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Electrical and Mechanical Performance of Hybrid and Non-hybrid Composites

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ABSTRACT

This paper investigated the moisture absorption, mechanical behavior and the dielectric performance of hybrid and non-hybrid polymeric composites. Hand lay-up technique was used for processing carbon; glass reinforced polyester resin composites (non-hybrid) and carbon-glass/polyester hybrid composites with various fiber configurations. The maximum resistance of water absorption was obtained for the hybrid composites with combinations [2C-2G], where the water absorption ratio reached to 1%. In addition, the maximum tensile, flexural strengths and ILSS of this combination were 123 MPa, 1397 MPa, and 22.35 MPa, respectively. This is due to the higher tensile strength of polyester matrix and good adhesion between the glass and carbon fabrics with the polyester matrix. The dielectric constant of non-hybrid composite with codes [C] is higher than non-hybrid composite with codes [G] and dielectric constant for all hybrid composites lies between non-hybrid composites.

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1. INTRODUCTION

One of the most important purposes in the field of scientific research is finding new engineering composites that combine strength and lightweight. Hybrid composites were used now successfully as a replacement to the traditional composites in various applications such the automobile parts, wind power turbine, aerospace, shape memory, solar cell and electronics industry (switches, terminals, electrical contacts, interlayer dielectric, lids, interconnections, and printed circuit boards) because of their low density, wear resistance, high stiffness and strength [1–4]. The required properties of the hybrid composites are obtained through selection of suitable fibers and resin matrix. Carbon fiber exhibit high stiffness and strength but at the same time quite brittle, high costly and lower strain to failure compared to the glass fiber. Therefore, the combination between the glass and carbon fibers in hybrid composite give good mechanical properties. Effect of fiber configuration on the microstructure and the tensile properties of glass - carbon /Epoxy hybrid composite ply laminates were studied and it was observed a good interfacial bonding at the interface between the fiber and matrix [5]. The influence of fiber configuration consisting of 4 layers on the mechanical properties of hybrid glass/carbon epoxy composites obtained by the hand layup technique was investigated [6]. The fiber configuration with code 4C, gives the highest values of tensile (462 MPa), flexural (573.27 MPa) and impact strength (100.20 kJ/m^2) compared to the other fiber configurations of hybrid composite laminates. In addition, Turla et al. [7] studied the ILSS of non-hybrid and hybrid glass-carbon/epoxy composites. The hybrid composites gives maximum ILSS up to 40 MPa compared to the non-hybrid composites such as GFRP (28.19 MPa) and CFRP (30.11 MPa). Jagannatha and Harish [8] used the vacuum bagging procedure to manufacture the hybrid carbon-glass/epoxy composites and studied the mechanical properties. The conventional composite (carbon-reinforced epoxy) gives maximum micro hardness over the other hybrid composites. Randjbaran et al. [9] used three types of fibers (carbon, glass and Kevlar) reinforced epoxy to produce the new hybrid. When the glass fiber was placed at the external layers and the carbon, Kevlar fiber at the core for the hybrid (G/C/K/C/K/G), the

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absorption energy has reached maximum to 95.17 J. The dynamic characteristics of hybrid E-glass-carbon basalt/polyester composites are analyzed. Addition of basalt fiber improved the static and dynamic of hybrid polymeric composites [10]. Braga et al. [11] demonstrated the mechanical properties and the microstructure of hybrid jute-glass /epoxy composites and found that the physical and mechanical properties of this hybrid were significantly improved. Tensile and shear properties of epoxy composite reinforced by two different types of fibers, unidirectional (glass and carbon) and woven fibers (glass, aramid and carbon), were investigated [12]. Tensile properties of aramid fiber of the woven type are higher than that the glass and carbon fibers. El-wazery [13] investigated the influence the fiber configurations on the mechanical characterization and microstructure of hybrid glass/basalt/carbon-polyester composites laminate. The stacking sequences [C/B/C/B/C] gave best mechanical properties compared to other stacking sequences. In addition, the influence of glass fiber concentration on the tensile and bending strength of the non-hybrid composites was studied and found that a maximum tensile and bending strength, were 28.25 MPa and 78.83 MPa, respectively [14], obtained at 60 wt. % glass fiber. The effect of the frequency variations on the dynamic behavior of jute /epoxy composite was investigated and it concluded that the storage modulus increased with a variation in frequencies [15]. The electrical properties of aluminum alloy-glass/epoxy hybrid composite were measured and it was noted that the CFRP composite is insulator but the surface resistivity was 10 power2: 10 power 3 ohm [16]. In addition, the electrical resistivity of continuous carbon/epoxy composite laminates through thickness direction is studied. The contact resistivity decreased as the curing pressure was increased [17].

