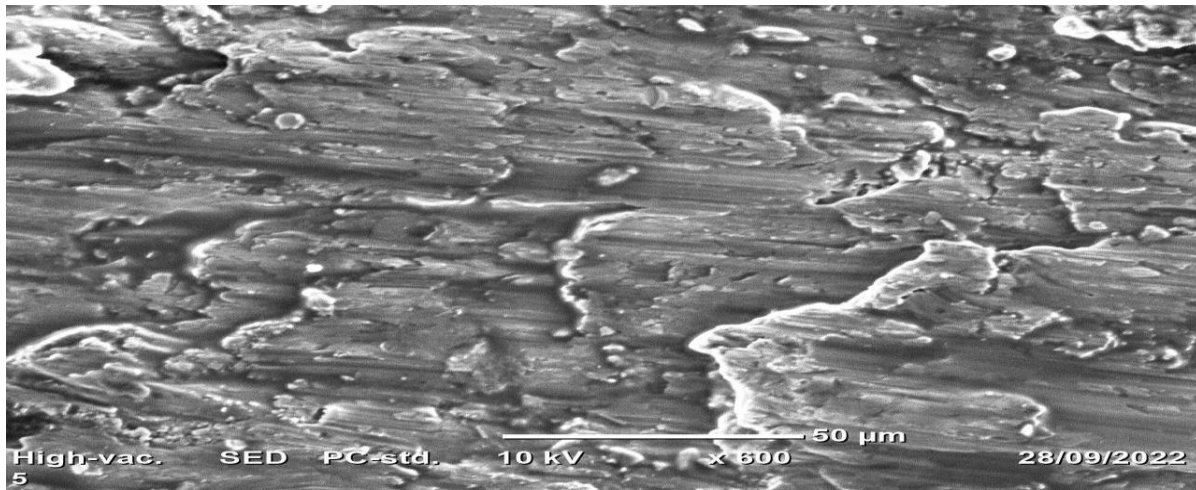


Figure 4.13 Al-10%SiC-10%Bagasse ash-9%aloevera ash

Figure 4.13 shows the microstructure at 50μm of the sample. The microstructural study of prepared composite reveals the uniform distribution of silicon carbide, aloe vera and bagasse ash particles with base material. So that is why it results a good compression strength, wear resistance, hardness, and impact energy as observed the results.

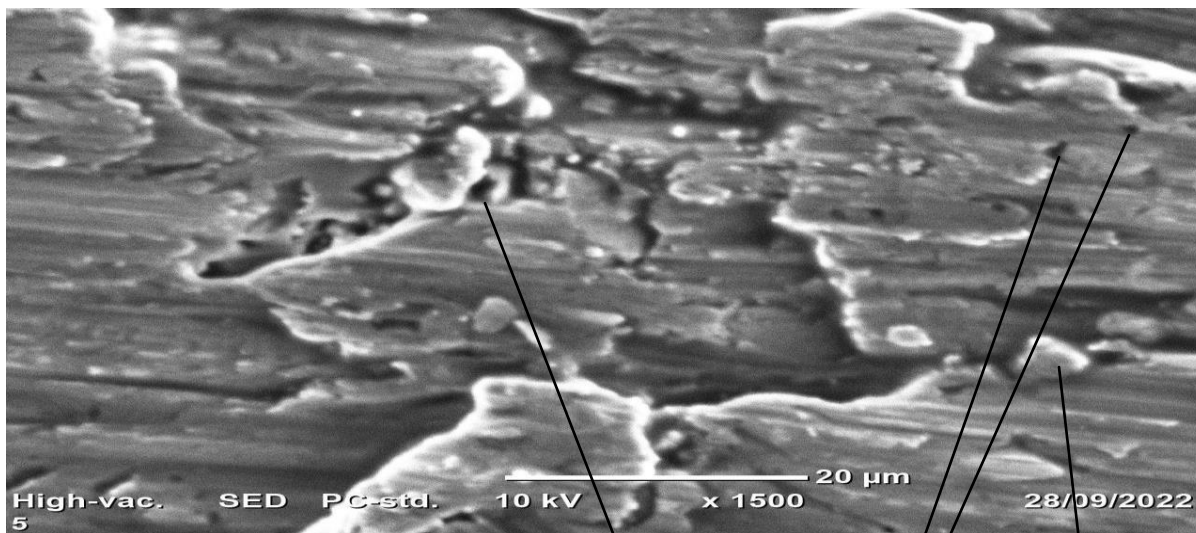


Figure 4. 14 Microstructure of Al 6061/SiC, bagasse ash, aloe vera ash composite

Ash

Porosity

Silicon carbide

Figure 4.14 shows microstructure at 20µm the structure of the sample seen clearly this helps to analyze the structure and its results. The samples have more porosity and also irregular shape.

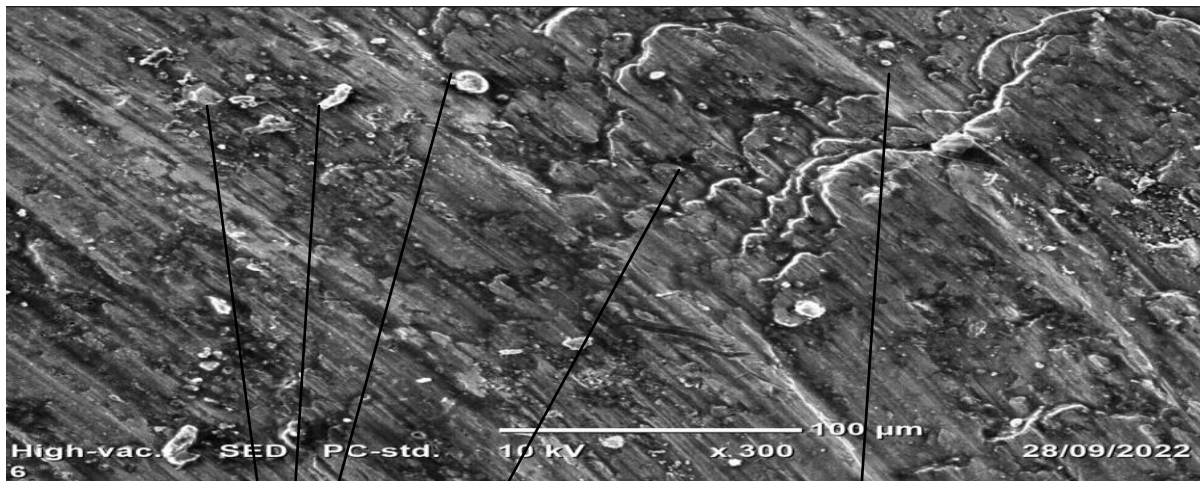


Figure 4.15 Al-10%SiC-9%bagasse-11%Aloev ash
Ashes
Porosity
SiC

Figure 4.15 shows microstructure at 100µm it has low porosity and well distribution of the reinforcement and form good structure.

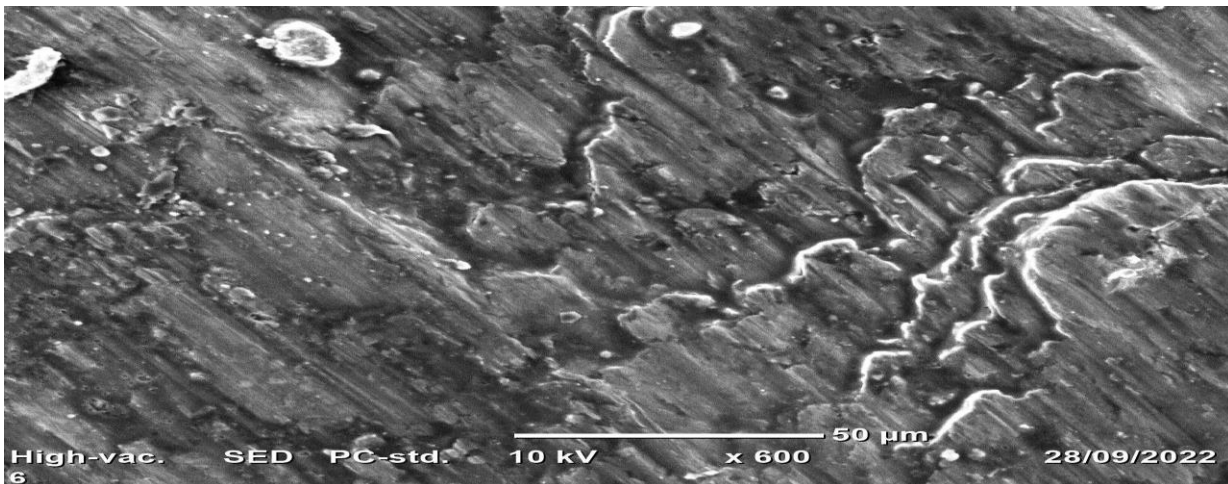


Figure 4.16 Al-10%SiC-9%bagasse-11%Aloev ash

Figure 4.16 shows the microstructure at 50µm of the sample. The microstructural study of prepared composite reveals the uniform distribution of silicon carbide, aloe vera and bagasse ash particles with base material. So that is why it results a good compression strength, wear resistance, hardness, and impact energy as observed the results.

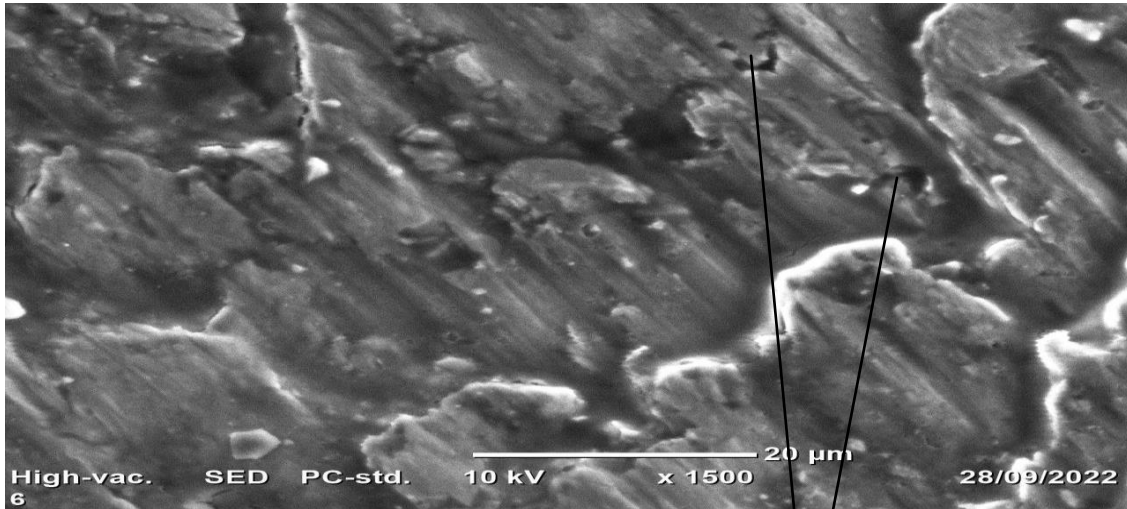


Figure 4.17 microstructure of Al6061/SiC/bagasse ash/ aloevera ash composite (Sample 6)

Porosity

Figure 4.17 shows microstructure at 20μm the structure of the sample seen clearly this helps to analyze the structure and its results. The samples have more porosity and also irregular shape.

