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FABRICATION, MECHANICAL CHARACTERIZATION OF PINEAPPLE LEAF FIBER (PALF) REINFORCED VINYLESTER HYBRID COMPOSITES

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Abstract

Natural fibre based composites are under intensive study due to their eco friendly nature and peculiar properties. The advantage of natural fibres is their continuous supply, easy and safe handling, and biodegradable nature. Although natural fibres exhibit admirable physical and mechanical properties, it varies with the plant source, species, geography, and so forth. Pineapple leave fibre (PALF) is one of the abundantly available waste materials in India and has not been studied yet. The work has been carried out to fabrication and study the mechanical characterization of Pineapple Leaf fiber reinforced Vinylester composites filled with different particulate fillers. These results are compared with those of a similar set of glass fiber reinforced Vinylester composites filled with same particulate fillers. It is evident that the density values for Pineapple leaf fiber (PALF) - Vinylester composites increase with the particulate filler content and void fractions in these composites also increase. The test results show that with the presence of particulate fillers, micro hardness of the PALF-Vinylester composites has improved. Among all the composites under this investigation, the maximum hardness value is recorded for PALF-Vinylester composite filled with 20 wt% alumina. In this investigation the maximum value of ILSS has been recorded for the PALF-Vinylester composite with 20 wt% of Flyash.

Keywords: Natural fibre, Pineapple leaf fiber (PALF), Polymer matrix composites, PALF based Hybrid composite, Vinylester, Particulate filler, Mechanical properties

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1. Introduction

Composites are materials consisting of two or more chemically distinct constituents, on a macro-scale, having a distinct interface separating them. One or more discontinuous phases are, therefore, embedded in a continuous phase to form a composite [1]. The discontinuous phase is usually harder and stronger than the continuous phase and is called the *reinforcement*, whereas, the continuous phase is termed as the *matrix*. The matrix material can be Metallic, Polymeric or can even be Ceramic. When the matrix is a polymer, the composite is called polymer matrix composite (PMC).

Over the past few decades, it is found that polymers have replaced many of the conventional metals/materials in various applications. This is possible because of the advantages such as ease of processing, productivity, cost reduction etc. offered by polymers over conventional materials. In most of these applications, the properties of polymers are modified by using fibers to suit the high strength/high modulus requirements. All synthetic polymers (Thermoplastics, Thermoset and Elastomers) can be used as matrices in PMCs. As far as the reinforcement is concerned, extensive use has been made of inorganic man-made fibers such as glass and organic fibers such as carbon and aramid. As all these reinforcing fibers are expensive, various fibers like cellulose, wool, silk etc. abundantly available in natures are also used in composites. Cellulosic fibers like henequen, sisal, coconut fiber (coir), jute, palm, bamboo, Pineapple leaves fiber (PALF) and wood, in their natural conditions and several waste cellulosic products such as shell flour, wood flour and pulp have also been used as reinforcing agents of different thermosetting and thermoplastic resins. It is well known that natural fibers impart high specific stiffness, strength and biodegradability to polymer matrix composites. Also, cellulosic fibers are readily available from natural sources and most importantly, they have low cost per unit volume.

There are many natural resources available which has potential to be applied in industries as raw materials such as pineapple, kenaf, coir, abaca, sisal, cotton, jute, bamboo, banana, Palmyra, talipot, hemp, and flex [2,3]. Among them Pineapple leaf fibre (PALF) is one of the waste materials in agriculture sector, which is widely grown in India as well as Asia. After banana and Citrus, Pineapple (*Ananas comosus*) is one of the most essential tropical fruits in the world [4]. Commercially pineapple leaves are considered as waste materials of fruit which is being used for producing natural fibres. The chemical composition of PALF constitute holocellulose (70– 82%), lignin (5–12%), and ash (1.1%).

Major constituents in a natural fiber reinforced composite are the reinforcing fibers and a matrix, which acts as a binder for the fibers. In addition, particulate fillers can also be used with some polymeric matrices primarily to reduce cost and improve their dimensional stability. So, although a judicious selection of matrix and the reinforcing phase can lead to a composite with a combination of strength and modulus comparable to or even better than those of conventional metallic materials [5], the physical and mechanical characteristics can further be modified by adding a solid filler phase to the matrix body during the composite preparation. The fillers play a major role in determining the properties and behaviour of particulate reinforced composites. The term 'filler' is very broad and encompasses a very wide range of materials. It is arbitrarily defined as a variety of natural or synthetic solid particulates (inorganic, organic) that may be irregular, circular, fibrous or flakey. The improved performance of polymers and their composites in industrial and structural applications by the addition of particulate fillers has shown a great promise and so has lately been a subject of considerable interest.

Another possibility that the incorporation of both particulates and fibers in polymer could provide a synergism in terms of improved properties and wear performance has not been adequately explored so far. However, some recent reports suggest that by incorporating filler particles into the matrix of fibre reinforced composites, synergistic effects may be achieved in the form of higher modulus and reduced material cost, yet accompanied with decreased strength and impact toughness. Such multi-component composites consisting of a matrix phase reinforced with a fiber and filled with particulates are termed as *hybrid* composites.

