Fabrication, characterization and evaluation of mechanical properties of Aluminium hybrid matrix composite (Al6063/SiC-bagasse fly-ash)

A thesis submitted
by

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Under the Supervision & Guidance of

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ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIAL ENGINEERING

DEPARTMENT OF MECHANICAL DESIGN AND MANUFACTURING ENGINEERING

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Approved by Board of Examiners

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External Examiner	Signature	Date

CANDIDATE DECLARATION

I hereby declare that the work which is being presented in this thesis entitled **"Fabrication, characterization and evaluation of mechanical properties of Aluminium hybrid matrix composite (Al6063/SiC-bagasse fly ash) for disk brake''** in partial fulfillment of requirements for the award of the degree of masters of science in Manufacturing Engineering is an authentic record of my own work carried out **September to May 2018** under the supervision of **Dr. PERUMALLA JANAKI RAMULU** and **Dr. Ch.Venkatesh,** Program of Mechanical Design and Manufacturing Engineering, Adama Science and Technology University, Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duty acknowledged.

Getachew Gashaw Worku ____________________ __________________

Candidate Signature Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge and belief. This has been submitted for examination with our approval.

Dr. Perumalla Janaki Ramulu ____________________ __________________

Advisor Signature Date

Dr. Ch. Venkatesh __________________.

Co-Advisor Signature Date

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ABSTRACT

The number of engineering application in industry demands need best mechanical properties of material such as aerospace, automotive industry, automotive components, propeller and manufacturing turbine blade. To satisfy these requirements, MMCs have certain superior mechanical properties, namely higher transvers strength and stiffness, greater shear and compressive strengths and better high temperature capabilities than other polymeric and ceramic composites. The fabrication, microstructure characteristics and mechanical behaviour of Al-Mg-Si alloy matrix composites reinforced with silicon carbide (SiC) and bagasse fly-ash was investigated in this work. This was aimed at assessing the viability of developing high performance Al matrix composites using low cost reinforcements from industrial waste products. In addition, the fabrication and experimental investigation of mechanical properties of Aluminium matrix (Al/SiC) composite with and without addition of bagasse fly ash by varying wt. % of reinforcements was investigated. Bagasse fly-ash particulates added with 7.5, 10, and 12wt% SiC were utilized to prepare 10 and 12wt% of the reinforcing phase with Al-Mg-Si alloy as matrix using stir casting method. Chemical composition of reinforcement, weighted the required amount of matrix and reinforcements, powder mixing, stirring the slurry at 500rpm speed and 5-10 minute were the parameters used to develop the Al/SiC-bagasse fly-ash hybrid composite. Tensile testing, compression strength testing, micro-hardness measurement and optical microscopy were used to characterize the composites produced. The results showed that The hardness of the hybrid composites increased slightly with increase in bagasse fly-ash content with a maximum increment of 17% observed for the Al6063-7.5% SiC-10% bagasse ash composition (in comparison with the Al-10 wt% SiC-7.5 fly-ash reinforced composition). Tensile strength reduced of maximum value of 90MPa to 68 MPa at 7.5 SiC- 7.5 bagasse ash compositions, while the compression strength maximum improved from 295MPa to 380.1MPa. In hybrid composite superior properties are observed in tensile strength, compression strength, and hardness than single reinforced Al/SiC MMC.

Keywords*: SiC; bagasse fly-ash; wt. %, stir casting; MMCs; optical microscope; Al/SiC.*

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LIST OF SYMBOLS & ABBREVIATIONS

Al	- Aluminum
Al/SiC	- Aluminum Silicon Carbide
Al/Sic-fly ash	- Aluminium Silicon Carbide Fly ash
Al_2O_3	- Alumina
AMCS	- Aluminum matrix composite
ASTM	- American Society for Testing of Materials
B_4C	- Boron carbide
BFA	- Bagasse fly-ash
BHN	- Brinel hardness number
BLA	- Bamboo leaf ash
cm	- Centimeter
CMC	- Ceramic matrix composite
CO_2	- Carbon dioxide
GCI	- Grey cast iron
GSA	- Ground nut shell ash
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
RHA	- Rice hask ash
RPM	- Revolution per minute
SEM	- Scanning Electron Microscope
SiC	- Silicon Carbide
SiO_2	- Silicon dioxide
TiB_2	- Titanium Di bromide

TiC	- Titanium Carbide
UTS	- Universal Testing Machine
v. %	- Volume percentage
VHR	- Vickers hardness
WC	- Tungsten Carbide
wt. %	- weight percentage
μm	- Micro meter

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the study

Historically, MMCs, such as steel-wire reinforced copper, were among the first continuous-fiber reinforced composites studied as a model system. Initial work in late 1960s was stimulated by the high-performance needs of the aerospace and aviation industries. In these development efforts, performance, not cost, was the primary driver. The extensive use of aluminium alloys in manufacturing aerospace and automobile structures is well recognised in past years. Nevertheless, aluminium alloys cannot meet all engineering requirements in the advanced fields of science and technology. Their main weaknesses are poor high-temperature performance and low wear resistance. To overcome these problems, new engineering materials have been developed by reinforcing aluminium alloys with ceramic particles/whiskers; these are known as metal matrix composites (MMCs) (*Paulo Davi. (2007)).*

A composite material is a material system composed of a suitably arranged mixture or combination of two or more Nano, micro, or macro constituents with an interface separating them that differ in form and chemical composition and are essentially insoluble in each other the discrete constituent is called the reinforcement and the continuous phase is called the-matrix.

1.2 Classification of composites

Based on the geometry of reinforcements composites are classified as particle reinforced composite, short fiber composites (whiskers) and continuous fiber composites. According to the chemical nature of the matrix phase, composite is classified as metal matrix (MMC), polymer matrix (PMC) and ceramic matrix composites (CMC) (*Kalaa et al.(2014*)).

1.3 Introduction to metal matrix composites

Metal matrix composites (MMCs) are engineering materials in which a strong ceramic reinforcement is incorporated into a metal matrix to improve its properties. MMCs combine metallic properties of matrix alloys (ductility and toughness) with ceramic properties of reinforcements (high strength and high modulus), leading to greater strength in shear and compression and higher service temperature capabilities (Kok (2005). Metals which are used as matrix material are aluminium, magnesium, and titanium etc. SiC, Al_2O_3, TiB_2, TiC, B_4C used as reinforcements.

1.3.1 Comparison of metal matrix composite to other composite materials

Metal matrix composites are good for where high temperature working area required. In comparison with most polymer matrix composites, MMCs have certain superior mechanical properties, namely higher transvers strength and stiffness, greater shear and compressive strengths and better high temperature capabilities as shown in Table 1.1. There also advantages in some of physical attributes of MMCs such as no significance moisture absorption properties, non-in flammability, high electrical and thermal conductivities, and resistance to most radiations (*Rosso (2006)).*

Table 1. 1 Summary of the properties and processing methods (*Trinh. (2016))*

Property	**Polymer matrix composite**	**Metal matrix composite**	**Ceramic matrix composite**
Modulus	Medium	Very high	Very high
Strength	Very high (tension) High (compression)	High (tension) High (compression)	Medium (tension) High (compression)
Density	Low	Medium	Medium
Creep resistance	High	High	Low
Fracture toughness	High	Medium	Low
Fatigue	High	Medium	Low

1.3.2 Aluminium matrix composites

Aluminium matrix composites (AMCS) have significant properties than other metal matrix composites in terms of its high strength to weight ratio. Particulates such as SiC, TiC, TiB_2 and fly-ash were used to reinforce Al alloys to improve their mechanical properties and wear resistance (*Suresh et al.(2010*)).

From the literature study revealed that among all reinforcements SiC was chemically compatible with aluminium and forms an adequate bond with the matrix without developing inter- metallic phase and have other advantages such as excellent thermal conductivity, good workability and low cost (*Venkatesan. et al.(2014*)). One essential factor which limits the application of AMCs is the high cost of fabrication which can be minimized by using inexpensive reinforcements such as fly ash and natural minerals. Fly ash is cheaper compared to other reinforcements such as SiC, Al_2O_3, B_4C, TiC etc. In recent years, the use of fly ash as reinforcement material in Al alloys was reported to be desirable from both environmental and economic significance due to its low cost. The cost of current MMCs compared to aluminium alloys was inhibited production on a large industrial scale, for example, in the automotive industry *(Alanemea et al. (2013)).*

To overcome this, several research and development programmes were focused on Al MMCs using low cost industrial waste by products as the reinforcement particulate (*Kalaa et al. (2016*)). Investigation of mechanical behaviour of aluminium alloy reinforced by nano and micro hard particles such as Al_2O_3 and SiC is an interesting area of research (Sajjdi *et al.* (2012)). The present work interested on Aluminium hybrid matrix composite with reinforcements such as, Silicon-Carbide particle and waste of sugar cane bagasse fly ash particle. Al/SiC-bagasse fly ash composite provides more wear resistance, high coefficient of thermal expansion and high strength. Silicon carbide (SiC) is hard, wear resistance, high heat resistance ceramic material. One of the most important properties of ceramics is that they are very good insulator of heat which means the can hold very high temperature without any failure. Bagasse fly-ash is one of the most inexpensive and low-density reinforcement available in large quantities as solid waste by-product during combustion of coal in thermal power plants. Hence, composites with fly-ash as reinforcement are likely to overcome the cost barrier for wide spread application in automotive industry.

1.5 Hybrid metal matrix (HMMCs) composite

The usage of more than one material as a reinforcement for production and manufacturing of metal matrix composites reduced the challenges during machining of metal matrix composites. The property of the developed material changed due to different properties of the matrix and reinforcements. Metal matrix hybrid composites are the second-generation composite materials that have potential to substitute single reinforced composite by which improving properties (*Singh and Amit, (2016), Oluwatosin et al. (2015*)). When more than two materials are presenting, it is called a hybrid composite. Metal matrix hybrid composites (MMHCs) are now gaining their usage in aerospace, automotive, and other industries because of their inherent properties like high strength to weight ratio, hardness and good creep behaviour, light weight and design flexibility (*Chaithanyasaia et al.(2014*)).

For many automotive components, such as pistons, cylinders, engine blocks, brakes, drive shafts, disc and drum brakes aluminium matrix composites were used to reduce weight of vehicles and improve performance *(Mohan and Arjunra, (2014))*. For automotive manufactures to reach 95g CO_2/Kg requirement by 2020, the implementation of light weight construction cannot solely be based on steel and aluminium advancements. To accomplish this, a reduction of component weight must exceed 50% *(Hendrik et al.,2015)*. Al/SiC/fly ash-MMC is one of the important hybrids composite among MMCs, which have SiC & fly ash particles with Aluminium matrix.

1.6 Challenges in MMCs

The addition of ceramic particles in the Al alloy increases the hardness of the developed composite. During Machining of MMCs difficult to minimize the tool wear rate. One of the methods to improve machinability of the composite is using multiple reinforcements.

1.7 Statement of problem

- Natural fibers have good mechanical property, but they are finite (limited resources). The usage of their wastage such as, fly ash and plant wastes from industries as reinforcement is recommendable. Bagasse fly ash is a waste by product of coal combustion in thermal power plants which is available in large quantities in Ethiopian sugar factories which polluting the environment, land used and affect human health. The usage of this waste fly ash particle reinforced in to Aluminium alloys, which can effectively enhance the various mechanical properties of the aluminium alloy.
- Automotive heavy components fabricated from metals, Due to increase the weight of components consumption of fuel increases.
- Increasing volume percentage of SiC reinforcement the weight of the composite increase. Bagasse fly ash leads to decrease the density of the composite when using some percentage with silicon carbide as reinforcement for developing Al/SiC/fly ash composite.

1.8 Objective of the research work

1.8.1 General objective

Characterization and evaluation of mechanical properties of Aluminium matrix (Al/SiC) composite with and without addition of bagasse fly ash by varying wt. % of reinforcements.

1.8.2 Specific objectives

- To fabricate Al/SiC-fly ash hybrid matrix composite.
- To analyse mechanical properties such as, tensile test, hardness, compression strength of Al/SiC composite and Al/SiC fly ash hybrid composite.
- To study and correlate microstructure of composite specimen with mechanical properties.

1.9 Scope of the research work

The scope of this research work is to successfully fabricate Al/SiC/bagasse fly ash hybrid composite. In addition, the percentage volume variation effect of bagasse fly ash on mechanical properties, such as tensile strength, hardness, compression strength analyzed. The characterization of mechanical properties of Al/SiC composite with and without addition of bagasse fly ash was investigated and compared.

1.10 Significance of the research

Now a day’s, automotive manufacture industries focused on production of light weight vehicles using cost effective composite materials instead of steels and aluminium alloys. The proper selection of cost effective reinforcements decreases the cost barrier of vehicles. The research gives important to reduction of fuel consumption of vehicles by reduce weight of automotive components. The land usages of bagasse waste minimized and reduce pollution of environment in our country of sugar industry sites.

This project will help:

- As teaching aid and reference material for technology education besides further researches in developing composites.
- Minimizing pollution and reducing fossil fuel consumption.
- It substitutes the metals which are used in automotive parts with comparing properties.

1.11 Limitation of the work

The challenges which were faced on work are:

- Lack of stir casting set up in our country challenges the uniform distribution of particles in the matrix.
- The brittleness of samples during machining on laze more challenged the work.
- Budget scarcity for all process and to conduct more number of experiments.

1.12 Output

At the end of the work, the different experimental outputs are achieved such as:

- The percentage volume effect of reinforcements on improvement of mechanical properties.
- The bagasse ash particles improve properties of Al/SiC composite.
- The product (Al/SiC-bagasse fly-ash) which used for automotive components.

1.13 Thesis organization

This thesis consists of five chapters and essence of each chapter is detailed below.

The first chapter is organized about background of study and introduction, problem statement, objectives, research scope, limitation of the work, output of work and the organization of the thesis.

In the second chapter, it is explained about the literature review of some other researches about the method and mechanical testing on developed new single reinforced and hybrid metal matrix composites, In addition microstructure characterization of metal matrix composites. Literature gap of the present work also discussed.

In Chapter 3 is described about methodology of the work, wt. % percentage reinforcements used, the process of fabrication method that used in this research to fabricate the hybrid Al/SiC-bagasse ash composite.

The result of microstructure and mechanical properties of the manufactured specimens Al/SiC-bagasse ash composite discussed in the Chapter 4.

Finally, Chapter 5 presents the concluded and recommended future works.

CHAPTER TWO

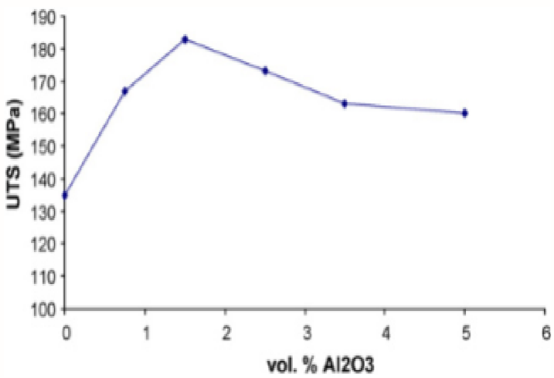
2. LITERATURE REVIEW

The chapter gives detail discussion about previous works related to Aluminium matrix composite and Aluminium hybrid composites. The summery of a number of research papers that have been studied during the present research work are cited in this chapter. The result of mechanical properties (tensile, compression and hardness tests) of some studies done by varying the wt. % of reinforcements on aluminium reinforced metal matrix composites are given below in different headings. Further, investigations and studies of gap areas are also discussed in detail.

2.1 Single- reinforced metal matrix composite

Kumar et al. (2008) fabricated Al-7Si alloy composite reinforced with in situ TiB2 and investigated it's mechanical and wear behaviour. The authors observed that the increase in values of the hardness, ultimate tensile strength, the yield strength and the young modulus were observed with increase in weight percentage of TiB2. Also the coefficient of friction and war rate decreased with addition of TiB2 compared to pure alloy.

Mazahery et al. (2009) produced stir cast A356 alloy matrix composite reinforced with nano-Al_2O_3 particles. The author has revealed that the values of the yield strength, the ultimate tensile strength and ductility of the composite increased with the increase in volume percentage of the nano particles. Also the hardness of the composite improved compared to pure alloy.



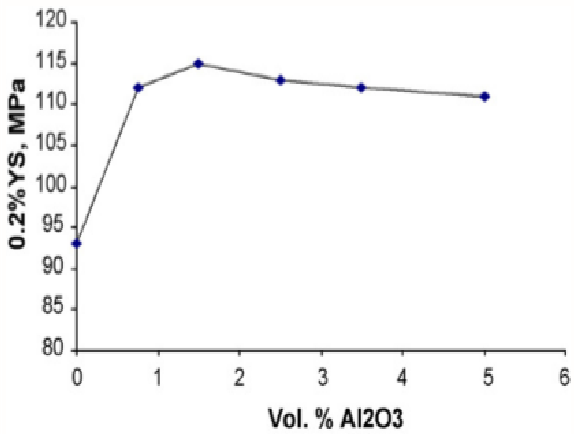


Figure2. 1(a)Variation of UTS with Al2O3 content with Al2O3 content (Mazahery et al.(2009))

Fig 2.1 (b)Variation of yield strength (Mazahery et al.(2009))

Ling et al (2010) fabricated Aluminium matrix composite reinforced with Al9 (Co, Ni) 2 particles. They observed that the ultimate tensile strength and the yield strength of the composite increased with increase in volume fraction of reinforcement. While the elongation fracture first increased and then decreased with increase in reinforcement.

Aigbodion et al. (2010) produced Al/bagasse ash composite by double stir-casting method. They added 2-10 wt. % of bagasse ash to study mechanical properties and microstructure using SEM and XRD methods. They found that the yield strength and ultimate tensile strength increased by 49.76% and 34.25% by adding up to maximum of 8 wt.% bagasse ash. The increases in strength and hardness values were attributed to the distribution of hard and brittle ceramic phases in the ductile metal matrix. The micro structure revealed dark ceramic and white metal phases, which resulted in to increase in the dislocation density at the particle matrix interfaces. The results showed that better properties are achievable by the addition of bagasse ash to Al-Cu-Mg alloy.

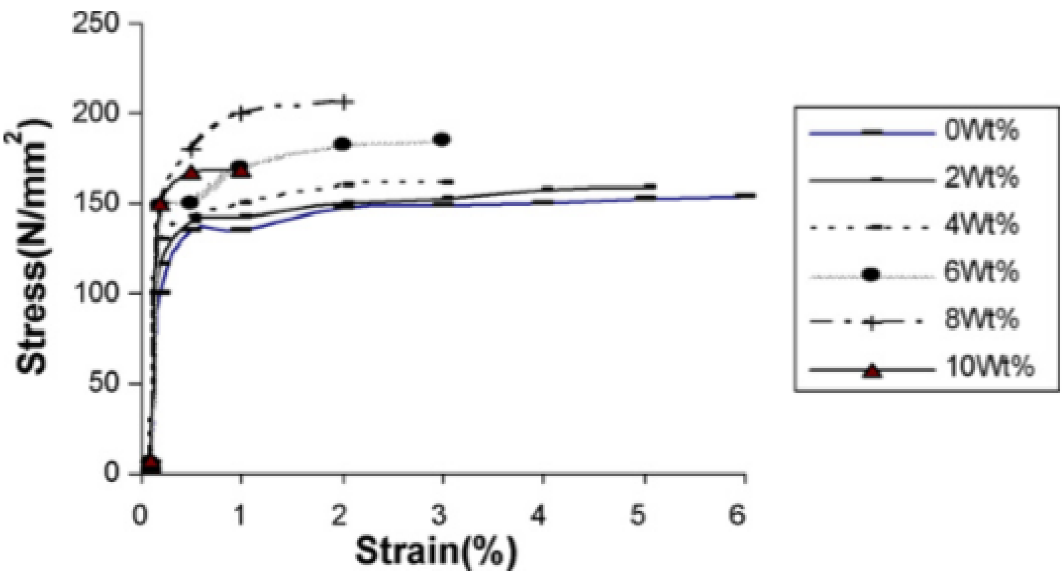


Figure2. 2 Variation of stress with strain at various bagasse ash additions (*Aigbodion et al 2010))*

Kakaiselvan et al. (2011) produced Al (6061-T6)/B4C composite and investigated its mechanical properties. They observed that the hardness (fig 2.1 a) and the tensile strength (fig 2.1 b) of the composite are linearly increasing with increasing weight percentage of the B4C particulate.