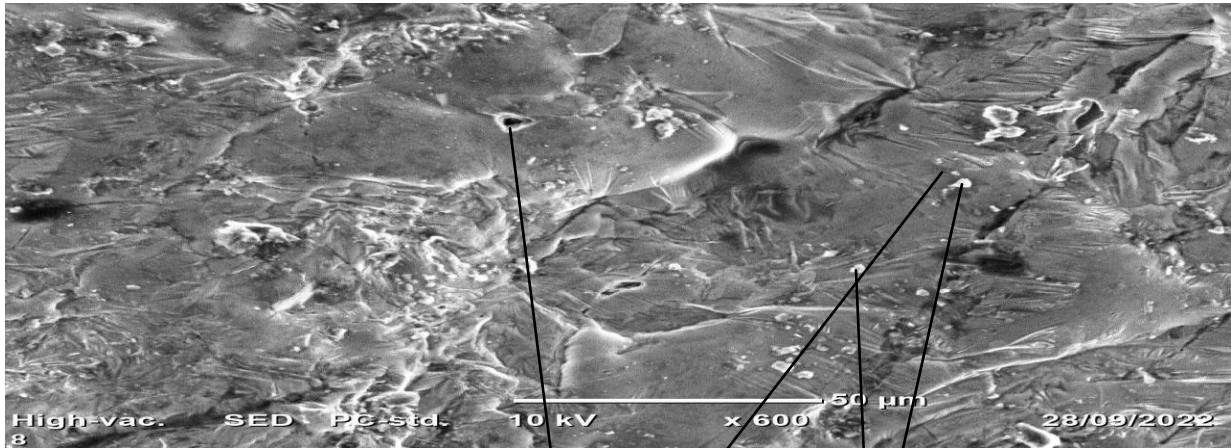


Figure 4. 18 Microstructure of Al 6061/SiC (sample 8)

Porosity

SiC

Figure 4.18 shows microstructure at 50μm without the two ashes Al6061 with SiC only it shows different structure.

Chapter five

Conclusion and Recommendation

5.1 Conclusion

The main objective of this research work was to develop and characterize mechanical properties of Al6061/SiC with Bagasse fly-ash and aloe-vera ash hybrid composite material for drum brake application.

The Al6061/SiC- bagasse fly-ash/Aloe-vera ash hybrid composite is successfully manufactured with different weight percentage of SiC, Bagasse ash and aloe-vera ash reinforcements (7.5 wt. % and 10 wt.% of SiC, 7.5 wt. %, 10 wt. % and 9 wt.% bagasse fly-ash, 6.5 wt.%, 9 wt.% and 11 wt.% Aloe vera ash). Compression strength, wear strength and impact strength of the developed hybrid and single reinforcement composite were conducted and compared.

The conclusions drawn from this experimental work are pointed out as follows

- Bagasse fly-ash, the waste generated from sugar cane plant and Aloe vera ash locally available material could be successfully used as a reinforcing material to produce Metal-Matrix Composite (MMC) component in aluminum matrix to be used in light weight applications like drum brake of internal automotive body parts.
- The compression strength, hardness and wear resistance of the hybrid composite enhanced with increasing wt. % of reinforcements. As it is explained in result section when it is compared with the percentage composition of filler by keeping SiC constant wt.% 10 while the values of wt.% of Bagasse ash and Aloe Vera ash (7.5%, 6.5%), (10%,9%), (9%,11%) the average compression strength taken was 335.83, 358.63 and 376.3 MP respectively.
- As it is already discussed in the result section the hybrid Al6061/SiC-bagasse ash/ Aloe Vera ash composite had average compression strength of 376.3 MP while the single reinforced or composite without Bagasse ash and Aloe Vera ash had average compression strength of 209.96 MP.
- Sample 6 (Al6061-10 %SiC-9% bagasse ash - 11 % Aloe vera ash) has better mechanical properties and good wear resistance as compared to other combinations based on conducted experiments. Compression strength 376.3Mpa, wear value 64.8 microns, wear

loss 0.0017gm, impact strength 4.79kj,

- From the studies in overall it can be concluded that the Al6061-10 %SiC-9% bagasse ash - 11 % Aloe vera ash composite is exhibit good mechanical properties and it is suitable for the applications where requires low density, high compression strength up to 376.3 MP, good wear resistance 156250 and high impact strength 4.79 J.
- Stir casting method can be successfully used to manufacture metal matrix composite with desired properties.
- Reinforcing Aluminum and its alloys with ceramics particles has shown an appreciable increase in its mechanical properties.
- A few authors have reported about modified stir casting methods for improving the distribution of the reinforcement in the matrix. However, there is a lack of work regarding availability of efficient techniques for Nano level reinforcements.
- Organic reinforcements like bagasse ash, aloevera ash also improved the mechanical properties of the aluminum along with the tribological behavior of the composite.

5.2 Recommendations for future work

There are numerous industrial machinery parts and automotive components that should be promoted for their superior specific strength and stiffness of MMCs. Still fabrications of MMCs of aluminum with different grades as a base metal is not well investigated. The following works are suggested for each aspect for future works in the field of Al-SiC- bagasse fly-ash MMCs:

- In the present work compression strength, wear resistance, hardness and impact test of MMC were investigated. Other mechanical properties such as fatigue strength required by the drum brake selection and it attract the future researchers in this area.
- Nano-size SiC, Alovera ash and bagasse fly-ash MMCs may attract the future researchers.
- The micro structure of MMCs studied by optical microscope, better and detail observations; studies of reinforcement's and filler materials grain size can be included in future work
- Machinability of Al/SiC/ bagasse fly ash-Aloe Vera ash hybrid composite also needs future research work.

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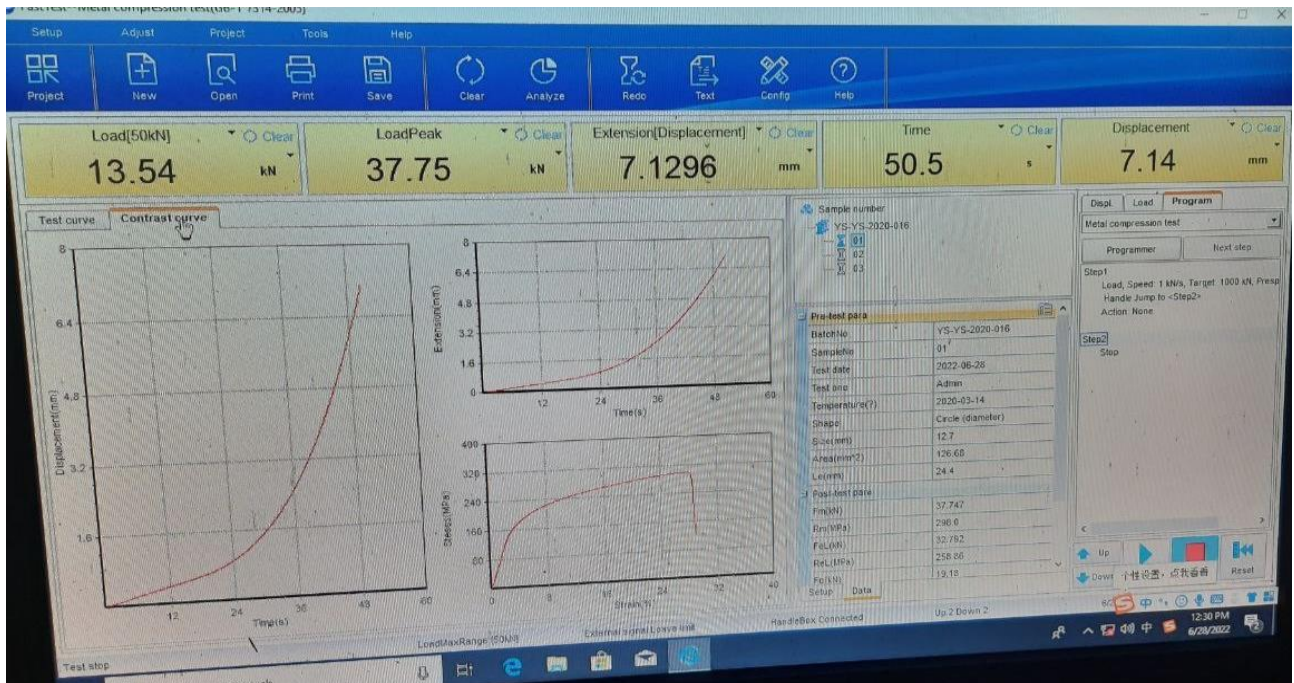
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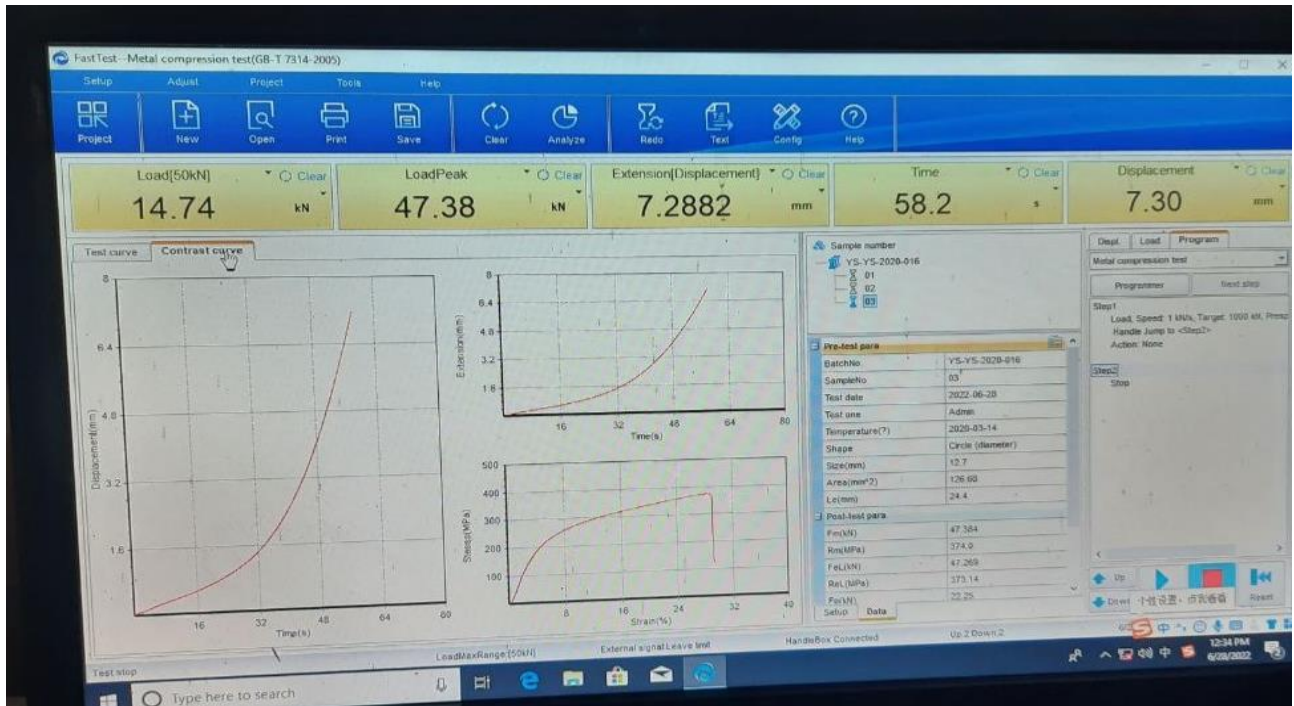
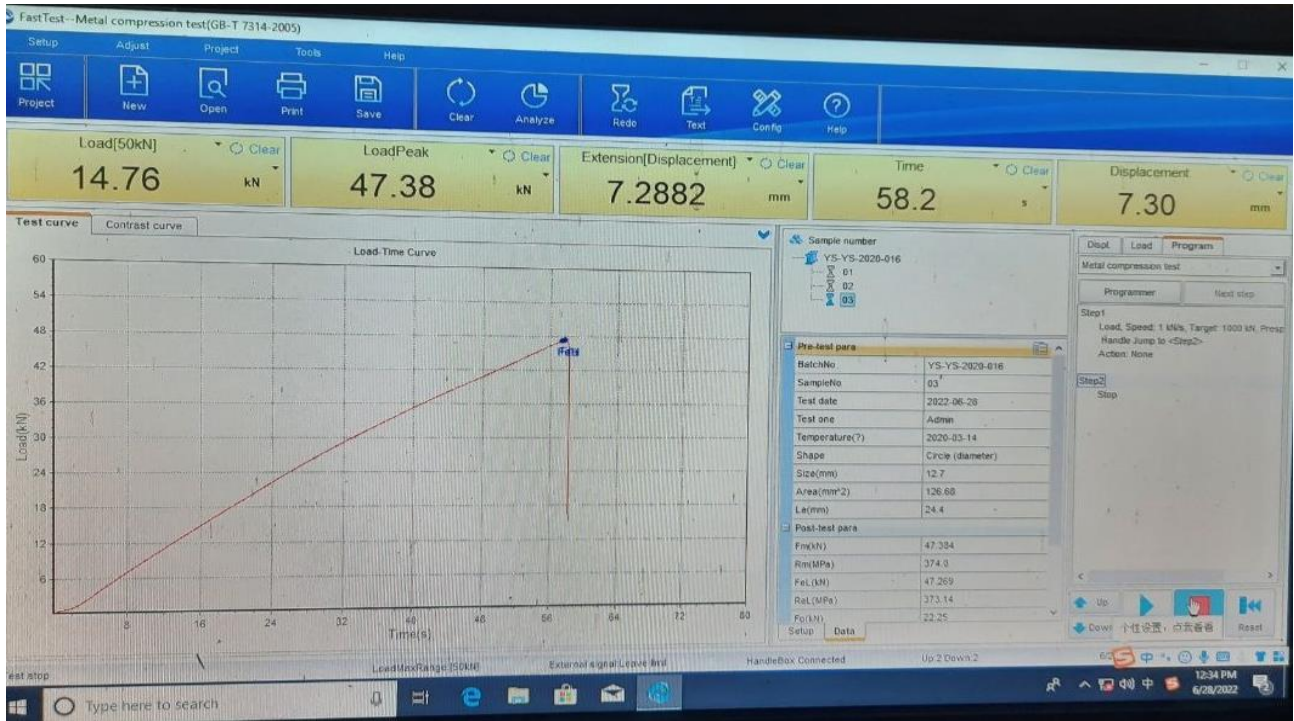
Appendices

