Potential Applications of Fly-Ash and Sisal Hybrid Fibre Reinforced Plastic Composites

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Abstract *—This paper presents the discussion on the potential application of hybrid fly-ash and sisal fiber to be used as a reinforcing tool in polymeric composites. Based on the literature survey, it is found that a tremendous amount works on the use of fly-ash and sisal fibers individually as reinforcing tool in polymeric composites. It is hard to find related papers on the hybridizations of fly-ash and sisal fibers in reinforcing the polymeric composites. Therefore, this paper explains some important points of mechanical behavior of fly-ash, sisal, and hybridized fibers reinforced polymeric composites.*

Keywords — *Epoxy resin, Fly ash, Sisal fiber, hybrid composites, and mechanical properties.*

I. INTRODUCTION

The process of burning coal in power plants produces solid waste. The resulting solid waste is expected to increase significantly, and increase if it cannot be utilized on a large scale and causes water and air pollution. Micron and nano-size fly ash fillers. The size of fly ash in microns is converted to nano units using a planetary ball mill. Finally, it produces crystallites as fillers on the Nanometer-scale. In the experiment, Fly ash was obtained from the Thermal Power Plant process. Fly ash is often used as a mixture of concrete, cement, and liquid waste stabilizers. The use of fly ash as a carbon enhancer in composites uses carbon present in iron and steel. Fly ash as a filler is used to improve the mechanical and thermal properties of composites because the cost is very `economical, strength is increased, corrosion and thermal resistance. [1]

Sisal fiber is a natural fiber that serves as a good reinforcement for polymer composites, because it has a high impact strength, has good tensile and flexural strength. Sisal fiber is one of the most commonly used natural fibers as an element of several constructions and can be easily cultivated in various countries. Sisal plants grow around 100-200 leaves during the feeding period, and each leaf contains straight fibers whose length can be extracted using a special process. Sisal fiber has the added benefit of consisting of higher strength and weight ratio, is more environmentally friendly than synthetic fibers, and is more complicated for users.

Natural fiber in addition to having many advantages, in fact, natural fibers also have many disadvantages, including low strength especially against shock loads, low reliability, easy to absorb water, cannot stand high temperatures, quality varies greatly depending on the season, age, soil conditions, and the environment. The advantages of natural fibers if used as reinforcement in the polymer matrix include lower specific gravity when compared between glass fibers and natural fibers, the resulting composite will be lighter and more competitive in mechanical properties, abundant renewables, cheaper investment, process environmentally friendly production, and does not abrasive on machines. Fiber classification includes natural fibers: Flax, Banana, Sisal, Luffa, Palm, Rice Husk, Kenaf, Cotton, Abaca, Rooster Feather, Hemp, Flax, Coir, etc. [5,9].

Epoxy resins as compounds that contain two or more epoxide rings per molecule, and are among the best types of materials as composite manufacturing materials, because of their superiority, which can adhere well to various surfaces of fillers and fibers, and are resistant to chemicals and have good electrical insulation properties [3,6].

Composite materials are widely used by various industries, such as the railroad, shipbuilding, automotive, military, sports equipment, medical, and civil building construction. Composite materials have also been used widely for applications in the military field. The main driving factors in the use of composite materials are their low density, high specific mechanical properties, performance comparable to metals, corrosion resistance, and easy to make [7,8].

Composite hybrids are a type of mixture that consists of more than one type of amplifier into one matrix. The mixing rate can be on a small scale (fiber) or large scale (layer). The purpose of hybridization is to arrange new materials that contain the advantages of its constituents. They have better fiber than other fiber ingredients. The main function of a matrix is to transfer voltage to the fiber because the fiber is stronger and has a higher elastic modulus than the matrix. Composite responses to work stress depend on the nature of the fiber and the matrix phase, relative volume fraction, fiber length, and fiber orientation relative to the direction of work stress [3].

Many discoveries have been made to make new materials, one of the methods developed is the composite technique, which combines two or more ingredients mixed with certain conditions and treatments. This technology is experiencing very rapid development, especially in reinforcement either from metals, polymers, or natural materials.

