

Effect of fiber hybridization on bi-directionally oriented natural and glass fiber reinforced polymer composites

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ABSTRACT

In recent days the natural fiber reinforced polymer composites getting more attention due to their eco-friendly and reliability in many parts of the industries. The lignocellulosic content in natural fibers influenced to use in corrosion and thermal free applications. The hybrid fiber reinforced composites additionally provides the combination of material properties together, the orientation of fiber reflects in strength of the composites as it acting as load bearing factor of the fiber reinforced composites. So, the present work investigates the effect of hybridization and stacking sequence on various material properties such as density, moisture intake by the material, tensile, impact, hardness and thermal stability. The structural characteristics of the fabricated composites is analyzed through Scanning Electron Microscope. The results concludes that the hybridization of glass fiber mat with cellulose fibers mat such as Pineapple Leaf fiber (PALF) and areca fiber depicts the more acceptable bonding relationship with the matrix thus results in improved properties. The fabricated new set of natural and glass reinforced polymer composites have found the tensile strength between 40–65 MPa, Young's modulus in the range 950–1400 MPa, Impact strength of about 130–190 KJ/mm² and thermal stability up to 340–390 °C which is higher than the earlier studies reported.

Keywords: Lignocellulosic fibers; Glass fiber; Physical; Mechanical characterization; Thermal degradation; Microstructural Analysis.

1. INTRODUCTION

The application of natural fibers as reinforcement in composites is a predominant in the field of transportation vehicle components. It is because of the easy procurement of fibers, easy to handle, lessor in weight, less corrosion and nonabrasive characteristics [1]. So far, many natural fibers were used such as jute, hemp, flax, sisal, banana, coir, Kenaf, bamboo etc [2], [3]. but use of areca pineapple leaf (PALF) fiber is limited. Even though there is not investigations were found on the bidirectional woven areca and PALF fiberon determining the material quality. The PALF fibers have a higher cellulosic content which is the main course to improve the mechanical properties of the composite [4]. Also, the coarse structure at the outer surface of the PALF fiber has higher tendency to improve the adhesion characteristics [5]. The cellulose fibers have commonly hydrophilic in nature. Due to its, the wetting issue reduces the interfacial adhesion thus reduces the material properties. It can be improved by adding the glass fiber as the protecting layer at the outer layer in the mat reinforced polymer composites. Form the earlier studies on natural composites, there is up to 25–30% reduction in the production cost and 30–45% reduction in the weight of the material when using the natural fiber composite in place of synthetic fibers [6]. The natural fiber composites are popular in using it for European automobile manufacturing industries for the parts such as door panel, headliners, dashboards, roofs, trunk, tray and bumpers [7]. Automakers worldwide are constantly searching for methods to reduce expenses without compromising quality in order to maintain their competitiveness in the market. As a result, the automotive sector is increasingly investigating natural fiber composites [8, 9]. According to authors, bidirectional fiber oriented epoxy composites' tensile strength and young's modulus were unaffected by the fiber orientation in the composites. Randomly oriented fiber and matrix and aligned fiber and matrix interacted effectively and shows the variations [10]. A comparative study of epoxy composites reinforced with jute fiber, glass, and E and N glass, as well as their hybrid composites, was

conducted and concluded that the viscoelastic characteristics of the composites improved as a result of the good interaction between the different hybrid fiber reinforcements and the epoxy matrix at the interface [11, 12].

In general, Bi directional fibers have the more tensile strength in all direction than the random or unidirectional fiber reinforcement. Also, it has more resistant to crack, bending and impact loads. The mechanical parameters like tensile, flexural, impact strength, and hardness were significantly improved by combining the hemp and PALF cellulose fibers with the epoxy. Better mechanical qualities are produced by fiber hybridization because it enhances the interlocking of the fiber with the matrix. From the above factors, it is identified that the important of fiber composition and orientation has major impact on the mechanical properties. So the present work focuses to analyze the effect of combination of PALF, areca and glass fibers with the epoxy matrix on different material properties identification. Fabrication of four different series of hybrid composites by changing the stacking sequence of the PALF, areca and glass fibers with epoxy matrix (GPPG, GAAG, GPAG and GAPG) using compression moulding method. The identification of role of fiber orientation in adhesion characteristics, thermal stability and suitability to both the structural and non-structural applications.

2. EXPERIMENTATION

The bidirectional woven fibers such as PALF, areca and glass are used as the reinforcement materials, epoxy LY556 and the corresponding hardener HY951 is used as the matrix material. The properties of the fibers used are listed in Table 1. The four different hybrid composites were fabricated as per the fiber composition and stacking sequence given in Table 2. The composites were developed using the compression molding technique which has the two metal based dies. In this, the bottom die consist cavity for the composite laminate to layup and is fixed one. The heat of about 150°C – 180°C is applied over the bottom die after placing the fiber and matrix impregnated layup in the mould cavity. Another mold is movable and it applies the pressure to the bottom of the mold and to the composite laminate when it closing. The simultaneous pressure and heat on the bottom mould removes the air inside the mould and cures the laminate within 15–20 minutes. Later, the mould is cooled to remove the cured composite laminate for test specimen preparation according to the ASTM standard.