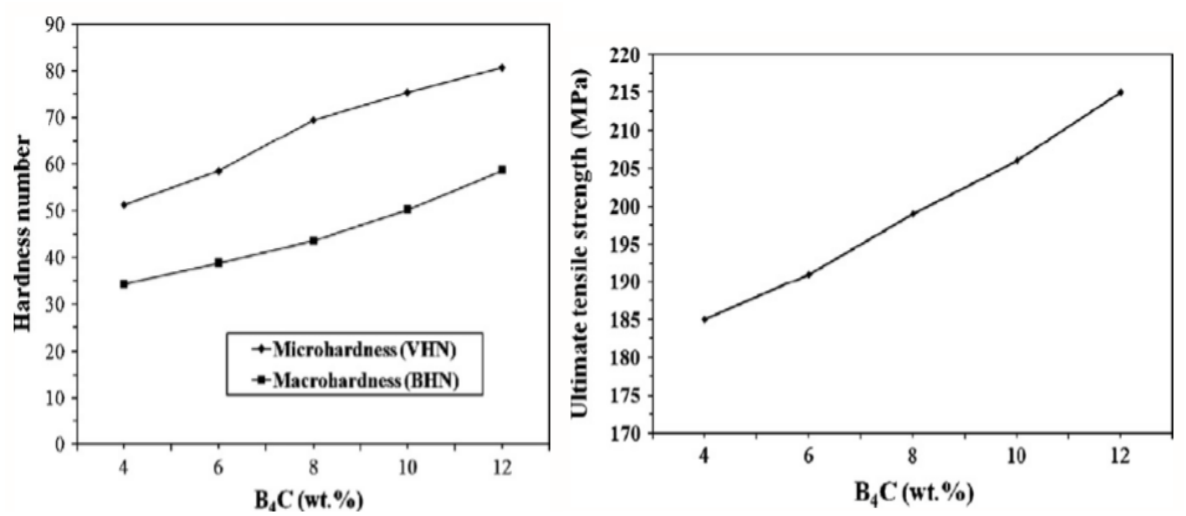


Figure2. 3(a) Variation of hardness with B4C content Figure2. 3 (b)Variation of UTS with
B4C content (Kakaiselvan et al.(2011)) (Kakaiselvan et al.(2011))

Kumar et al. (2012) investigated the mechanical behaviour of stir cast Al (6061) matrix composite reinforced with Al-N particles and concluded that ultimate tensile strength and yield strength of the composite was better than pure alloy. The author revealed that micro hardness and macro hardness of the composite increased with increase in percentage of Al-N into the alloy matrix.

Atuanya et al. (2012) fabricated breadfruit seed hull ash reinforced Al-Si-Fe alloy matrix composite using stir casting technique. The author reported an increase in tensile strength and hardness values for the composite while the impact strength decreased compared to matrix alloy. *Akbari et al. (2013)* fabricated samples of Al (A356) alloy matrix composite reinforced with mixture of milled nano Al2O3 and Al particles and with nano Al_2O_3 and Cu particles. The authors observed that ultimate tensile strength and compressive strength of the composite is higher than that of pure alloy. The increase in mechanical properties is higher in case of Al (A356)/ Al2O3/Cu composite.

Karvanis et al. (2016) produced Al/SiC metal matrix composite by varying volume percentage of silicon carbide using centrifugal casting machine. The mechanical properties and macrostructure of the composite investigated in order to determine the optimum percentage of silicon carbide in the metal matrix composite. They concluded that the tensile, compressive strength and hardness of the composite increased due to increasing v. % of silicon carbide. The SEM microscopy showed that silicon carbide particles broken in smaller pieces.

Vijayakumar et al. (2016) studied the tensile strength and hardness of Al6061/SiC composite by varying the wt. % SiC reinforcements 3-18%. The composite was manufactured by using stir casting of 600rpm, 5 minute stirring speed and stirring time respectively. The ultimate tensile strength and Rockwell hardness results showed that the tensile strength and hardness of the developed metal matrix more improved during increasing the wt. % of silicon carbide.

2.2 Hybrid metal matrix (HMM) composites with two reinforcements

This type of hybrid AMCs was developed basically to perform optimization with less consideration on the production cost.

Ramachandra et al. (2007) investigated the wear and friction characteristics of Al (12% sic) matrix composite reinforced with fly ash particles. The authors observed that wear resistance of the composite increased with increase in weight percent of fly ash while it decreased with increase in normal load and sliding velocity. With increase in fly ash content the slurry erosive wear resistance of the composite increased and the corrosion resistance decreased.

Dwivedi et al. (2010) statistically studied the dry reciprocating wear behavior of Al-Si-SiC_p composite and observed that composite with high silicon content shoed lower wear loses compared to that of low silicon content composite. Sliding distance is the main factor which affects the wear behavior of the composite followed by load, reciprocating velocity and weight percentage of silicon. The interaction between load and sliding distance also had a pronounced effect on wear behaviour. In case of friction behaviour load is the controlling factor followed by weight percentage of silicon.

Sudarshan and Surappa, (2008) studied aluminium alloy (A356) composite containing 6 and 12 Vol. % of fly ash particles. The dry sliding wear behaviour of unreinforced alloy and composites were studied using a pin on disk machine at different loads of 10, 20, 50, 65 and 80N at a constant sliding velocity of 1 m/s. Results showed that the dry sliding wear resistance of Al-fly ash composite was almost similar to that of Al_2O_3 and SiC reinforced Al-alloy. Incorporation of 6 vol. % of fly ash particles results decreased in dry sliding wear rates at low loads (10-20 N) and 12 vol. % of fly-ash reinforced showed the low wear rate compared to un reinforced alloy in the load range 20-80 N.

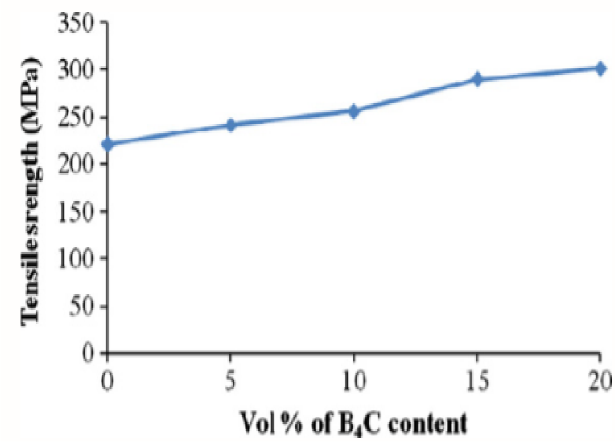
Kumar et al. (2013) investigated the tribological behaviour of dual reinforced aluminium based metal matrix composite incorporated with zircon sand and silicon carbide. The author observed that wear resistance of the dual reinforced composite was higher than both single reinforced composite and pure alloy at low and high loads.

Mazaheri et al (2013) conducted a comparative study of mechanical properties of Al-TiC, Al-B_4C and AlTiC-B_4C hybrid composite. The author has revealed that Al/TiC/ B 4C composite possessed highest hardness. Highest yield strength and tensile strength was shown by Al-B4C composite and Al-TiC showed maximum elongation.

Kumar et al. (2013) fabricated A359/ Al_2O_3 composite via electromagnetic stir casting method. The author revealed that the hardness values increased to 72.8 HRC compared to pure alloy (46HRC). Also the tensile strength of the composite increased to 148.7N/mm2 as compared to pure alloy (103.7N/mm^2

David et al. (2013) focused on synthesized and characterization of Al6061-Fly Ash_p-SiC_p composites with various weight percentages of SiC particulates and a constant weight percentage of Fly Ash (7.5 wt. % of fly ash and varying weight percentage 7.5 and 10wt.% of SiC) by modified stir casting and compo-casting method. The wettability of SiC and Fly ash particles in the matrix was improved by adding magnesium into the melt. The optical and scanning electron micrographs showed a homogeneous dispersion of both SiC and Fly ash particles in the aluminium matrix and addition of Fly Ash helped to prevent SiC_p dissolution and the formation of Al_4C_3, with respect to addition of weight percentage of SiC and constant weight percentage of FA particles. The reinforcement of particles has enhanced the tensile strength of aluminium matrix and composites from 173 MPa to 213 MPa. The micro and macro hardness of the composites were increased from 69.53 HV to 78.8 HV and 49.4 BHN to 57.21 BHN.

Baradeswarn et al. (2013) studied the mechanical behaviour of B_4C reinforced Al-7075 matrix composite. The author has revealed that the ultimate tensile strength (fig 2.4 a), the compressive strength (fig 2.4c) and the hardness (fig 2.4b) of the composite increased linearly with increase in volume percentage of B4C.



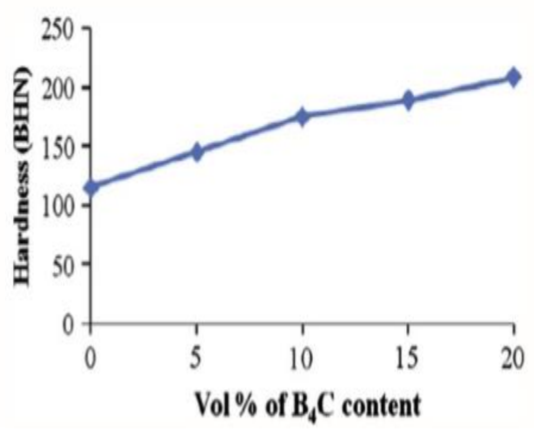


Figure2. 4(a) Variation of TS with B4c content (Baradeswarn et al.(2013))

Figure2. 4(b) Variation of hardness with B4c content (Baradeswarn et al.(2013))

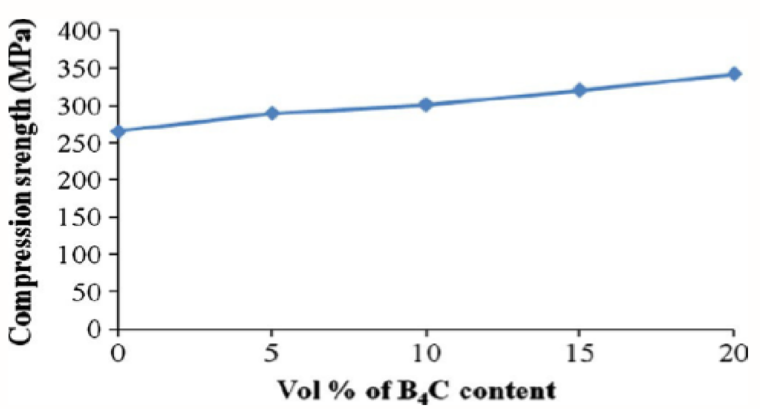


Figure 2. 4(c) Variation of compressive strength with B4c content (Baradeswarn et al. (2013))

Baradeswaran and Perumal, (2014) investigated the mechanical and wear properties of Al7075-Al_2O_3-graphite hybrid composites were fabricated by using liquid metallurgy route. The Al7075-Al_2O_3-Graphite hybrid composite was prepared with 5 wt. % graphite particles addition and 2, 4, 6 and 8 wt. % of Al_2O_3. The hardness, tensile strength, flexural strength and compression strength of the Al7075-Al_2O_3-graphite hybrid composites were found to be increased by increased weight percentage of ceramic phase. The wear properties of the hybrid composites containing graphite exhibited the superior wear resistance properties.

James et al. (2014) prepared hybrid aluminum metal matrix reinforced With SiC and TiB_2 composite to study its machining and mechanical properties. Average grain sizes of 25 microns, 10 microns were selected for SiC and TiB_2 respectively. Parameters have been used are melting temperature of matrix Al6061 750°C, stirring speed 350 rpm, stirring time 15 minute, wear test load of 50N and 70N. It was concluded from hardness measurement that, addition of reinforcements was effect on hardness value, but addition of TiB_2 up to 5% leads to porosity which affects hardness value. From tensile test results, it observed that addition of reinforcement SiC to base metal added 20% strength to the composite but addition of TiB_2 reduction in 50-60% strength is recorded. Experimental results proved that the quantity of wear of SiC 10% - TiB_2 0% is 20% more than SiC 10% - TiB_2 2.5% specimen. *Saravanakuma et al. (2014)* studied mechanical behaviour of the AA 6063-x wt. % Al_2O_3-1wt.% Gr (x = 0, 3, 6, 9 and 12 wt.%) hybrid composites manufactured by stir casting method. The matrix was Melted temperature of at 800°C and Al_2O_3 and Gr heating furnace (25-30 minutes) at 400-450°C of Particles of average size 80µm, 20µm respectively and 465 rpm, 7 minute stirring speed and Stirring time respectively. Results showed that the scanning electron micrographs revealed the effect of reinforcement on the matrix grain size, distribution of reinforcement and clustering/agglomeration of reinforcement in the matrix. Highest hardness, compressive strength, impact strength and flexural strength was obtained for AA 6063-6 wt.% Al_2O_3-1 wt.% Gr hybrid composite. Silicon carbide (SiC), alumina (Al_2O_3), boron carbide (B_4C), and silica (SiO_2) were some of the synthetic ceramic particulate that studied but silicon carbide and alumina were utilized compared to other synthetic particulates (*Oluwatosin et al. (2015)*). *Mohan Kumar et al. (2015)* investigated and studied the mechanical properties of Al- 4.5wt. % Cu Alloy reinforced with Fly ash and Silicon Carbide metal matrix composites produced by stir cast technique. In stir casting method reinforcements, stirrer and permanent mold were preheated to 400°C to remove moisture and gases from the surface of the reinforcements and equipment's before casting the composite. The Al - 4.5wt%Cu alloy was melted at a temperature of 730°C in a graphite crucible in induction furnace and degassing was carried out using hexa-chloroethane degassing Tablet. Results showed that the Al-4.5wt. % Cu Alloy/SiC/Fly ash composite was found to be higher hardness value than the base matrix Al-4.5wt% Cu alloy. Ultimate Tensile Strength of Al-4.5 wt. % Cu-3wt. % Fly ash-3wt. % SiC composites were found to be higher than base matrix. The improvement obtained in ultimate tensile strength of Al-4.5wt. % Cu alloy after insertion of 3 wt. % Fly ash and 3wt. % SiC particulates were 25.33% as compared to the base alloy. The micro structure study was showed that uniform distribution of reinforced particle in the matrix.

Mohammed et al. (2016) fabricated Al7075/bagasse ash-graphite of hybrid metal matrix composite (HMMC) by stir casting method. Reinforcements were added with three cases. In first case 2% constant of bagasse ash with varying graphite 1%, 3%, and 5%, in second case 4% bagasse ash, and in third case 6% constant with varying graphite percentage. Results showed that 6 % bagasse ash with varying graphite 1%, 3%, and 5% more enhanced mechanical properties achieved as compared to case one and two of bagasse–ash combination. The hardness, ultimate tensile strength and yielding strength of the developed composites were gradually increased with increasing the wt. % of reinforcement, while ductility decreased.

Keneth *et al.* (2016) fabricated and characterized physical and mechanical behaviour of Al-Mg-Si alloy matrix composites reinforced with alumina (0, 2,3 and 4 wt.% of Al_2O_3) and 10 wt.% of rice husk ash (RHA, an agro-waste) using two-step stir casting method. Final results showed that the hardness of the hybrid composites decreases with a maximum reduction of less than 11% for the Al-4 wt% RHA-6wt% Al_2O_3 composition (in comparison with the Al-10 wt% Al_2O_3 single reinforced composition). Tensile strength reductions of 8% and 13%, and specific strengths which were 3.56% and 7.7% lower were respectively observed for the 3 wt% and 4 wt% RHA containing hybrid composites. The specific strength, percent elongation and fracture toughness of the 2 wt% RHA containing hybrid composite was however, higher than that of the single Al_2O_3 reinforced and other hybrid composite compositions worked on.

Kenneth et al. (2018) studied microstructure, mechanical and fracture properties of groundnut shell ash (GSA) and silicon carbide (SiC) (weight ratios 0:1, 1:3, 1:1, 3:1, and 1:0 respectively) of aluminum matrix composites and manufactured by stir casting method. were used Groundnut shell ash of particle size less than 50 µm and average particle size of SiC is 28 µm and process parameters, Al–Mg–Si alloy billet melting temperature 750±30 $^{\circ}$C, Stirring slurry time 5-10 minute in 600°C, super-heated temperature 850±50°C, rotation of stirrer 400 rpm and stirring time 10 min. Results was showed that Hardness and tensile strength increased with increasing weight percent of the reinforcing phase but the strength and hardness dropped slightly with an increase in GSA content in the reinforcing phase, but lower than both RHA and bamboo leaf ash (BLA) reinforced aluminum hybrid composites. Percentage elongation improved marginally with increasing GSA content. For the 6 wt. % Al–Mg–Si/SiC–GSA grades, an average improvement of fracture toughness of 15.7% achieved as compared to 7.33% achieved in the 10 wt. % composite grades.

2.3 Effectible parameters on the properties of composite

The variable such as manufacturing methods, composition of matrix, reinforced particle distribution, weight percentage affect the mechanical properties of the composite but weight percentage of reinforcement was more affected on the mechanical properties like wear resistance, hardness, tensile strength (*Singh.et al. (2015*)).

2.4 Manufacturing methods and processing of metal matrix composites

Metal matrix composites are processing and developed by three types of production methods summarized as shown in Fig. 2.1.

- Solid metallurgical process
- Liquid metallurgical process
- In-situ processing

Solid metallurgical process includes; power blending and consolidation, diffusion bonding and physical vapour deposition. Liquid state processing includes; stir casting, squeeze casting, liquid infiltration, spray disposition. Stir- casting is very cost-effective manufacturing method than other types of methods.

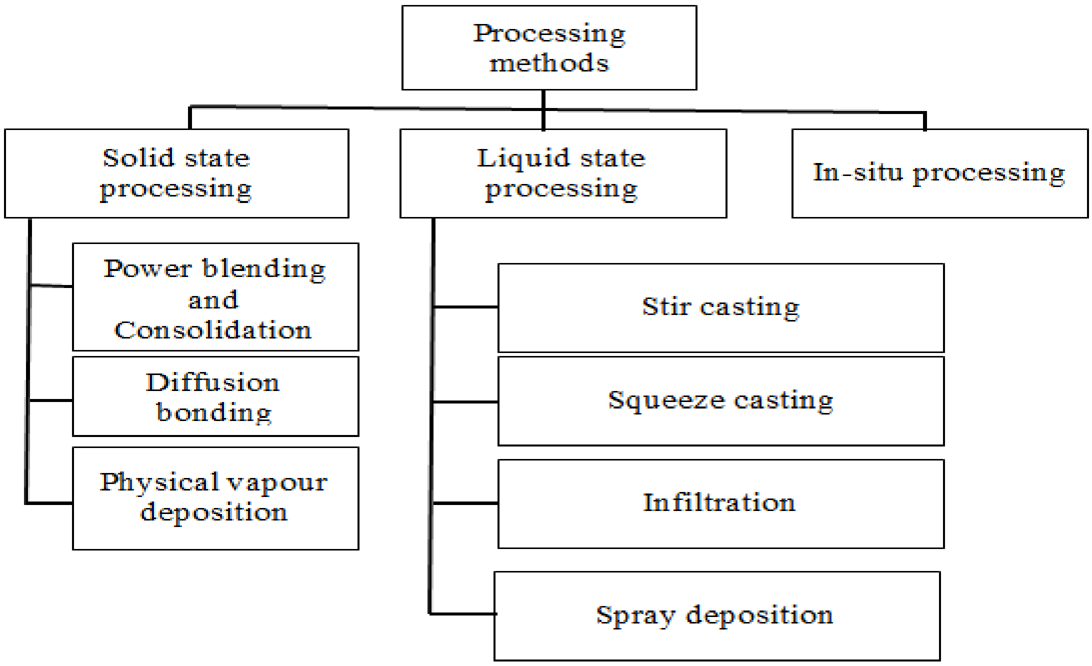


Figure2. 5Types of processing methods of metal matrix composites *(Trinh (2016))*

2.4.1 Stir casting

In a stir casting process, usually the particulate reinforcement is distributed into the aluminium melt by mechanical stirring. A recent development in stir casting process is a double stir casting or two-step mixing process. In this process, first the matrix material is heated to above its liquidus temperature. The melt is then cooled down to a temperature between the liquidus and solidus points to a semi-solid state. At this point the preheated reinforcement particles are added and mixed. Again the slurry is heated to a fully liquid state and mixed thoroughly. In double stir casting the resulting microstructure has been found to be more uniform as compared with conventional stirring. *Su et al. (2012)* designed a new three step stir casting method for fabrication of nano particle reinforced composite. First the reinforcement and Al particles are mixed using ball mills to break the initial clustering of nano particles. The composite powder is then incorporated into the melt with along with mechanical stirring. After adequate stirring the composite slurry is sonicated using an ultrasonic probe or transducer in order to improve the distribution of reinforced particles. The major advantage of stir casting process is its applicability to mass production. Compared to other fabrication methods, stir casting process costs as low as $1/3^{rd}$ to $1/10^{th}$ for mass production of metal matrix composites. *Maruyama (1998); Surappa et al. (1981).* Because of the above reasons, stir casting is the most widely used commercial method of producing aluminium based composites.

2.5 Reinforcements used for developing the composite

2.5.1 Silicon carbide

The silicon carbide (SiC) is a compound of silicon and carbon known as carborundum. Silicon carbide is produced by a solid-state reaction between sand (silicon dioxide) and petroleum coke (carbon) at very high temperatures in an electric arc furnace. As silicon and carbon atom both have four valence electrons in their outermost shell it reacts as covalent bond that eventually forms silicon carbide (carborundum).

2.4.2 Bagasse ash

Bagasse is a by-product from sugar industries which is burnt to generate power required for different activities in the factory. The burning of bagasse produces bagasse ash as a waste, which has a pozzolanic property that would potentially use as ceramic replacement material. Availability of bagasse fly ash is very abundant throughout the world sugar industries. It was found that about 1500 million ton of sugar cane produced every year in the world *(Ajay et al. (2007)).* Literatures indicated that there was about 300,000 tons of sugar production in Ethiopia. Sugar cane consisted about 30% bagasse whereas the sugar recovered was about 10%, and the bagasse left about 8% bagasse ash (this depends on the quality and type of the boiler, modern boilers release lower amount of bagasse ash) as a waste *(Ajay et al.(2007)) and Amin,(2010)).* Bagasse fly ash was tested in the world for utilization as a partial silicon carbide replacement material. Bagasse ash had rich in SiO_2 which helps to increasing the strength of aluminium such as high hardness, low coefficient of thermal expansion, high wear resistant and also good mechanical properties including high strength, thermal conductivity.