Carmisciano et al. [18] investigated the electrical and flexural properties of basalt/E-glass/epoxy composites and it was observed that the basalt/epoxy composites give higher flexural modulus compared to E-glass/epoxy [19].

The objective of this research was investigated the effect of fiber configurations of carbon-E-glass/ polyester hybrid composites laminates manufactured by the hand layup procedure on the moisture absorption, dielectric performance, and mechanical characteristics. The failure modes of the hybrid composites were analyzed using scanning electron microscope (SEM).

2. MATERIALS

Open mould procedure (Hand layup) was used to fabricate the hybrid (E-glass-carbon/ polyester) and non-hybrid (E-glass/polyester and carbon/polyester) composites. E-glass (biaxial weave 300 g/sqmt.) and twill weave carbon fabric (C120-3K- Twill 2x2), were used as a reinforcement phase.

Twill weave carbon fabric has better drapability compared to the plain weave fabric. A diagonal rib structured by one warp yarn floating over at least two filling yarns demonstrated the weave pattern. Unsaturated Polyester resin (ECMAS 411) was used as matrix phase with a methyl ethyl ketone peroxide hardener. The physical and mechanical characteristics of the E-glass and carbon fabric reinforcements are presented in previous work [20].

2. 1. Hybrid and Non-hybrid Composites Processing

The hybrid composites laminates were manufactured by reinforcing carbon and glass fibers in the polyester resin matrix in the form of 4 layers by the hand lay-up procedure. The wood mould dimensions that used for producing the hybrid and non-hybrid composites are 260mm x 260mm x 4mm (see Figure 1.).

The mechanical tests were performed in accordance to ASTM standards. The weight fraction percent of the polyester resin and peroxide hardener were 17.80 and 22.20 wt. %, respectively. More details about the hand lay-up procedure, hybrid, and non-hybrid composites fabrication, were given in the previous works [9, 21]. Configurations design structure of hybrid and non-hybrid composite are listed in Table 1.

2. 2. Moisture Absorption

The non-hybrid (pure carbon and glass composites) and hybrid carbon-glass/

Figure 1. Preparation of Carbon/glass hybrid composites

TABLE 1. Configurations of hybrid and non-hybrid composites

Code	Fiber configurations	Carbon contents (wt.%)	Glass contents (wt.%)	Volume fraction (v%)		
				polyester	carbon	glass
C	[4C]	60	0	49.85	50.15	0
G	[4G]	0	60	59.63	0	40.37
H1	[2C-2G]	30	30	54.32	27.31	18.37
H2	[2G-2C]	30	30	54.32	27.31	18.37
H3	[C-2G-C]	30	30	54.32	27.31	18.37
H4	[G-2C-G]	30	30	54.32	27.31	18.37
H5	[C-G-C-G]	30	30	54.32	27.31	18.37
H6	[G-C-G-C]	30	30	54.32	27.31	18.37

polyester composite laminates specimens were immersed in distilled water bath at room temperature for several times up to 264 hours. These specimens with dimensions 30 x 30 x 4 mm^3. according to the standards ASTM D570-98 were cut by CNC milling machine. In this procedure, the mass of each sample was measured before immersion in distilled water as well as after immersion in distilled water for every 24 hours by using electronic balance device (0.001g). The water absorption percentage for each stacking sequence is evaluated according to Equation (1).

$$water\ absorption\ (\%) = \frac{m_r - m_o}{m_o} \times 100 \qquad (1)$$

where m_o and m_r are the mass of hybrid and non hybrid samples before and after immersion in the distilled water at several times.

2. 3. Electrical Properties

Hybrid and non-hybrid composites used in electrical application so the electrical properties for it should be studied. Dielectric parameters which include dielectric constant, and electric conductivity were performed on LCR bridge (Hioko3532–50 Hi tester). The dielectric constant represents the ability of dipole movement in material to become aligned with external field. Required samples from hybrid and non-hybrid polymeric composites have been placed between two electrodes with fixed load by spring. Each of dielectric parameter was measured at each frequency 15 times by The LabVIEW-based software. Then the average value for each parameter at each frequency was calculated.

2. 4. Mechanical Properties

2. 4. 1. Tensile Strength

Tension tests were performed to measure the tensile strength of the carbon; glass reinforced polyester composites and carbon-glass/ polyester hybrid composites on a universal testing machine (INSTRON 8801). Five specimens were prepared according to ASTM D 638, thickness 4mm, of each stacking sequence to obtain an accurate result of the tensile strength with a crosshead speed of 2 mm/min.