The fiber orientation in the composite is important factor as the load distribution at the interface is directly depends on the fibers and matrix adhesion characteristics. These are all evaluated in the present study according to the ASTM standards. Totally 3 specimens from each composite laminate is used to conduct each testing process. The force required to break the samples under tensile load evaluated according to the ASTM D638 standard [14] using universal testing machine. During the shock load, the energy absorbed by the specimens were noted in the plastic Izod impact testing machine. The specimen to perform the impact test is prepared as per ASTM D256 standard [15] and the tensile and impact specimen is shown in Figure 1 and Figure 2.

The indentation formed when applying the load using the 1/16” steel ball indenter on the composite surface is identified with respect to ASTM D785 [16]. The deviations in the weight of the fabricated composites

Table 1: Properties of sterculia foetida and epoxy resin [7, 8, 13].

FIBER TYPE	DENSITY (g/cm ³)	FIBER DIAMETER (mm)	TENSILE STRENGTH (MPa)	YOUNG'S MODULUS (GPa)	ELONGATION AT BREAK (%)	WATER ABSORPTION, (24 HRS.' AT 20°C)
PALF	0.93–1.5	62–98	280–335	5.3–9.62	2.9–6.7	0.6–1.19
Glass Fiber	2.2–2.8	11–27	2050–3550	68–89	2.2–3	–
Areca	0.78–0.99	31–4	142–330	2.5–3.3	2.5–10	0.65–7.1
Epoxy	1.25–1.42	–	37–121	2.8–7.6	0.9–7	0.15–0.52

Table 2: Composition and designation of composites.

SL. NO	COMPOSITE DESCRIPTION	STACKING SEQUENCE
1	GPPG – A	Glass + PALF + PALF + Glass
2	GAAG – B	Glass + Areca + Areca + Glass
3	GPAG – C	Glass + PALF + Areca + Glass
4	GAPG – D	Glass + Areca + PALF + Glass

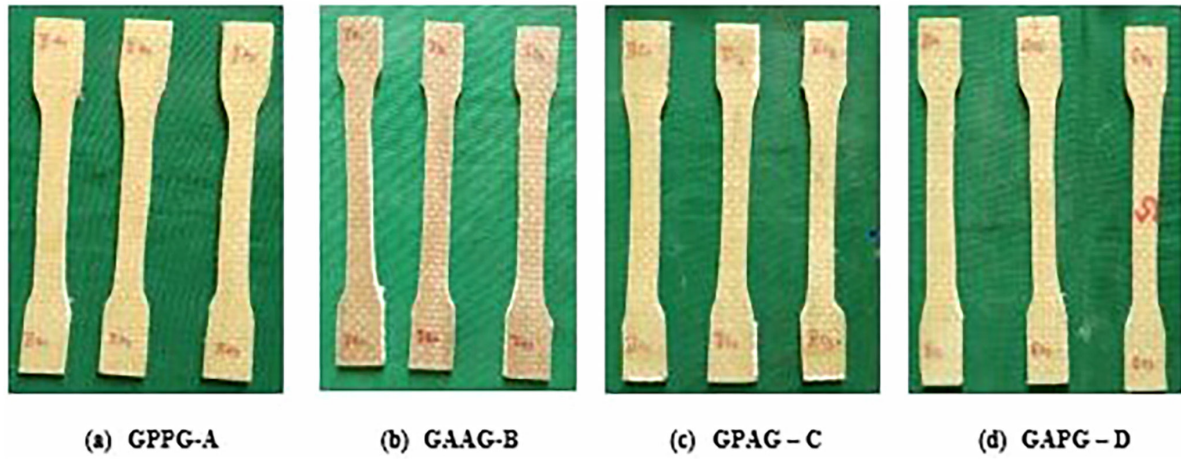


Figure 1: Tensile test specimens prepared.

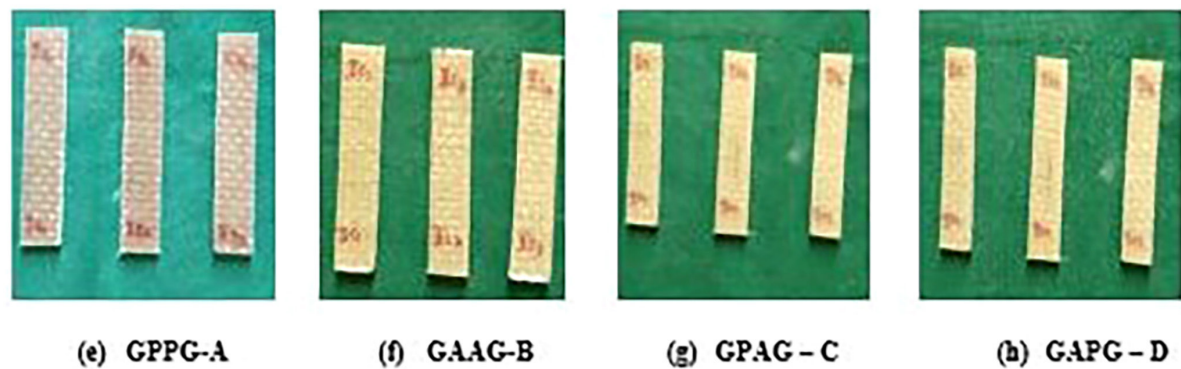


Figure 2: Impact test specimens prepared.