II. COMPOSITE MATERIALS

Composites are defined as materials consisting of two or more that have different properties or structures that are physically mixed to form mechanical bonds with microscopic and heterogeneous structures microscopically [9]. The mixture will produce a new material that has superior properties compared to forming material. Composites contain at least fiber as a reinforcement and matrix as a binder. The amplifier functions as a structural material while the matrix functions to glue the amplifier, keeping it from changing positions, moving and distributing external forces that work and protect it from the weather.

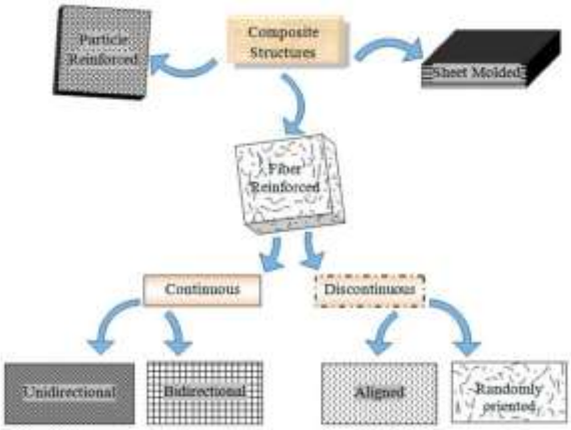


Fig. 1: Composite Classification [9].

Composites can be classified based on the structural content of their constituent components as shown in Figure 1. Composites with fibers as constituents bound by a matrix. Particles are reinforcement in the composite matrix [9]. The nature of the composite material is influenced by the forming material, the interrupted phase distribution, and the interaction between the forming material. In simple terms, composite properties are a combination of the properties of the constituent materials in the volume fraction and are also influenced by interaction factors between the matrix and the reinforced ones as well as the type, size, reinforcement distribution, so that often the composite properties are not the same as the combination of the forming properties [10]. Composites are classified based on the structural content of their constituent components. Fibrous, composite with fibers as constituents bound by a matrix. Particulates are composites with particles as reinforcement in the matrix. Composites with polymers as matrices are classified into Fibrous Composites, Particulate composites, and Laminate Composites [9].

A. *Fly Ash Reinforced Composite*

Fly ash comes from the combustion process of coal-fired power plants, which contain chemical elements, namely Si, Al, FeO, Ca, Mg, etc. So fly ash has a mixture of a metal ball and metal oxide properties. Fly ash as a filler in composite materials has economic properties, increases tensile strength, impact strength and flexural strength to some extent, and to improve process capability [10]. Composite material with fly ash filling material is processed by mixing planetary ball mill techniques, casting in molds, and hand lay-up techniques [11]. In experimental investigations, Fly ash is obtained from the combustion process in Thermal Power Plants [1,7]. The properties of fly ash are shown in Table 1. The process of making specimens from the process of mixing fly ash with epoxy is schematically illustrated in Figure 2 [1].

I. TABLE I

COMPOSITIONS OF FLY-ASH

No.	Ingredient	Value (%)
1	Silica	56.87
2	Aluminum trioxide	27.66
3	Ferric oxide	6,27
4	Titanium dioxide	0.32
5	Calcium oxide	3.71
6	Magnesium oxide	0.35
7	Sulfate and	0.26
8	Loss of ignition	4.46

B. *Sisal Fiber Reinforced Composites*

The use of sisal fiber as a reinforcing material in polymer composites in terms of the structure and nature of natural fibers depends on the origin and age of the fiber. This is due to the low density and high specific nature of sisal fiber. The tensile strength of sisal fibers is not the same along the fibers. The bottom of the fiber generally has a lower tensile strength and modulus than the top of the fiber. But the breaking strength of the part is higher. The center of the fiber is stronger and stiffer [28]. This fiber-based composite has very good implications in the automotive and transportation industries. [14]

C. *Fly Ash and Sisal Reinforced Hybrids Composites*

Composite response to work stress depends on the nature of the fiber and the matrix phase, relative volume fraction, fiber length, and fiber orientation relative to the direction of the working stress. Composite fibers in one direction alone are called the unidirectional lamina. Composite laminae can consist of one or more layers because more than one layer is called lamination and all fibers are in the same direction [15].