Nowadays much attention is devoted towards the study of solid particle erosion behaviour of polymer composites due to the high potential use of these materials in many mechanical and structural applications. Hence, erosion resistance of polymer composites has become an important material property, particularly in selection of alternative materials and therefore the study of solid particle erosion characteristics of the polymeric composites has become highly relevant. Differences in the erosion behaviour of various types of composite materials are caused by the Amount, Type, Orientation and Properties of the reinforcement on one hand and by the type and properties of the matrix and its adhesion to the fibers/fillers on the other hand. A full understanding of the effects of all system variables on the wear rate is necessary in order to undertake appropriate steps in

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the design of machine or structural component and in the choice of materials to reduce/control wear [6].

The present research work thus is undertaken to fabrication and study the characterization of Pineapple leaf fiber (PALF) reinforced Vinylester composites with and without particulate fillers. Attempts have also been made to explore the possible use of some industrial wastes such as flyash and red mud as filler materials in these composites.

2. Materials and Methodology

2.1 Materials

In this present research work Vinylester is chosen as the matrix material, i.e. grade of FB-701, Density 1.35 gm/cc, Elastic modulus 3.25 Gpa, (Supplied by *Zenith Industrial supplies, Bangalore*) and the Raw natural Pineapple leaf fiber(PALF) mat is unidirectional horizontal. The width is 17 inch and thickness is 2.8 mm, Density 1.56 gm/cc, Elastic Modulus 62.1 Gpa, (supplied by *Go-green products, Chennai*) are used as the reinforcing phase in the composites.

Though the present research work is focused mainly on the pineapple leaf fiber reinforced composites, their relative evaluation can only be made on comparing them with a similar set of composites with some conventional synthetic fiber. In the present work, E-glass fibers chopped strand mat density 2.54 gm/cc; modulus 72.4 Gpa, (supplied by *Zenith Industrial supplies, Bangalore*) has been used as the reinforcing material in the composites. The major constituents of E-glass are silicon oxide (54 wt. %), aluminum oxide (15 wt. %), calcium oxide (17 wt. %), boron oxide (8 wt. %) and magnesium oxide (4.5 wt. %).

A variety of natural or synthetic solid particulates, both organic and inorganic is already being commercially used as reinforcing fillers in polymeric composites. While ceramic powders such as alumina (Al_2O_3), silicon carbide (SiC) , silica (SiO_2), titanium (TiO_2) etc. are widely used as conventional fillers, the use of industrial wastes for such purpose is hardly found. In view of this, in the present work two industrial wastes such as flyash and red mud are chosen as particulate fillers to be used in the composites. The red mud used in this work has been collected from the site of NALCO alumina plant at Damanjodi in India. The other industrial waste used in this investigation is fly ash used here is of Cenosphere type and has been collected from the Captive

Power Plant of National Aluminium Co. (NALCO) located at Angul in India. Fly ash is a finely divided powder generated in huge quantities during power generation in coal based power plants. It is essentially a mixture of ceramic materials such as: SiO_2, Fe_2O_3, Al_2O_3 and TiO_2 etc.

Aluminium oxide (Al_2O_3) commonly referred to as alumina, can exist in several crystalline phases which all revert to the most stable hexagonal alpha phase at elevated temperatures. This is the phase of particular interest for structural applications. Alumina is the most cost effective and widely used material in the family of engineering ceramics. It is hard, wear-resistant, has excellent dielectric properties, resistance to strong acid and alkali attack at elevated temperatures, high strength and stiffness. With an excellent combination of properties and a reasonable price, it is no surprise that fine grain technical grade alumina has a very wide range of applications. Similarly, the other conventional filler chosen for this work is SiC, which has a great potential to be used in various polymeric matrices. It is the only chemical compound of carbon and silicon

Table 2.1 Chemical compositions and Densities of filler materials

Filler	Composition/Chemical formula	Density (gm/cc)
Alumina	Al_2O_3	2.1
Silicon Carbide	SiC	2.6
Flyash	SiO_2 (48.3%), Al_2O_3 (20.2%), Fe_2O_3 (6.4%), TiO_2 (1.9%)	1.3
Red mud	Fe_2O_3 (40%), Al_2O_3 (20%), SiO_2 (14%), Na_2O (6%), CaO (4%), TiO_2 (2%)	3.26

2.2 Composite Fabrication

The resin used in this research work is Vinylester FB-701 resin (*density 1.35 gm/cc*, *Elastic modulus 3.25Gpa*) and reinforcing phase a unidirectional Pineapple Leaves Fiber (PALF) and E-glass fibers are reinforced separately in Vinylester resin to prepare the fiber reinforced composites P_1 and G_1 in which no particulate filler Material is used. The other composite samples $P_2 – P_9$ and

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$G_2 - G_9$ with four different particulate fillers of varied amount but with fixed fiber loading (30 wt %) are fabricated. The composition and designation of the composites prepare for this study are listed in **Table 2.2**