from the desired weight as per the volume fractions is analyzed according to the ASTM C693 [17] using water immersion technique. The moisture regain by the samples on the regular intervals is investigated according to ASTM D570-98 standard [18]. The thermal stability of the glass added at outer layer of the cellulose fiber composites is determined in keeping with standard ASTM E1131 [19]. The heat applied during the test is 30 °C to 850 °C, with gradual increase in heating rate of 2 °C per minute. Finally, inter molecular structural properties are captured on the surface of the tensile test fractured specimens through Scanning Electron Microscopic (SEM) technique.

$$\text{Experimental density } \rho_{ce} = \text{Mass (m)} / \text{Volume (V)} \quad (1)$$

$$\text{Theoretical density of composites } \rho_{ct} = \rho_f V_f + \rho_m V_m \quad (2)$$

$$\text{Percentage erroring densities} = \frac{\text{Experimental density} - \text{Theoretical density}}{\text{Theoretical density}} \times 100 \quad (3)$$

3. RESULTS AND DISCUSSIONS

3.1. Physical properties

3.1.1. Density and percentage error

The voids in the composite is developed due to the air bubbles that formed during the material fabrication. From Figure 3, the percetbage error calculated can show the amount of voids in the composites. The PALF fiber mats placed at the middle obtained lower percentage error than the areca and both PALF/areca filled

composites. The voids during fabrication is present in the composite GAAG-B, as it is due to the higher amount of hemicellulose and legnin conetent present in the areca fiber structure [20].

Eventhough, when comparing the present work density with earlier studies on coir/epoxy, hemp/glass/epoxy showed that the density is less for the present study. The glass fiber mat is placed at top and bottom of the stacking sequence which trapped out the air at the surface of the composites due to its non-wettability nature [21].

3.1.2. Water absorption

It is common that the moisture gain in the composites is directly depends on the amount voids present. As it is confirmed in the density test that the amount of voids is higher for GAAG-B composite laminate. The moisture uptake by this composite is proved that the voids severely attacks the composites in properties. It is seen in the Figure 4, water gain was lower for glass with PALF fiber as compared to the other composites

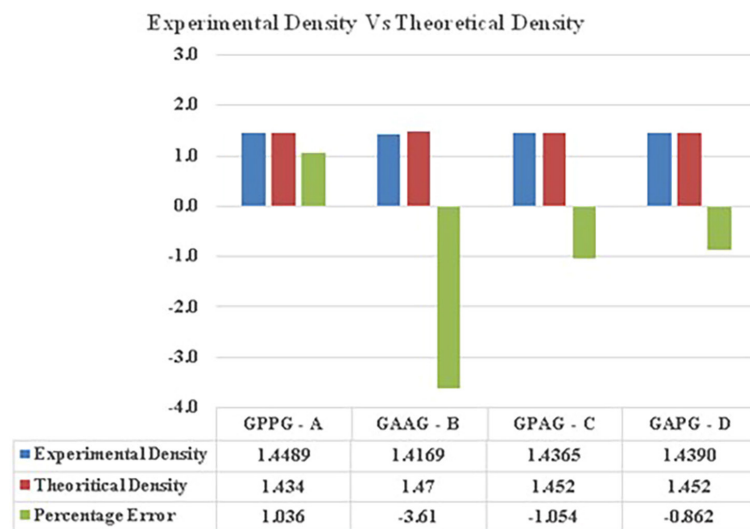


Figure 3: Percentage error between experimental density and theoretical density.

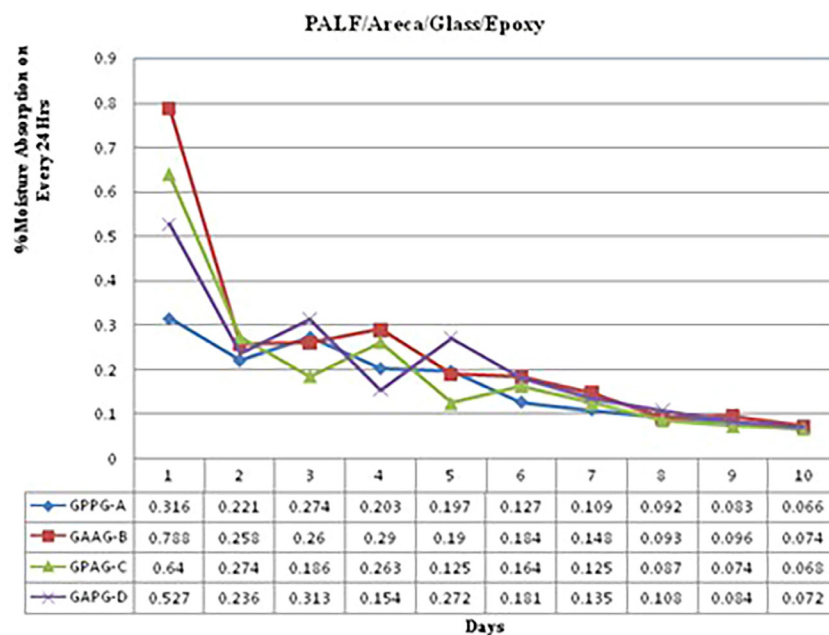


Figure 4: Percentage moisture absorption at every 24 hrs.

considered. The effect outer layer resist the penetration of the water inside the composite structure as a result lower moisture absorption observed for the present study. It is also proved on the experiment done on the glass/epoxy composites with coir fiber incorporation [22].