Fly ash which is rich in Si and alumina is as a filler or reinforcement material and sisal fiber in the epoxy resin matrix which was previously used as a reinforcement in composite hybrids. Cellulose fiber reinforcement in composite particles namely fly ash particles containing silica and alumina increases the quality of hybrid composites better. The resulting hybrid composites have a high potential for use in the transportation, building, and architecture industries. The effective use of fly ash and sisal fibers as reinforcing materials will develop rapidly in the composite industry [13].

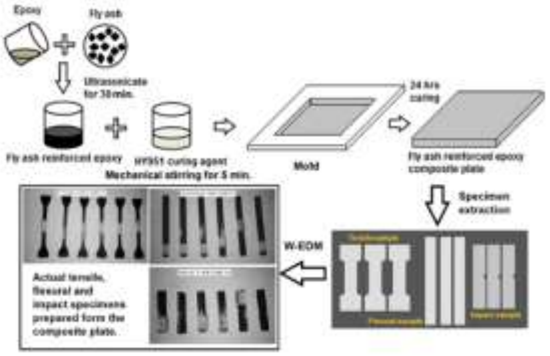
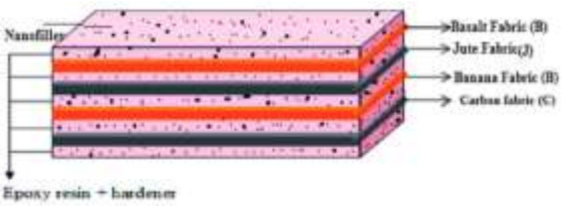
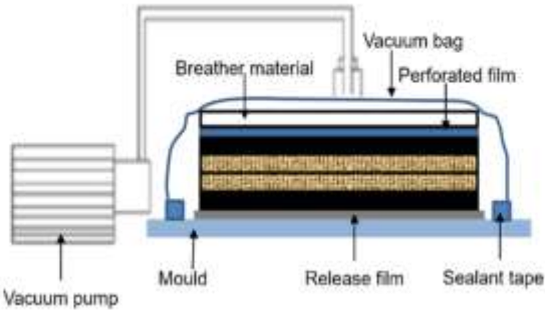


Fig. 2: Schematic illustration of the preparation of fly ash reinforced composite epoxy and specimen extraction [1].



a. hybrid composite laminates [7]



b. Vaccine Discharging Process

Fig. 3: Amination process of hybrid composites [16].

This composite consists of several layers of the fiber-reinforced lamina or lamina-reinforced particles or metal lamina, hive lamina, thin sheet lamina, or a combination of lamina-lamina with different materials where the layers are bonded together. Lamination is made by stacking layers in the same direction with different or stacking composite layers that are reinforced by fibers and layers that are reinforced by particles or their combinations [4,6].

The lamination process there are several methods of making hybrid composites including Hand lay-up which is a method of laying manually or applying reinforcing material into a mold Vacuum bagging is a method of suctioning or compressing air in the lamination layer. Compression uses an airtight bag to compress laminates, fibers, and other molded layers until the layers are fused [4]. Abduraohman et al [4] states that the lamina process with vacuum bagging has the highest maximum strength value and elastic modulus of 346.15 MPa and 10673.4 MPa.

III. MECHANICAL BEHAVIOR OF FLY ASH/ SISAL REINFORCED COMPOSITES

A. Sample Characterization

Characterization carried out on samples from several mechanical studies are:

a. Tension Test: The specimen is tested on a tensile testing machine to determine the tensile strength and modulus of elasticity of the composite.
b. Impact Test: The specimen was tested on an Izod impact test machine to determine the strength and energy impact of the composite.
c. Bending test: Specimens were tested on bending testing machines to determine the bending strength.
d. Fatigue test: Specimens were tested with a fatigue testing machine to determine fatigue life.