The fabrication of the composite slabs is done by conventional hand-lay-up technique followed by light compression moulding technique. The Cobalt Naphthenate 2% is mixed thoroughly in Vinylester resin and then 2% methyl ethyl ketone peroxide (MEKP), 2% N- dimethylaniline is mixed in the resins prior to reinforcement. The fiber loading weight fraction of unidirectional Pineapple Leaves Fiber (PALF) or E-glass fiber chopped strand mat in the composite is kept 30 wt% for all the samples. The stacking procedure consists of placing the fabric one above the other with the resin mix well spread between the fabrics on a mould release sheet. A porous Teflon film was again used to complete the stack. To ensure uniform thickness of the sample, a 4mm spacer was used. The mould plates were coated with release agent in order to aid the ease of separation on curing. A metal roller was used so that uniform thickness and compactness could obtain The whole assembly is placed in the light compression molding machine at a pressure of 40Kgf/cm^2 and allowed to cure at room temperature for 24hrs. The laminate sheets of sizes 210 x 210 x 4mm were prepared. Specimens of suitable dimensions were cut using a diamond cutter for physical and mechanical characterization as per ASTM standard.

Table 2.2 Designations and detailed compositions of the composites

Designation	Composition
P_1	Vinylester (70 wt%) + PALF (30 wt%)
P_2	Vinylester (60 wt%) + PALF (30 wt%) + Fly ash (10 wt%)
P_3	Vinylester (50 wt%) + PALF (30 wt%) + Fly ash (20 wt%)
P_4	Vinylester (60 wt%) + PALF (30 wt%) + Red mud (10 wt%)

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P_5	Vinylester (50 wt%) + PALF (30 wt%) + Red mud (20 wt%)
P_6	Vinylester (60 wt%) + PALF (30 wt%) + Alumina (10 wt%)
P_7	Vinylester (50 wt%) + PALF (30 wt%) + Alumina (20 wt%)
P_8	Vinylester (60 wt%) + PALF (30 wt%) + SiC (10 wt%)
P_9	Vinylester (50 wt%) + PALF (30 wt%) + SiC (20 wt%)
G_1	Vinylester (70 wt%) + Glass Fiber (30 wt%)
G_2	Vinylester (60 wt%) + Glass Fiber (30 wt%) + Fly ash (10 wt%)
G_3	Vinylester (50 wt%) + Glass Fiber (30 wt%) + Fly ash (20 wt%)
G_4	Vinylester (60 wt%) + Glass Fiber (30 wt%) + Red mud (10 wt%)
G_5	Vinyl ester (50 wt%) + Glass Fiber (30 wt%) + Red mud (20 wt%)
G_6	Vinylester (60 wt%) + Glass fiber (30 wt%) + Alumina (10 wt%)
G_7	Vinylester (50 wt%) + Glass Fiber (30 wt%) + Alumina (20 wt%)
G_8	Vinylester (60 wt%) + Glass Fiber (30 wt%) + SiC (10 wt%)
G_9	Vinylester (50 wt%) + Glass Fiber (30 wt%) + SiC (20 wt%)

3. Mechanical characterization

3.1 Density

The theoretical density (ρ_{ct}) of composite materials in terms of weight fractions of different constituents can easily be obtained as for the following equation given by Agarwal and Broutman [1]. Where, W and ρ represent the weight fraction and density respectively.

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$$\rho_{ct} = \frac{1}{(W_f/\rho_f) + (W_m/\rho_m)} \tag{3.1}$$

The suffixes *f* and *m* stand for the fiber and matrix respectively. Since the composites under this investigation consist of three components namely matrix, fiber and particulate filler, the expression for the density has been modified as

$$\rho_{ct} = \frac{1}{(W_f/\rho_f) + (W_m/\rho_m) + (W_p/\rho_p)} \tag{3.2}$$

Where, the suffix *p* stands for the particulate fillers. The actual density (ρ_{ca}) of the composite, however, can be determined experimentally by simple water immersion technique. The volume fraction of voids (V_v) in the composites is calculated using the following equation:

$$V_V = \frac{\rho_{ct} - \rho_{ca}}{\rho_{ct}} \tag{3.3}$$

3.2 Micro-hardness

Micro-hardness measurement is done using a Leitz micro-hardness tester. A diamond indenter, in the form of a right pyramid with a square base and an angle 136° between opposite faces, is forced into the material under a load *F*. The two diagonals *X* and *Y* of the indentation left on the surface of the material after removal of the load are measured and their arithmetic mean *L* is calculated. In the present study, the load considered *F* = 24.54N and Vickers hardness number is calculated using the following equation.

$$H_V = 0.1889 \frac{F}{L^2} \tag{3.4}$$

$$\text{Where,} \quad L = \frac{X + Y}{2}$$

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Where, *F* is the applied load (*N*), *L* is the diagonal of square impression (mm), *X* is the horizontal length (mm), *Y* is the vertical length (mm).

3.3 Tensile Strength

The tensile test is generally performed on flat specimens. The dimension of the specimen is 150 mm ×10 mm × 4 mm and a uni-axial load is applied through both the ends. The ASTM standard test method for tensile properties of fiber-resin composites has the designation D 3039-76. In the present work, this test is performed in the universal testing machine Instron 1195 at a crosshead speed of 10 mm/min and the results are used to calculate the tensile strength of composite samples. The test is repeated three times on each composite type and the mean value is reported as the tensile strength of that composite.