2. 4. 2. Flexural Properties

The flexural properties such as flexural strength and inter-laminar shear strength (ILSS) of the hybrid and non-hybrid composites were determined according to ASTM D790-10 with dimensions 125 x 13 x 4 mm^3.

The flexural strength and ILSS was estimated by the following Equations (2) and (3):

$$Flexural\ strength = \frac{3fL}{2bd^2} \qquad (2)$$

$$ILLS = 0.75\frac{f}{bd} \qquad (3)$$

where f, L, d, b and $ILLS$ is the flexural load (N), the span (gauge) length (mm), thickness (mm), the width (mm) and the inter-laminar shear strength (MPa).

3. RESULTS AND DISCUSSIONS

3. 1. Water Absorption

Figure 2 shows the water absorption ratio for hybrid and non-hybrid composites samples under various water immersion times up to 364 h. Figure 2 reflects that the moisture absorption ratios increase for the hybrid and non-hybrid composites samples with the immersion time. The hydrophobic for all component carbon fiber, glass fiber, and polyester resin causes small value of moisture absorption ratio for all samples. The maximum moisture ratio of non-hybrid composites samples [4G] and [4C] are (3%) and (1%), respectively at period time 264 hour. The high water saturation ratio of the glass-reinforced composite attributed to the high density of glass fabric (**2.66 g/cm^{-3}**) compared to the low density of carbon-reinforced composite ((**1.79 g/cm^{-3}**). More specifically, high volume fraction of carbon leads to more interaction zone with polyester that prevents moisture absorption. At the same period, the moisture ratio of the samples H1 with combination [2C-2G] as well as H3 with combination [C-2G-C] gives minimum ratio around of 1%. The drooping in the moisture absorption ratio for stacking sequences H1 and H3 can be attributed to the arrangement of fiber in closed manner as well as more interaction between them.

3. 2. Electrical Properties

Figure 3 demonstrates the effect of frequency on dielectric constant for hybrid with multi stacking sequence arrangements and non-hybrid composites. It can be seen that a common decreasing trend in dielectric constant is appeared with increasing in the applied frequency range for hybrid and non-hybrid composites. The decrease in dielectric constant with increasing in frequency is a common trend [22, 23]. Dielectric constant, which represents the ability of orientation of dipoles in material, was decreased with increasing frequency since the dipole in composite has less time to orient themselves in the direction of the alternating field. For all frequency range, the dielectric

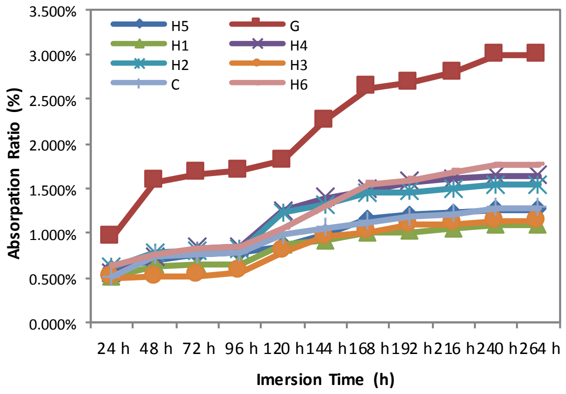

Figure 2. Effect of the stacking sequences of hybrid and non-hybrid composites on water absorption ratio

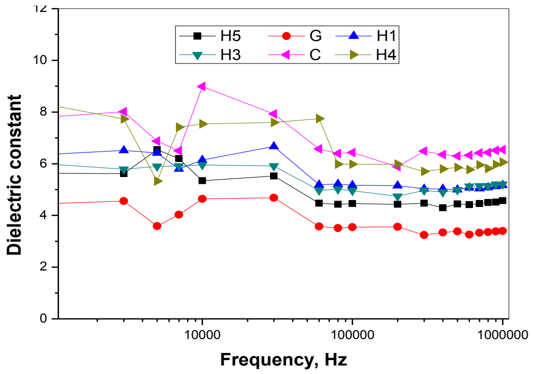

Figure 3. Variation of dielectric constant for hybrid and non-hybrid composite with applied frequency

due to a lower dielectric constant for the glass than that for the carbon. The dielectric constant of hybrid composites is appeared between non-hybrid composite with codes [G] and [C], which agree with the well-known mixing rule for dielectric constant of a multi-component material [24].