The process of making composites, specimens, and mechanical properties of several studies as shown in Table 3.

B. Mechanical Properties of Composites

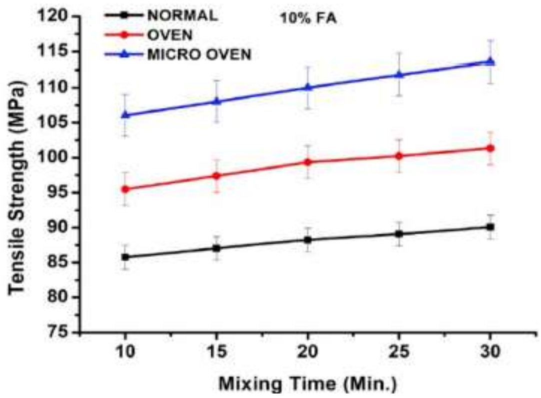
This study mainly focuses on strengths including tensile, flexural, impact, and fatigue. Figure 4 and Figure 5 show the variation in tensile strength (σ_s) of epoxy composites reinforced by Fly Ash with mixing time, percentage of fly ash reinforcement, and curing conditions. Specimens containing 10% FA with a mixing time of 10 minutes and microwave cured have tensile strength, maximum flexural strength. While the toughness and impact energy at 10% of the time the FA mixed 30 minutes with microwaves recovering 6.5% higher than ambient and cured ovens with FA contents and at the same time [1].

Figure 6 shows the material's performance in terms of tensile strength, modulus, and elongation compared to other materials. Hybrid composites reinforced by fly ash and sisal fibers increase tensile strength and elastic modulus. Whereas composites with a sisal matrix reinforced with epoxy have greater tensile strength than other materials. However, an excellent surface finish can only be achieved by the addition of fly ash particles. In fly ash enriched composite materials which have a chemical composition in such silica oxide, alumina, and titanium increase the modulus of elasticity and surface finish [14]. Composites with epoxy resin matrix filled with fly ash improve the mechanical properties of this composite. This increase is caused by fly ash particle fillers [10].

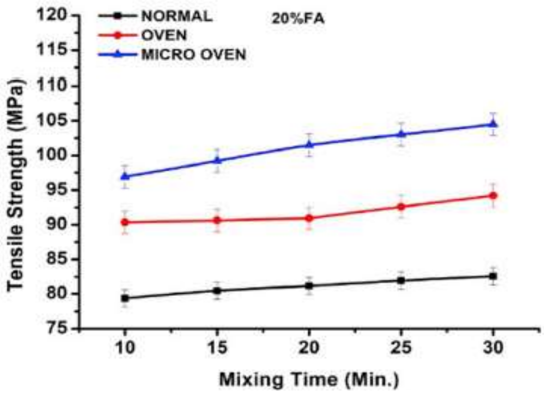
II. TABLE II
FIBER REINFORCED COMPOSITES

Reinforced Fiber	Matrix	Year	Reference
Fly ash	Epoxy	2019	[1]
Sisal	Epoxy	2019	[2]
Sisal and flax	Epoxy	2019	[3]
E-Glass	Epoxy	2018	[4]
Sisal	Epoxy	2019	[5]
Graphene Nanoplates (GNPs) and Nano Carbon Aerogels (NCAs).	Epoxy	2019	[6]
Basalt, Jute, Banana, and Carbon	Epoxy	2020	[7]
Hemp fiber, SiC, Al_2O_3	Epoxy	2019	[8]
Sisal	Epoxy	2019	[10]
E-Glass, Flying Ash	Epoxy	2010	[11]
Flax	Epoxy	2019	[13]
Fly Ash and Sisal	Epoxy	2017	[14]
Fly Ash	Polyoxym ethylene	2004	[15]
Sisal	Epoxy	2019	[16]
Glass Cloth, Fly Ash	Epoxy	2016	[18]
Fly Ash	Epoxy	2016	[20]
Oil Fly Ash	Epoxy	2016	[21]
Bamboo Fiber, Caryota Fiber	Epoxy	2019	[22]
Carbon, Jute	Epoxy	2019	[23]
Glass, Carbon, and Hemp Fabric.	Epoxy	2019	[24]
S-Glass, Carbon	Epoxy	2019	[25]
Carbon	Epoxy	2019	[26]