3.4 Flexural and Inter-Laminar Shear Strength (ILSS)

The flexural strength of a composite is the maximum tensile stress that it can withstand during bending before reaching the breaking point. The three point bend test is conducted on all the composite samples in the universal testing machine Instron 1195. The dimension of each specimen is 150 mm ×13 mm × 4 mm. Span length of 40 mm and the cross head speed of 10 mm/min are maintained. For both flexural strength and ILSS, the test is repeated three times for each composite type and the mean value is reported. The flexural strength of the composite specimen is determined using the following equation.

$$\text{Flexural Strength} = \frac{3PL}{2bt^2} \tag{3.5}$$

Where, *L* is the span length of the sample (mm), *P* is maximum load (N), *b* the width of specimen (mm), *t* the thickness of specimen (mm).The data recorded during the 3-point bend test is used to evaluate the ILSS also. The ILSS values are calculated as follows:

$$\text{ILSS} = \frac{3P}{4bt} \tag{3.6}$$

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3.5 Impact Strength

Low velocity instrumented impact tests are carried out on the composite specimens. The tests are done as per ASTM D 256 using an impact tester. The pendulum impact testing machine ascertains the notch impact strength of the material by shattering the V notched specimen with a pendulum hammer, measuring the spent energy and relating it to the cross section of the specimen. The standard specimen size as per ASTM D 256 is 64 mm× 12 mm × 4 mm and the depth under the notch is 10 mm. The respective values of impact energy of different specimens are recorded directly from the dial indicator.

IV. Results and Discussion

4.1 Density and Void Fraction

Density is a material property which is of prime importance in several weight sensitive applications. Thus, in many such applications polymer composites are found to replace conventional metals and materials primarily for their low densities. Density of a composite depends on the relative proportion of matrix and the reinforcing materials. There is always a difference between the measured and the theoretical density values of a composite due to the presence of voids and pores. These voids significantly affect some of the mechanical properties and even the performance of composites. Higher void contents usually mean lower fatigue resistance, greater susceptibility to water penetration and weathering.

Table 4.1 Measured and theoretical densities along with the void fractions of the Vinylester-PALF composites with different particulate fillers

Composition	Measured density (gm/cc)	Theoretical Density (gm/cc)	Volume fraction of voids (%)
PALF (30 wt%) +Vinylester (70 wt%)	1.401	1.413	0.849

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PALF (30 wt%) +Vinylester (60 wt%) + FA (10wt%)	1.382	1.480	6.621
PALF (30 wt %) +Vinylester (50 wt%) + FA (20 wt%)	1.295	1.403	7.697
PALF (30 wt%) +Vinylester (60 wt%) + RM (10 wt%)	1.542	1.604	3.865
PALF (30 wt%) +Vinylester (50 wt%) + RM (20 wt%)	1.685	1.795	6.128
PALF (30 wt%) +Vinylester (60 wt%) + Al_2O_3 (10 wt%)	1.415	1.488	4.905
PALF (30 wt%) +Vinylester (50 wt%) + Al_2O_3 (20 wt%)	1.460	1.563	6.589
PALF (30 wt%) +Vinylester (60 wt%) + SiC (10 wt%)	1.480	1.538	3.771
PALF (30 wt%) +Vinylester (50 wt%) + SiC (20 wt%)	1.536	1.663	7.636

Table 4.2 Measured and theoretical densities along with the void fractions of the Vinylester-glass composites with different particulate fillers

Composition	**Measured density (gm/cc)**	**Theoretical Density (gm/cc)**	**Volume fraction of voids (%)**
GF (30 wt%) + Vinylester (70 wt%)	1.708	1.722	0.813

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GF (30 wt%) + Vinylester (60 wt%) + FA (10 wt%)	1.654	1.77	6.554
GF (30 wt%) + Vinylester (50 wt%) + FA (20 wt%)	1.552	1.697	8.544
GF (30 wt%) + Vinylester (60 wt%) + RM (10 wt%)	1.843	1.898	2.898
GF (30 wt%) + Vinylester (50 wt%) + RM (20 wt%)	1.941	2.089	7.085
GF (30 wt%) + Vinylester (60 wt%) + Al_2O_3 (10 wt%)	1.692	1.782	5.051
GF (30 wt%) + Vinylester (50 wt%) + Al_2O_3 (20 wt%)	1.724	1.857	7.162
GF (30 wt%) + Vinylester (60 wt%) + SiC (10 wt%)	1.615	1.697	4.832
GF (30 wt%) + Vinylester (50 wt%) + SiC (20 wt%)	1.805	1.957	7.767

The knowledge of void content is desirable for estimation of the quality of the composites. In the present research work, the theoretical and measured densities of Pineapple leaf fiber (PALF) - Vinylester and Glass-Vinylester composites, along with the corresponding volume fraction of voids are presented in **Table 4.1** and **Table 4.2** respectively. It is found that the composite density values calculated theoretically from weight fractions using **Eq. (3.2)** are not equal to the experimentally measured values, as expected. It is evident from **Table 4.1** that the density values for Pineapple leaf fiber (PALF) - Vinylester composites increase with the particulate filler content. It is further observed that with the incorporation of particulate fillers, the void fractions in these composites also increase. Similar trends are noticed for the glass-Vinylester composites as well irrespective of the filler type.