2.5 Application of bagasse fly ash

Bagasse fly ash and bagasse fibre efficiently used in different filed of industries like as a raw material in production of cement and reinforcement for composite materials etc. Utilization of industrial and agricultural waste products in the industry has been the focus of research for developing new materials (*Aigbodion.et al.* (*2010)).*

2.6 Interface between aluminum and fly-ash

There is no interfacial reaction between fly ash particle and aluminum matrix during casting. Such interfacial reaction would often result in the formation of brittle intermetallic compounds in the composite and degrade the mechanical and tribological properties. *David Raja et al. (2013)* reported a wider interfacial reaction zone and the formation of $MgAl_2O_4$ spinal at the fly ash-aluminum interface in the A356/fly ash AMC produced by stir casting.

2.7 Characterization and Industrial application of Aluminium hybrid matrix-Composite

Nosa idusuy et al. (2014) formulated a computational Study on the use of an Aluminum metal matrix composite and Aramid as alternative Brake disc and Brake Pad material using COMSOL multi physics software. The alternative material-aramid is suitable for the required function of a friction pad material. In the case of the aluminum metal matrix composite, the results showed that it is a suitable alternative though the conventionally used grey cast irons are no danger to the health and are affordable, AMC has a lower density and higher thermal conductivity as compared to grey cast iron (GCI) and it results in weight reduction of up to 50–60% in brake systems.

Pawar and Utpat *(2014)* developed of aluminum based silicon carbide particulate metal matrix composite for spur gear by stir casting technique using Melting temperature 750^{o}C. A composite was developed by adding silicon carbide in Aluminum metal by mass ratio 2.5%, 5%, 7.5% and 10% to study hardness, microstructure tests. The design analysis was done based on (Lewis Formula Hertz Theory) and Modeling and Finite Element Analysis by CATIA V5 and ANSYS 14.0 using input parameters; Input Power 10 kW, Input speed 1440 rpm, Gear material Al/SiC composite (With hardness 60 BHN, Gear Ratio 1, Pressure angle 20º, Number of teeth on driver (Z_1) 18 (Assumed initially for 20º involutes). Experimental results showed that of increased silicon carbide content, the hardness, and material toughness are enhanced and highest value is obtained at 10% SiC content. Micrographs of samples showed that homogeneous distribution of particles in the samples. The application of these composites can be for making power transmitting elements such as gears, which are subjected to continuous loading. Analytical results showed that stress highest stress distribution obtained in FEA analysis at tip of the teeth.

Rana et al. (2015) developed and synthesized Al5083 alloy and different weight % of Nano SiC (1, 2, 3 and 4 wt. %) of composite and wear Analysis of Al- Nano SiC Composite Automotive Cam to substitute the steel cam. Composite was developed by stir casting with melt temperature 760°C, N_2 gas for degassing at temperature of 680°C, size of reinforcement used, 35μm SiC and 40 nm SiC. Cam with values of different parameters as shown Fig 2.1: Base circle radius: 19.5 mm, Nose circle radius: 4.5 mm, Distance between both Centers: 24 mm, Total lift: 9 mm, Angle of lift: 150° were used.

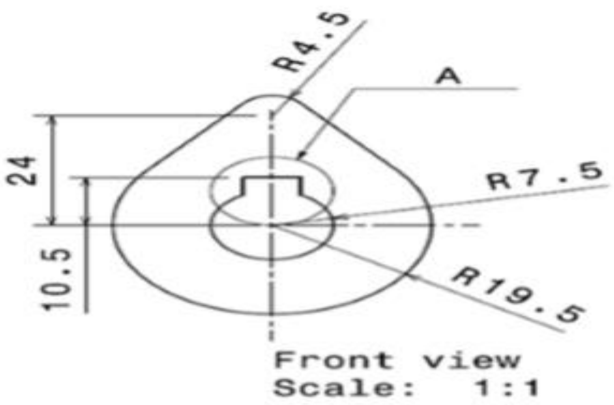


Figure2. 6 Detail drawing of cams

They were found that Al- 4 wt. % Nano SiC_p composite showed highest value of hardness (79 BHN) among the tested composite samples as shown Fig.2.4. At constant load of 1 kg and speed 250 rpm, CAM profile with Al-4 wt. % Nano SiC_p composites showed lowest wear at the test duration of 2 hours. The existing alloy steel cam has shown more wear than Al-4 % Nano SiC_p composites at 2 and 4-hour test durations. They concluded that the Al-SiC_p composites can be used as alternative material for the cam due to better mechanical properties, lighter weight and similar wear resistance to the existing alloy steel cams.

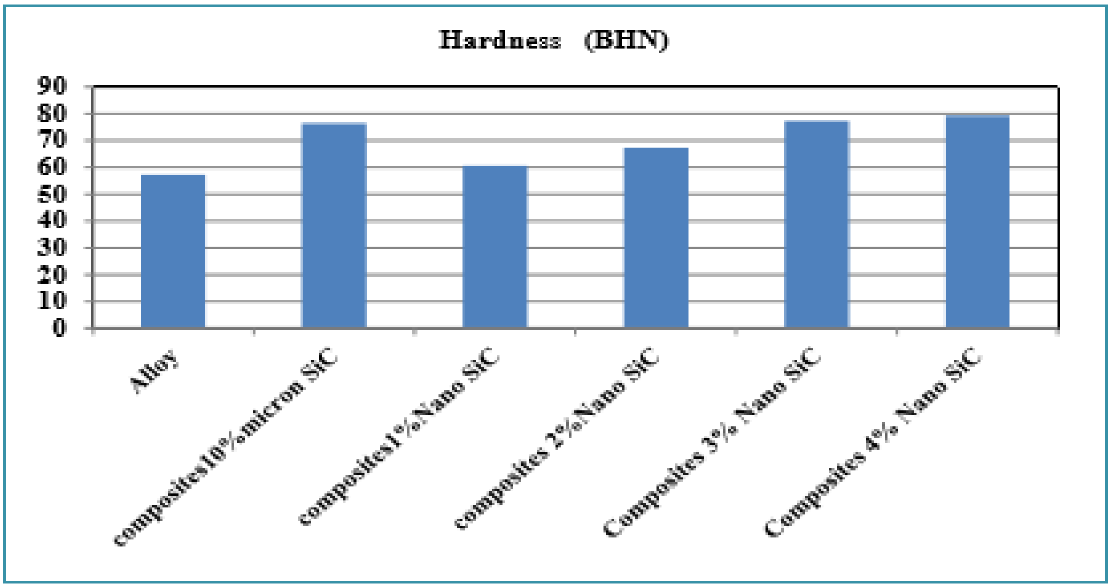


Figure2. 7 Comparison of Hardness of Alloy, composites with Micron SiC_p and Composites with Nano SiC_p *(R. S. Rana et al., (2015)).*

Sijo et al. (2016) reviewed contemplates the need of simulation or numerical methods for the prediction of mechanical characteristics of Al/SiC MMC manufactured by solid phase processes such as powder metallurgy and diffusion bonding, liquid phase processes such as stir casting, infiltration of liquid matrix into the reinforcements and in situ processes, and semi-solid method such as spray and rheo-casting and compo casting. Recent works cleared that clustering of reinforcement particles, wettability of reinforcement (SiC) in molten aluminum are the prime concern in the production of composites through stir casting. There concluded that experimental works to find out the optimum values are difficult and costly. Since stir casting process involves very high temperature, experimentation is difficult and dangerous. So proper simulations of stir casting process considering all relevant factors are necessary to yield good results, and it will help the researchers to identify strategies for experimentation.

Govindan and Viji (2017) analyzed the behavior of the brake disc with aluminum metal matrix composite material and conventional grey cast iron material in finite element software ANSYS. Parameters were used; Dimensions of the Disc Plate, Dimensions of the vehicle and body temperature and the Specification of HUYNDAI i20 car (Front Disc Brake Rotor). Comparison of stress distribution, displacement and temperature distribution for conventional and proposed material indicated that Al/SiC MMC with 10% SiC satisfies the requirement for disc brake application. There was concluded that Al/SiC MMC with 10% SiC can be used in automotive to replace the conventional material for improved vehicle performance.

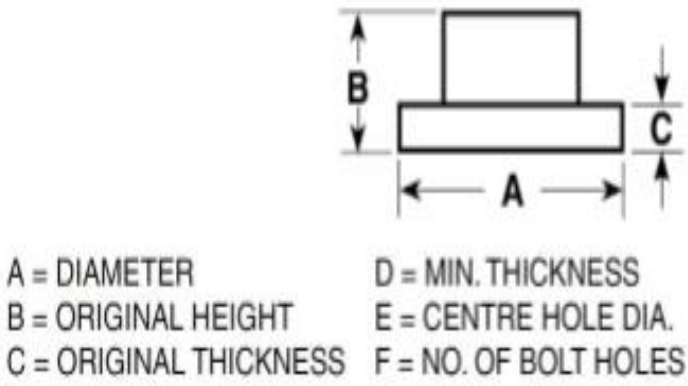


Figure2. 8 Specification of Disc Rotor (*M. Govindan and B.Viji, 2017*)

2.8 Summery of literatures

From the literature, it showed that different researchers developed new composite materials in different time by using different manufacturing methods. Based on their work the following review used to identify the research areas which will need further studies.

- Most researchers developed new composite materials and study mechanical properties of metal matrix composites.
- Some studies were on development of Al/bagasse ash and Al/SiC composites and not further studded on hybrid metal matrix (Al/SiC-bagasse fly ash) composite.
- Most studies were on weight percentage of reinforcements limited up to 10% addition.
- After reviewing for the existing literatures, it is observed that there is not enough research work was done on bagasse fly ash which used as reinforcement.

2.8. 1 Literature gaps

The previous researchers developed and studied different types of composites. The next generation manufacturing technology will show interest on production of cost effective, environmental friendly and good performance products using infinite (unlimited) resources. Natural fibres have good properties and cost effective for fabrication vehicle body parts. Those reinforcements are limited and finite resources for continuous production of composites (*Keneth et al.(2016)).*

The present work will be focused on fabrication and experimental analysis of Al/SiC composite using additional reinforcement bagasse fly ash which is largely abundant in Ethiopia sugar factories wasted from thermal power plant. This waste particle of ash causes serious environmental problems, such as land use, health hazards, and environmental danger. The usages of this waste as reinforcement for production of composite safeguard the human life and cost effective.

CHAPTER THREE

3. METHODOLOGY

The matrix and reinforcement selection for the hybrid metal matrix composite materials and fabrication requirements discussed in detail. In addition, the equipment used, fabrication method adopted and fabrication procedures, sample preparation and experimental procedure of the MMCs are also presented in this chapter. Further, the steps follow during mechanical tests and microstructure observation of the developed metal matrix composite (MMCs) also discussed.

3.1 Matrix and reinforcement materials

3.1.1 Aluminium alloy (Al6063)

Mg and Si are principal alloys in 6xxx series of aluminium alloys. Six series aluminium alloys have excellent properties such as machinability, weld -ability and formability to form complex structures. Mg-Si aluminium alloys have also light weight and good thermal stability properties. The Al6xxx alloys are chosen because of its wide use in automotive components and architectural materials, includes pistons, disk rotors, cylinder liners and decorative parts, rivets etc. Alloy 6063 is perhaps the most widely used because of its extrudability and is used for the automotive space frame parts *(Oyinbo (2015))*. Because it is much more than dispersing glue in MMC, the matrix alloy should be chosen only after giving careful consideration to its chemical compatibility with the reinforcement, to its ability to wet the reinforcement, and to its own characteristics properties and processing behavior. Due to this property and the availability of Al6063 is used as the working matrix material**.**

Table 3. 1 Physical and mechanical properties of Al 6063 (Oyinbo (2015)).

No.	**Physical properties**	Value
1	Density (x1000kg/m^3)	2.7
2	Melting point	655^0c
3	Electrical Resistivity(Ω .m)	0.033 x10^{-6}
4	Emissivity	0.02-0.1
5	Electrical Resistivity	52%IACS
	Mechanical properties	
1	Poisson’s Ratio	0.33
2	Elastic Modulus (GPa)	70-80
3	Tensile Strength (MPa)	90
4	Yield Strength (MPa)	48
5	Hardness (HB500)	25
6	Compression-strength (MPa)	295

3.1.1.2 Silicon carbide (SiC)

Silicon carbide (carborundum) is ceramic material made up of silicon and carbon atoms. It is rarely found in natural as mineral, but it has been produced in powder form. Silicon carbide material is chosen as a reinforcement material because it is widely used in high hardness and high thermal resistance applications, such as automotive brakes, cylinders, clutches, valves and bullet proof vests, semiconductor electronics etc. it also applicable in abrasive cutters, cutting tools, grinding wheels, nuclear reactors due to high temperature resistance, high thermal conductivity and low nuclear activation *(Lorrette et al. (2012))*. The grain size of silicon carbide varies micro to Nano sizes. One way of improving mechanical properties of composite is reducing grain size of reinforcements depends on processing methods.

The very small sizes of powder particle of SiC create agglomeration (mud) during casting of poor stirring. To over-come such problems Proper stirring action used from 5-10 minutes.

Figure 3.1 shows the micron level silicon carbide powders which used as a reinforcement ceramic material to fabricate Al/SiC-bagasse fly-ash hybrid composite.

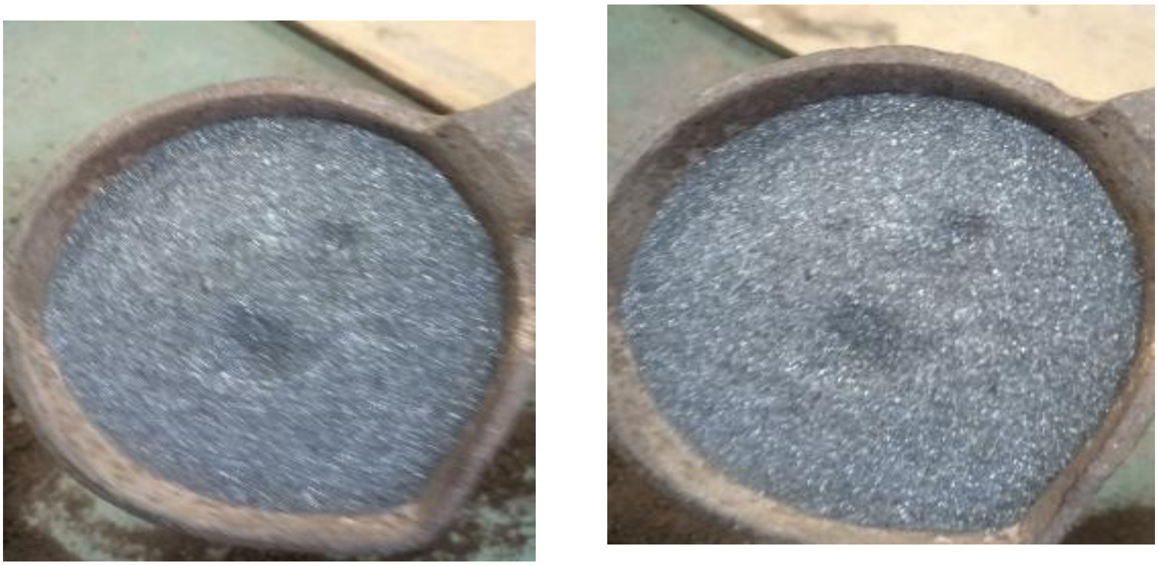


Figure 3. 1Silicon carbide powders

3.1.1.3 Bagasse fly ash (BFA)

Bagasse is a produced from sugar cane plant during processing in sugar production. It is largely abundant in sugar industries in the world. Bagasse fly ash has been produced during combustion of bagasse to generate steam power which used to generate electrical power in sugar industries. This ash powder causes series problem in environmental pollution, land use, health risks etc. the major composition of the ash different weight percentage of SiO_2, Al_2O_3, Fe_2O_3, MgO, but it varies in different countries. For present work, the bagasse ash was taken from Wenjji Shewa Ethiopia sugar factory which is largely abundant as shown in Fig. 3. 2. Bagasse fly-ash is chosen due to its low weight and density and increase the strength of the composite in which it is added. The ash was manually crushed and screened using sieves to make fine powder particles.

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

3.2 Methods

3.2.1. Physical Properties and chemical composition of bagasse fly-ash

Density – 1.96g/cc

The specific gravity of fly ash varies in the range of 0.6-2.8 gm/cc.

Table shows the chemical composition of the bagasse fly-ash by chemical analysis. The test was done on Dangote cement industries (Ethiopia) PLC.

Table 3. 2 Chemical composition of bagasse ash in weight percentage

composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
	%	%	%	%	%
wt.%	66.55	10.25	5.48	3.26	1.17

The sugar cane bagasse ash has rich in SiO_2, which is good to replace SiC and used as reinforcement for metal matrix composites.(*Baradeswaran and Perumal (2014))* reported that Alumina (Al_2O_3) also a promise reinforcement material for production of metal matrix composite.

3.2.2 Powders mixing

Al-5% volume of SiC powders are mixed by stirrer on milling machine. The calculation for mass of aluminium, silicon carbide and bagasse fly-ash powder needed for a sample of 130mm length and 15mm diameter. Pre-hearing of reinforcements from 600-700^{o}C of temperature before added in molten metal. Weight of powder added in to matrix depends the sample size.

3.2.3 Stirring reinforcements in molten metal

The blade of stirrer assembled on rotating part of milling machine speed of 500 rpm, 5-10 minute stirring speed and time respectively, used to mix matrix and reinforcements.

3.2.4 Mold preparation and fabrication the composite

To facilitate the easy removal of compacted specimen, tapered section has been used. The size of mold depends on the size of samples which were used for tests. The required amount of reinforcements and matrix for each sample weighed and added in the crucible. Three samples were manufactured on one mold which has same composition of reinforcement. This is because of three trials of conducted experiments.

The following chart shows general procedure of research work clearly summarized.

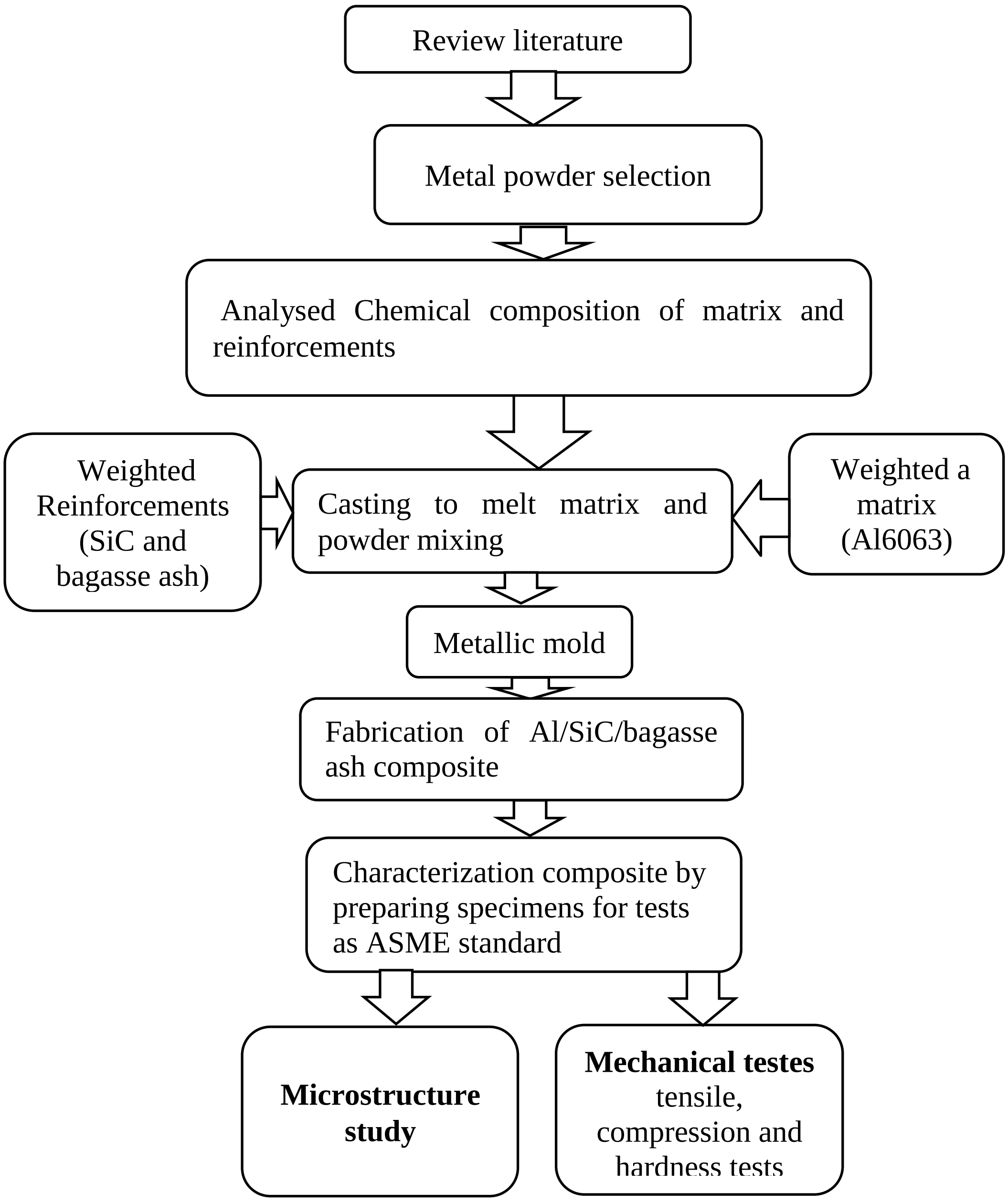


Figure 3. 3General Procedure of the research work

3.3 Sampling and sample method

The total number of experiments were conducted in the work are 8 (eight) with three trials for each type of mechanical testes. The wt. % composition of reinforcements was taken from literatures, which have highest improvement in mechanical properties. The composition are 7.5, 10 wt. % of SiC and 7.5, 10, 12 wt. % of bagasse fly-ash and form eight combination of experiments. For specimen preparation which have different percentage composition of reinforcements manufactured as shown in Table 3.3 and Table 3.4.