A: Compression test result reading

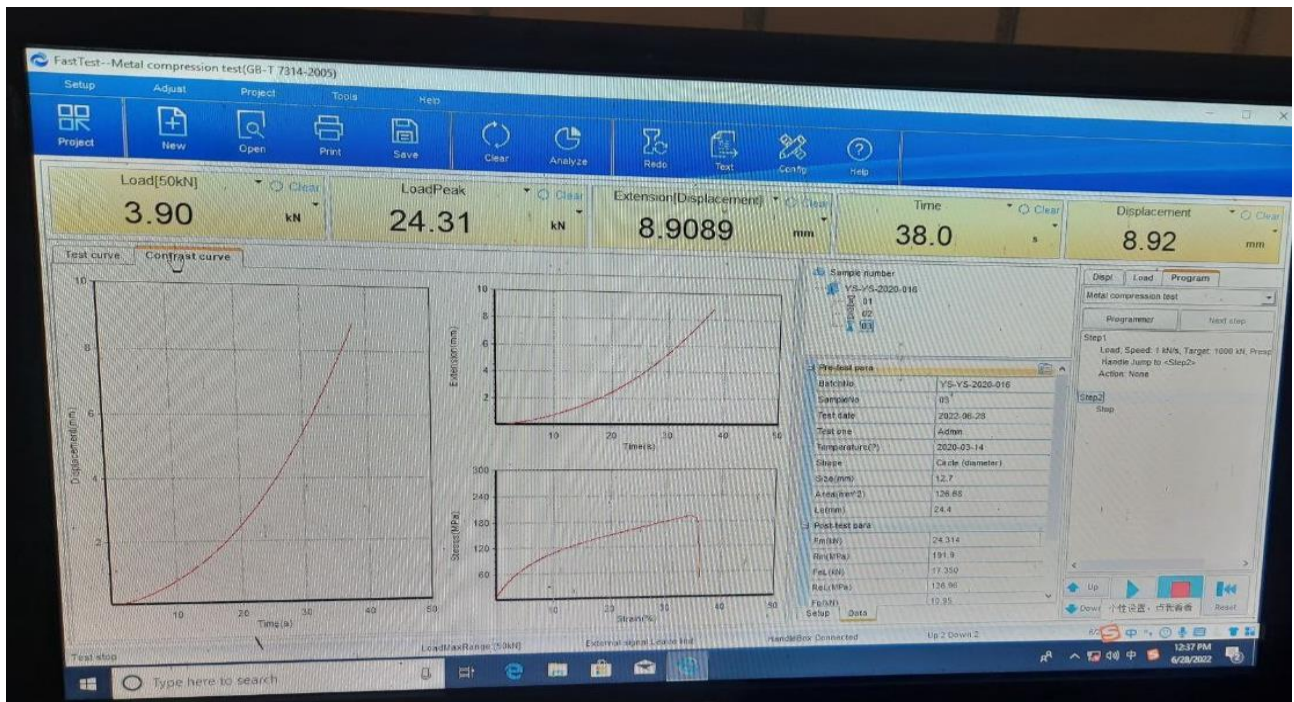
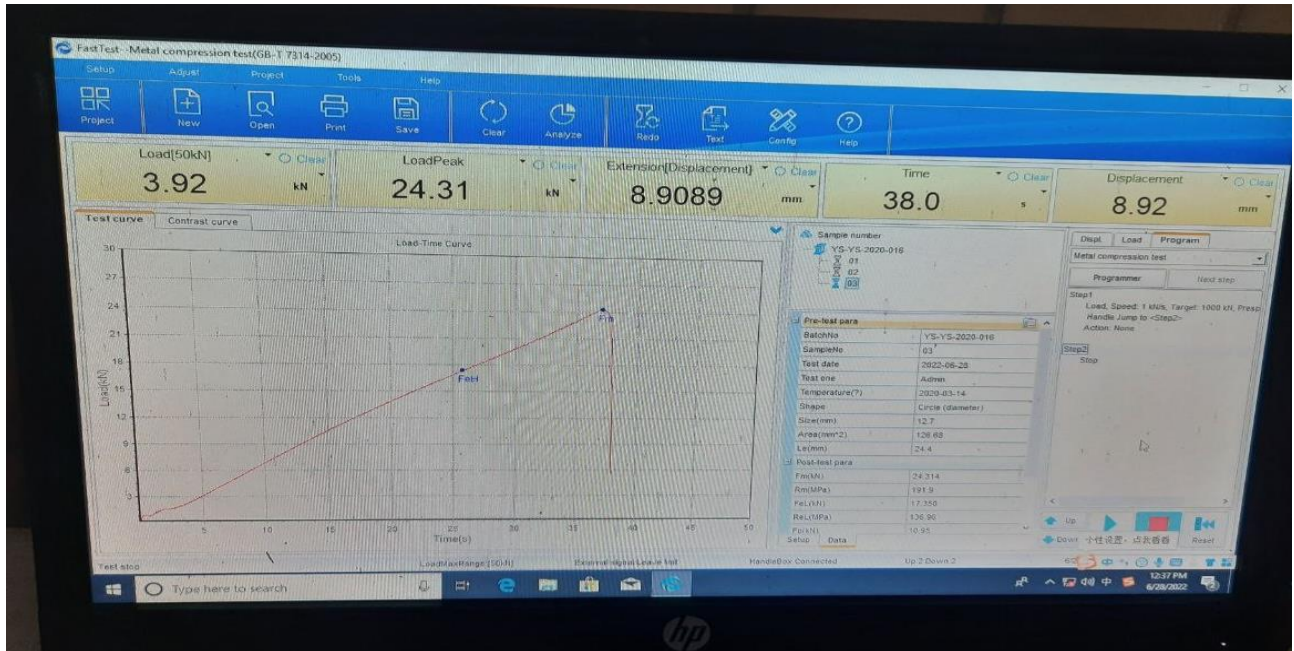
Sample 1



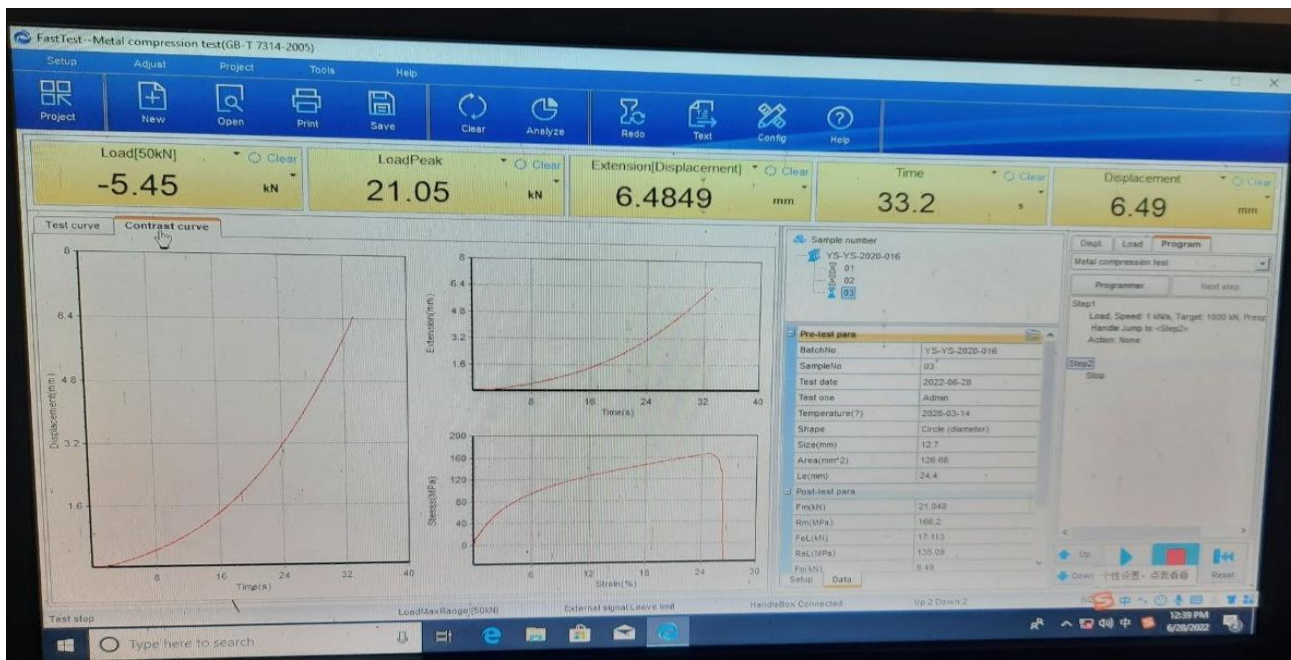
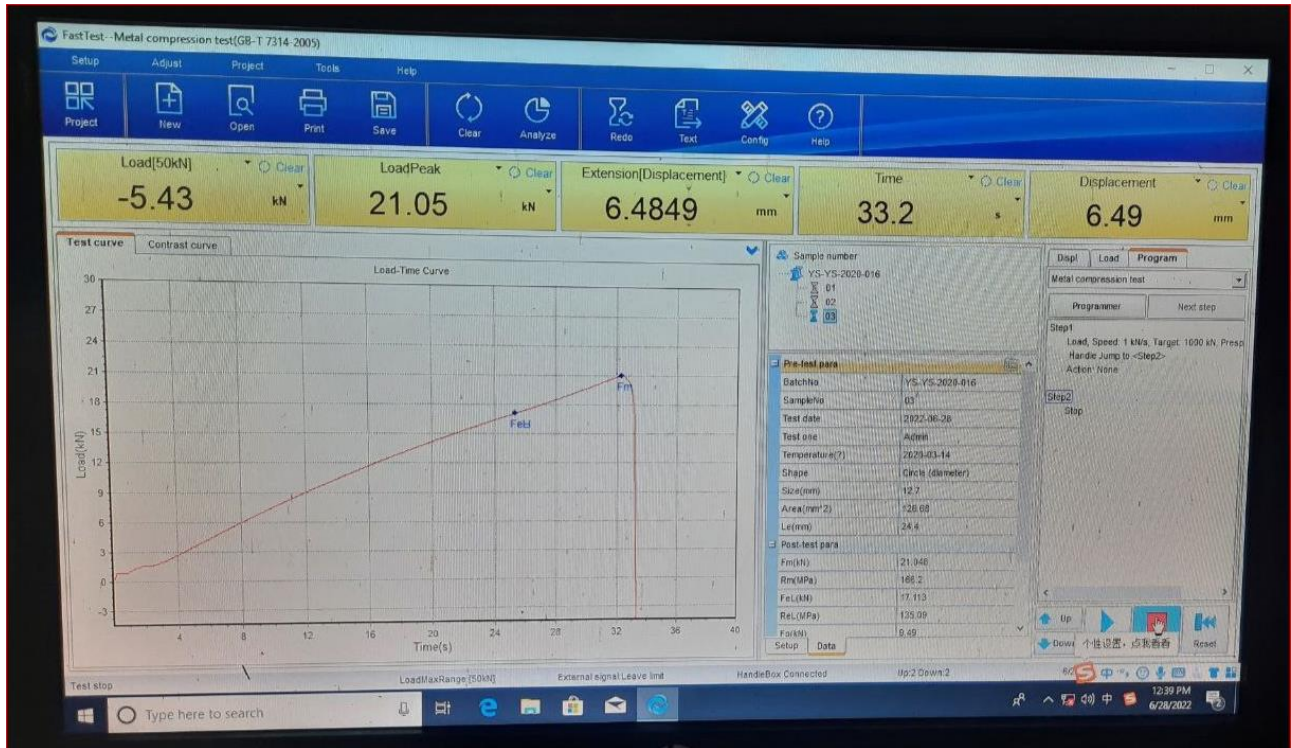
Sample 2