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4.2 Micro-hardness

Hardness is considered as one of the most important factors that govern the wear resistance of any material. In the present work, micro-hardness values of the PALF-Vinylester composites with different particulate fillers have been obtained and are compared with those of a similar set of glass-Vinylester composites. The test results (**Figure 4.1**) show that with the presence of particulate fillers, micro hardness of the PALF-Vinylester composites is improved and this improvement is a function of the filler content. This trend of improvement of hardness with filler content is also observed in case of the glass-Vinylester composites. As far as the comparison between the composites with PALF and glass fiber reinforcement is concerned, the PALF-Vinylester composites exhibit superior micro-hardness values for all filler materials except SiC. Even the PALF-Vinylester composite without any particulate filler possesses greater hardness than the unfilled glass-Vinylester composite. Among all the composites under this investigation, the maximum hardness value is recorded for PALF-Vinylester composite filled with 20 wt% alumina.

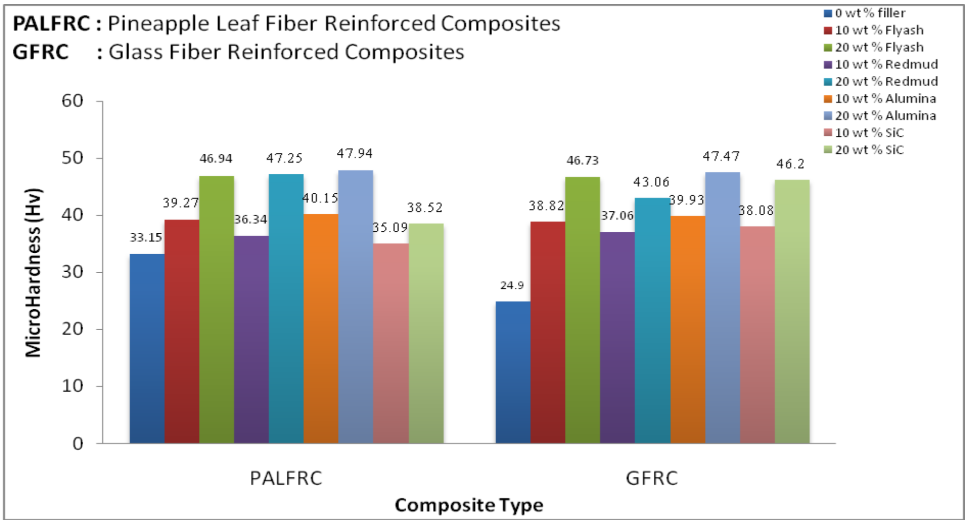

Figure 4.1 Micro-hardness of composites with different particulate fillers

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4.3 Tensile Properties

The variations of tensile strength of both the PALF- Vinylester and glass-Vinylester composites with different fillers are presented in **Figure 4.2**. Marginal improvement in tensile strength for the PALF- Vinylester composites with the addition of 10 wt% of filler as compared to the unfilled ones is observed. However, with the incorporation of 20 wt% of the filler, the tensile strengths of these composites are found to be decreasing irrespective of the filler type. In case of glass-Vinylester composites, the variation of tensile strength with filler content shows a different trend. As seen in **Figure 4.2**, the tensile strengths of these composites decrease invariably with increase in filler content irrespective of the type of filler.

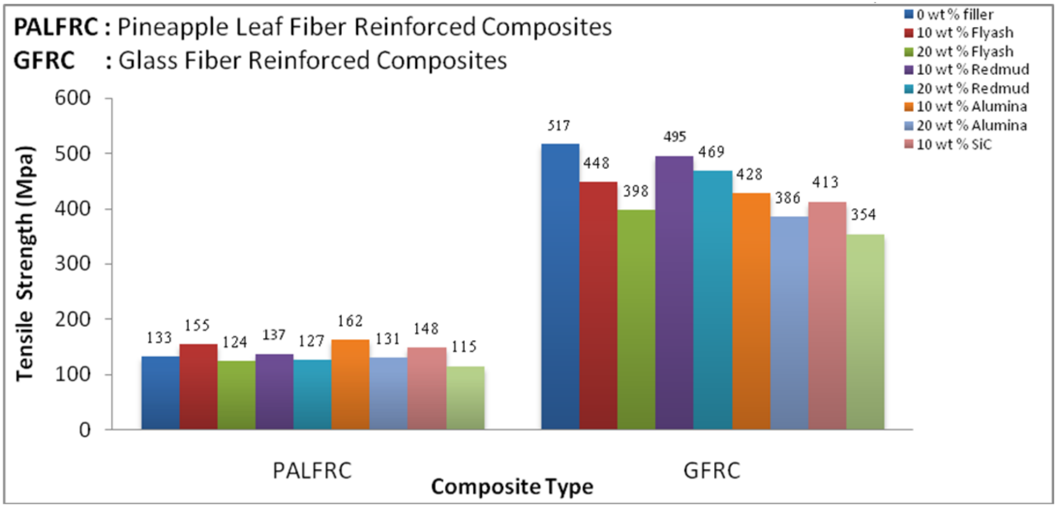

Figure 4.2 Tensile Strength of composites with different particulate fillers

This decline in strength may be attributed to two reasons: one possibility is that the due to the presence of pores at the interface between the filler particles and the matrix, the interfacial adhesion may be too weak to transfer the tensile stress; the other is that the corner points of the irregular shaped particulates result in stress concentration in the matrix body. The variation of tensile modulus with filler content for both PALF-Vinylester as well as glass- Vinylester composites with different fillers is shown in **Figure 4.3.** It is observed that the tensile moduli of PALF-Vinylester composites improve significantly with 10 wt% of filler content irrespective of