The fly ash particle ball is transformed into a 450 nm round hollow structure with wet grinding for 5 hours. The nanoparticles obtained are then inserted into the epoxy matrix and mixture are placed between each layer of lamina woven glass in three layers of the lamina.



(a)



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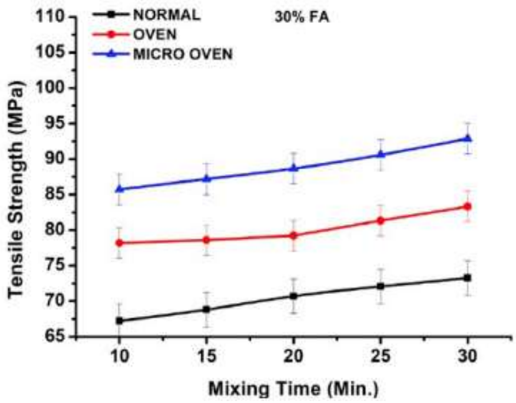

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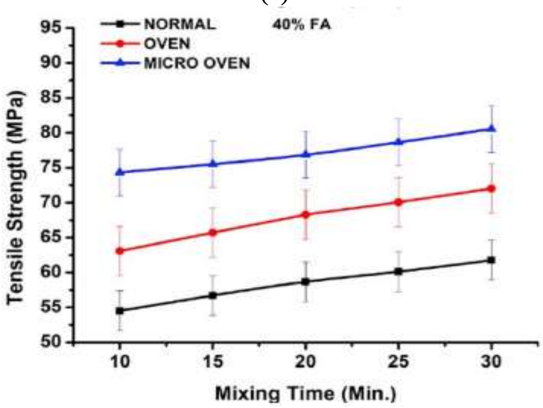

(d)

Fig. 4: Variation in tensile strength (σs) of composites concerning mixing time at different percentages of reinforcement fly ash under ambient, oven, and microwave curing.

Composites reinforced with active fly ash between 3 and 5% increase maximum strength and thermomechanical properties are better than fly ash that is not ground as a composite reinforcement. Flying ash after wet grinding is uniformly distributed into the epoxy matrix thereby increasing their interface interactions. The nature of the fly ash interface increases because it is activated so that an effective stress distribution occurs from the composite matrix to the particles as a filler and from the composite matrix to the individual glass layers. Impact strength increased by 1.66 times from 253.75 kJ / m² in fly ash filled with 3% by weight of the composite. Thus dynamic mechanical properties can increase the damping factor of fly ash as a composite filler because it increases the percentage in hollow structures after wet grinding [17].