3.2. Mechanical properties

3.2.1. Tensile properties

The tensile strength of the woven hybrid cellulosic and glass fiber polymer composites is given in the Figure 5. It is found that the tensile strength is almost closer for the all the composite laminate. The composite GAAG-B obtained slightly lower tensile strength than the other composites. It is due to the higher cementite constituent like hemi cellulose, lignin and pectin is usually higher in areca fibers [23]. This could be the reason for low value than the other composite samples. The failure of the composite under the external load is subject to the fiber characteristics such as fiber alignment, arrangement and fiber properties [24]. These are mainly strikes the crack

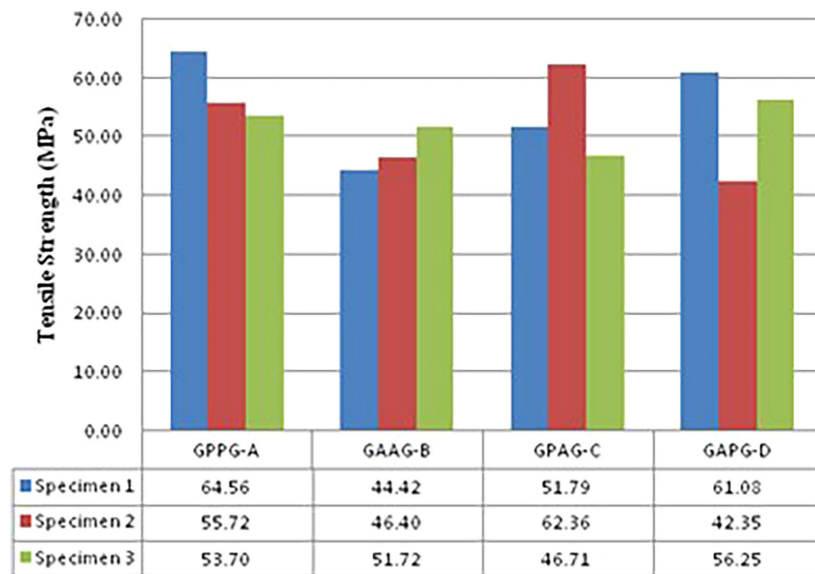


Figure 5: Tensile strength of composites.

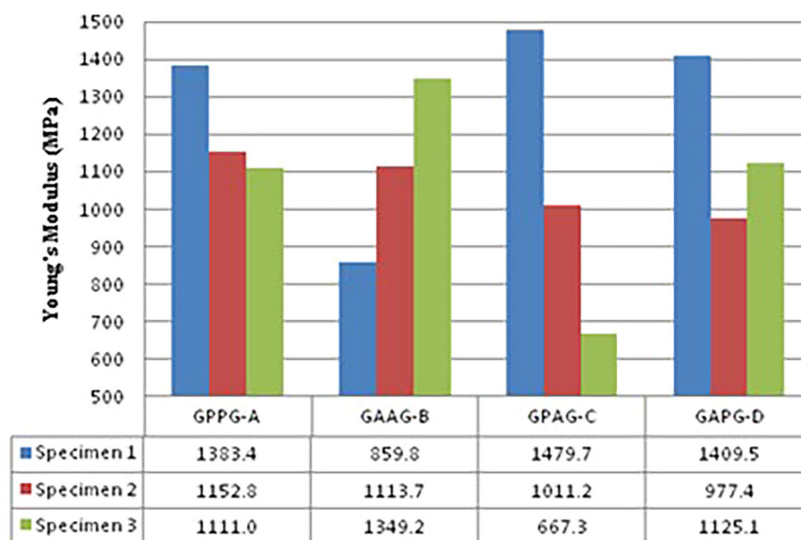


Figure 6: Tensile modulus or young's modulus of composites.

development, propagation and finally breaking. Young's modulus depicts (Figure 6) that the stiffness of the PALF and areca fiber composite is increased when adding the glass as the outer layer during fabrication of the composites. The hybridization improves the tensile strength and young's modulus than the composite reinforced only with natural fibers. Study made by PALF/Epoxy, Areca/epoxy found that the tensile strength was 24–37 MPa up to 30% volume of fiber content considered [25, 26].

3.2.2. Impact strength

The Izod impact test also called V-notch test is performed in order to determine the energy absorption. Generally, the natural fibers have low energy absorption capability as compared to synthetic materials and metals used in industries [27]. Whereas in the present study, the glass fibers incorporation with the natural fibers improved the impact strength of the composites. It is noted in the Figure 7, the higher percentage of areca fiber in composite (GAAG-B) shows that due to the insufficient stress transfer at the interface the ability to absorb energy during sudden strike of the sample is reduced. The PALF fiber provides the stability to crack propagation against sudden load thus resulting in higher impact strength values. The rich matrix in the composite observed in SEM image for GAAG-B resulted in sudden failure without propagation of crack [28]. The investigation on flax/glass/epoxy composite obtained impact strength of 82–107 KJ.mm². In current study, the obtained results were 48–72% higher in impact strength.