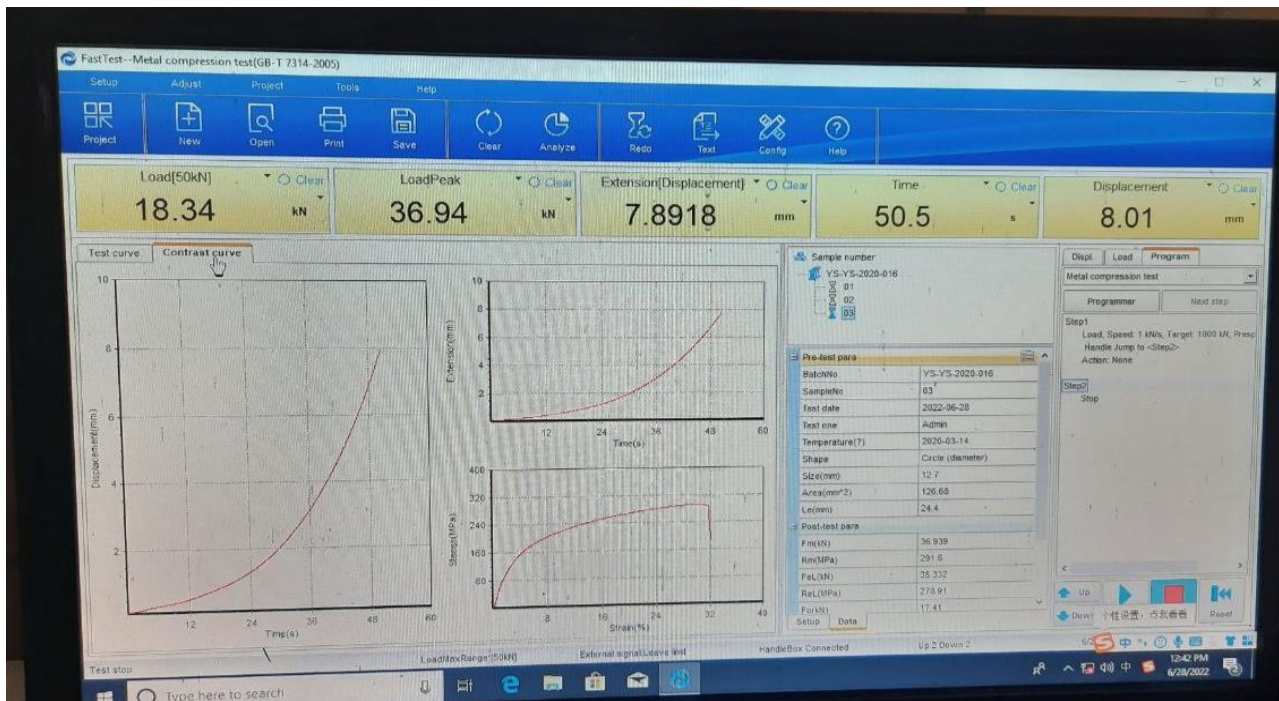
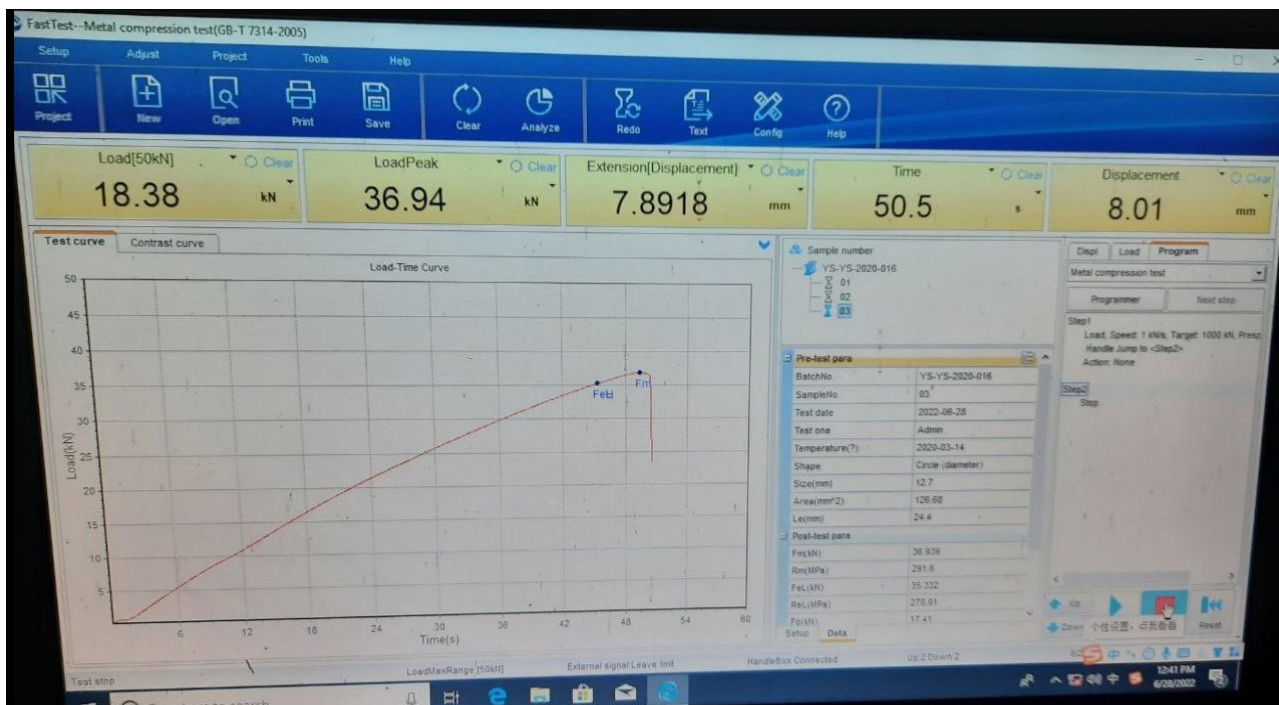
Sample 3