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

S.No	Wt. % of Silicon carbide (SiC)	Wt. % of Bagasse fly-ash	Al/SiC/ bagasse fly-ash
1	7.5	7.5	Al6063-7.5%SiC-7.5% bagasse ash
2	7.5	10	Al6063-7.5% SiC-10% bagasse ash
3	7.5	12	Al6063-7.5%SiC-12% bagasse ash
4	10	7.5	Al6063-10%SiC-7.5% bagasse ash
5	10	10	Al6063-10%SiC-10%bagasse ash
6	10	12	Al6063-10%SiC-12% bagasse ash

Table 3. 4Composite content in wt. % of silicon carbide only

S.No	Wt. % of Al	Wt. % of SiC	Al/SiC
1	92.5	7.5	Al6063-7.5%SiC
2	90	10	Al6063-10%SiC

3.4 Equipment's used for the project work

Table 3.6 shows the main equipment's which were used for testing mechanical properties of the developed composite. Casting set up was used to melt the matrix aluminium alloy during fabrication of Al/SiC –bagasse ash composite.

Table 3. 5Equipment's required for the project work

S. No	Equipment	Task (Test name)	Machine model
1	Universal test machine (UTS)	Tensile strength test	WP 310 HYDROLIC UTM-Gunt Hamburg
2	Vickers hardness test machine	Hardness test	HVS-50
3	Optical microscope	Micro structure test	Huvitz HR-300 series
4	casting set up	To melt and stir materials	

3.5 Mold preparation and fabrication

The sand mold was prepared for fabrication of Al/SiC/fly-ash hybrid composite based on the size of required specimens. 30mm diameter and 150mm length, 20mm diameter and 60mm length, specimen size was prepared for tensile test and compression test respectively, while for Micro hardness and microstructure specimens cut from each tensile test specimens by abrasive cuter machine.

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.

3.5.1 Fabrication

The matrix aluminum melted in a crucible which placed inside furnace. It melted at a temperature of 700°C and reinforcements added and stirring with a molten metal for 5-10 minute. The stirrer blade assembled on hand drilling machine. Process parameters should be considered during casting of metal matrix composite materials are:

- ✓ Melting temperature
- ✓ Stirring speed and stirring time
- ✓ Percentage composition of reinforcements

The stirring of slurry during fabrication shown as Figure 3.4, the stirrer assembled on drilling machine which can be stirring the reinforcements with molten metal inside a crucible.

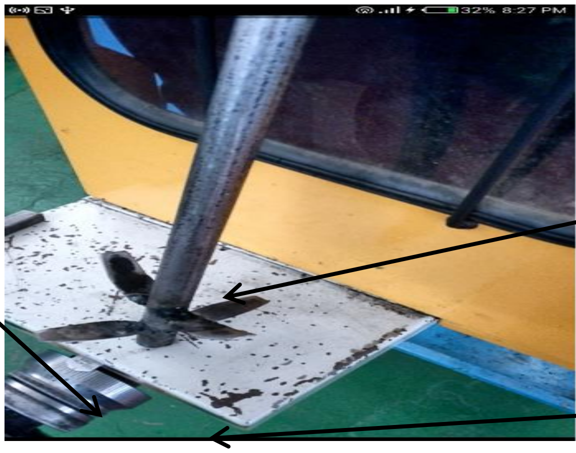


Figure 3. 4 stirrer set up on drilling machine

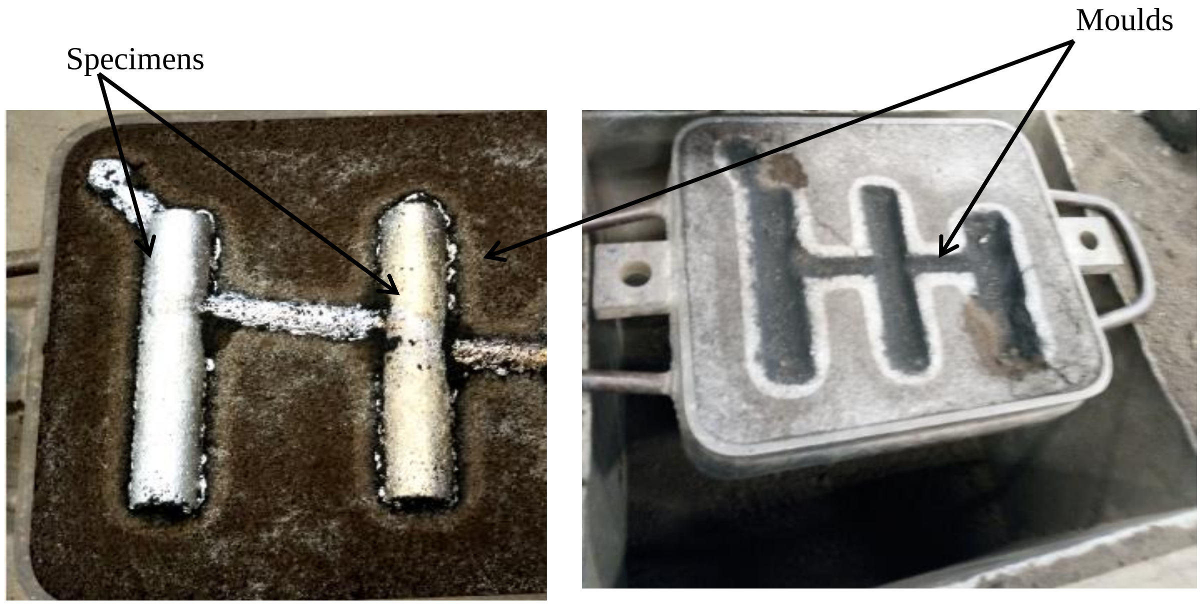


Figure 3. 5 Mold and casted specimen

3.5.2 Machining of samples for testing

Al/SiC –bagasse fly-ash composite specimens machined on laze for each type of mechanical testes shown as Figure 3.6. In addition, abrasive cutter was used for cutting the specimens.

Figure 3. 6 Machining of samples

3.5.3 Tensile test specimen

The tensile test specimens of metal matrix composites are prepared based on the ASTM Standard D 3552.the flat and round configuration of metal matrix specimens are adopted. If the composite produced by diffusion bonding, flat shape of specimen would produce. In other case, metal matrix composite produced by various liquid infiltrations and other methods used for producing massive materials are better suited to circular cross-sectional shapes *(Davis and Associates, (2004)).*

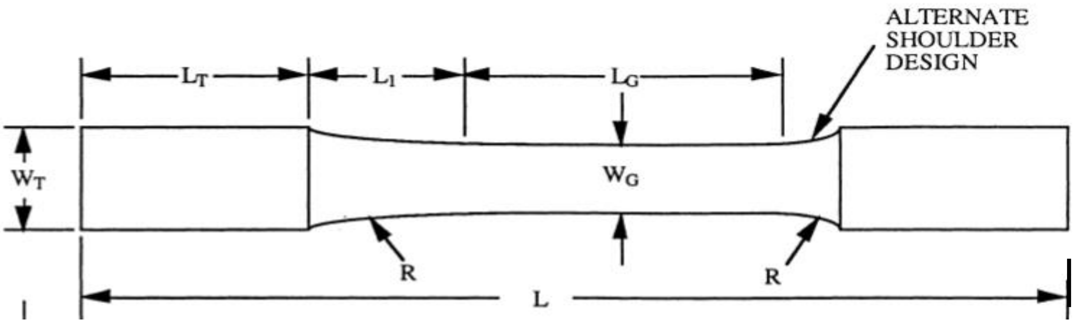


Figure 3. 7 Metal matrix tensile test specimen (*Davis & Associates, 2004)*

Based on the ASTM Standard D 3552:

L_G= 25.4mm	W_G =6.35 or 9.525mm
L_T= 25.4	W_T =19.05mm
L_1= 25.4	R=12.7mm
L= 114.3	

3.5.4 Compression tests

The specimen was prepared by cutting the cast hybrid composite based on the proportion of diameter with height of specimen.

$$H = 3D$$

Where:

H height of specimen

D diameter of specimen

For the present work the diameter of specimen used 15mm and height of the specimen is 45mm used.

3. 5.5 Microstructure and micro hardness specimen preparation

Microstructures of the developed composite were studied by scanning electron microscope and optical microscope. In the present investigation optical microscope (model Huvitz HR-300 series) was used for analyzing microstructure of the hybrid composite. For the microstructure examine of the composites, the casted samples were ground using abrasive silicon carbide paper of different grit sizes (polished using diamond paste). The specimen was etched using Keller’s reagent before it is examined using optical microscopy.

The specimen preparation procedure is as follows.

- Cut the specimen by 20mm diameter and 10mm height using abrasive cutter.
- Smooth the surface using sand paper (grinding).
- Mounting.
- Standard polishing

- Etching the specimens using chemicals.
- Conduct the test (microstructure on optical microscope).

3.5.5.1 Mounting

Meta press- A is consist of upper ram, lower ram, cylinder, heating part, cooling part, mold. This system automatic mounting press has automatically operated pressure, heat, cooling by water as shown in Figure 3.8.

Figure 3. 8 Mounting press machines.

3.5.5.2 Standard polishing and etching

Metal matrix composites are polished using high performance diamond suspension. Keller's etchants used to observe detail grains boundary and refinement.

Table 3. 6 Keller's etchant preparation for microstructure observation

Keller's etchant	Concentration	Conditions
Methanol	25ml	10-30 seconds
Hydro-chloric acid	25ml	
Nitric acid	25ml	
Hydrofluoric acid	1 drop	

CHAPTER FOUR

4. EXPERIMENTAL ANALYSIS

4.1 Experimental procedures

4.1.1 Sample preparation

4.1.1.1 Fabrication of the hybrid (Al/SiC/bagasse fly-ash) composite

The composite consists of aluminum 6063 cast as matrix and SiC and bagasse fly-ash as reinforcement materials. In this work, the least cost and flexible design type method of fabrication is used. Stir casting technique used to fabricate the hybrid composite Al/SiC-bagasse fly-ash. The mechanical tests hardness, tensile and compression tests of the Al/SiC and Al/SiC/fly-ash composite investigated.

The steps in involved in composite preparation were;

- Weighted the required amount of aluminium and place in crucible in to a furnace.
- Heated the crucible above the liquids temperature of aluminium (above 710°C).
- Once the temperature is attained, same temperature is maintained for 10 minutes to confirm molten state of the metal.
- The corresponding wt. % of reinforcement (SiC and fly-ash) is weighted and preheats to 400°C to remove moisture. And also, pre heat the mould to minimize cast defects.
- After achieving complete liquid state adding the SiC and bagasse ash, the melt was stirred and after stirring 5-10 minutes the slag was removed and the melt was powered in the permanent moulds.
- Prepared eight different moulds for samples with varying wt. % of reinforcements and two additional moulds without addition of bagasse fly-ash and for base metal (Al) sample.
- Withdrawal of the composite from the mould after solidification.
- Sample produced based on ASTM standards and ready for tests.

The size and shape of the specimen prepared based on ASTM standard for each type of mechanical tests. The composites produced is given designation based on the weight percent of the reinforcing phase and the weight ratio of SiC and bagasse fly-ash in the reinforcement. The composite content adjusted so as to contain 7.5%, 10%, of SiC and 7.5%, 10%, 12%, of bagasse fly-ash.

The specimens were prepared by the steps include:

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

4.1.2 Estimate Wt. % percentage of reinforcements and matrix

Volume of reinforcement estimated by:

$$V_f = m_f \times \rho_f$$

The dimension of the specimen to be manufactured depends on the type of test conducted. The input parameters for specimen dimension 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).

Based on the Tensile testing machine UTM of WP 310 ASTM standard

Maximum holding size of grip=12 mm

Minimum vertical movement= 50 mm

Maximum vertical movement =800 mm

The volume of mold estimated used for weighted the required amount of matrix (Al6063) and reinforcements (SiC and bagasse fly-ash) to manufacture the specimen. The size and shape of samples depends types of tests conducted, such as;

- ➢ Tensile test specimen
- ➢ Compression test specimen
- ➢ Hardness test sample
- ➢ Microstructure specimen preparation

4.1.2.1 Tensile test specimen production

The size of specimens depends on mold size and shape, which estimated as follows.

$$\text{Volume (area } \times \text{ height) of mold} = \pi(d^2/4) \times H$$

Where: d is diameter of mold and H is height of mold

$$\text{Volume} = \pi\,(3^2/4) \times 15 = 106\text{cm}^3$$

Density of SiC alloy=3.21g/cm^3

Density of Al alloy=2.72g/cm^3

Density of bagasse ash =1.95g/cm^3

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

For addition of 7.5% of SiC and 7.5% of bagasse fly-ash

$$\text{Weight of aluminum alloy} = (85/100)\,X106X2.72 = 245.07\text{grams}$$

$$\text{Weight of SiC} = (7.5/100)X106X3.21 = 25.52\text{grams}$$

$$\text{Weight of fly} - \text{ash} = (7.5/100) \times 106 \times 1.95 = 15.5\text{gram}$$

For addition of 7.5% of SiC and 10% of bagasse fly-ash

$$\text{Weight of aluminum alloy} = \left(\frac{82.5}{100}\right)X106X2.72 = 237.86\text{grams}$$

$$\text{Weight of SiC} = (7.5/100)X106X3.21 = 25.52\text{grams}$$

$$\text{Weight of fly} - \text{ash} = (10/100) \times 106 \times 1.95 = 20.67\text{grams}$$

For addition of 7.5% of SiC and 12% of bagasse fly-ash

$$\text{Weight of aluminum alloy} = \left(\frac{80.5}{100}\right)X106X2.72 = 232.09\text{grams} = 696.27$$

$$\text{Weight of SiC} = (7.5/100)X106X3.21 = 25.52\text{grams} = 76.56$$

$$\text{Weight of fly} - \text{ash} = (12/100) \times 106 \times 1.95 = 24.80\text{grams}$$

For Addition of 10% SiC and 7.5% bagasse fly-ash

$$\text{Weight of aluminum alloy} = \left(\frac{82.5}{100}\right)X106X2.72 = 237.86\text{grams}$$

$$\text{Weight of SiC} = (10/100)\,X106X3.21 = 34.03\text{grams}$$

$$\text{Weight of bagasse ash} = (7.5/100) \times 106 \times 1.95 = 15.50\text{gram}$$

For Addition of 10% SiC and 10% bagasse fly-ash

$$\text{Weight of aluminum alloy} = (80/100)\,X106X2.72 = 230.65\text{gram}$$

$$\text{Weight of SiC} = (10/100)\,X106X3.21 = 34.03\text{grams}$$

$$\text{Weight of bagasse ash} = (10/100) \times 106 \times 1.95 = 20.67\text{grams}$$

For Addition of 10% SiC and 12% bagasse fly-ash

$$\text{Weight of aluminum alloy} = (78/100)\,X106X2.7 = 224.88\text{grams}$$

$$\text{Weight of SiC} = (10/100)\,X106X3.21 = 34.03\text{grams}$$

$$\text{Weight of bagasse ash} = (12/100) \times 106 \times 1.95 = 24.80\text{grams}$$

For addition of 7.5% of SiC only

$$\text{Weight of aluminum alloy} = (92.5/100)X106X2.72 = 266.69\text{grams}$$

$$Weight\ \text{of SiC} = (7.5/100)X106X3.21 = 25.52\text{grams}$$

For addition of 10% of SiC only

$$\text{Weight of aluminum alloy} = (90/100)X106X2.72 = 259.49\text{grams}$$

$$\text{Weight of SiC} = (10/100)\,X106X3.21 = 34.03\text{grams}$$

$$\text{Total Aluminum required} = 2 \times 1.408\text{kg} + 2 \times 0.526\text{kg} = 3.87\text{kg}$$

$$\text{Total silicon carbide} = 2 \times 178.65\text{grams} + 2 \times 59.55\text{grams} = 476\text{grams}$$

$$\text{Total weight of bagasse ash} = 2 \times 121.94\text{grams} = 243.88\text{grams}$$

4.1.2.2 Compression and hardness test specimen production

$$\text{Volume (area } \times \text{length) of composite} = \pi\,(42/4) \times 5 = 62.8\text{cm}^3$$

Where: A is area of mold and

L is length of mold

V= 35.33cm^3

Density of SiC alloy=3.21g/cm^3

Density of Al alloy=2.72g/cm^3

Density of bagasse ash =1.95g/cm^3

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

For addition of 7.5% of SiC and 7.5% of bagasse fly-ash

$$\text{Weight of aluminum alloy} = (85/100)\,\text{X}35.33\text{X}2.72 = 81.68\text{gram}$$

$$\text{Weight of SiC} = (7.5/100)\text{X}35.33\text{X}3.21 = 8.51\text{gram}$$

$$\text{Weight of fly} - \text{ash} = (7.5/100) \times 35.33 \times 1.95 = 5.17\text{gram}$$

For addition of 7.5% of SiC and 10% of bagasse fly-ash

$$\text{Weight of aluminum alloy} = (82.5/100)\,\text{X}35.33\text{X}2.72 = 79.28\text{gram}$$

$$\text{Weight of SiC} = (7.5/100)\text{X}35.33\text{X}3.21 = 8.51\text{grams}$$

$$\text{Weight of fly} - \text{ash} = (10/100) \times 35.33 \times 1.95 = 6.89\text{gram}$$

For addition of 7.5% of SiC and 12% of bagasse fly-ash

$$Weight\ of\ aluminum\ alloy = (80.5/100)\,X35.33X2.72 = 77.36gram$$

$$\text{Weight of SiC} = (7.5/100)\text{X}35.33\text{X}3.21 = 8.51\text{grams}$$

$$\text{Weight of fly} - \text{ash} = (12/100) \times 35.33 \times 1.95 = 8.27\text{gram}$$

For addition of 7.5% of SiC only

$$\text{Weight of aluminum alloy} = (92.5/100)\text{X}35.33\text{X}2.72 = 88.89\text{gram}$$

$$\text{Weight of SiC} = (7.5/100)\text{X}35.33\text{X}3.21 = 8.51\text{gram}$$

Total Aluminum required= 327.21

Total silicon carbide =34.04gram

Total weight of bagasse ash= 20.33gra

CHAPTER FIVE

5. RESULT AND DESICCATION

5.1 Fabrication of Al/SiC/bagasse ash composite

Figure 4.1 shows the manufactured samples removed from molds which was ready for machining and prepared samples.

Figure 5. 1 Manufacturing of Al/SiC-bagasse ash composite

5.1.1 Machining

Machining is performed on laze machine using carbide cutting tool. The specimens prepared based on ASME standard to conduct tensile, compression, hardness and microstructure tests. Figure 4.2 (a) showed the specimens machined and prepared for tensile tests

Figure 5. 2(a) Tensile test specimens   Figure 5. 2(b) Specimens for tensile and Compression test

5.2 Mechanical tests of the Al/SiC-bagasse ash composite

5.2.1 Tensile test

Tensile strength of a material is the ability of resist loads which applied in the longitudinal direction of sample. Circular specimens are machined with a specific gage length, specimen diameter (D), notch diameter (d), fillet radius (r) of 100mm, 12mm, 7.5mm and 9mm respectively. The tensile test is conducted on WP 310 computerized hydraulic universal testing machine (UTM) as shown Fig 4.3 (A) and plastic deformation of the the tensile test specimen shown in Fig 5.3 (B) and Fig 5.4. This test is carried out at a constant crosshead speed of 5 mm/min in a WP-300 hydraulic tensile testing machine of 50 kN capacities. The results of the tensile tests for different composites are presented in Table-5.1. The test results showed the compared results between single reinforced composite (Al/SiC) and hybrid metal matrix composite (Al/SiC- bagasse ash) in addition to base metal (Al6063). The variation of average tensile strength in each single and hybrid composite presented in Table 5.1 and 5.2. Tensile test results showed that increasing percentage of reinforcement (SiC) only in the matrix reduce average tensile strength while increasing reinforcements, SiC and Bagasse ash improves tensile strength of Al/SiC- bagasse ash composite. At 10% SiC- 10% bagasse ash hybrid composite have better improvement than other single and hybrid composites.