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filler type. But in case of glass- Vinylester composites, similar trend is observed only for flyash and SiC fillers. Previous reports demonstrate that normally the fibers in the composite restrain the deformation of the matrix polymer, reducing the tensile strain [7, 8]. So even if the strength decreases with filler addition, the tensile modulus of the composite is expected to increase as has been observed in the present investigation. But further increase in filler content up to 20 wt%, the tensile moduli of the composites are found to be decreasing. It is further noted that as far as the tensile properties are concerned, PALF-Vinylester composites are found not as good as the glass-Vinylester composites both with and without particulate fillers.

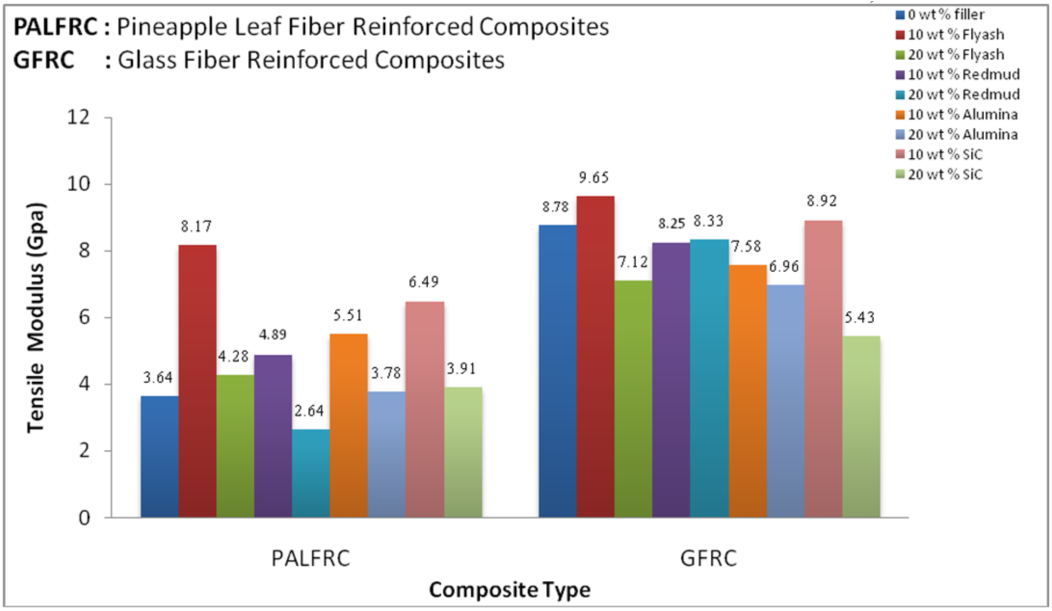

Figure 4.3 Tensile modulus of composites with different particulate fillers

4.4 Flexural Strength

Composite materials used in structures are prone to fail in bending and therefore the development of new composites with improved flexural characteristics is essential. In the present work, the variation of flexural strength of both the PALF-Vinylester and glass-Vinylester composites with different particulate fillers is shown in **Figure 4.4.** A gradual improvement in flexural strength with filler content is recorded in case of Redmud filled PALF-Vinylester composites. But for the composites with flyash, there is a drop in flexural strength with 10 wt% of filler content followed by a marginal rise with 20 wt% of filler content. However, in case of the PALF-Vinylester composites filled with Alumina and SiC, it is noticed that while the flexural strengths improve with 10wt% of filler content, further increase up to 20 wt%, the strengths are found to be decreasing. The reduction in the flexural strengths of the composites with filler content is probably caused by an incompatibility of the particulates and the Vinylester matrix, leading to poor interfacial bonding. The lower values of flexural properties may also be attributed to fiber to fiber interaction, voids and dispersion problems. However, it also depends on other factors such as the size, shape and type of the filler material. Influence of the particulate fillers on the flexural strength is noticed also for the glass- Vinylester composites. Remarkable improvement in flexural strength is observed in Flyash (10 wt %) filled glass- Vinylester and SiC (10 wt %) filled glass-Vinylester composites as compared to the unfilled one. It is evident from this study that as far as the flexural strength is concerned, PALF-Vinylester composites are found not as good as the glass-Vinylester composites either with or without particulate fillers.