3.2.3. Rockwell hardness

The Rockwell hardness number of the fabricated laminates was determined based on the 'L' scale, which is commonly used Scale for soft plastics and composites. The penetration of the tool is greatly restricted by the bi-directional natural and glass fiber composites. The woven fiber mat has higher tendency to restrict the deformation along the axis of force. It is because fibers in perpendicular direction to the force of action resist the crack propagation [29]. Similarly, it reported from the previous studies that the glass fibers laying at the top and bottom of the laminate provides higher hardness properties [30, 31]. The Figure 8 shows the hardness identified for the present work.

3.3. Thermogravimetric analysis

The thermal degradation of the powder samples prepared from each composite in terms of different percentage weight loss is given in the Table 3. Usually, the thermal loss of material as function of increasing temperature

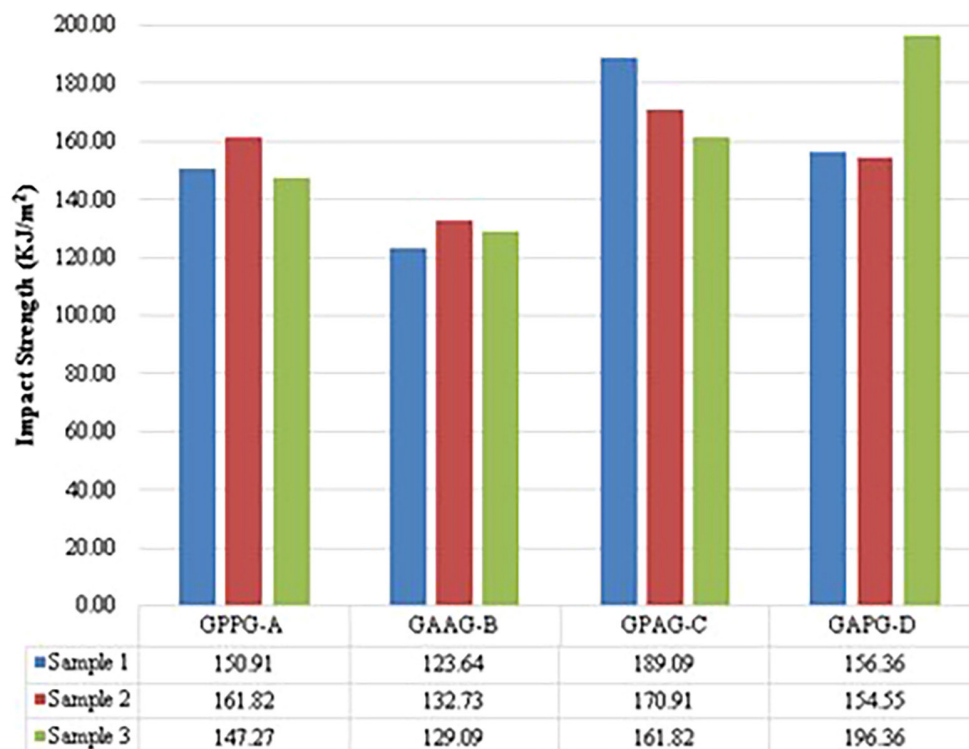


Figure 7: Impact strength of composites.

can be obtained in three different regions. Similar kind of loss was observed for the present study as seen in the Figure 9. The first level of degradation is observed up to 390 °C. The wetness of the sample is dried in this period. There is 2–10 percentage of weight of the sample is lost during this stage. The second level of degradation starts at 390 – 540 °C. During this region, the constituent of the cellulose fibers starts to degrade.