Sample 4



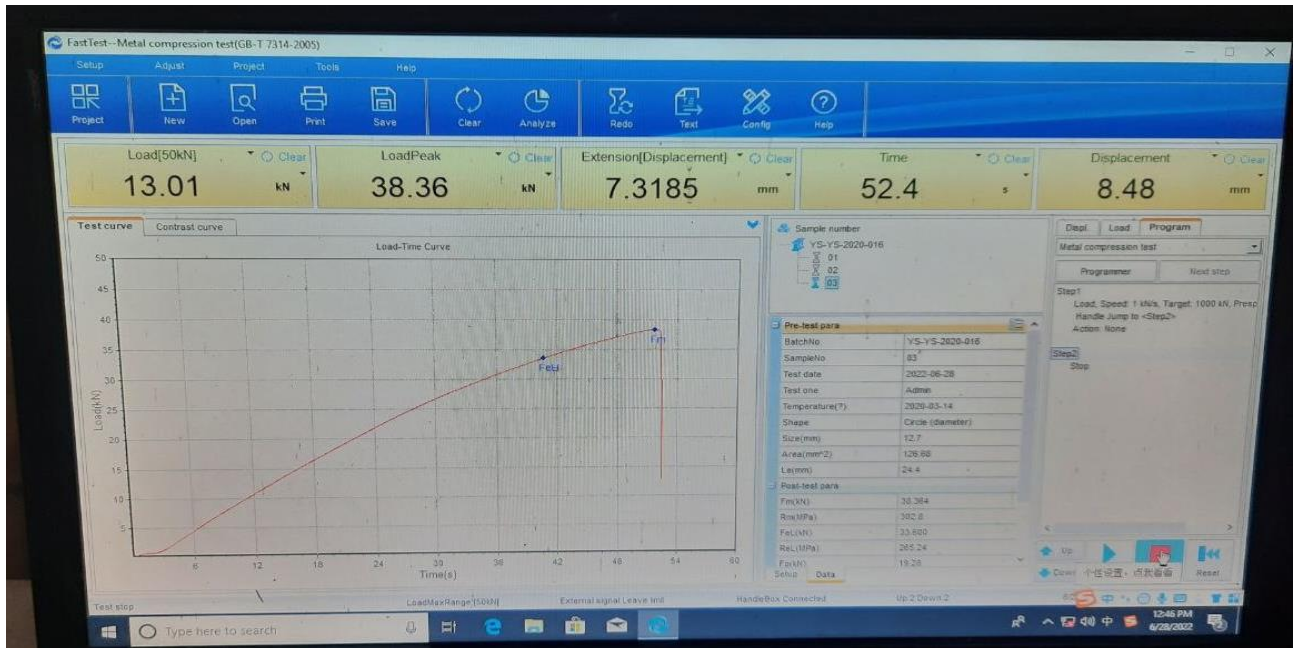
Sample 5



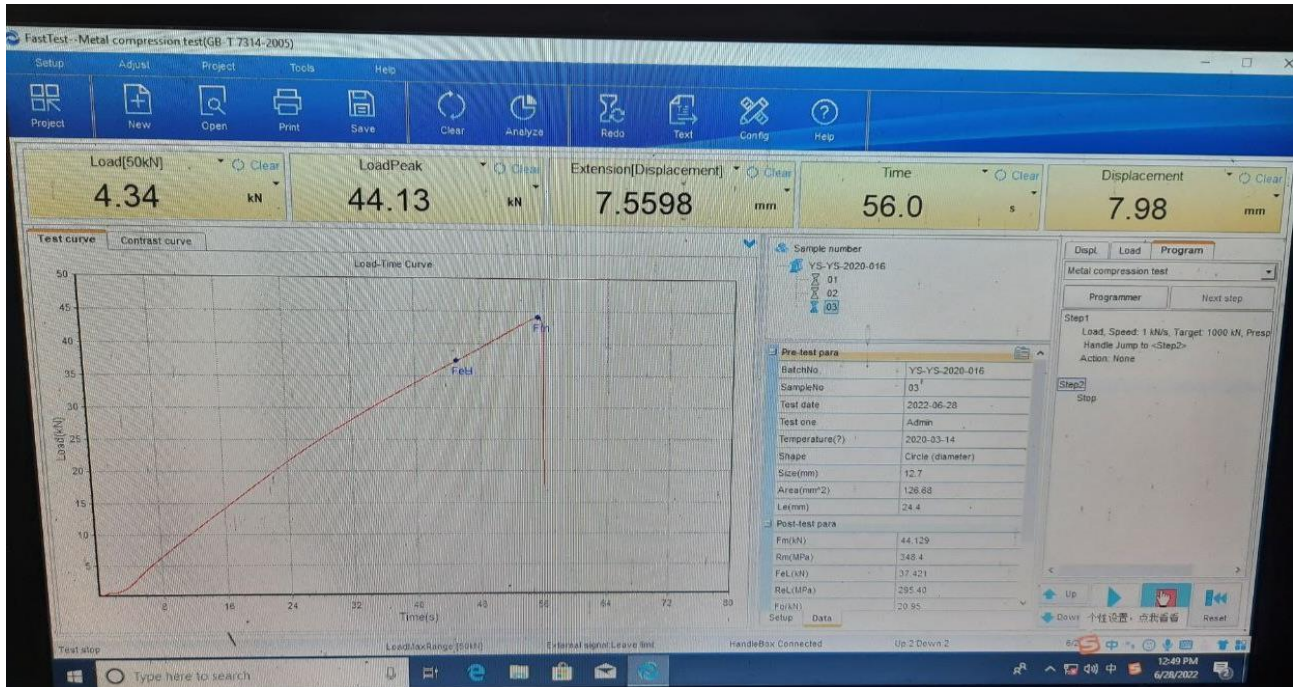
Sample 6



Sample 7



Sample 8



B: Wear test results

B1: combination 1

Time; FF (N); NL (N); SPEED (rpm); Wear (Microns); Pin Temp (Deg C); Heater Temp (Deg C)
0.000; 0.002; 30.000; 0.000 -0.354; 181.104; 22.802; 0.000; 0.000; 0.00000;
0.944; 11.992; 30.000; 16.611 -22.231; 181.059; 23.310; 0.019; 0.022; 0.00000;
2.058; 13.732; 30.000; 107.587 -7.514; 181.040; 23.483; 0.281; 0.141; 0.00001;
3.101; 13.605; 30.000; 197.150 -2.698; 180.988; 23.446; 0.786; 0.258; 0.00003;
195.482; 13.745; 30.000; 600.281 15.046; 181.071; 23.388; 2.597; 0.786; 0.00008;
196.494; 14.444; 30.000; 600.015 85.183; 181.281; 23.042; 154.286; 0.785; 0.00008;
197.597; 14.294; 30.000; 599.851 87.102; 181.347; 23.052; 155.108; 0.785; 0.00008;
305.547; 14.334; 30.000; 600.097 91.912; 181.486; 23.120; 155.920; 0.786; 0.00008;
306.560; 14.358; 30.000; 599.939 107.586; 182.026; 23.548; 240.707; 0.785; 0.00008;
307.604; 13.973; 30.000; 600.135 108.047; 182.018; 23.595; 241.606; 0.786; 0.00008;
308.709; 14.695; 30.000; 600.249 106.781; 182.027; 23.624; 242.515; 0.786; 0.00008;
309.755; 12.792; 30.000; 600.157 108.698; 182.027; 23.637; 243.308; 0.786; 0.00008;
310.860; 13.551; 30.000; 600.085 108.823; 181.996; 23.654; 244.142; 0.786; 0.00008;
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332.913; 14.605; 30.000; 599.985 108.677; 182.024; 23.647; 245.395; 0.785; 0.00008;
333.931; 14.774; 30.000; 600.276 111.422; 181.989; 23.699; 262.348; 0.786; 0.00008;
334.983; 15.935; 30.000; 600.167 110.862; 181.979; 23.719; 263.126; 0.786; 0.00008;
336.032; 14.452; 30.000; 600.129 112.359; 181.969; 23.716; 263.932; 0.786; 0.00008;
337.079; 15.370; 30.000; 600.030 112.111; 181.923; 23.740; 264.716; 0.785; 0.00008;
338.127; 15.495; 30.000; 599.957 111.780; 181.946; 23.751; 265.512; 0.785; 0.00008;
339.227; 15.333; 30.000; 600.037 111.864; 181.932; 23.739; 266.410; 0.785; 0.00008;
340.281; 15.051; 30.000; 600.038 112.687; 181.956; 23.720; 267.234; 0.785; 0.00008;
341.332; 15.297; 30.000; 599.838 112.732; 181.941; 23.737; 267.978; 0.785; 0.00008;
342.375; 15.047; 30.000; 600.007 113.117; 181.921; 23.748; 268.867; 0.785; 0.00008;
343.432; 15.780; 30.000; 600.345 112.449; 181.922; 23.733; 269.844; 0.786; 0.00008;
344.529; 15.474; 30.000; 600.339 112.374; 181.918; 23.744; 270.704; 0.786; 0.00008;
345.630; 15.612; 30.000; 600.113 112.478; 181.936; 23.745; 271.468; 0.786; 0.00008;
346.725; 14.632; 30.000; 600.163 113.783; 181.970; 23.748; 272.353; 0.786; 0.00008;
347.827; 15.189; 30.000; 600.022 114.160; 181.950; 23.762; 273.157; 0.785; 0.00008;
348.881; 15.297; 30.000; 599.808 113.253; 181.957; 23.743; 273.880; 0.785; 0.00008;
349.932; 15.123; 30.000; 599.466 114.699; 182.032; 23.710; 274.547; 0.785; 0.00008;
350.982; 15.392; 30.000; 599.434 114.826; 182.201; 23.622; 275.359; 0.785; 0.00008;
352.029; 15.851; 30.000; 599.094 114.685; 182.264; 23.588; 276.026; 0.784; 0.00008;
353.132; 16.749; 30.000; 599.137 114.252; 182.405; 23.531; 276.910; 0.784; 0.00008;
354.183; 13.695; 30.000; 599.037 116.283; 182.576; 23.426; 277.689; 0.784; 0.00008;
355.233; 14.554; 30.000; 598.945 115.276; 181.901; 23.420; 278.465; 0.784; 0.00008;
356.329; 14.802; 30.000; 599.190 114.760; 181.772; 23.414; 279.446; 0.784; 0.00008;
357.382; 14.511; 30.000; 599.071 114.652; 181.731; 23.402; 280.209; 0.784; 0.00008;
358.430; 14.161; 30.000; 599.201 115.558; 181.724; 23.402; 281.097; 0.784; 0.00008;
359.482; 14.897; 30.000; 599.455 114.647; 181.689; 23.408; 282.039; 0.785; 0.00008;

B2: combination 4

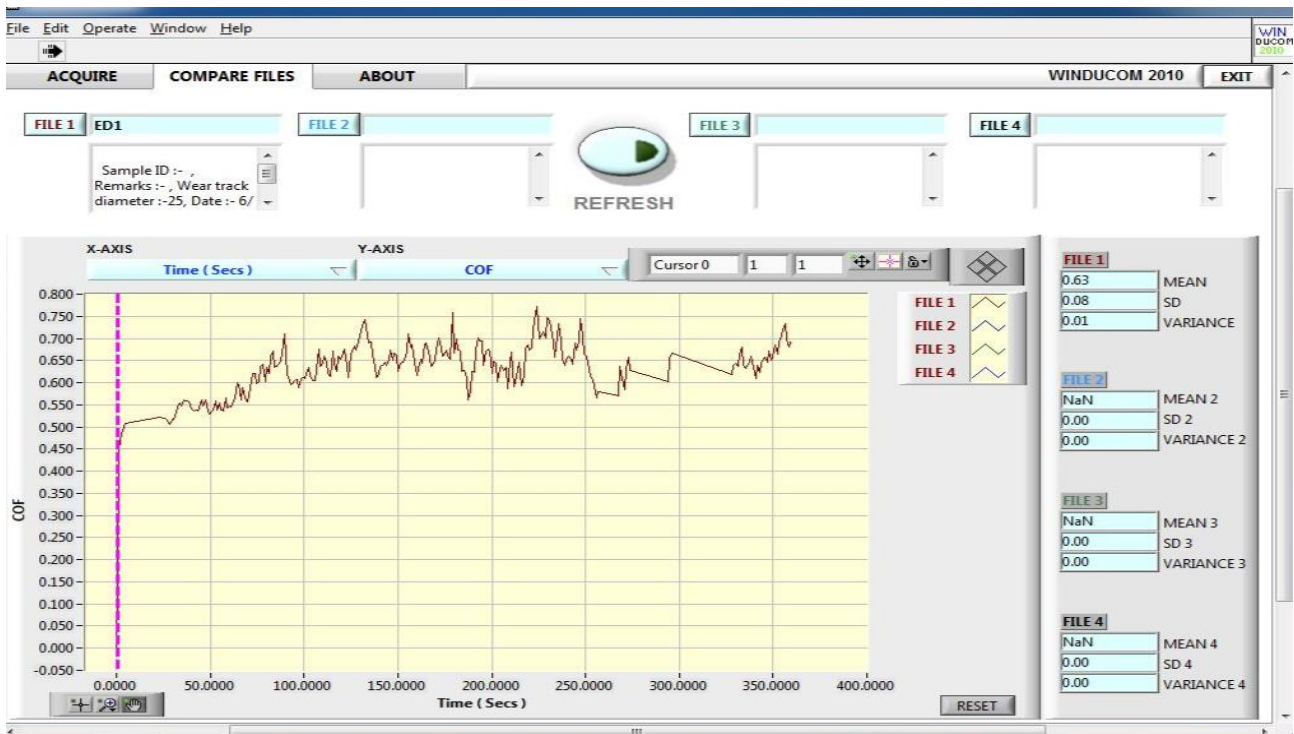
Time; FF (N); NL (N); SPEED (rpm); Wear (Microns); Pin Temp (Deg C); Heater Temp (Deg C)