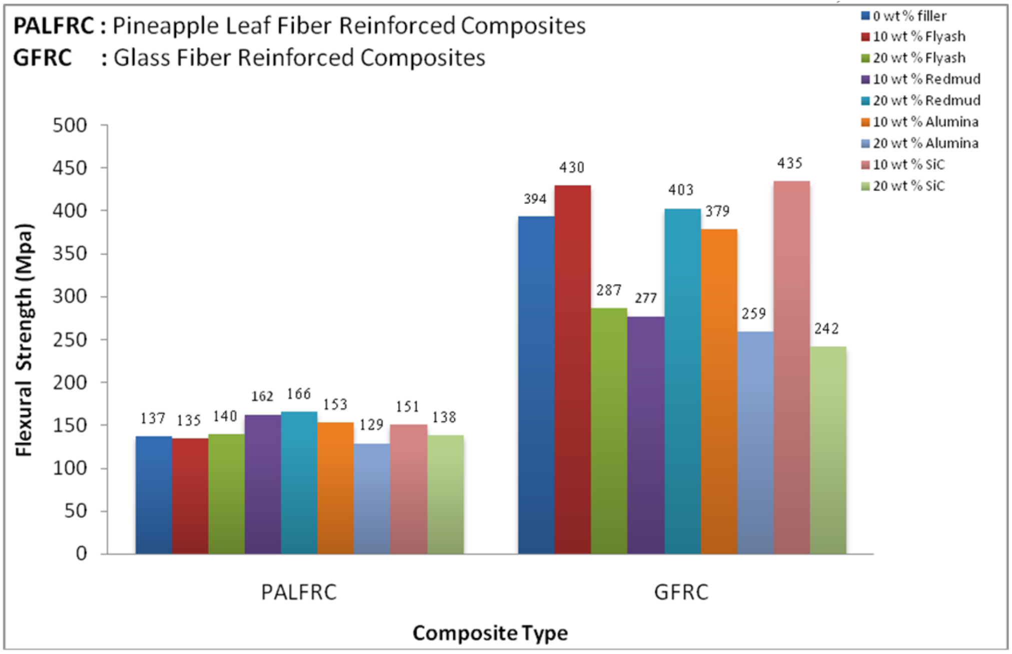

Figure 4.4 Flexural strength of composites with different particulate fillers

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4.5 Inter-Laminar Shear Strength (ILSS)

Short beam shear test is carried out on the composites with different particulate fillers to determine the inter-laminar shear strength (ILSS). The variation of ILSS of PALF-Vinylester and glass-Vinylester composites with filler content is presented in **Figure 4.5.** It is observed that with the addition of 10 wt% Redmud, the ILSS of PALF-Vinylester composite increases slightly but starts decreasing on further addition. In case of glass-Vinylester composites, with the addition of Redmud, no improvement of the ILSS value is noticed. For PALF-Vinylester composites filled with Flyash, the ILSS increases monotonically as the filler content increases from 0 wt% to 20 wt%. But the trend exhibited by the flyash filled glass -Vinylester composites is just opposite. There is a gradual reduction in ILSS with the Flyash weight percentage in the composites. With the addition of Alumina, ILSS of the PALF-Vinylester composites decreases substantially. Similar trend is observed in case of alumina filled glass-Vinylester composites as well. As far as the SiC filled composites are concerned, it is noted that the ILSS is increasing with the addition of filler up to 10 wt% and is decreasing with further increase in filler content up to 20 wt%. This trend is exhibited by both PALF-Vinylester as well as glass-Vinylester composites filled with SiC particles. This reduction may be due to the formation of voids in the matrix which is generally located at the inter-laminar region of composites. It is interesting to note that the inter-laminar shear strengths of PALF-Vinylester composites with different particulate fillers are comparable to and often even superior to those of glass- Vinylester composites. In the present investigation, the maximum value of ILSS has been recorded for the PALF-Vinylester composite with 20 wt% of Flyash.

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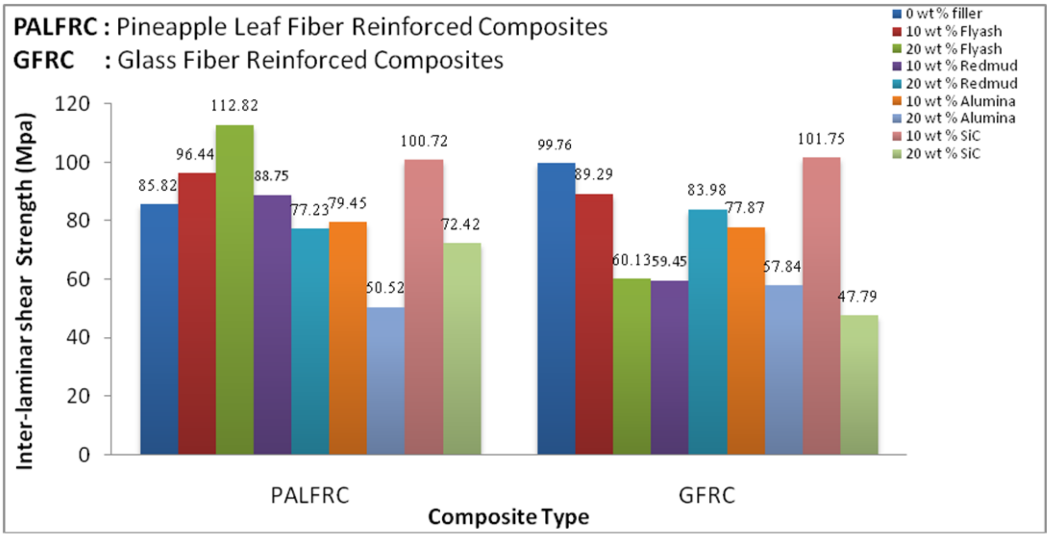