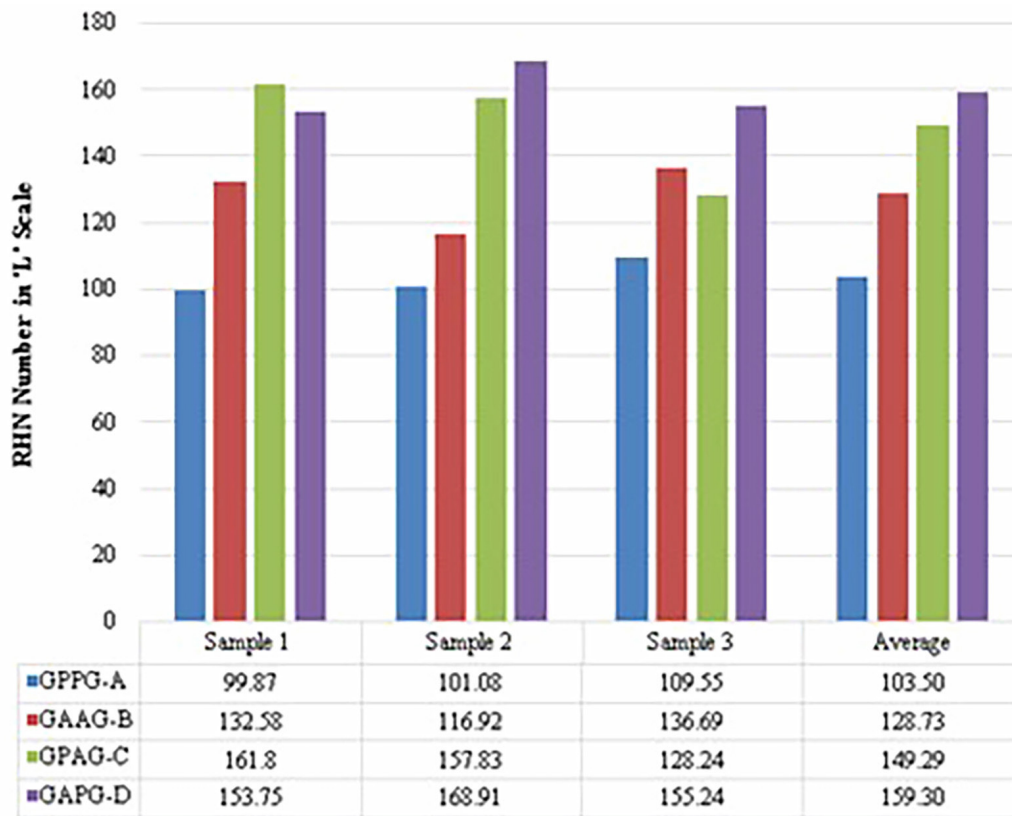


Figure 8: Rockwell hardness of composites.

Table 3: Temperature at different percentage weight loss of the composites.

SL.NO	WEIGHT LOSS %	TEMPERATURE OBSERVED IN °C			
		GPPG-A	GAAG-B	GPAG-C	GAPG-D
1	2	168	207	181	153
2	5	328	357	335	290
3	10	379	396	387	371
4	15	397	414	416	402
5	20	406	428	432	412
6	30	429	441	468	427
7	40	457	459	511	439
8	50	465	478	530	451
9	60	473	499	549	470
10	70	494	528	594	483
11	80	548	595	644	564
12	90	590	631	671	693

The thermal stability is higher for the GAAG composites, due to higher cementite structure of areca fiber. The loss of material under increasing temperature takes more time for the areca fiber composites. The reason to this is high amount of hemicellulose and lignin content in areca fiber has higher heat resistance thus improved the thermal stability [32]. The final and third stage of degradation begins at 520–540 °C. The complete loss in

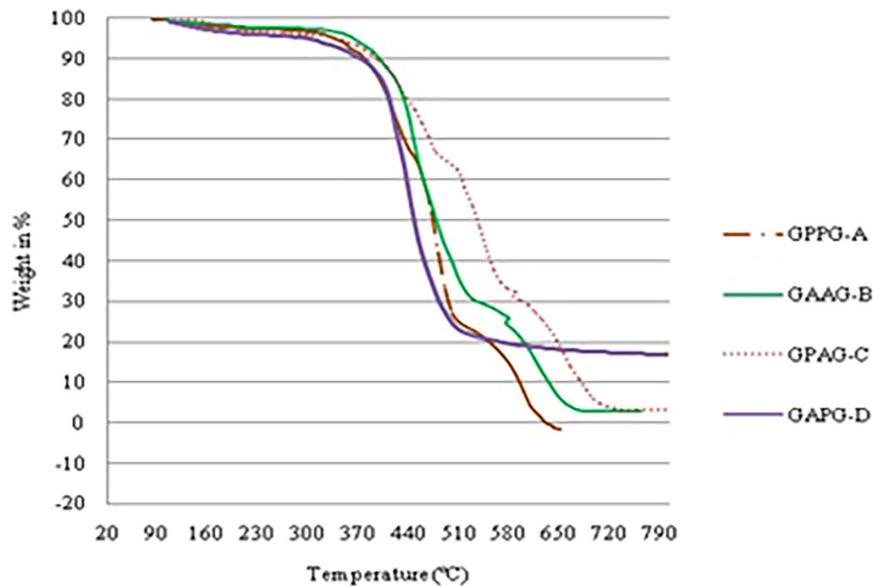


Figure 9: Thermal degradation of composites.