Figure 5. 3 (A) Tensile test set up on UTM

Figure 5. 3(B) Sample failure during test

Figure 5. 4 Failure of tensile test specimens

Table 5. 1 Tensile strength of the developed hybrid metal matrix composites

S. No	Al/SiC/fly-ash composite	Ultimate tensile strength (MPa)			Average ultimate tensile strength (MPa)
		Test 1	Test 2	Test 3	
1	Al6063-7.5%SiC-7.5% bagasse ash	52.49	81.71	70.4	68.2
2	Al6063-7.5% SiC-10% bagasse ash	88.5	76.43	60.7	75.2
3	Al6063-7.5%SiC-12% bagasse ash	74.5	61.12	78.98	71.6
4	Al6063-10%SiC-7.5% bagasse ash	76.8	68.8	76.32	73.89
5	Al6063-10%SiC-10%bagasse ash	84.71	87.53	76.62	82.95
6	Al6063-10%SiC-12% bagasse ash	87.5	79.00	85.09	83.86

Table 5. 2 Tensile strength of the developed Al/SiC matrix composites

S.No	Al/SiC composite	Ultimate tensile strength (MPa)			Average ultimate tensile strength (MPa)
		Test1	Test 2	Test 3	
1	Al6063-7.5%SiC	78.46	45.4	64.87	62.91
2	Al6063-10%SiC	74.24	65.34	47.5	62.36

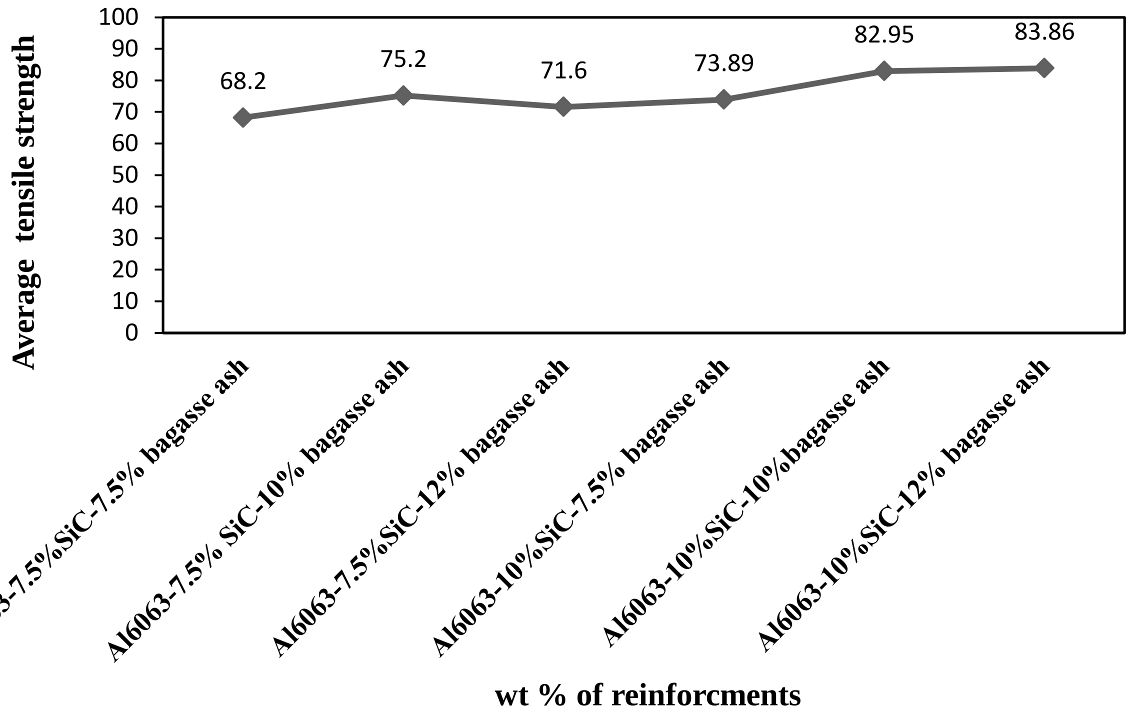


Figure 5. 5Tensile strength and weight percentage of reinforcements

SiC and FA particles are very effective in improving the tensile strength of the composite. It may be due to the strengthening mechanism by load transfer of the reinforcement. The addition of SiC and Fly ash particles in the matrix induces much strength to matrix alloy by offering more resistance to tensile stresses. It is well known that the thermal expansion coefficient of SiC and Fly ash particle is 3.25 x 10^6/°C and for aluminium alloy is 23 x 10^6/°C. The thermal mismatch between matrix and the reinforcement causes higher dislocation density in the matrix and load bearing capacity of the hard particles which subsequently increases the composite strength. Fig. 5.5 reveals the fracture surface of AA6063 10wt. %SiC 7.5wt. % Fly ash composite. It shows a network of dimples whose size is smaller compared to matrix alloy. The Fly ash and Silicon carbide refined the grain size of matrix alloy and reduced the ductility which resulted in smaller size dimples.

5.2.2 Compression test

45 mm height and 15 mm specimen dimensions are used to carry out compression test of Al/SiC composite with and without addition of bagasse fly-ash. The test was conducted three trial of the same composition of specimens. The compression strength of Al/SiC single reinforced composite and hybrid Al/SiC –bagasse ash composite compared on Table 5.3 and Table 5.4, in addition it has been shown in Appendix A. Results clearly showed that higher average compression strength obtained by adding bagasse fly-ash than single reinforced (Al/SiC) composite. The average compression strength increases when increasing wt. % of reinforcements as shown below in Fig. 5.8. Al/ 10Wt. % SiC-12 Wt. % bagasse ash composite has highest average compression strength value among all single reinforced and hybrid reinforced composite samples. The percentage elongation of composite increased with increasing the weight percentage of reinforcements. In-case of Al/SiC composite elongation of the developed composite decreased while it is improved adding bagasse fly-ash. The highest improvement is obtained in both tensile and compression strengths, when increasing wt. % of bagasse ash up to 12%.

Figure 5. 6 Tensile and compression test samples

Figure 5. 7 Failure of compression test samples

Table 5. 3 Compression strength of Al/SiC/bagasse ash composite of different Wt. % of reinforcements

S.No	**Al/SiC/fly-ash composite**	**Compression strength (MPa)**			**Average Compression strength (MPa)**
		Test 1	Test 2	Test 3	
1	Al6063-7.5%SiC-7.5% bagasse ash	225.79	385.76	396	335.85
2	Al6063-7.5%SiC-10% bagasse ash	322.3	382.4	309.4	338.03
3	Al6063-7.5%SiC-12% bagasse ash	375.57	324.52	333.83	344.64
4	Al6063-10%SiC-7.5% bagasse ash	329.03	367.5	346.54	347.69
5	Al6063-10%SiC-10%bagasse ash	334.34	407.53	309.24	350.37
6	Al6063-10%SiC-12% bagasse ash	361.9	390.7	387.7	380.10

Table 5. 4Compression strength of Al/SiC composite fabricated with-out addition of bagasse fly-ash

S.No	Al/SiC composite	Compression strength (MPa)			Average compression strength
		Test 1	Test 2	Test 3	
1	Al6063-7.5%SiC	313.36	320.87	305.75	313.32
2	Al6063-10%SiC	342.98	376.13	290.85	336.65

From the experimental results of Table 5.3 and Table 5.4, the average compression strength of hybrid matrix composite have more improved compared with single reinforced composites. The results showed that the compression strength slightly increased with increasing composition of SiC and bagasse fly-ash as shown figure 5.8. The maximum increment of compression value showed at Al6063-10%SiC-12% bagasse ash composition compared to single and hybrid composites. This is because of increasing the dislocation density of bagasse fly ash in a matrix material.

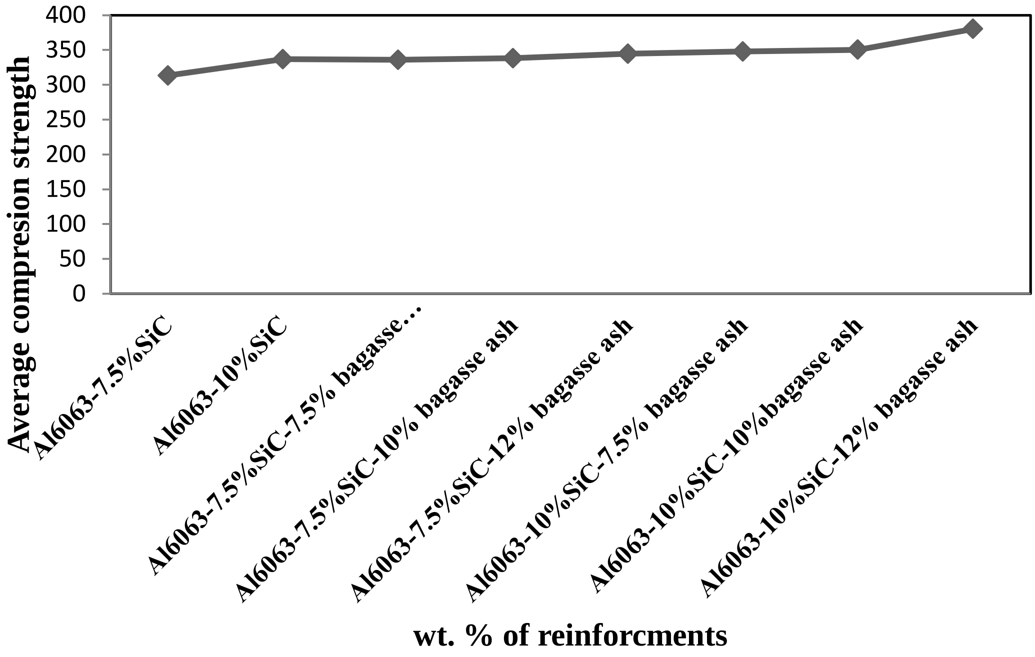


Figure 5. 8Compression strength and wt. % of reinforcements

5.2.3 Vickers hardness test

The Rockwell hardness test conducted using 5kg and 10kg force of indenter on HVS-50 model hardness test machine. The indenter applies different forces at different portion of sample surface. The six trials (three trials using 5kg load and three trial using 10Kg load) of tests conducted on specific sample and were taken the average value.

Table 5. 5Hardness strength of Al/SiC/bagasse ash composite

S.No	Al/SiC/fly-ash composite	Vickers hardness (HV)			Average HV
		Test 1	Test 2	Test 3	
1	Al6063-7.5%SiC-7.5% bagasse ash	91.2.4	85.01	84.3	84.7
2	Al6063-7.5% SiC-10% bagasse ash	95.6	95.4	99.8	96.9
3	Al6063-7.5%SiC-12% bagasse ash	71.6	75.8	70.8	72.7
4	Al6063-10%SiC-7.5% bagasse ash	78.13	71.07	84.3	77.83
5	Al6063-10%SiC-10%bagasse ash	83.5	88.6	97.4	89.8
6	Al6063-10%SiC-12% bagasse ash	68.13	85.63	79.91	77.89

Table 5. 6Hardness of Al/SiC composite fabricated with-out addition of bagasse fly-ash.

No	Al/SiC composite	Vickers hardness (HV)			Average HV
		Test 1	test 2	test 3	
1	Al6063-7.5%SiC	93.2	43.6	43.3	60
2	Al6063-10%SiC	90.2	67.5	78.4	78.7

The Vickers micro-hardness of cast Al6063 base matrix and their composites containing 7.5,10 SiC and 7.5, 10, and 12 bagasse fly- ash compositions by wt. % are evaluated using diamond indenter at an applied load of 5 and 10N are presented in Fig 5.10. From the Figure, it can be observed that the hardness of the composite is greater than that of its cast matrix alloy. The composites containing higher filler content exhibits higher hardness. Further, it can be observed that the hardness of the Al6063/SiC- bagasse fly-ash composite are higher than that of the composite of Al6063-SiC. Experimental results show that the Al/7.5%SiC-10% bagasse ash and Al/10%SiC-10% bagasse ash composite has highest hardness value as shown Table 5.5 and Table 5.6. Vickers hardness test of hybrid composite increased with increasing weight percentage of reinforcements up to maximum addition of 10 wt. % as shown Fig. 5.9. Addition of reinforcement particles in the matrix increases the surface area of the reinforcement and the matrix grain sizes are reduced. The presence of such hard surface area of particles offers more resistance to plastic deformation which leads to increase in the hardness of composites. (*David Raja et al. (2013))* reported that the presence of hard ceramic phase in the soft ductile matrix reduces the ductility of composites due to reduction of ductile metal content which significantly increases the hardness value evaluated against the weight percentage of SiC and Fly ash particulates. The hardness of the hybrid composites increased slightly with increase in bagasse fly-ash content with a maximum increment of 17% observed for the Al6063-7.5% SiC-10% bagasse ash composition (in comparison with the Al-10 wt% SiC-7.5 fly-ash reinforced composition) up to Al6063-10%SiC-12% bagasse ash composition.

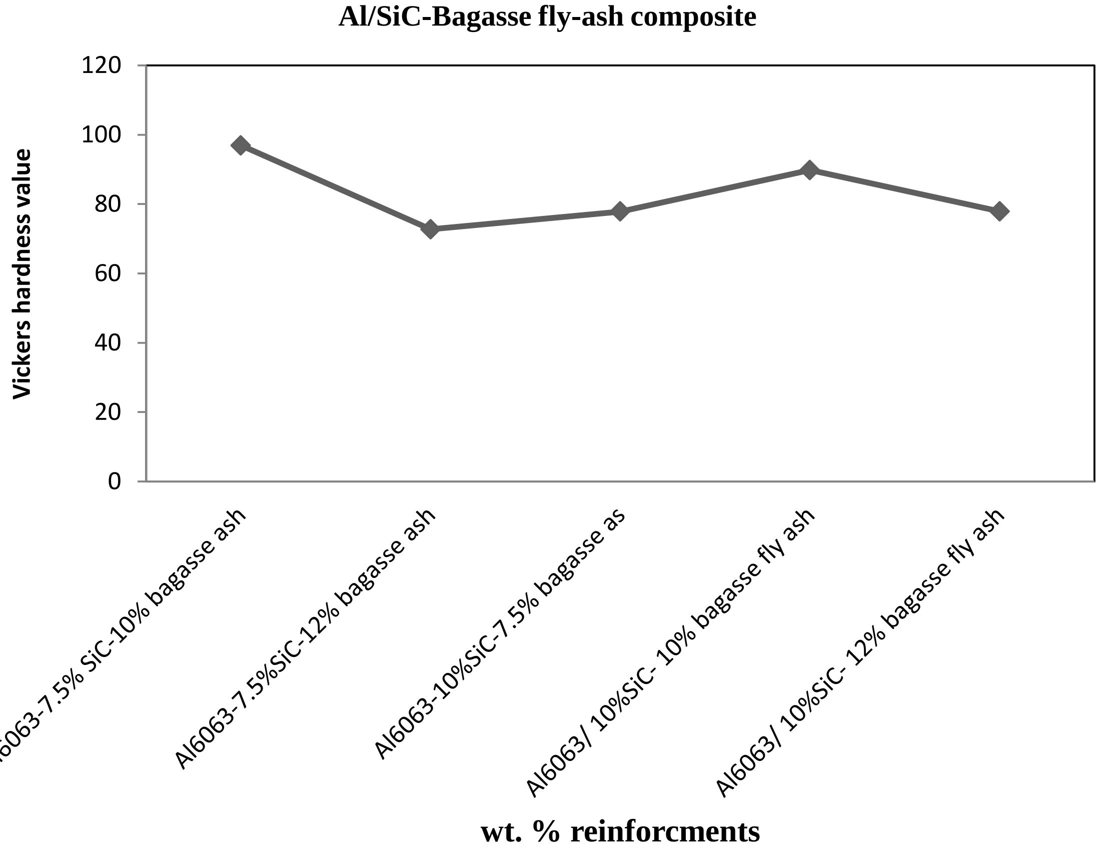
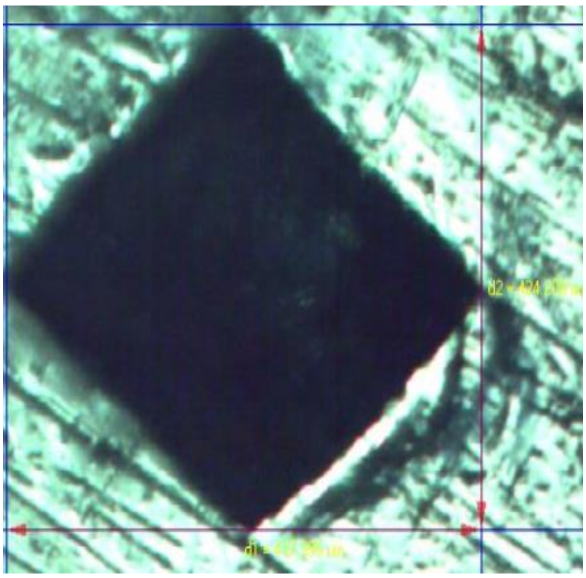


Figure 5. 9 Average Vickers hardness value of Al/SiC-bagasse fly-ash composite

With the help of microscope, indent caused by the ball indenter is measured, an inbuilt micrometres scale is present in the microscope, which is adjustable according to the position of indent we can adjust it to measure the diameter of indent.



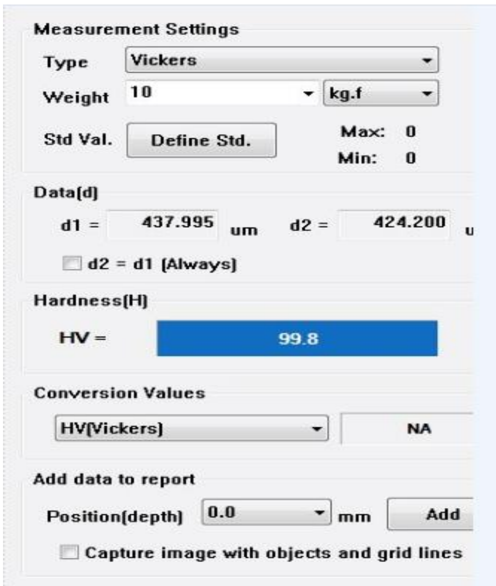


Figure 5. 10Vickers hardness test value of Al/7.5% SiC-10% bagasse fly-ash

4.3 Results on microstructural studies of the composite

The samples prepared were grinded using abrasive silicon carbide paper have a grift size 200, 1200, 2000, 3500. The samples were polished by using high performance diamond suspension. To observe clear micro graph the samples were etched by Keller's etchants.

The optical micrographs reveal that the dispersion of SiC and Fly-ash particles in the matrix. During composites are fabricated by the liquid infiltration route, degradation of SiC takes place. Some researchers were showed that SiC is potentially attacked by liquid aluminium during fabrication of Al/SiC metal matrix composite, according to the following reaction.

$$4\mathrm{Al} + 3\mathrm{SiC} \rightarrow \mathrm{Al_4C_3} + 3\mathrm{Si} \qquad (1)$$

(David Raja Selvam et al., (2013)) was reported that the addition of silicon in to aluminium matrix prevents SiC dissolution and consequently avoids the formation of the unwanted aluminium carbide (Al_4C_3). Bagasse fly-ash contains silicon dioxide (SiO_2) as a main constitute which is rich in silicon.

It is evident from the optical graph of Figure that the formation of the aluminium carbide (Al_4C_3) needle phase is successfully avoided by the presence of bagasse fly-ash (BFA) in the SiC_p preforms.

$$2Al + 2SiO_2 + Mg \rightarrow \mathrm{MgAl_2O_4} + 2\mathrm{Si} \qquad (2)$$

. The optical micrographs of Al-SiC-bagasse ash MMCs of different compositions are observed using optical microscopy as shown Fig. 5 below.

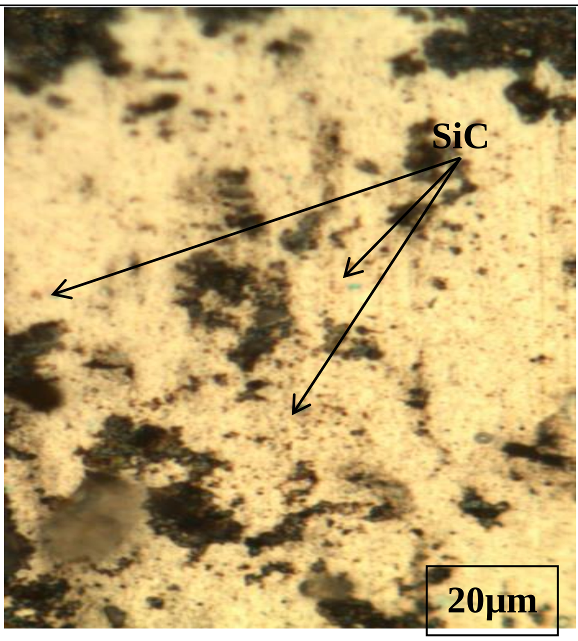


Figure 5. 11 (7.5%SiC specimen)

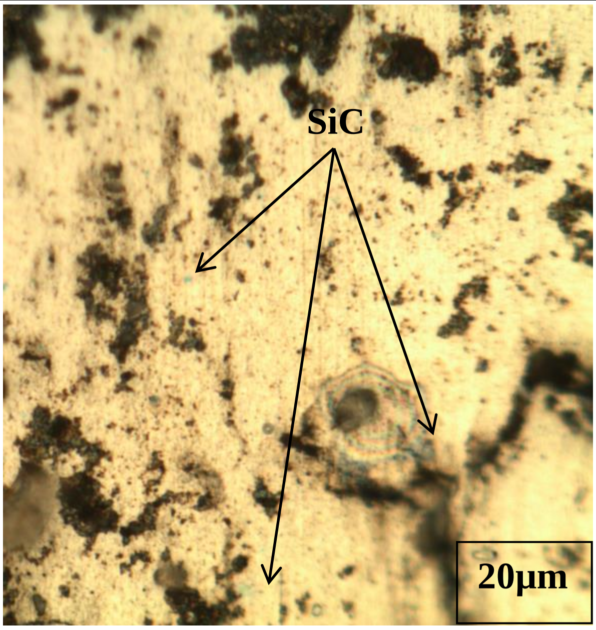


Figure 5. 12 (10% SiC specimen)

Figure 5.11 show that the SiC particles dispersed in the Al-Mg-Si matrix. Figure 5.12 Photomicrograph of the Al-Mg-Si/10wt% SiC composite showing a high density of particles dispersed in the Al-Mg-Si matrix.