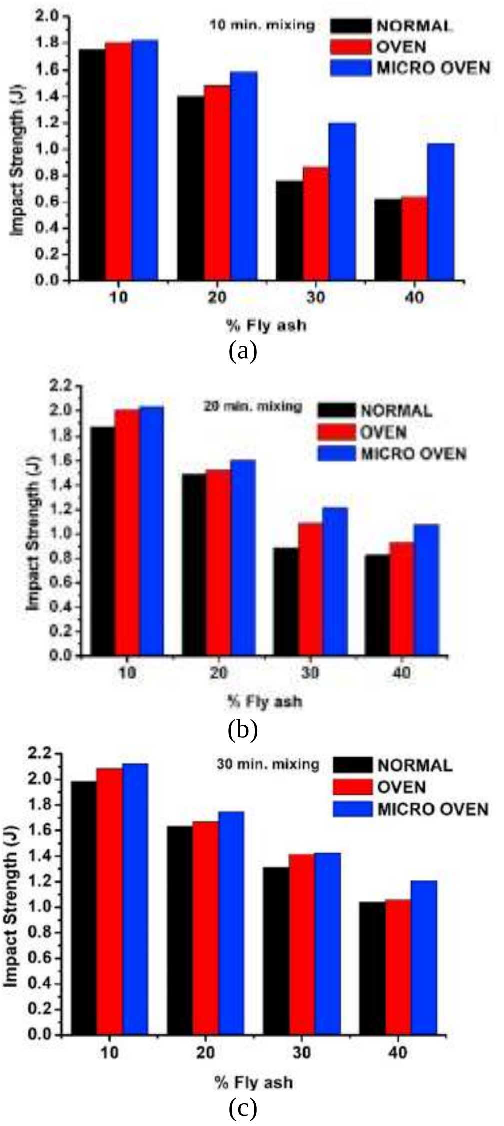

Fig. 5: **Variations in tensile strength (σ_s) of composites concerning the percentage of FA fillers at different mixing times under ambient, oven, and microwave curing. [1]**

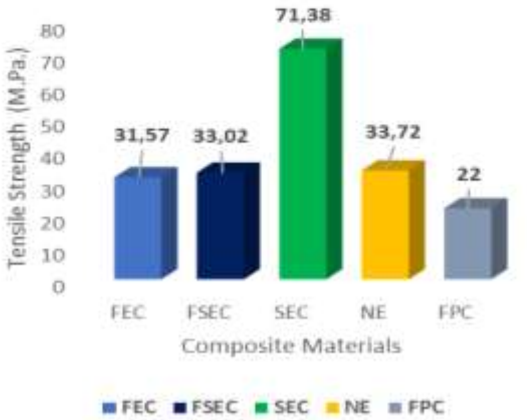

Fig. 6: **Comparison of the tensile strength of fly ash and composite reinforced sisal fiber vs. conventional materials [13].**

Figure 6 shows the material's performance in terms of tensile strength, modulus, and elongation compared to other materials. Hybrid composites reinforced by fly ash and sisal fibers increase tensile strength and elastic modulus. Whereas composites with a sisal matrix reinforced with epoxy have greater tensile strength than other materials. However, an excellent surface finish can only be achieved by the addition of fly ash particles. In fly ash enriched composite materials which have a chemical composition in such silica oxide, alumina, and titanium increase the modulus of elasticity and surface finish [13]. Composites with epoxy resin matrix filled with fly ash improve the mechanical properties of this composite. This increase is caused by fly ash particle fillers [10]

Fly ash is used as a filler or reinforcement for formamide and thermoplastic urea and thermoplastic glycerol. Ureaplastic and glycerol reinforced by fly ash can increase the tensile stress by 1.70 times from 4.56 M.Pa, and Young's modulus increases three times from 26.8 M.Pa, while tensile stress increases by two-point eighty-two from 4,56 M.Pa. and Young's modulus increased by seven-point twelve times from 76.4 M.Pa. for the fly-reinforced GPTPS (A-GPTPS) [18].

Composite epoxy resin reinforced with fly ash particles mixed with an ultrasonic stirring method. Signal to noise comparison analysis is an optimized parametric condition and produces a minimum level of wear, friction force, and coefficient of friction. The normal load which is charged greatly affects the increase in wear, friction, and the coefficient of friction followed by reinforcement, track diameter, speed, and time [19].

The weight fraction of Oil Fly Ash (OFA) reaches 4% as an epoxy composite filler. Higher mixing rotation frequency (37 kHz) with the ultra-sonication process is used to flatten OFA in the epoxy matrix. The shape and size of OFA particles are round and less than 30 µm. Optimal drying conditions for epoxy control matrices at 120 ^{0} C for 30 minutes, and 160

^{0} C for 60 minutes based on glass temperature transition, hardness characteristics, and Fourier Transform Infrared (FT-IR) spectrum. The thermal and mechanical properties in epoxy composites increase due to the even distribution of OFA particles in the epoxy matrix. [20].