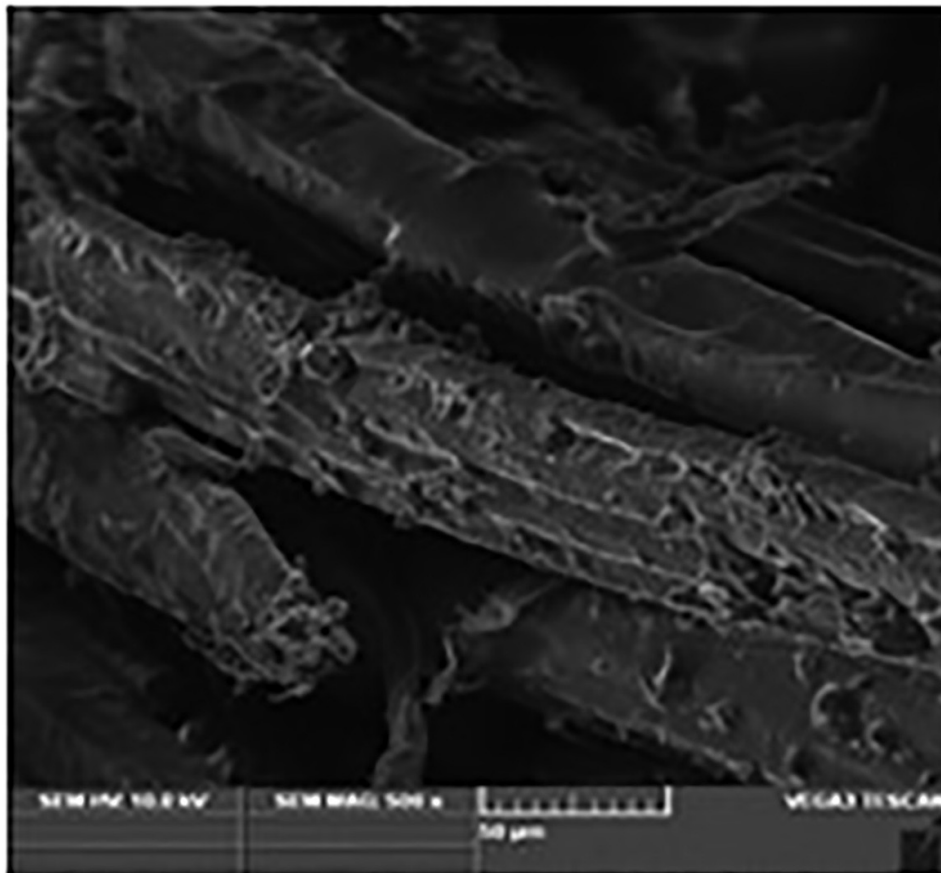


Figure 10: Microstructure of composite with GPPG sequence.

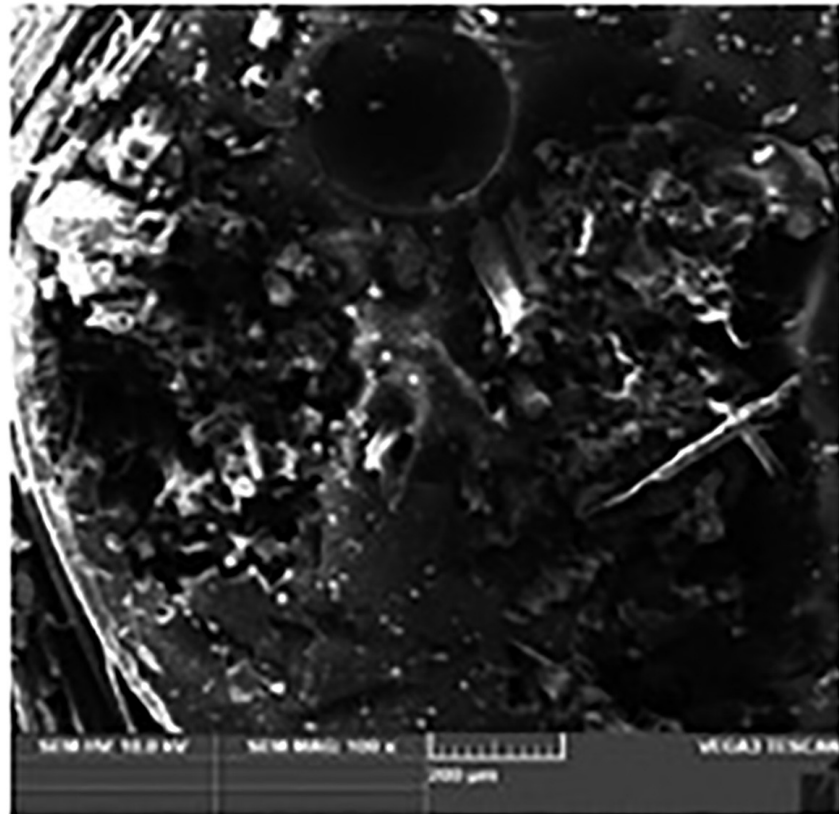


Figure 11: Microstructure of composite with GAAG sequence.

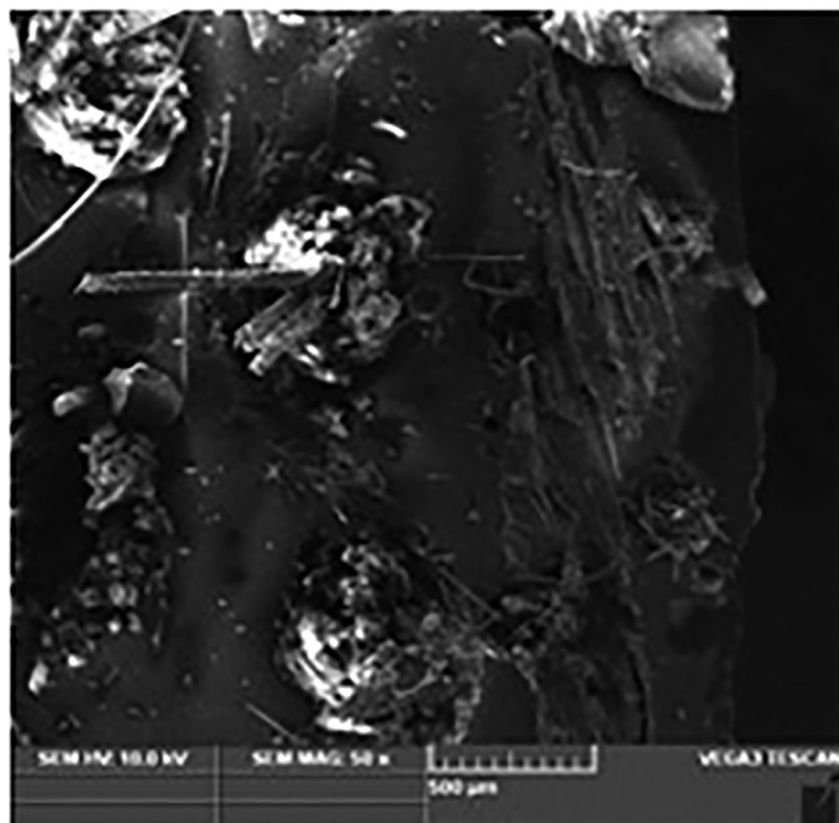


Figure 12: Microstructure of composite with GPAG sequence.