0.000; -0.012; 30.000; 0.000 0.371; 182.530; 24.464; 0.000; 0.000; 0.00000;
0.802; 7.203; 30.000; 8.614 -7.788; 182.492; 24.800; 0.008; 0.011; 0.00000;
1.856; 9.294; 30.000; 95.661 5.700; 182.487; 24.956; 0.225; 0.125; 0.00001;
208.240; 10.214; 30.000; 599.769 40.274; 182.507; 24.964; 1.733; 0.785; 0.00008;
209.335; 14.504; 30.000; 599.787 156.967; 182.637; 24.911; 164.310; 0.785; 0.00008;
210.385; 16.908; 30.000; 599.896 156.258; 182.641; 24.905; 165.164; 0.785; 0.00008;
211.480; 19.224; 30.000; 600.120 153.506; 182.618; 24.936; 166.090; 0.786; 0.00008;
212.532; 19.766; 30.000; 600.308 155.626; 182.600; 24.911; 166.967; 0.786; 0.00008;
213.637; 18.035; 30.000; 600.070 157.420; 182.582; 24.928; 167.765; 0.785; 0.00008;
214.730; 18.423; 30.000; 599.991 158.838; 182.558; 24.944; 168.606; 0.785; 0.00008;
215.783; 19.012; 30.000; 600.039 159.455; 182.541; 24.947; 169.446; 0.785; 0.00008;
216.884; 18.203; 30.000; 600.202 157.915; 182.532; 24.965; 170.358; 0.786; 0.00008;
217.978; 17.774; 30.000; 600.068 158.253; 182.543; 24.969; 171.182; 0.785; 0.00008;
219.077; 15.016; 30.000; 600.242 164.385; 182.510; 24.963; 172.097; 0.786; 0.00008;
220.184; 13.786; 30.000; 600.471 166.167; 182.571; 25.044; 173.024; 0.786; 0.00008;
221.286; 14.815; 30.000; 600.622 165.813; 182.598; 25.085; 173.936; 0.786; 0.00008;
222.335; 14.960; 30.000; 600.766 164.216; 182.653; 25.185; 174.801; 0.786; 0.00008;
223.429; 14.571; 30.000; 600.687 164.099; 182.656; 25.184; 175.644; 0.786; 0.00008;
224.487; 16.080; 30.000; 600.889 164.848; 182.659; 25.116; 176.527; 0.787; 0.00008;
225.584; 17.223; 30.000; 600.522 166.419; 182.810; 24.879; 177.287; 0.786; 0.00008;
226.638; 17.718; 30.000; 600.048 166.617; 182.782; 24.794; 177.974; 0.785; 0.00008;
227.732; 18.349; 30.000; 599.969 164.127; 182.839; 24.818; 178.813; 0.785; 0.00008;
228.779; 18.909; 30.000; 599.780 168.462; 182.921; 25.171; 179.578; 0.785; 0.00008;
229.832; 19.660; 30.000; 599.636 167.892; 183.044; 25.052; 180.363; 0.785; 0.00008;
230.878; 18.988; 30.000; 599.641 166.204; 182.791; 24.853; 181.183; 0.785; 0.00008;
231.928; 19.051; 30.000; 599.527 166.125; 182.736; 24.807; 181.979; 0.785; 0.00008;
233.032; 18.712; 30.000; 599.602 166.127; 182.715; 24.832; 182.861; 0.785; 0.00008;
234.082; 16.949; 30.000; 600.042 166.804; 182.703; 24.836; 183.824; 0.785; 0.00008;
235.135; 18.716; 30.000; 600.241 164.826; 182.674; 24.828; 184.708; 0.786; 0.00008;
236.181; 19.232; 30.000; 600.201 165.747; 182.684; 24.797; 185.528; 0.786; 0.00008;
237.233; 16.788; 30.000; 600.187 167.488; 182.669; 24.822; 186.340; 0.786; 0.00008;
238.279; 17.693; 30.000; 599.947 167.805; 182.670; 24.866; 187.102; 0.785; 0.00008;
239.334; 18.992; 30.000; 599.779 167.126; 182.695; 24.888; 187.865; 0.785; 0.00008;
240.384; 17.259; 30.000; 599.738 167.490; 182.640; 24.898; 188.675; 0.785; 0.00008;
241.434; 18.625; 30.000; 599.707 166.507; 182.620; 24.894; 189.490; 0.785; 0.00008;
242.480; 17.473; 30.000; 599.516 167.850; 182.647; 24.923; 190.256; 0.785; 0.00008;
243.536; 17.769; 30.000; 599.525 167.967; 182.675; 24.905; 191.080; 0.785; 0.00008;
244.582; 18.010; 30.000; 599.564 168.209; 182.672; 24.905; 191.916; 0.785; 0.00008;
245.633; 17.162; 30.000; 599.902 168.300; 182.661; 24.925; 192.844; 0.785; 0.00008;
246.730; 18.605; 30.000; 600.030 168.202; 182.662; 24.923; 193.752; 0.785; 0.00008;
247.825; 18.837; 30.000; 599.763 168.238; 182.655; 24.925; 194.527; 0.785; 0.00008;
248.933; 17.242; 30.000; 599.628 169.068; 182.650; 24.945; 195.347; 0.785; 0.00008;

249.984;	15.855;	30.000;	599.611	170.831;	182.640;	24.944;	196.164;	0.785;	0.00008;
251.078;	18.015;	30.000;	599.863	169.325;	182.596;	24.947;	197.110;	0.785;	0.00008;
252.129;	18.523;	30.000;	599.796	168.690;	182.607;	24.945;	197.914;	0.785;	0.00008;
253.178;	19.056;	30.000;	599.880	169.532;	182.601;	24.936;	198.766;	0.785;	0.00008;
254.227;	17.222;	30.000;	599.734	171.286;	182.613;	24.909;	199.543;	0.785;	0.00008;
255.277;	16.559;	30.000;	599.716	171.840;	182.617;	24.882;	200.365;	0.785;	0.00008;
256.332;	17.107;	30.000;	599.882	170.850;	182.631;	24.905;	201.242;	0.785;	0.00008;
257.379;	18.717;	30.000;	600.033	169.868;	182.611;	24.900;	202.118;	0.785;	0.00008;
258.438;	18.281;	30.000;	600.205	170.688;	182.601;	24.900;	203.001;	0.786;	0.00008;
259.483;	18.931;	30.000;	600.283	169.643;	182.606;	24.874;	203.855;	0.786;	0.00008;
260.536;	18.917;	30.000;	600.328	169.313;	182.597;	24.884;	204.693;	0.786;	0.00008;
261.580;	17.501;	30.000;	600.606	171.453;	182.580;	24.871;	205.613;	0.786;	0.00008;
329.323;	17.850;	30.000;	600.094	174.694;	182.580;	24.901;	205.791;	0.786;	0.00008;
330.356;	17.414;	30.000;	600.140	188.966;	182.679;	24.938;	259.478;	0.786;	0.00008;
331.404;	17.513;	30.000;	600.315	188.881;	182.644;	24.967;	260.378;	0.786;	0.00008;
332.451;	17.559;	30.000;	600.341	189.309;	182.627;	24.949;	261.216;	0.786;	0.00008;
365.841;	16.270;	30.000;	599.798	191.252;	182.621;	24.952;	261.376;	0.785;	0.00008;

C: Friction coefficient vs time graphs

C1: sample1(combination 1)

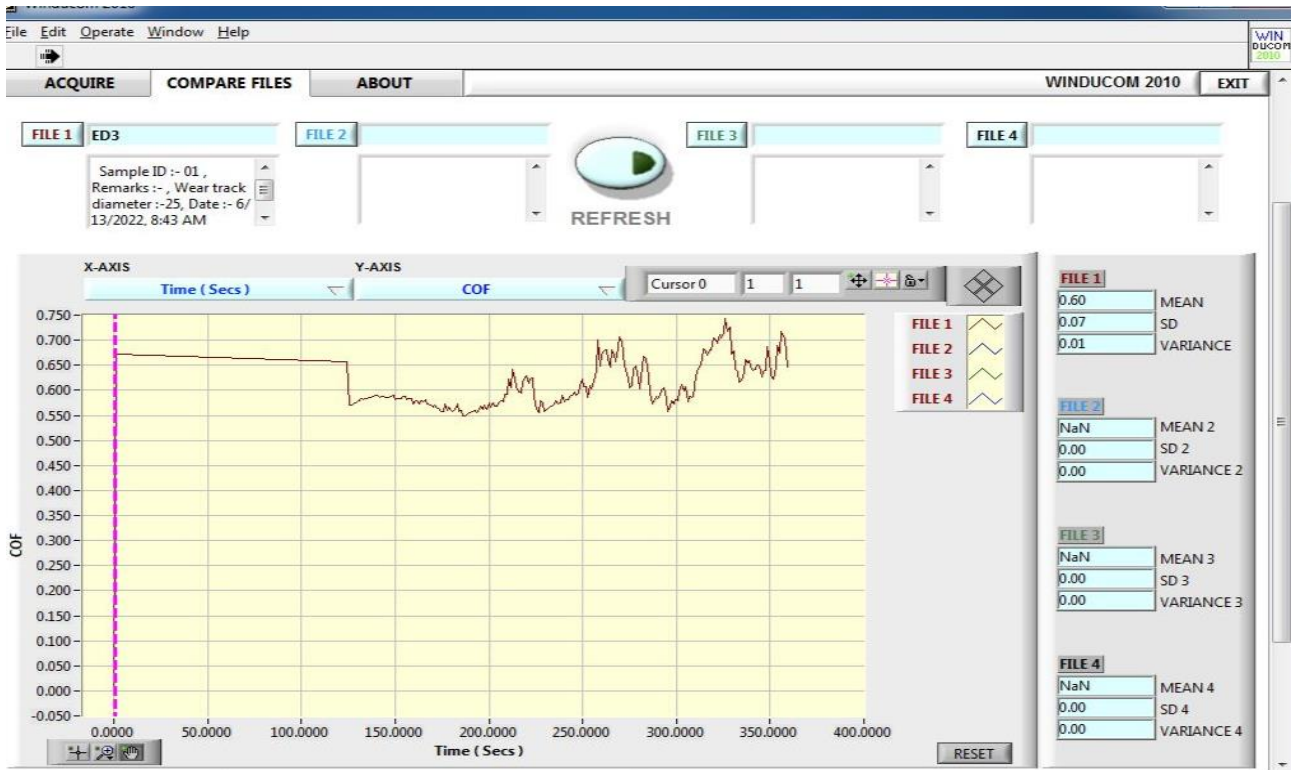


Development and characterization of Al6061/SiC/Bagasse ash/aloevera ash hybrid composite

C2: sample 2



C3: Sample 3

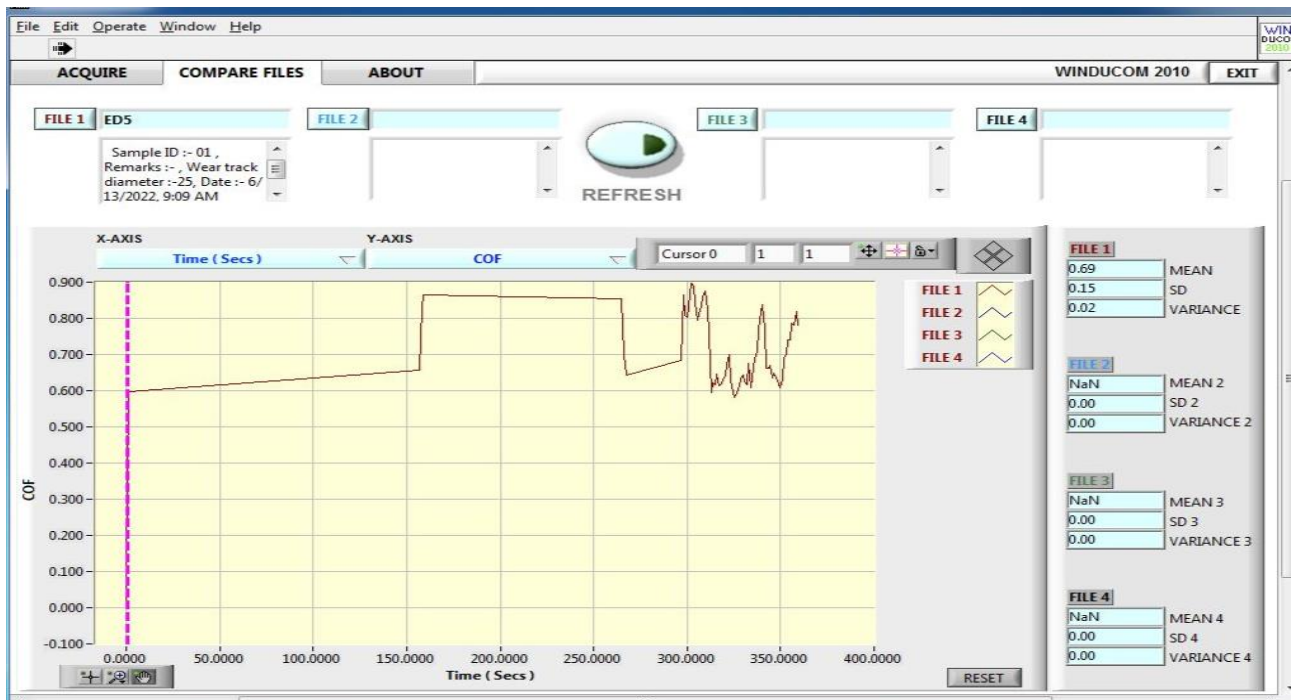


Development and characterization of Al6061/SiC/Bagasse ash/aloevera ash hybrid composite