Figure 4.5 Inter-laminar shear strength of composites with different fillers

4.6 Impact Strength

The impact strength of a material is its capacity to absorb and dissipate energies under impact or shock loading. **Figure 4.6** presents the measured impact energy values of the various particulate filled composites under this investigation. It is seen from this figure that the impact energies of the PALF-Vinylester composites increase gradually with the filler content increasing from 0 wt% to 20 wt% for all the fillers except SiC. In the SiC filled composites, the impact energy is found to be increasing initially with filler content of 10 wt%, but with further addition (20 wt %), there is reduction in the impact energy value. The variation of impact energy with filler content is not uniform in case of glass-Vinylester composites as well. For Flyash filled glass-Vinylester and alumina filled glass-Vinylester composites, gradual improvements in the impact energy value with filler content are recorded. However, for Redmud filled glass- Vinylester and SiC filled glass-Vinylester composites, the impact energy is found to be increasing with 10 wt% of filler and then with further filler addition (20 wt%), it is seen to decrease.

It is clear from this investigation that the PALF-Vinylester composites have lower impact strength than their glass fiber counterparts irrespective of the filler type. However, PALF fiber composites demonstrate better impact properties than composites reinforced with other natural fibers such as

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jute and kenaf [9]. Hence, for high performance applications, it is important to find ways to improve various strength properties of composites with PALF fiber reinforcement.

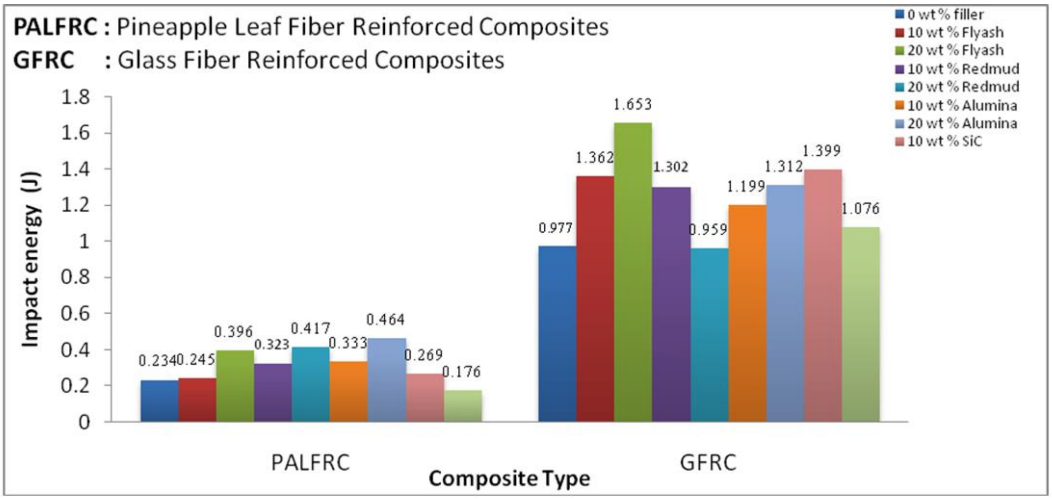

Figure 4.6 Impact strength of composites with different particulate fillers

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5. Conclusions

From the experimental results, the following can be concluded:

1) Successful fabrication of multi-component hybrid PALF/glass-Vinylester composites with reinforcement of conventional ceramic fillers such as Al_2O_3 and SiC is possible. Industrial waste like Flyash and Redmud can also be gainfully utilized as filler composite making.
2) Incorporation of these fillers modifies the tensile, flexural, impact and inter-laminar shear strengths of the composites both for PALF as well as for glass fiber reinforcement. The tensile modulus, micro-hardness and density of the composites are also greatly influenced by the type and content of fillers.
3) It is found that the composite density values calculated theoretically from weight fractions are not equal to the experimentally measured values, as expected. It is evident that the density values for Pineapple leaf fiber (PALF) - Vinylester composites increase with the particulate filler content. It is further observed that with the incorporation of particulate fillers, the void fractions in these composites also increase.
4) The test results show that with the presence of particulate fillers, micro hardness of the PALF-Vinylester composites is improved and this improvement is a function of the filler content. As far as the comparison between the composites with PALF and glass fiber reinforcement is concerned, the PALF-Vinylester composites exhibit superior micro-hardness values for all filler materials except SiC. Even the PALF-Vinylester composite without any particulate filler possesses greater hardness than the unfilled glass-Vinylester composite. Among all the composites under this investigation, the maximum hardness value is recorded for PALF-Vinylester composite filled with 20 wt% alumina.
5) It is observed that the inter-laminar shear strengths of PALF-Vinylester composites with different particulate fillers are comparable to and often even superior to those of glass-Vinylester composites. In the present investigation, the maximum value of ILSS has been recorded for the PALF-Vinylester composite with 20 wt% of Flyash.
6) PALF fiber composites demonstrate better impact properties than composites reinforced with other natural fibers such as jute and kenaf [8]. Hence, for high performance applications, it is important to find ways to improve various strength properties of composites with PALF fiber reinforcement.

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