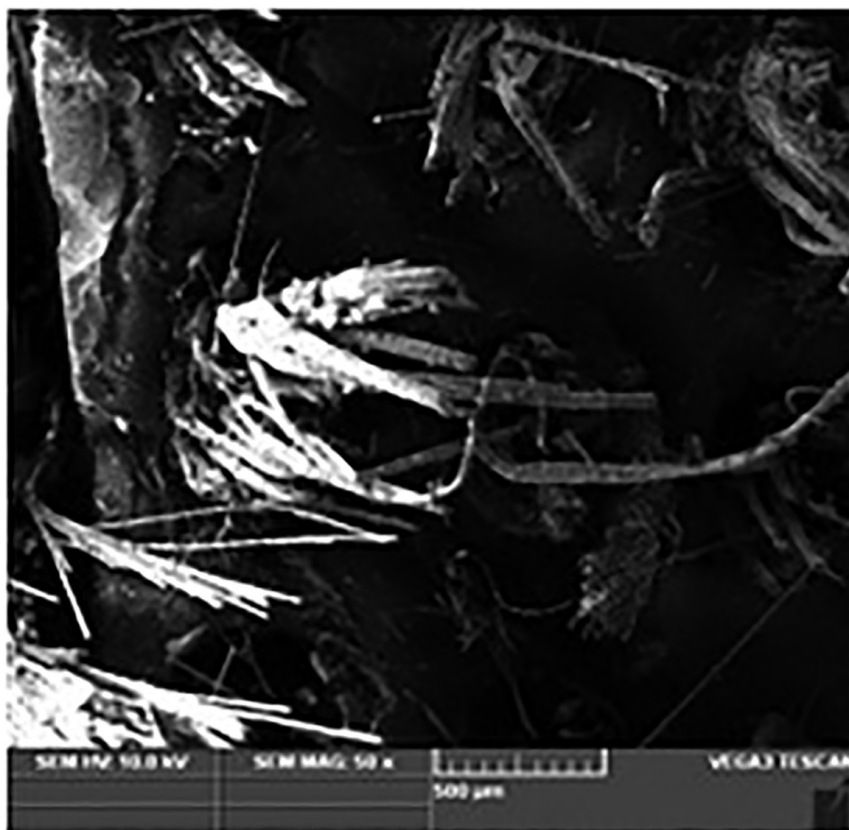


Figure 13: Microstructure of composite with GAPG sequence.

powder samples has observed in this region. The glass fiber has high thermal properties as it could be the reason for improved thermal stability than the earlier studies on TGA of natural fiber composites [33, 34].

3.4. Scanning electron microscopic analysis

The larger surface area of the PALF fiber was observed for the Composites GPPG-A (Figure 10). Thus resulting in the better bonding between each layers of woven mat with the epoxy matrix. Also the interlocking of fibers within the layers is increased when the matrix impregnate the layers in each stacking sequence. In Figure 11, presence of voids observed due to the fabrication error. But it is not evident throughout laminate surface. The properties at the voids or near the voids can be reduced due to lack of crack propagation ability to the material [35, 36]. The Figure 12 and Figure 13 also shown that the effective bonding was achieved since the peeling of fibers instead of complete removal, fibers withstanding, and fibrillation occurs during fracture of the specimen. This kind of results was obtained on SEM analysis done on fiber composites [37, 38].

4. CONCLUSIONS

The effect of bidirectional orientation and fiber composition of cellulose and glass fibers reinforced polymer composites on different material parameters were studied with varying stacking sequence of the fibers. The study revealed that the fiber arrangement has contributes to the important factor in changing the properties of the composites. PALF fiber placed in between of glass fiber mat obtained higher tensile, impact and hardness when comparing to the areca fibers (GAAG-B), PALF/areca (GPAG-C), Areca/PALF (GAPG-D) in middle. Similar kind of results were obtained for density and water absorption of the composites. The thermal stability was increased for the composite GAAG-B than the other composites considered. The bidirectional woven hybrid fiber reinforcement has plays a crucial factor for achieving the higher properties. SEM images proved that the combination of properties of the fibers increased the bonding with the matrix thus causes to the higher mechanical and thermal properties. The tensile strength between 40–65 MPa, Young's modulus in the range 950–1400 MPa, Impact strength of about 130–190 KJ/mm² and thermal stability up to 340–390 °C were obtained for present work composites. The results were good agreement with the earlier research works done on

the synthetic fiber such as carbon, Kevlar and aramid reinforced composites. The bidirectional PALF, areca and glass composites have improved the mechanical properties than the randomly oriented natural fiber reinforced polymer composites developed by various researchers. Because bidirectional orientation of fibers gives more resistant in all direction to the cracking of the samples during load applied. Incorporating the glass fiber with natural fiber can be used in both the structural and non-structural applications. Further surface treatment of the natural fiber mat with chemicals improves the internal adhesion between the fibers thus increases the strength of the composites. Extruding the continuous fibers through the polymer to drawing the fiber prepregs for additive manufacturing applications.

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