The microstructure with addition of bagasse fly-ash with different weight percentage discussed as follows.

The Volume fractions were measured to be 7.5% SiC and 7.5% bagasse fly ash, respectively. It was found that there was not significant effect of volume % on the microstructure. The distribution of particles in the microstructure is seen to be uniform. On etching fine grain structures are observed. Micro structure consist fine dendrites of aluminium, silicon carbide and bagasse ash, randomly dispersed reinforcement particles were seen in optical microscope. The optical microscope observation of Al/SiC MMCs without addition of bagasse ash showed in Fig. 5.11 and Fig. 5.12.

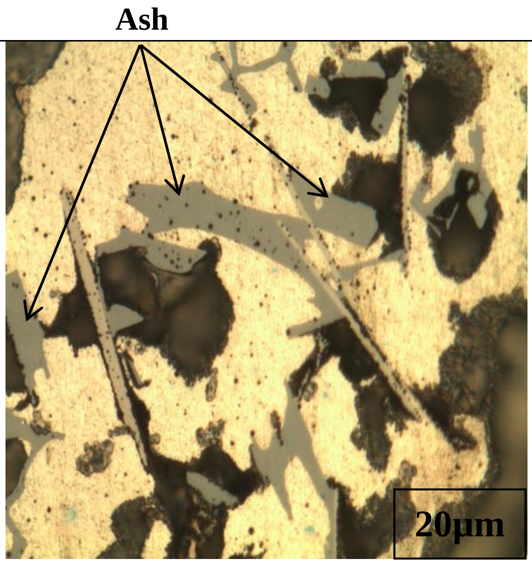


Figure 5. 13 (7.5 % of SiC -7.5% bagasse ash)

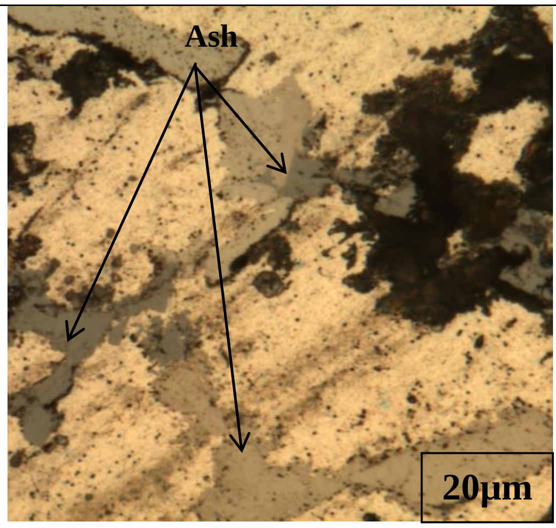


Figure 5. 14 (7.5% SiC-10% Bagasse ash)

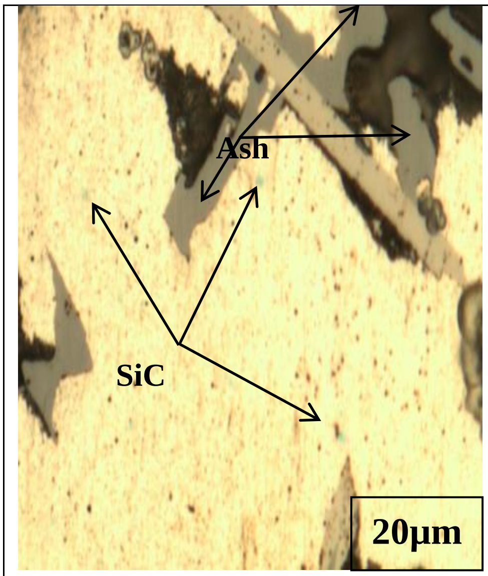


Figure 5. 15 (7.5 % of SiC -12% bagasse ash)

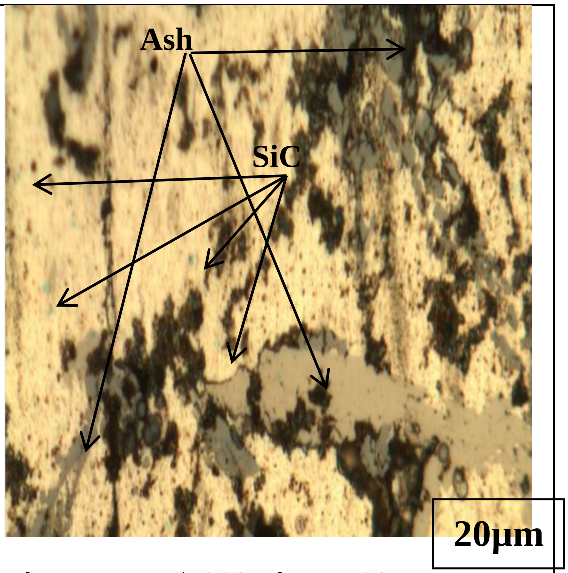


Figure 5. 16 (10% SiC-7.5% Bagasse fly- ash)

Micro structural analysis proves the presence of SiC and bagasse fly-ash reinforcements and its distribution in the metal matrix. From Fig. 4.18, it has been observed that clusters are formed around the SiC particle reinforcement. These clusters are mainly due to the increased weight percentage of bagasse fly- ash reinforcement. It is also noted that porosity is mainly located around the cluster formed regions. More distribution of both SiC and bagasse fly-ash particles observed in Fig. 5.17.

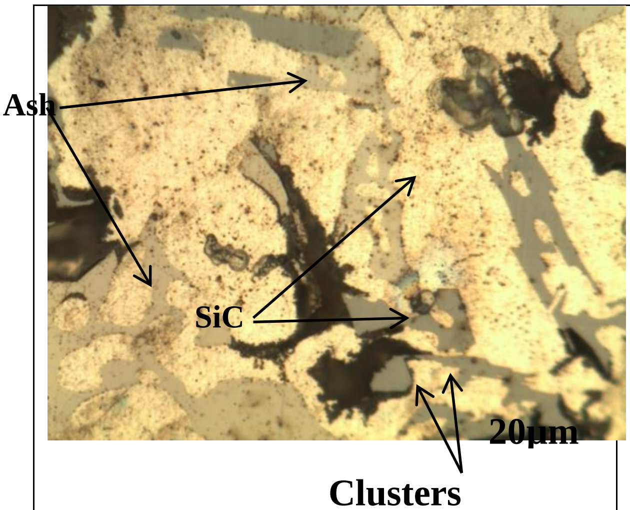


Figure 5. 17 (10 % of SiC -10% bagasse ash)

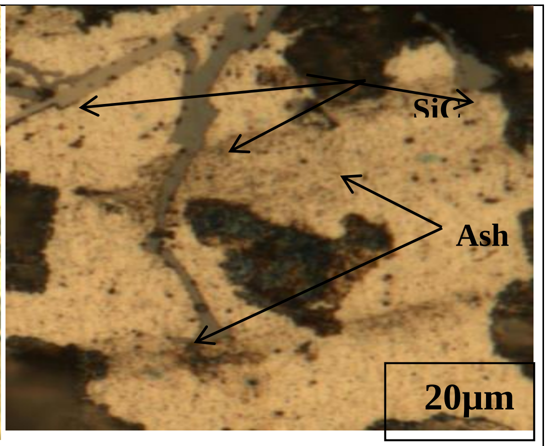


Figure 5. 18 (10% SiC-12% bagasse ash)

CHAPTER SIX

6. CONCLUSIONS AND RECOMMENDATION

6.1 Conclusions

The Al/SiC- bagasse fly-ash hybrid composite are successfully manufactured with different weight percentage of SiC and Bagasse fly-ash reinforcements (7.5 wt. % and 10 wt.% of SiC and 7.5 wt. %, 10 wt. % and 12 wt.% bagasse fly-ash). The microstructure and mechanical properties of the developed composite are studied with conducting different tests.

The conclusions drawn from the present investigation are as follows:

- Bagasse fly-ash, the waste generated from sugar cane plant can be successfully used as a reinforcing material to produce Metal-Matrix Composite (MMC) component in aluminium matrix to be used in light weight of automotive parts.
- The tensile strength, compression strength and hardness of the hybrid composite improved with increasing wt. % of reinforcements.
- The hybrid Al/SiC-bagasse ash composite were better mechanical properties with compared single reinforced Al/SiC composite.
- The optical micrographs show that good distribution of particles and low agglomeration of bagasse ash and silicon carbide.
- Experiments are conducted as per the intended data are shown in Appendix A, Appendix B.

6.2 Recommendation for Further Research

There are numerous industrial machinery parts and automotive components that should be promoted for superior specific strength and stiffness of MMCs. Still fabrications of MMCs of aluminium are not mature. There is a lot of potential for researches especially to optimize the process route, time and cost of production.

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 mechanical properties and hardness of MMC are investigated. Other mechanical properties as required by the designer for selection of material will be investigated.
    - The future area of research can include hybrid metal matrix process parameters.
    - Nano SiC and bagasse fly-ash MMCs may attract the future researchers.
    - The micro structure of MMCs studied by optical microscope, better and detail observation; studies of reinforcement's grain size can be obtained using SEM.
    - The machinability of the Al/SiC- bagasse fly ash hybrid composite also the future research.
    - The Al/ 10% SiC -10% bagasse ash developed hybrid composite material substitute the internal automotive components which have more improved in hardness, tensile strength and compression strength.
    - It can also substitute weighted parts of other machines, in addition to studying tribological behaviour.

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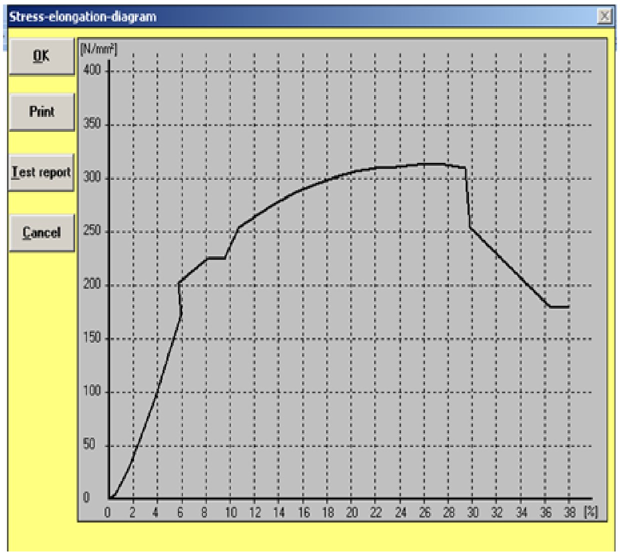
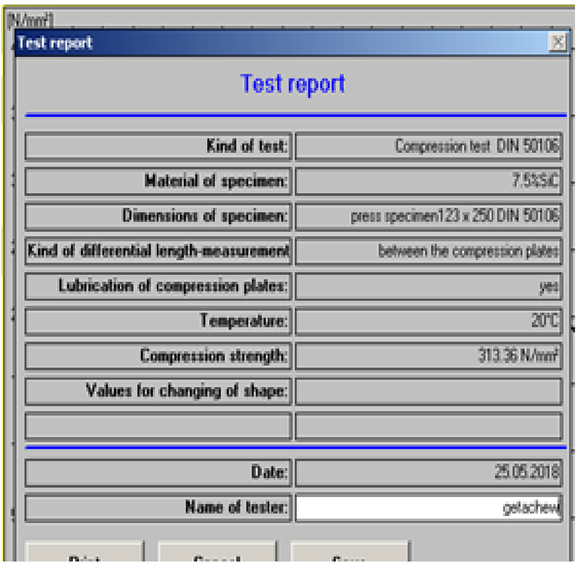
APPENDIX A

1. Figure shows stress elongation diagram of compression test on GUNT WP 310 Hydraulic Universal Testing Machine.





Test report

Kind of test:	Compression test DIN 50106
Material of specimen:	7.5%SiC
Dimensions of specimen:	press specimen123 x 250 DIN 50106
Kind of differential length-measurement	between the compression plates
Lubrication of compression plates:	yes
Temperature:	20°C
Compression strength:	313.36 N/mm²
Values for changing of shape:	
Date:	25.05.2018
Name of tester:	getachew

Figure (a) 1 Stress elongation diagram of Al/ 7.5% SiC composite

Table (a) 1Force elongation and stress elongation table of Al/ 7.5% SiC composite

Force-elongation-table

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.37	0.14
2	3.10	0.47
3	6.87	0.81
4	11.00	1.16
5	15.32	1.47
6	19.47	1.79
7	22.86	1.72
8	25.34	2.42
9	25.34	2.86
10	28.70	3.22
11	30.06	3.68
12	31.31	4.14
13	32.41	4.61
14	33.25	5.11
15	34.01	5.59
16	34.59	6.10

Force-elongation-table

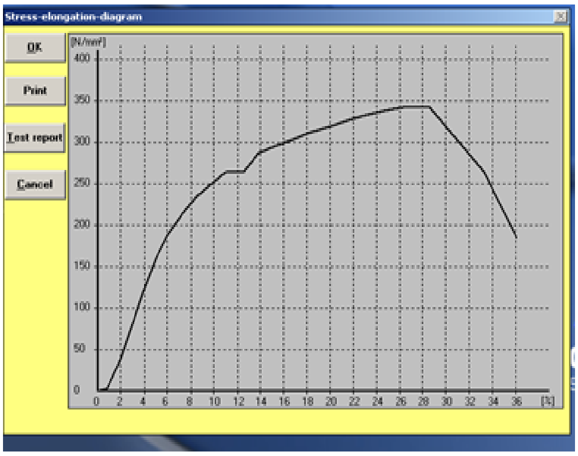
No.	F [kN]	dL [mm]
9	25.34	2.86
10	28.70	3.22
11	30.06	3.68
12	31.31	4.14
13	32.41	4.61
14	33.25	5.11
15	34.01	5.59
16	34.59	6.10
17	34.95	6.61
18	35.15	7.13
19	35.32	7.64
20	35.44	8.16
21	35.02	8.82
22	28.66	8.95
23	20.22	10.95
24	20.22	11.40

Stress-elongation-table

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	3.27	0.48
2	27.41	1.56
3	60.74	2.71
4	97.26	3.87
5	135.46	4.91
6	172.15	5.97
7	202.13	5.74
8	224.05	8.00
9	224.05	9.54
10	253.76	10.72
11	265.79	12.26
12	276.84	13.81
13	286.57	15.37
14	293.99	17.02
15	300.71	18.63
16	305.84	20.33

Stress-elongation-table

No.	S [N/mm²]	E [%]
9	224.05	9.54
10	253.76	10.72
11	265.79	12.26
12	276.84	13.81
13	286.57	15.37
14	293.99	17.02
15	300.71	18.63
16	305.84	20.33
17	309.03	22.04
18	310.79	23.76
19	312.30	25.40
20	313.36	27.20
21	309.65	29.40
22	253.41	29.02
23	178.78	36.49
24	178.78	37.99



Test report

Test report	
Kind of test:	Compression test DIN 50106
Material of specimen:	10%SiC
Dimensions of specimen:	press specimen123 x 250 DIN 50106
Kind of differential length-measurement	between the compression plates
Lubrication of compression plates:	yes
Temperature:	20°C
Compression strength:	342.98 N/mm²
Values for changing of shape:	
Date:	25.05.2018
Name of tester:	

Figure (a) 2 Stress elongation diagram of Al/ 10% SiC composite

Table (a) 2 Force elongation and stress elongation table of Al/ 10% SiC composite

Force-elongation-table

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.40	0.22
2	4.27	0.52
3	9.00	0.81
4	14.93	1.11
5	19.41	1.39
6	23.16	1.70
7	26.23	2.04
8	28.69	2.38
9	32.39	3.06
10	32.39	3.51
11	35.10	3.87
12	36.17	4.27
13	37.18	4.70
14	38.21	5.14
15	39.09	5.57
16	39.98	6.00

Force-elongation-table

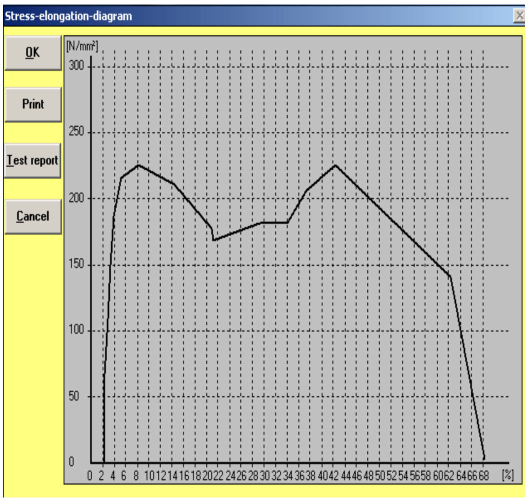
No.	F [kN]	dL [mm]
7	26.23	2.04
8	28.69	2.38
9	32.39	3.06
10	32.39	3.51
11	35.10	3.87
12	36.17	4.27
13	37.18	4.70
14	38.21	5.14
15	39.09	5.57
16	39.98	6.00
17	40.73	6.45
18	41.38	6.89
19	41.92	7.35
20	42.09	7.98
21	32.32	9.32
22	22.60	10.10

Stress-elongation-table

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	3.26	0.79
2	34.80	1.87
3	79.86	2.91
4	121.66	3.97
5	158.17	4.97
6	188.72	6.06
7	213.74	7.27
8	233.79	8.49
9	263.94	10.94
10	263.94	12.54
11	286.02	13.81
12	294.74	15.24
13	302.97	16.77
14	311.36	18.34
15	318.53	19.89
16	325.79	21.43

Stress-elongation-table

No.	S [N/mm²]	E [%]
7	213.74	7.27
8	233.79	8.49
9	263.94	10.94
10	263.94	12.54
11	286.02	13.81
12	294.74	15.24
13	302.97	16.77
14	311.36	18.34
15	318.53	19.89
16	325.79	21.43
17	331.90	23.02
18	337.19	24.62
19	341.60	26.26
20	342.98	28.49
21	263.37	33.30
22	184.16	36.06



Test report

Test report	
Kind of test:	Compression test DIN 50106
Material of specimen:	7.5% SiC & A
Dimensions of specimen:	press specimen123 x 250 DIN 50106
Kind of differential length-measurement	between the compression plates
Lubrication of compression plates:	yes
Temperature:	20°C
Compression strength:	225.79 N/mm²
Values for changing of shape:	
Date:	23.05.2018

Figure (a) 3 Stress elongation diagram of Al/ 7.5% SiC- 7.5% bagasse fly-ash composite

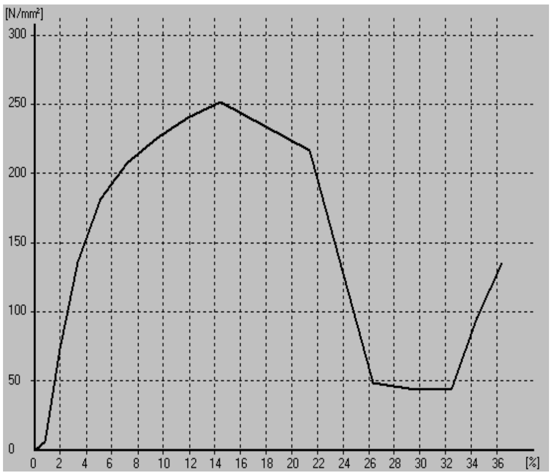
Table (a) 3 Force elongation and Stress elongation diagram of Al/ 7.5% SiC- 7.5% bagasse fly-ash composite

Force-elongation-table

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.00	0.21
2	8.96	0.21
3	14.49	0.26
4	19.82	0.30
5	24.68	0.35
6	28.61	0.47
7	29.97	0.74
8	28.00	1.30
9	23.49	1.88
10	22.36	1.90
11	24.03	2.63
12	24.03	3.06
13	27.35	3.35
14	29.90	3.81
15	18.71	5.62
16	0.40	6.14

Stress-elongation-table

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	0.00	2.33
2	67.50	2.34
3	109.17	2.89
4	149.32	3.37
5	185.94	3.85
6	215.55	5.20
7	225.79	8.23
8	210.95	14.44
9	176.97	20.89
10	168.46	21.14
11	181.04	29.22
12	181.04	33.99
13	206.05	37.26
14	225.27	42.36
15	140.96	62.40
16	3.01	68.24



Test report

Test report

Kind of test:	Compression test DIN 50106
Material of specimen:	7.5 SiC-10 A
Dimensions of specimen:	press specimen123 x 250 DIN 50106
Kind of differential length-measurement	between the compression plates
Lubrication of compression plates:	yes
Temperature:	20°C
Compression strength:	251.49 N/mm²
Values for changing of shape:	
Date:	24.05.2018
Name of tester:	

Figure (a) 4 Stress elongation diagram of Al/ 7.5% SiC- 10% bagasse fly-ash composite

Table (a) 4 Force elongation and Stress elongation diagram of Al/ 7.5% SiC- 10% bagasse fly-ash composite

Force-elongation-table

No.	F [kN]	dL [mm]
1	0.61	0.18
2	6.93	0.43
3	12.88	0.73
4	17.23	1.13
5	19.74	1.59
6	21.46	2.09
7	22.83	2.62
8	23.90	3.17
9	20.55	4.71
10	4.59	5.80
11	4.13	6.52
12	4.13	7.14
13	9.12	7.58
14	12.83	8.00

Stress-elongation-table

No.	S [N/mm²]	E [%]
1	6.42	0.81
2	72.92	1.96
3	135.53	3.33
4	181.31	5.12
5	207.72	7.21
6	225.82	9.50
7	240.23	11.92
8	251.49	14.42
9	216.24	21.40
10	48.30	26.36
11	43.46	29.62
12	43.46	32.44
13	95.97	34.44
14	135.01	36.38