C4: Sample 4

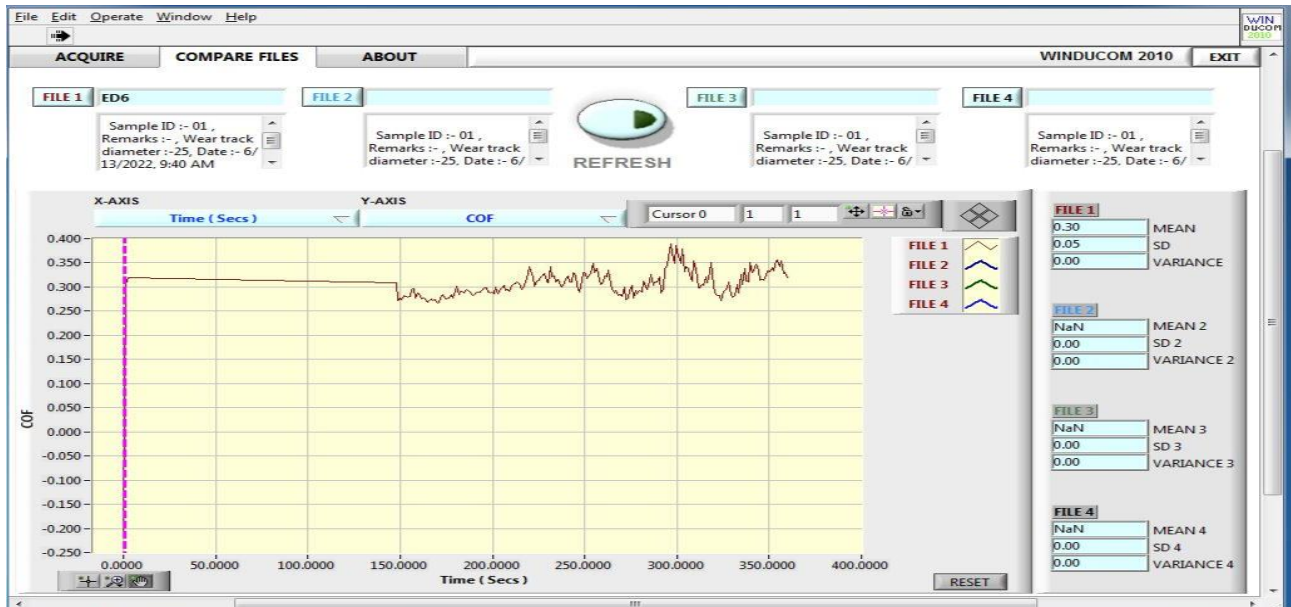


C5: Sample 5

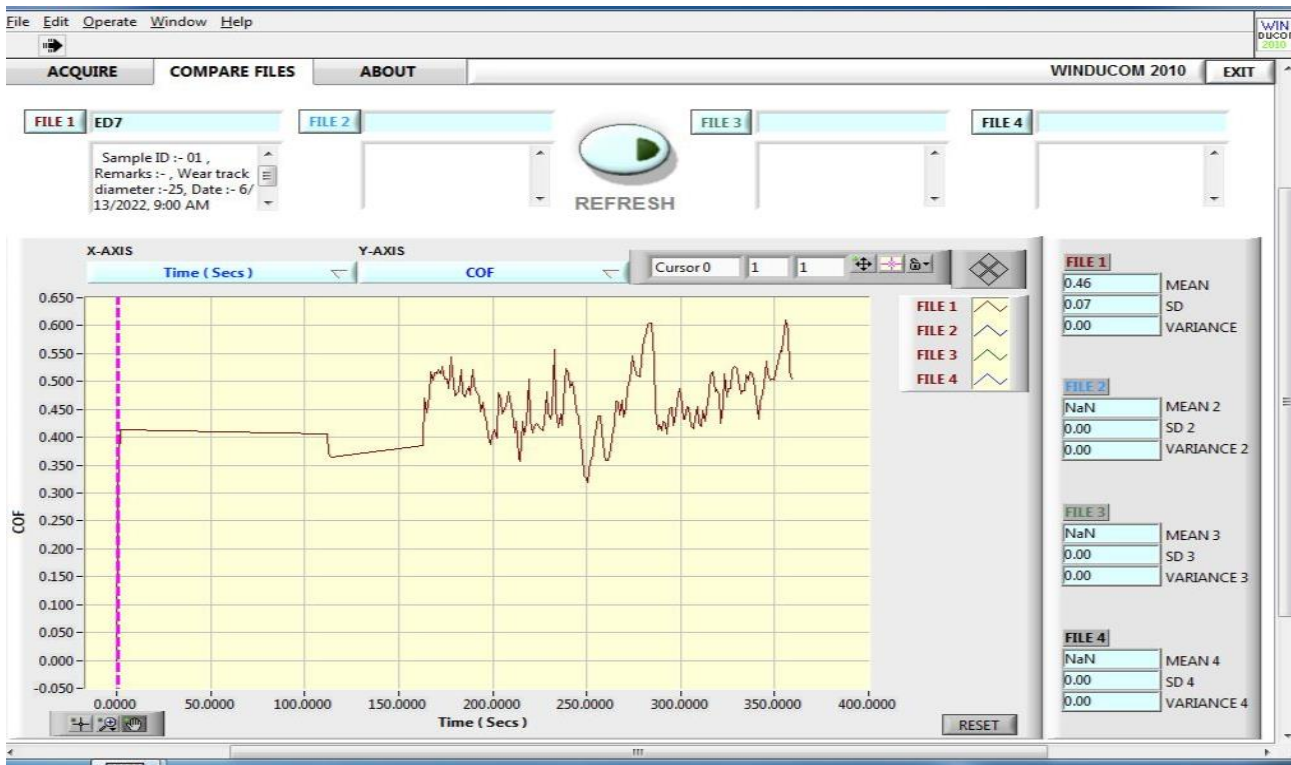


Development and characterization of Al6061/SiC/Bagasse ash/aloevera ash hybrid composite