Figure 4 presents the effect of frequency on electrical conductivity for hybrid composite with multi stacking sequence arrangements and non-hybrid composite. It can be seen that the increase in electrical conductivity with increasing in the applied frequency range for hybrid and non-hybrid composite with a convergence of values for different composites. The electrical conductivity is directly proportional to ω^n where ω and n are angular frequency and frequency exponent, which varies between zero and one [25]. The inset of Figure 4 represents the value of frequency exponent (n) for different stacking sequence, which lies in range between 0.3775 and 0.5332. More deeply, the voids and cracks formed into composite work as traps free charge, which decline the electrical conductivity. The stacking sequence [C-2G-C] hybrid composite has maximum frequency exponent (n) value. In contrast, the minimum frequency exponent (n) value was obtained for non-hybrid composite with stacking sequence [4G]. That means more voids, cracks in stacking sequences [4G] while less voids and cracks in stacking sequences [2C-2G], [C-G-G-C], [C-G-C-G], and good arrangement of fiber. This result confirmed with moisture absorption result.

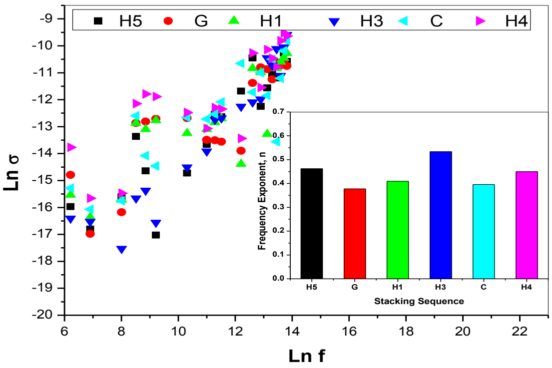

Figure 4. Variations of electrical conductivity for hybrid and non-hybrid composite with applied frequency. The inset represents value of exponent frequency (n) for all stacking sequence.

For low frequency of the applied field, charge carries are obliged to drift over spacious distances which tending to disturbance due to the insulating nature of the matrix. In contrast, as the frequency of the applied field increases, the displacement length of the charges is considerably decreased and in the meantime, the transport rate between nearby conductive sites is enhanced. At high frequency of applied field, all reasons are prompting improvement in electrical conductivity [26].

3. 3. Mechanical Properties

3. 3. 1. Tensile and Flexural Properties

The influences of the stacking sequences on the tensile strength, flexural strength, and ILSS of the hybrid and non-hybrid composites are shown in Figures 5 to 7. Figure 5 reflects that the tensile strength of the carbon and glass reinforced polyester resin composites (non-hybrid) with combinations [4C] and [4G] were 75.78 MPa and 33.33 MPa, respectively. The tensile strength of composite depends on tensile strength for all components, interaction between component, stability of matrix and arrangement of fibers. The increase in the tensile strength of the carbon fiber reinforced polyester with combination [4C], as compared with [4G], attributed the higher elastic modulus and stiffness of carbon fiber reinforced composite than the glass fiber reinforced composite. In addition, the higher carbon fiber volume fraction than the glass fiber reinforced composite leads to more interaction zone created between polyester and carbon fiber as compared with glass fiber. The tensile strength of the hybrid composite with combination [2C-2G] exhibits a maximum value (123 MPa) as compared to the other combinations. The enhancement in the tensile strength of this combination can be a direct result of the strong carbon fabrics when placed at upper side that giving higher tensile strength. In addition, this enhancement can be attributed to good arrangement of fiber through matrix and good interaction between components, which confirms from moisture absorption result.

When the two carbon fabrics were placed at the core between the glass fabrics, hybrid with this combination [G-2C-G] exhibited a lower tensile strength (66.22 MPa) as compared to the combination [C-2G-C] that gives high tensile strength as 109.14 MPa. This is due to sensitive of glass fabrics to cracks even in micron sizes compared with carbon fabrics. So the tensile strength was affected by the carbon fabric position and rigidity. Therefore, the placement of glass fabrics at outer surfaces and the two-carbon fabric in the center is not contributed to better