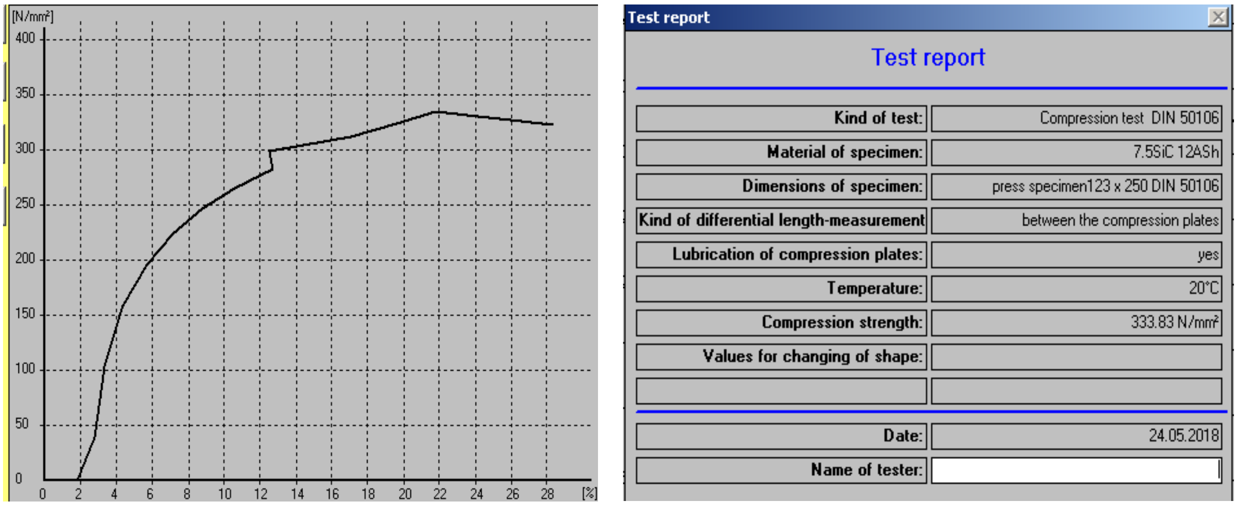
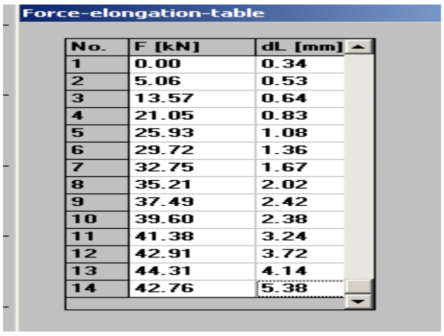


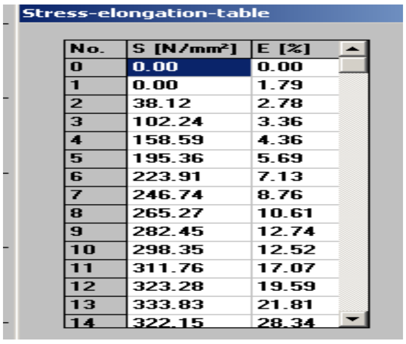
Figure (a) 5 Stress elongation diagram of Al/ 7.5% SiC- 12% bagasse fly-ash composite

Table (a) 5 Force elongation and Stress elongation diagram of Al/ 7.5% SiC- 12% bagasse fly-ash composite



Force-elongation-table

No.	F [kN]	dL [mm]
1	0.00	0.34
2	5.06	0.53
3	13.57	0.64
4	21.05	0.83
5	25.93	1.08
6	29.72	1.36
7	32.75	1.67
8	35.21	2.02
9	37.49	2.42
10	39.60	2.38
11	41.38	3.24
12	42.91	3.72
13	44.31	4.14
14	42.76	5.38



Stress-elongation-table

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	0.00	1.79
2	38.12	2.78
3	102.24	3.36
4	158.59	4.36
5	195.36	5.69
6	223.91	7.13
7	246.74	8.76
8	265.27	10.61
9	282.45	12.74
10	298.35	12.52
11	311.76	17.07
12	323.28	19.59
13	333.83	21.81
14	322.15	28.34

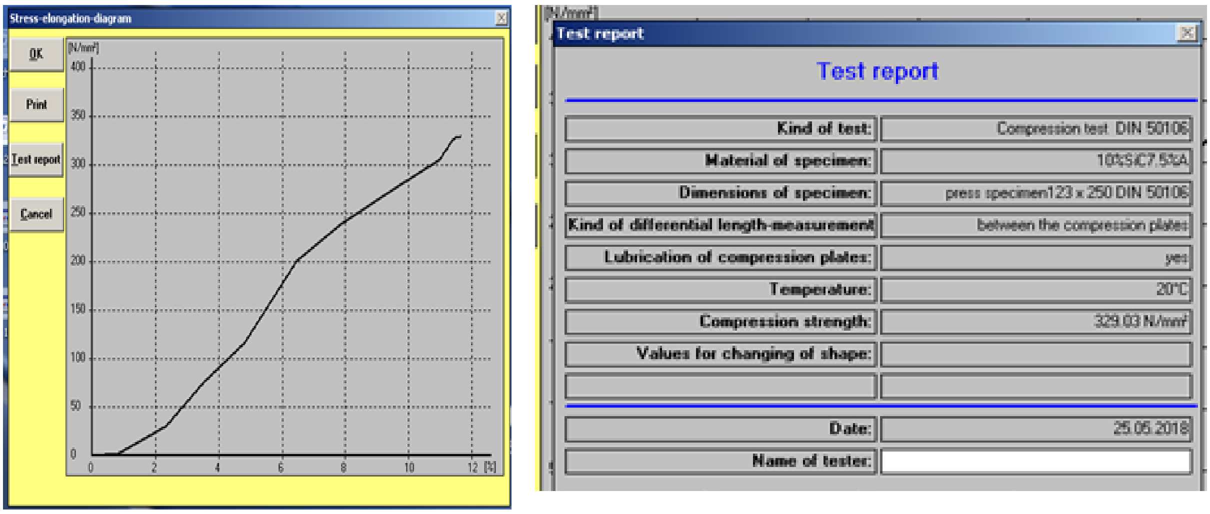


Figure (a) 6 Stress elongation diagram of Al/ 10% SiC-7.5% bagasse fly-ash composite

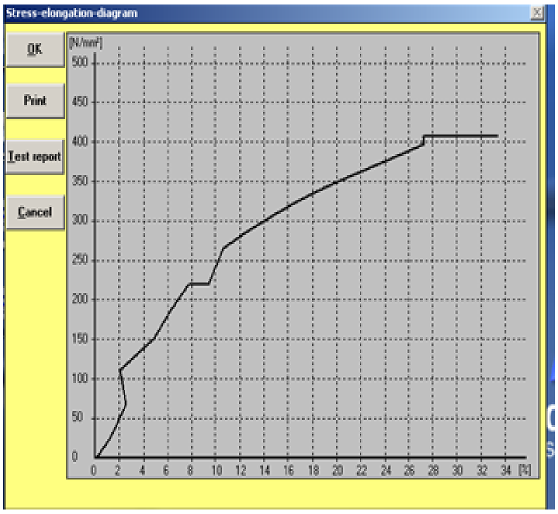
Table (a) 6 Force elongation and Stress elongation diagram of Al/ 10% SiC- 7.5% bagasse fly-ash composite

Force-elongation-table

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.30	0.09
2	4.64	0.27
3	11.62	0.41
4	17.86	0.55
5	30.88	0.74
6	36.77	0.90
7	42.23	1.10
8	46.97	1.26
9	49.78	1.30
10	50.47	1.32

Stress-elongation-table

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	1.95	0.82
2	30.14	2.32
3	75.48	3.54
4	116.02	4.81
5	200.60	6.46
6	238.86	7.87
7	274.33	9.53
8	305.12	10.96
9	323.38	11.34
10	327.86	11.48



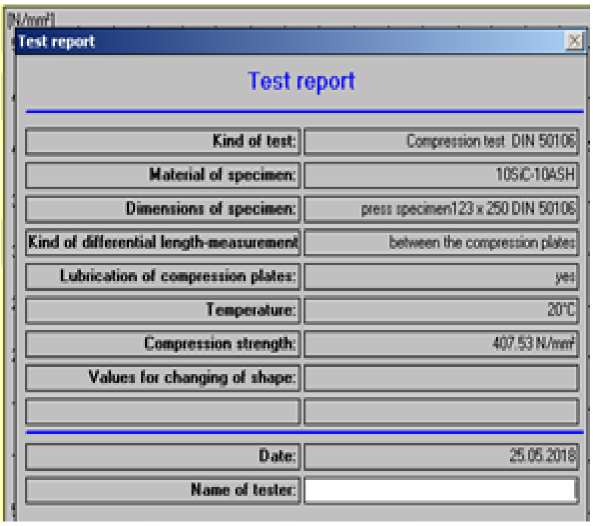


Figure (a) 7 Stress elongation diagram of Al/ 10% SiC-10% bagasse fly-ash composite

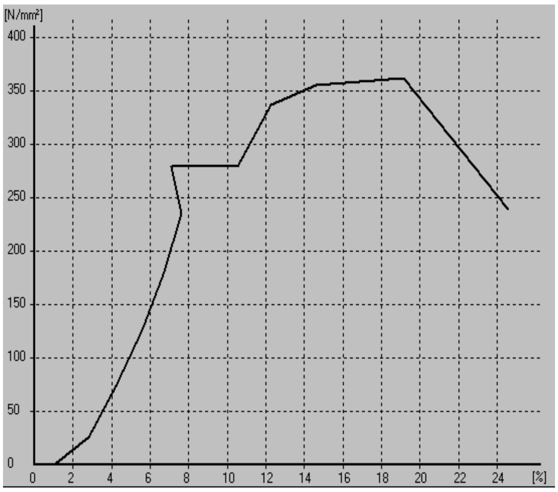
Table (a) 7 Force elongation and Stress elongation diagram of Al/ 10% SiC- 10% bagasse fly-ash composite

Force-elongation-table

No.	F [kN]	dL [mm]
4	17.17	1.11
5	21.37	1.43
6	24.88	1.74
7	24.88	2.11
8	30.06	2.40
9	32.19	2.80
10	34.26	3.20
11	36.16	3.64
12	37.87	4.05
13	39.42	4.48
14	40.86	4.90
15	42.26	5.31
16	43.61	5.73
17	44.91	6.13
18	46.09	6.11
19	46.09	7.50

Stress-elongation-table

No.	S [N/mm²]	E [%]
4	151.82	4.92
5	188.95	6.37
6	219.99	7.74
7	219.99	9.39
8	265.79	10.66
9	284.62	12.43
10	302.93	14.24
11	319.72	16.16
12	334.84	18.01
13	348.55	19.92
14	361.28	21.79
15	373.66	23.62
16	385.60	25.46
17	397.09	27.25
18	407.53	27.15
19	407.53	33.33



Test report

Kind of test:	Compression test DIN 50106
Material of specimen:	10SiC 12Ash
Dimensions of specimen:	press specimen123 x 250 DIN 50106
Kind of differential length-measurement	between the compression plates
Lubrication of compression plates:	yes
Temperature:	20°C
Compression strength:	361.90 N/mm²
Values for changing of shape:	
Date:	24.05.2018
Name of tester:	

Figure (a) 8Stress elongation diagram of Al/ 10% SiC-12% bagasse fly-ash composite

Table (a) 8 Force elongation and Stress elongation diagram of Al/ 10% SiC- 12% bagasse fly-ash composite

Force-elongation-table

No.	F [kN]	dL [mm]
1	0.05	0.21
2	2.84	0.53
3	8.31	0.80
4	14.16	1.06
5	20.12	1.27
6	26.48	1.45
7	31.51	1.35
8	31.51	2.00
9	38.03	2.33
10	40.18	2.78
11	40.93	3.64
12	26.99	4.67

Stress-elongation-table

No.	S [N/mm²]	E [%]
1	0.44	1.10
2	25.11	2.81
3	73.48	4.23
4	125.20	5.56
5	177.90	6.67
6	234.13	7.63
7	278.61	7.10
8	278.61	10.53
9	336.26	12.26
10	355.27	14.61
11	361.90	19.17
12	238.64	24.58

APPENDIX B

2. Figure shows stress elongation diagram of tensile test graphs on GUNT WP 310 Hydraulic Universal Testing Machine.

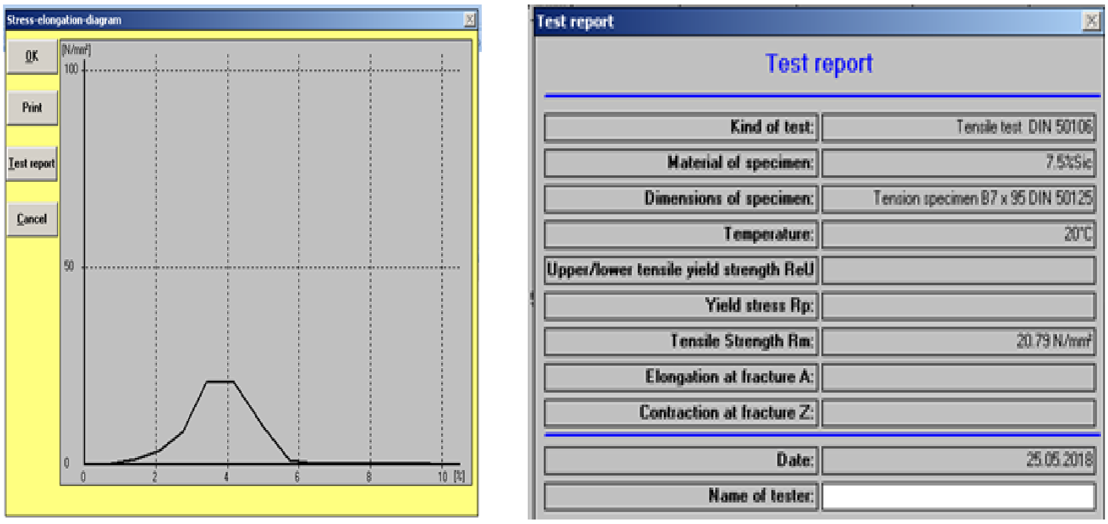


Figure (b) 1Stress elongation diagram of Al/ 7.5% SiC composite

Table (b) 1 Force elongation and stress elongation table of Al/ 7.5% SiC composite

Force-elongation-table

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.01	0.72
2	0.05	1.35
3	0.13	1.99
4	0.32	2.61
5	0.80	3.23
6	0.80	3.96
7	0.37	4.73
8	0.04	5.45
9	0.01	6.13
10	0.01	6.84
11	0.01	7.52
12	0.01	8.21
13	0.01	8.89
14	0.01	9.16

Stress-elongation-table

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	0.26	0.76
2	1.30	1.42
3	3.38	2.09
4	8.32	2.75
5	20.79	3.40
6	20.79	4.17
7	9.61	4.98
8	1.04	5.74
9	0.26	6.45
10	0.26	7.20
11	0.26	7.92
12	0.26	8.64
13	0.26	9.36
14	0.26	9.64

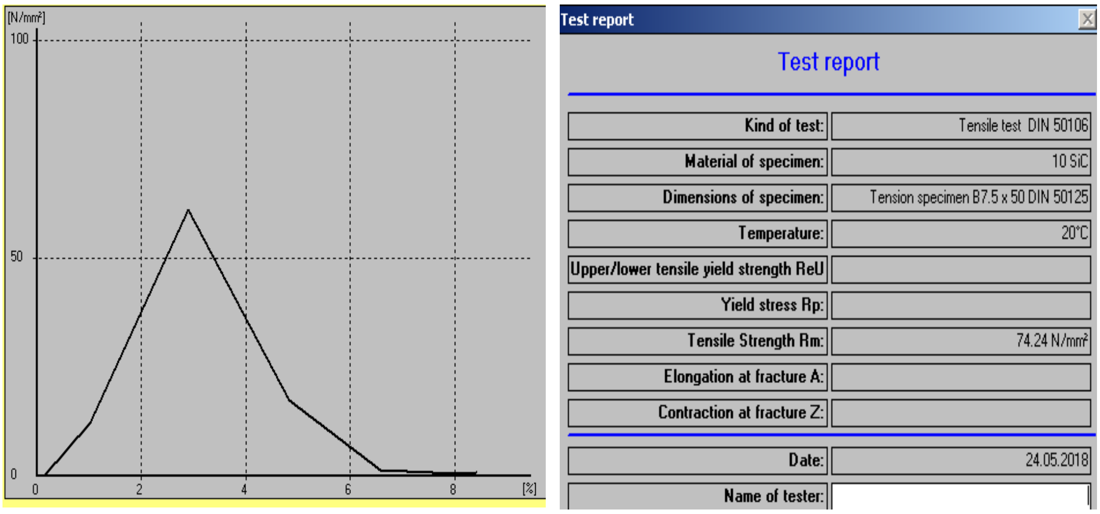


Figure (b) 9Stress elongation diagram of Al/ 10% SiC composite

Table (b) 2 Force elongation and stress elongation table of Al/ 10% SiC composite

Force-elongation-table

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.54	0.41
2	2.70	1.16
3	0.76	1.93
4	0.05	2.63
5	0.02	3.23

Stress-elongation-table

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	12.22	1.02
2	61.12	2.89
3	17.20	4.84
4	1.13	6.57
5	0.45	8.07

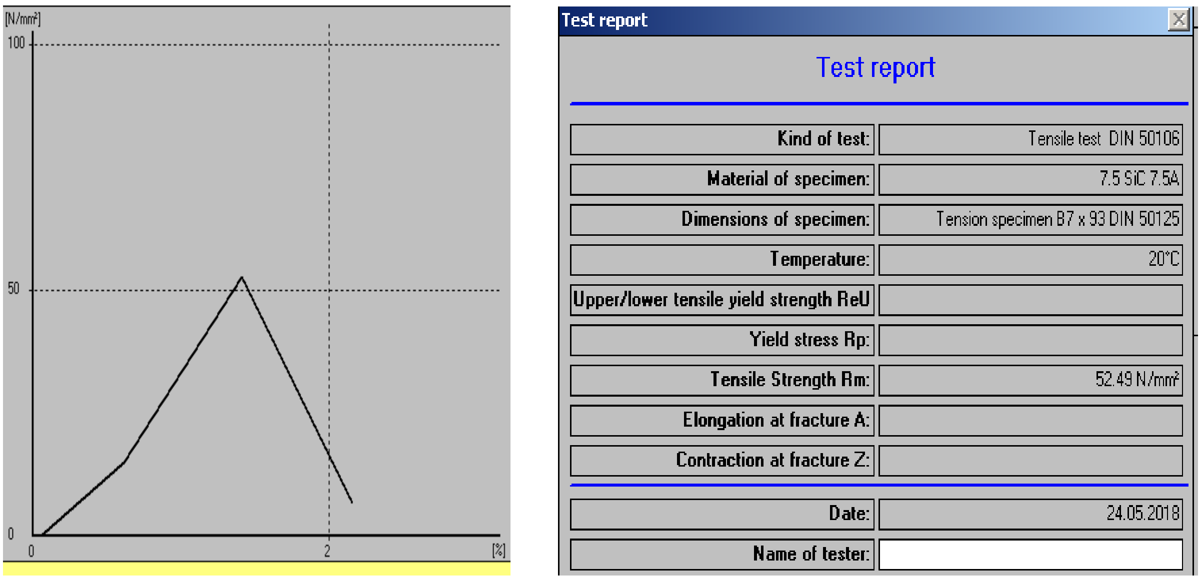


Figure (b) 10Stress elongation diagram of Al/ 7.5% SiC- 7.5% bagasse fly-ash composite

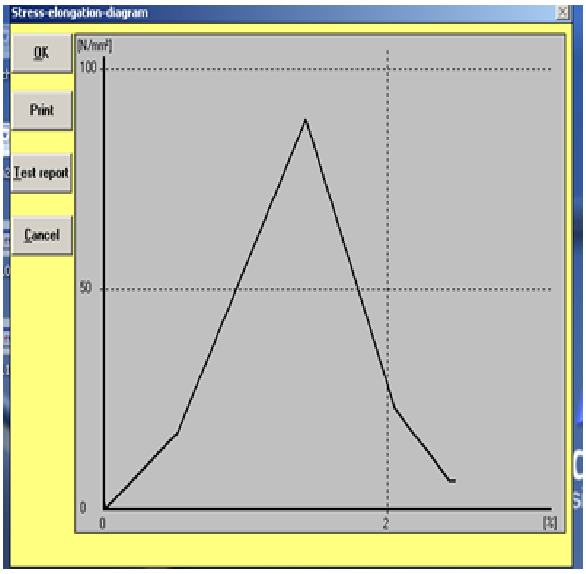
Table (b) 3 Force elongation and Stress elongation diagram of Al/ 7.5% SiC- 7.5% bagasse fly-ash composite