The addition of sisal fiber as an epoxy matrix reinforcement reduces tensile, bending, and compression strength, while impact strength increases. Flax/ epoxy fiber composites have higher tensile, flexural, and compression fiber strength than sisal/ epoxy composite fibers. However, the loading of the same fiber reinforcement on sisal/epoxy fibers has better impact strength on flax/ epoxy composites. [3]. The increased sisal fiber content in the epoxy matrix, increasing tensile strength, flexural, and impact. Composite S25 (25% by weight of sisal fiber) shows the maximum value for mechanical properties compared to composites with other sisal reinforcement [5].

The storage modulus and glass transition temperature increase with increasing sisal fiber length by up to fifteen millimeters in the epoxy resin matrix [15]. The mechanical properties of sisal fiber-reinforced epoxy resin composites are strongly influenced by fiber ratio and matrix. Where there is a decrease in mechanical properties when the fiber content exceeds 30% by weight, but the impact strength increases with increasing sisal fiber ratio [2].

The effect of fly ash nano as a filler and BJBC as reinforcement on epoxy composites increases tensile strength and flexural strength. Nano fly ash with a four percent weight fraction with BJBC composite fillers has increased tensile strength and flexural strength than hybrid composites with 0% FA weight with BJBC fillers [7].

Natural fibers that are treated with NaOH can provide better strength because this solution can increase the free space in woven fibers so that epoxy resins can bind fibers smoothly. The bamboo fiber treated with NaOH, as a reinforcement on the GFRP composite, has a higher tensile strength 126 M.Pa. Sodium Lauryl sulfate for the treatment of Garyfid Caryota composite fibers showed a better bending pressure of 110 MPa. Impact energy better than 3.85J is obtained in the Bamboo-Caryota-GFRP composite [21].

Laminated specimens have many outer carbon layers, CCJCC. Hybrid composites have the highest flexural strength compared to other layers because the greater stiffness value comes from carbon reinforcement. Impact damage on hybrid composites can provide information that the impact strength is reduced by reducing the percentage of carbon weight fraction [22].

Natural hybrid composites FFFF, GFCF, GCFG & GCFC. Where hybrid GCFG and GCFC composites have the highest tensile strength and flexural strength compared to other hybrid composites, due to an increase in the percentage of carbon twill fabric [23]. When hybrid lamination is overloaded 70% and 80% it reduces the value of stiffness which is more gradual, and propagation of damage is slower than that of hybrid composites which have an overload at 90% load level. [25]

Flax fiber reinforced epoxy composites combined with SiC and Al_2O_3 can significantly increase tensile, flexural and impact strength, which is produced by 8% by weight of SiC from the combined composition of 2-10% by weight of SiC and Al_2O_3 and increases Inter Laminar Shear Strength (ILSS), and vice versa with an increase in Al_2O_3 a decrease in ILSS. Whereas compositions outside of 8% by weight of SiC content result in reduced mechanical properties. Thus it can be concluded that the composites obtained will act as low cost, lightweight, and environmentally friendly composites that will be used for brake pads, because of their better mechanical properties [8].

Hybrid composite with laminated graphene nanoplatelet (GNP) / nano-carbon air gel (NCA) / epoxy nanocomposite and GNP / NCA / epoxy/carbon fiber composite (CFRP), the value of mechanical properties is optimized by strengthening through the addition of GNP / NCA hybrids. The mechanical properties produced by nanocomposites containing one weight percent of hybrid GNP / NCA are better than nanocomposites containing one weight percent of single carbon nanocomposite and pure epoxy resin. The ability to crack crackers by mechanical testing on CFRP laminates reinforced with GNP / NCA, which is identified by testing by marking cracks to determine crack growth where cracks grow in interlamination [6].

Dynamic tensile stress caused by dynamic tensile loading with an amplitude of zero points one decreases continuously from the maximum load as a function of the cycle. From the dynamic loading, a maximum tensile stress-strain of about one hundred and forty megapascals is measured for one hundred eight cycles, so that this material does not reach the fatigue limit and the maximum stress reduction as a function of the cycle reaches at least one hundred and eight cycles, and this is a consideration when designing epoxy composite structures flax [12].