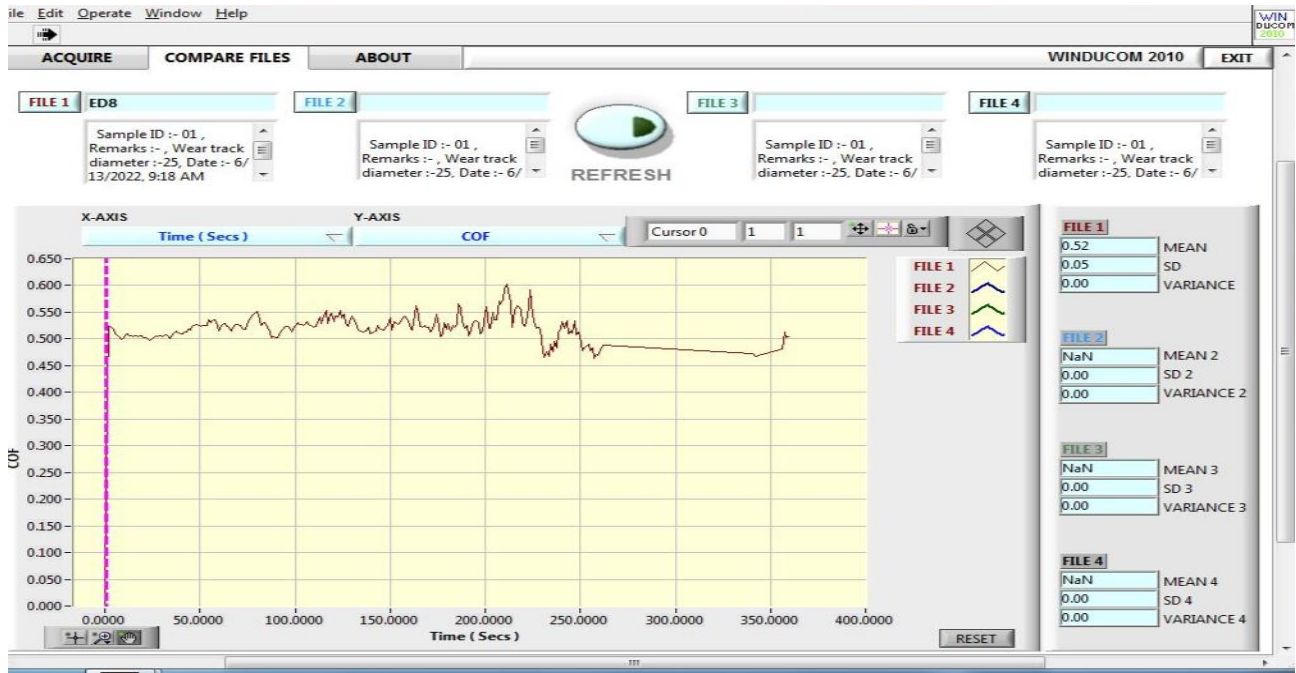
C6: Sample 6



C7: Sample 7

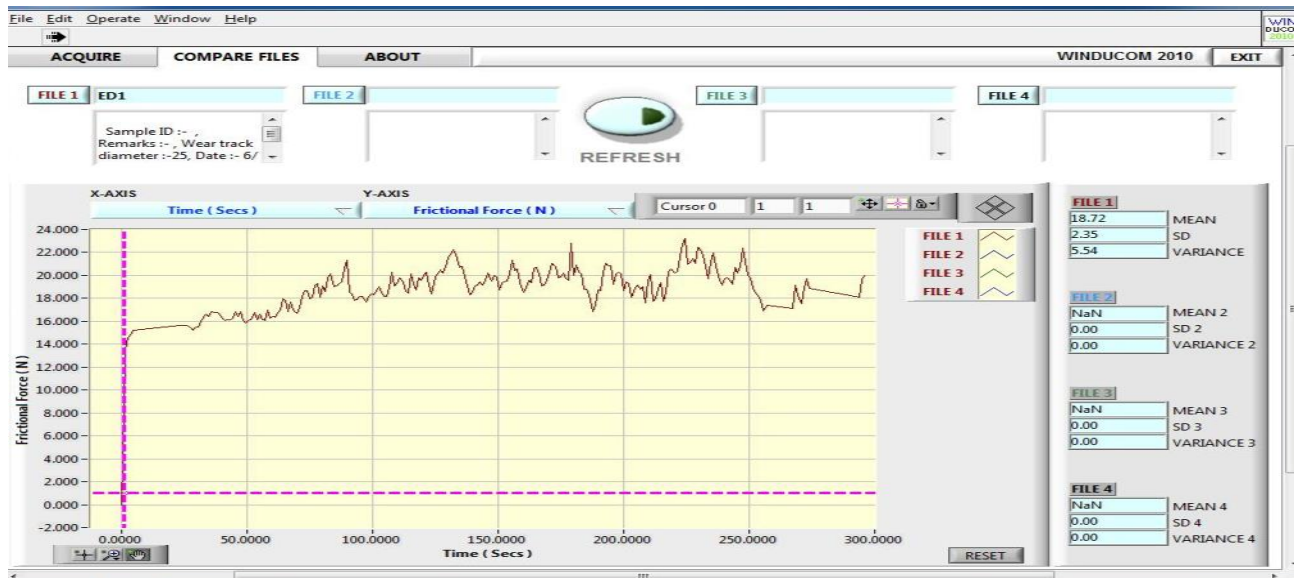


C8: Sample 8

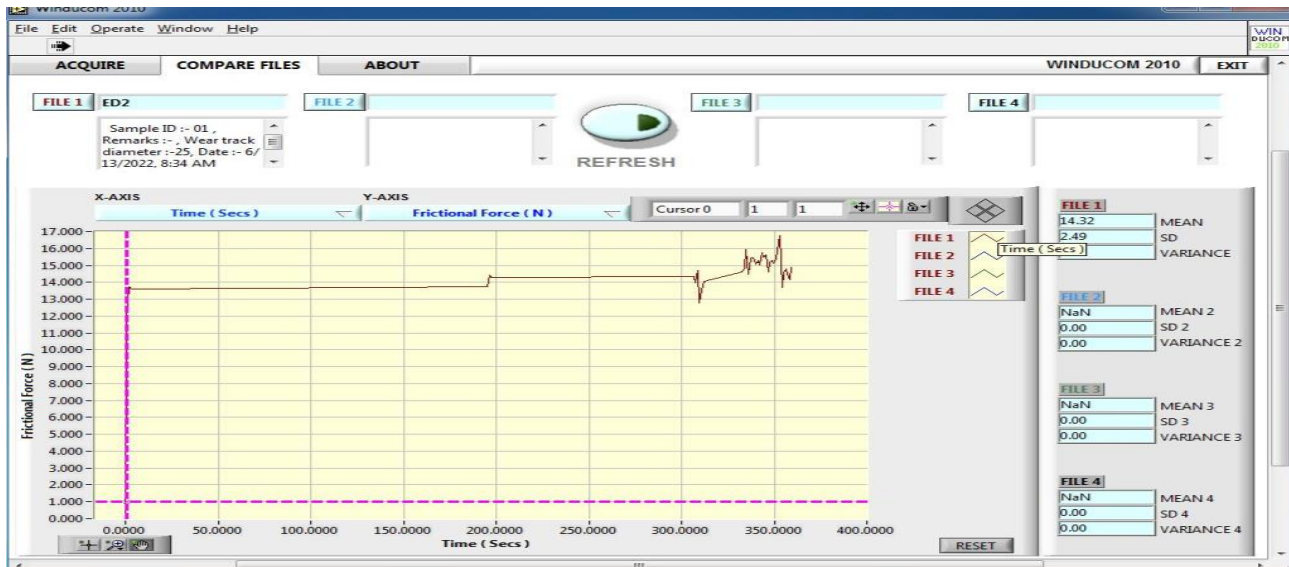


D: Frictional force vs time graphs

D1: Sample 1



Sample 2:



Sample 6:



E: Direct wear reading from pin on disc

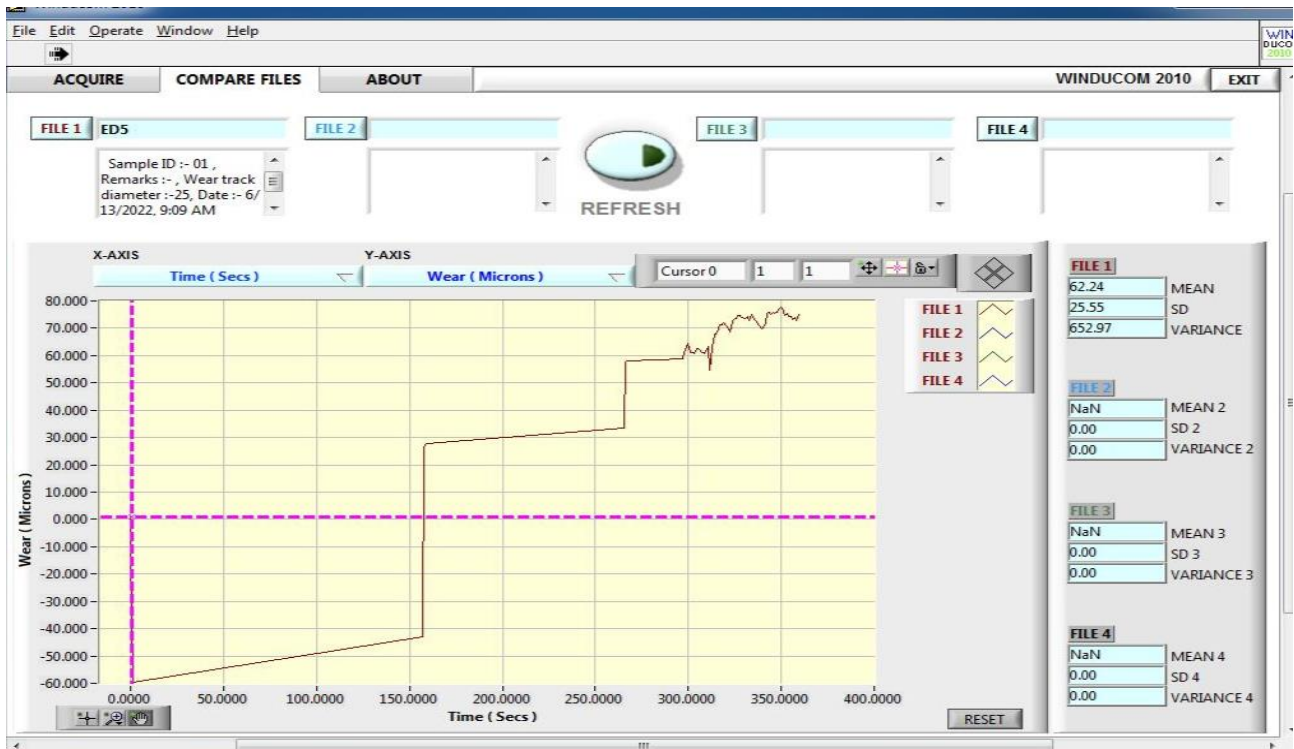
E1: Sample 1



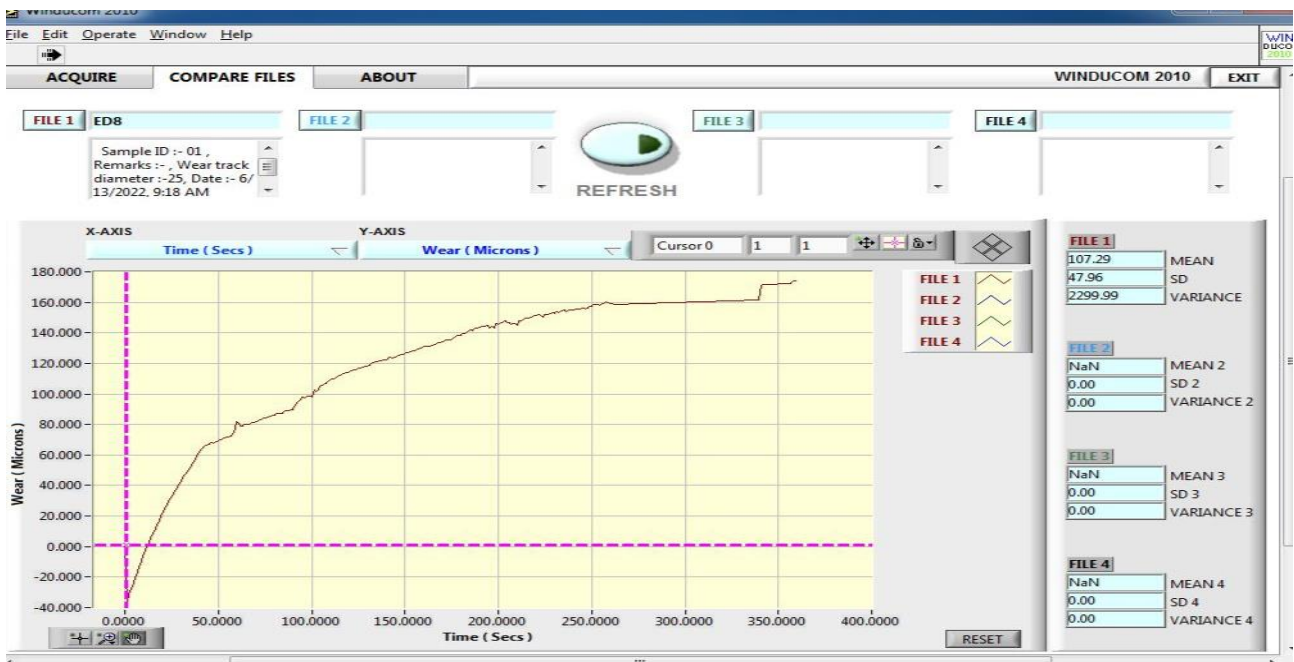
Sample 2:



Sample 6:

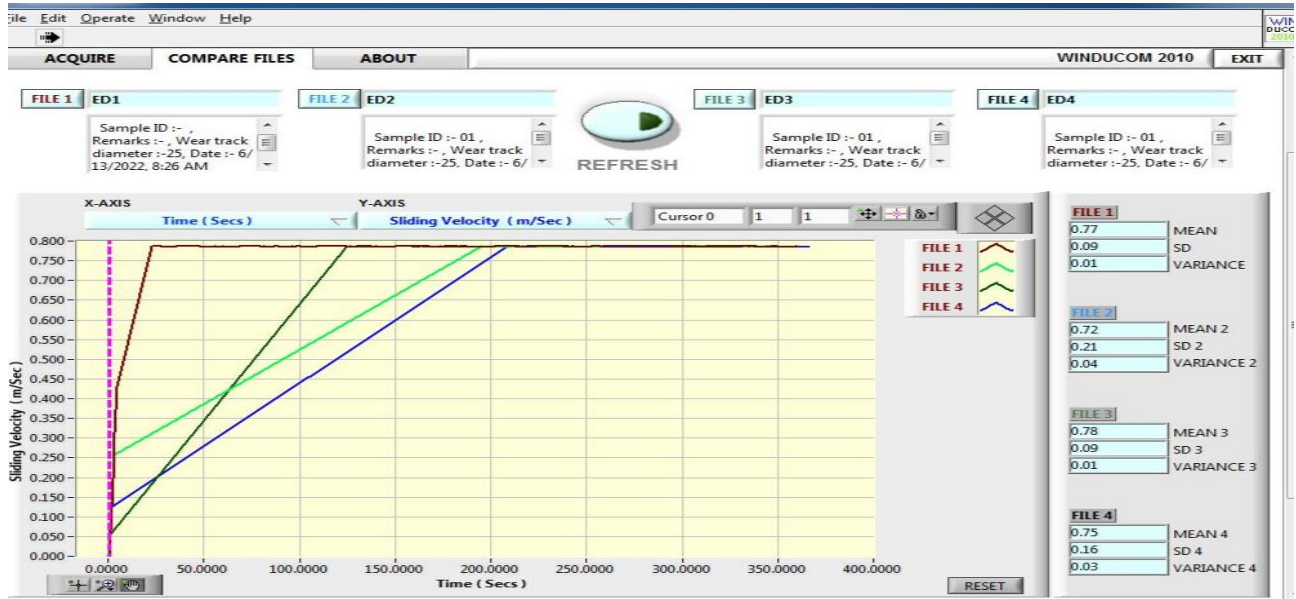


Sample 8:



F: Sliding velocity vs time graph

F1: Sliding velocity graph of the first four samples



F2: Sliding distance graph of the first four samples



G: measurement of weight loss for samples

date 12/06/2022

specimens	weight before wear test (gm)	weight after wear test	weight loss
sample 1	0.8402	0.836	0.0042
sample 2	0.8438	0.839	0.0048
sample 3	0.7672	0.7491	0.0181
sample 4	0.6490	0.647	0.002
sample 5	0.7169	0.715	0.0019
sample 6	0.6831	0.6813	0.0018
sample 7	0.8633	0.800	0.0633
sample 8	0.8895	0.711	0.1785