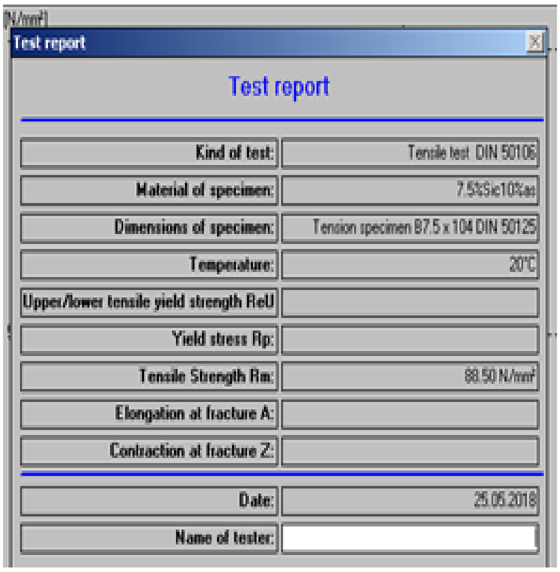
Force-elongation-table

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.57	0.57
2	2.02	1.31
3	0.26	2.00

Stress-elongation-table

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	14.81	0.61
2	52.49	1.41
3	6.76	2.16




Test report

Kind of test:	Tensile test DIN 50106
Material of specimen:	7.5%Sic10%as
Dimensions of specimen:	Tension specimen B7.5 x 104 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU	
Yield stress Rp:	
Tensile Strength Rm:	88.50 N/mm²
Elongation at fracture A:	
Contraction at fracture Z:	
Date:	25.05.2018
Name of tester:	

Figure (b) 11Stress elongation diagram of Al/ 7.5% SiC- 10% bagasse fly-ash composite

Table (b) 4 Force elongation and Stress elongation diagram of Al/ 7.5% SiC- 10% bagasse fly-ash composite

Force-elongation-table

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.76	0.53
2	3.91	1.40
3	1.01	2.13
4	0.28	2.53

Stress-elongation-table

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	17.20	0.51
2	88.50	1.42
3	22.86	2.05
4	6.34	2.44

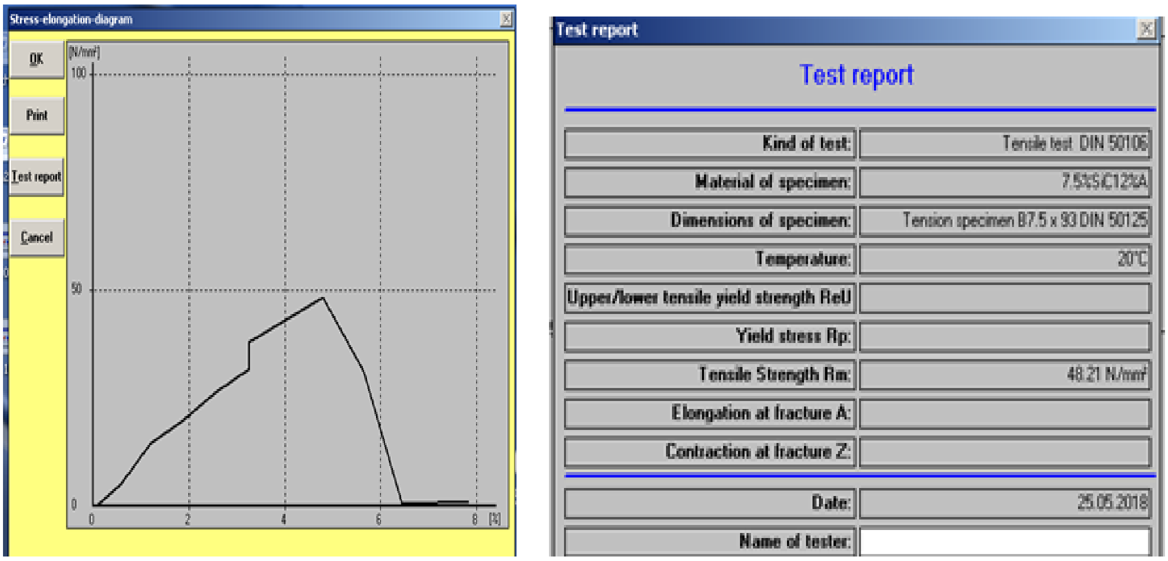


Figure (b) 12Stress elongation diagram of Al/ 7.5% SiC- 12% bagasse fly-ash composite

Table (b) 5 Force elongation and Stress elongation diagram of Al/ 7.5% SiC- 12% bagasse fly-ash composite

Force-elongation-table

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.22	0.55
2	0.63	1.11
3	0.87	1.73
4	1.16	2.38
5	1.40	3.03
6	1.68	3.03
7	2.13	4.46
8	1.38	5.25
9	0.02	5.99
10	0.03	6.68
11	0.03	7.21

Stress-elongation-table

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	4.98	0.59
2	14.26	1.19
3	19.69	1.86
4	26.26	2.56
5	31.69	3.26
6	38.03	3.25
7	48.21	4.79
8	31.24	5.65
9	0.45	6.44
10	0.68	7.18
11	0.68	7.75

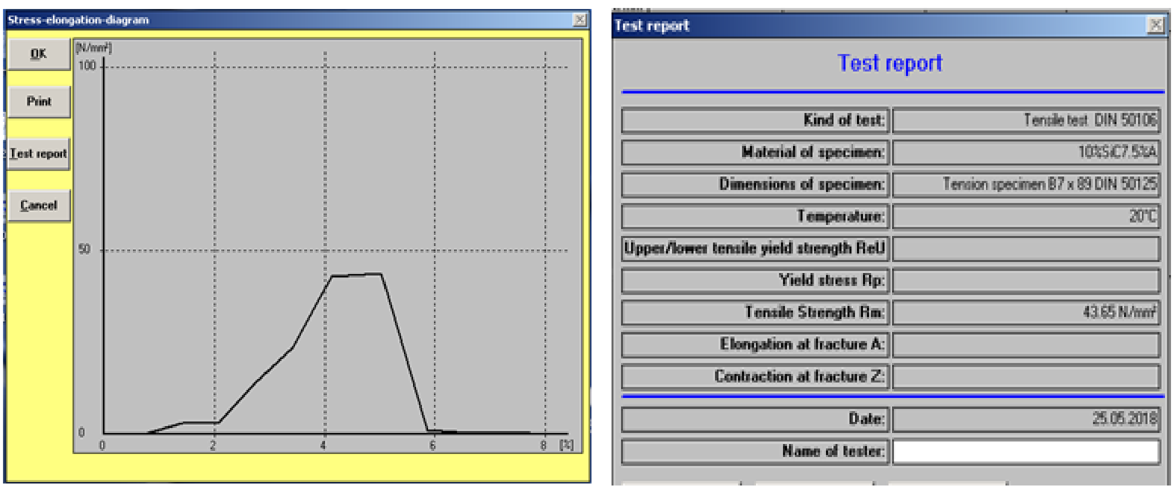


Figure (a) 13 Stress elongation diagram of Al/ 10% SiC-7.5% bagasse fly-ash composite

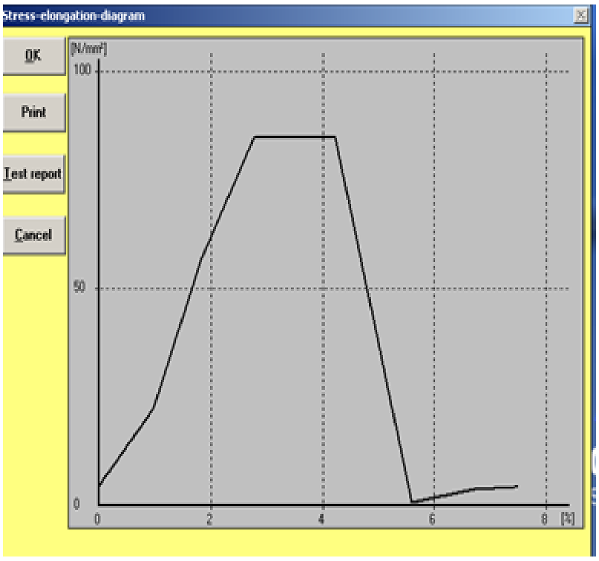
Table (b) 6 Force elongation and Stress elongation diagram of Al/ 10% SiC- 7.5% bagasse fly-ash composite

Force-elongation-table

No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.00	0.66
2	0.11	1.26
3	0.11	1.85
4	0.53	2.44
5	0.91	3.05
6	1.65	3.67
7	1.68	4.48
8	0.04	5.22
9	0.01	5.91
10	0.01	6.77

Stress-elongation-table

No.	S [N/mm²]	E [%]
0	0.00	0.00
1	0.00	0.74
2	2.86	1.41
3	2.86	2.08
4	13.77	2.74
5	23.65	3.43
6	42.87	4.12
7	43.65	5.03
8	1.04	5.86
9	0.26	6.64
10	0.26	7.61



Test report

Kind of test:	Tensile test DIN 50106
Material of specimen:	10%SiC10%ash
Dimensions of specimen:	Tension specimen B 7 x 61 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU	
Yield stress Rp:	
Tensile Strength Rm:	84.71 N/mm²
Elongation at fracture A:	
Contraction at fracture Z:	
Date:	25.05.2018
Name of tester:	

Figure (a) 14 Stress elongation diagram of Al/ 10% SiC-10% bagasse fly-ash composite

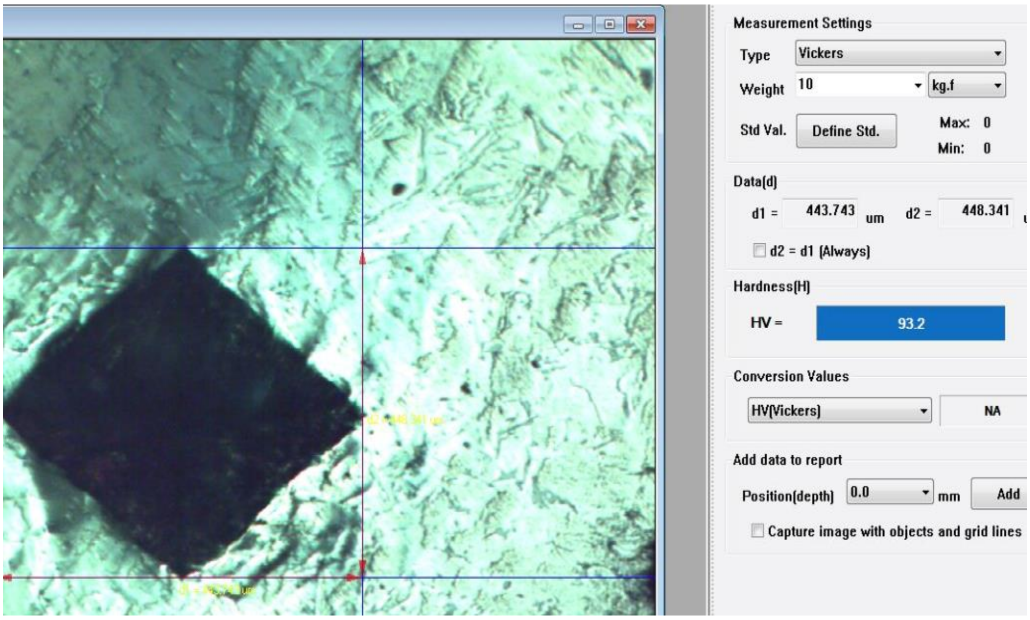
Table (b) 7 Force elongation and Stress elongation diagram of Al/ 10% SiC- 10% bagasse fly-ash composite

Force-elongation-table

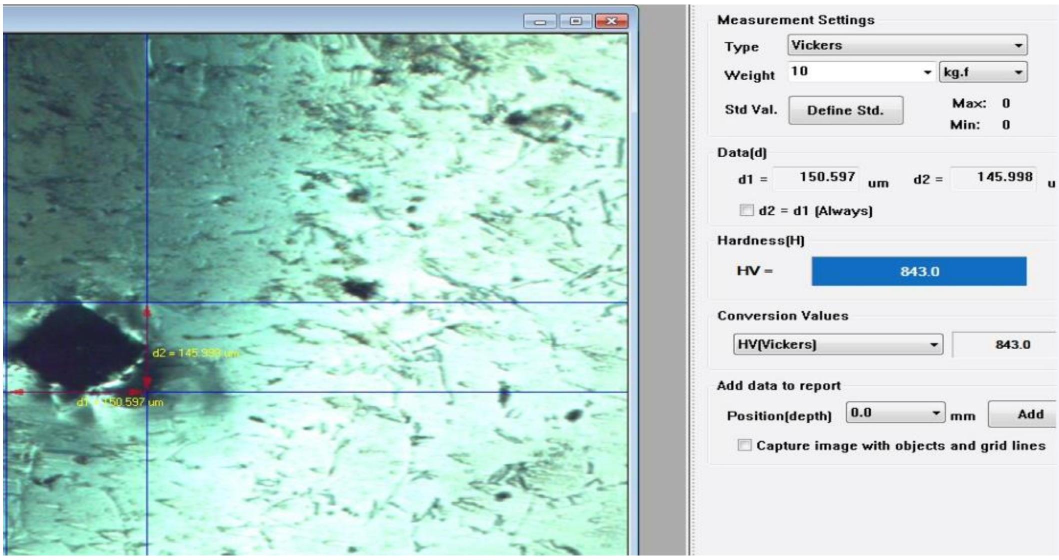
No.	F [kN]	dL [mm]
0	0.00	0.00
1	0.85	0.59
2	2.19	1.12
3	3.26	1.69
4	3.26	2.57
5	0.03	3.41
6	0.14	4.10
7	0.16	4.53

Stress-elongation-table

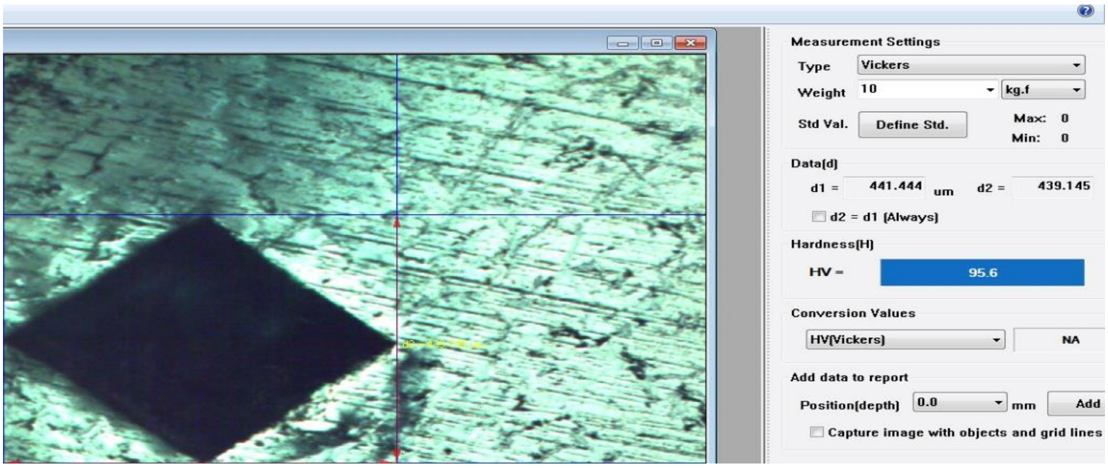
No.	S [N/mm²]	E [%]
0	0.00	0.00
1	22.09	0.97
2	56.91	1.83
3	84.71	2.78
4	84.71	4.22
5	0.78	5.59
6	3.64	6.72
7	4.16	7.42



Sample 1



Sample 2



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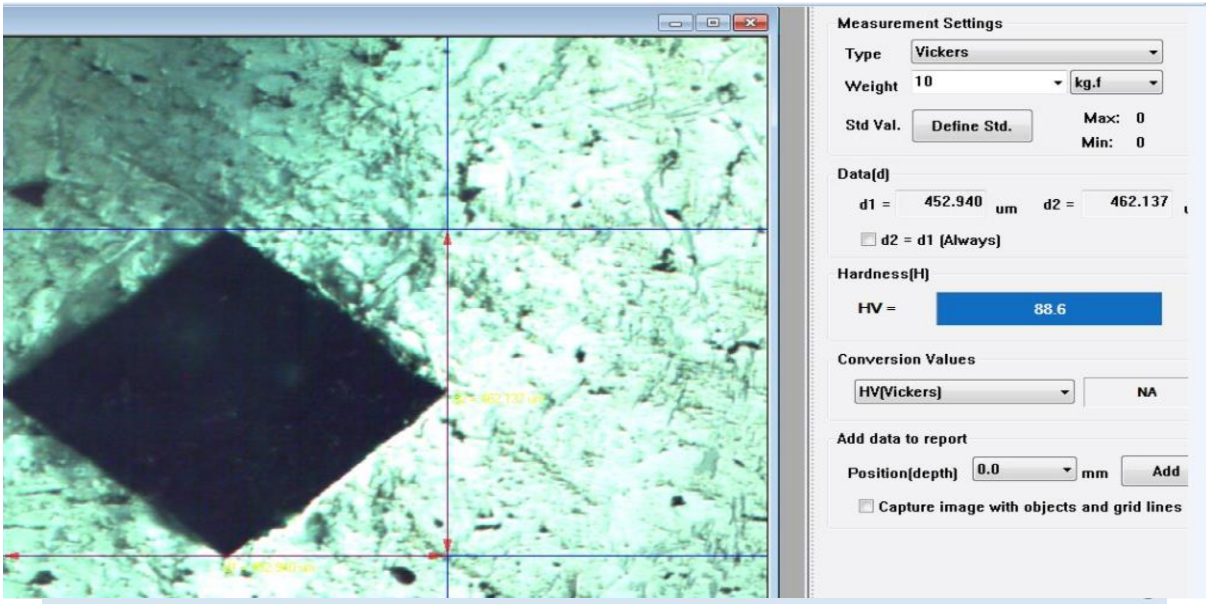
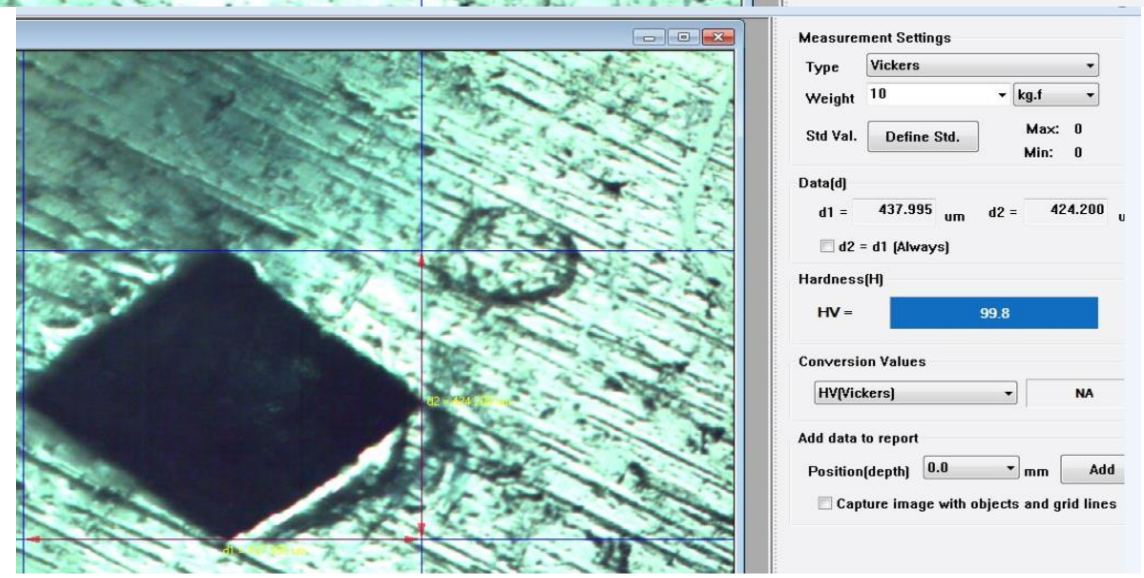
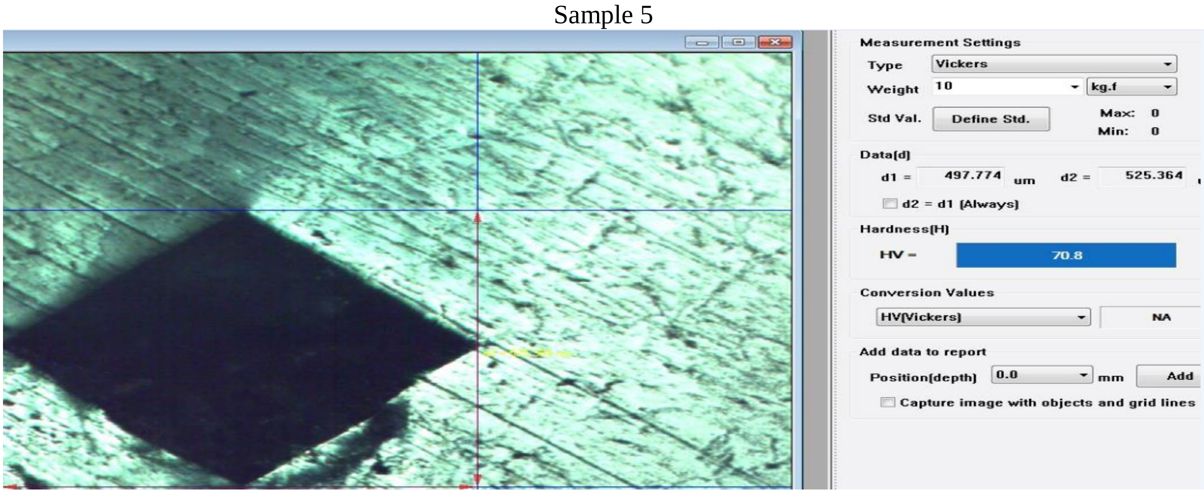




Sample 4

Sample 5



Sample 6

Fgure (c) 1 Vickers hardness value for samples (1, 2, 3,4 ,5 ,6) with different composition.