The relatively low slope for room temperature testing and 130ºC shows that NCF failure is a matrix dominated failure mode. For 130 ° C fatigue data, the fatigue strength for NCF may be better for design use because the slope of the SN curve is very low [30].

IV. MECHANICAL BEHAVIOUR OF FLY ASH/ SISAL REINFORCED COMPOSITES

Tensile strength is considered necessary because the tensile strength of a material is the maximum tensile strength acting on material due to the forces acting on the cross-section of the material, so the tensile strength possessed by the material obtained from tensile testing must be much greater. The epoxy hybrid composites filled with fly ash and reinforced with chopped sisal fibers showed a slight increase in strength, tensile elongation, and reduced stretch elongation, and reduced density compared to epoxy composites filled with fly ash [13].

Hybrid composites filled with fly ash and reinforced with sisal fibers have better performance, namely an increase in strength, and tensile modulus followed by a decrease in density compared to hybrid composites of polyester resin matrix filled with fly ash and reinforced by burlap [29].

Epoxy resin matrix composites reinforced with sisal fibers have better tensile strength, tensile modulus, tensile modulus, and elongation, but there is a decrease in density when compared to composites enriched with fly ash. Whereas the tensile strength, the tensile modulus is obtained much lower compared to hybrid composites filled with fly ash and reinforced sisal fibers [13].

Epoxy resin composites filled with fly ash which have a weight percentage of 10% mixed and stirred for 30 minutes have higher strength than epoxy resin composites containing other fly ash with stirring time regardless of curing conditions. epoxy resin composite filled with fly ash with 10% weight fraction mixed and stirred for 3 minutes then cured under three different conditions, it can be seen that the modulus of elasticity increased from 114 MPa. to 38.7GPa while the modulus of elasticity of cured oven specimens was slightly lower at 9.5% [1].

V. RESEARCH GAP OR RESEARCH RELATED TO FLY ASH / SISAL REINFORCED COMPOSITES

It has been observed that epoxy resin composites with fly ash fillers, and epoxy resin matrix composites with sisal fiber reinforcement. Composite specimens were made using fly ash as a reinforcement in the epoxy polymer system. Fly ash particulates on the composite epoxy matrix were made using fly ash 1:0.5, from observations obtained the tensile strength of the epoxy resin composite reinforced with fly ash has a value of 31.57 MPa [13]. Whereas in making epoxy resin composite matrix which is filled by varying the volume of fly ash volume, varying the mixing time of each fraction and varying the normal drying process, oven and micro wave oven. From the observations it was found that the tensile strength is better than 10% fly ash, the mixing time is 30 minutes with the cured micro wave oven process of 113 MPa [1]. From the results of this study it can be seen that the mechanical strength values of epoxy resin matrix composites filled with fly ash depend on the volume of fly ash volume and the manufacturing process, there is an increase in empty content and the actual density decreases with increasing levels of fly ash in composites. Mixing time in a given time gives homogeneous mixture of fillers and matrices that the secondary particles are evenly distributed compared to other mixing times. The fly ash fraction amplifies the epoxy of composite specimens cured in microwaves requiring less heat energy to reach ~ 99% of the degree of crosslinking. Both microwaves and ovens can achieve 99% curing but microwaves outperform ovens with faster curing.

From comparative analysis data which has the best mechanical properties taken to make hybrid composites with epoxy resin matrix reinforced with fly ash and sisal fiber.

VI. CONCLUSIONS

In general, the applications of fly-ash and sisal as reinforcing fibers promote to develop green technology, sustainability awareness, and increase the utilization of environmentally-friendly materials since these two materials are abundant resources. According to a literature survey, a huge number of publications worked on fly-ash and sisal fiber separately as reinforcing fiber in polymeric composites. On the other hand, information related to combining these two fibers or hybridization is hard to find. Some of the important aspects to be investigated such as mechanical and physical performances.

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