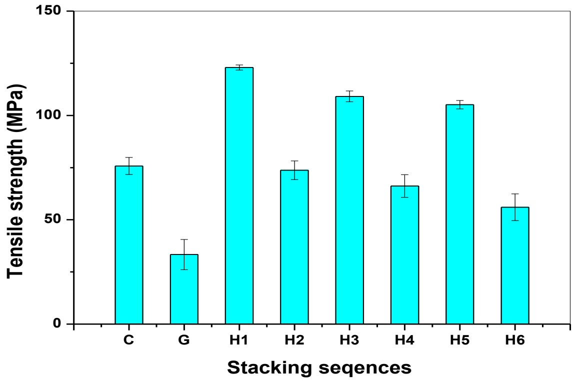

Figure 5. Tensile strength versus stacking sequences

withstanding tensile load. The tensile strength of the code H5 with combination [C-G-C-G] and code H6 with combination [G-C-G-C] was 105 and 56 MPa, respectively. Figures 6 and 7, show the dependency of the flexure strength as well as ILSS on fiber type and fiber configurations. It is clearly seen from Figures 6 and 7, that the flexural strength as well as the ILLS of non-hybrid with combinations [4C] is higher than non-hybrid with combinations [4G]. Also, the hybrid composite specimen with combination [2C-2G] has high flexural strength as well as ILLS as compared to other combination. The flexural strength of the non-hybrid composites (two phase) with the combinations [4C] and [4G] were 757.20 MPa, 360 MPa, respectively. This increase in the flexural strength of the non-hybrid combination [4C] explained due to the highest volume fraction of carbon fiber that was 50 v%, compared with glass fiber was 40 v%. In addition, the carbon fibers are candidate material for high strength to weight-ratio in the most structure applications.

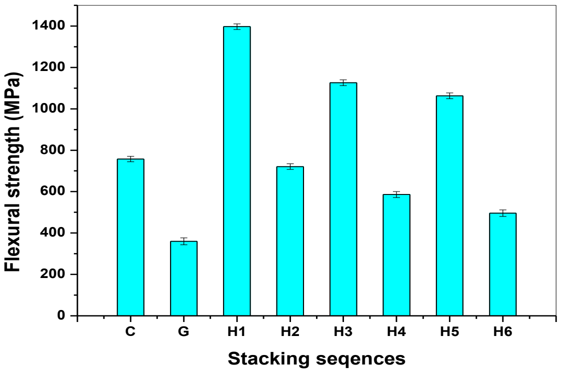

Figure 6. Flexural strength versus stacking sequences

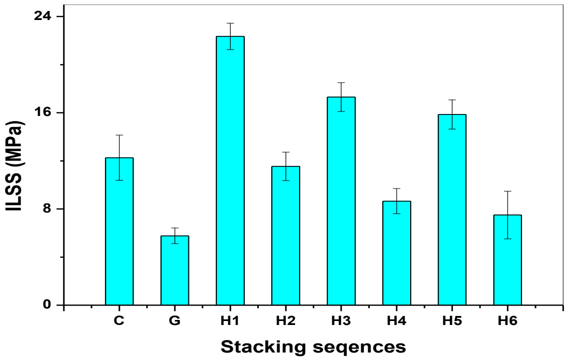

Figure 7. Inter-laminar shear strength (ILSS) versus stacking sequences

The hybrid composite specimen with combination [C-2G-C] has high flexural strength and ILLS compared to the combination [G-2C-G]. Code H5 with combination [C-G-C-G], has high the flexural strength compared to code H6 with combination [G-C-G-C]. Hybrid composite with combination [2C-2G] exhibited highest flexural strength and ILLS values of 1397 MPa and 22.35 MPa, respectively compared to the other fiber configurations. In general, the flexure strength of combinations with single or double carbon fiber layer at upper surface has high value as compared to combinations with single or double glass fiber at upper surface. This is due to high volume fraction as well as high modulus of carbon fabrics, which give high resistance to the bending loading compared to the glass fabrics with the low modulus.

The increase in the ILLS of the combination [2C-2G] attributed to the higher tensile strength of polyester matrix, positive hybridization between both carbon and glass fibers and good adhesion between the carbon, glass fibers with the polyester matrix so the ILLS depends on the characteristics of the polyester matrix and interfacial strength of glass-carbon / polyester.

3. 4. Failure Modes Figure 8 shows the SEM images of the fractured surfaces of the tensile failed hybrid composite with two combinations [C-G-C-G] and [G-C-G-C], respectively. From Figure 8a, few micro voids and fiber breakage at the interface between the matrix and fibers were observed.

The carbon plies were relatively smooth and the fibers pullout in warp direction at the large scale appear in the sample H6 with combination [C-G-C-G] hybrid composites and are shown in Figure 8b. In addition, the delamination was observed at the interface between the carbon and glass fabrics where the delamination was considered one of the most fracture mechanisms of the hybrid composites under tensile loading. The appearance of these debonding (Figure 8b) explains the reduction in composite strength with such configuration. Hence the weak interface between laminate fails as debonds upon loading become in capable for transforming the shear from the matrix do the reinforcing phase, leading do a drop in tensile strength (56 MPa) compared with better surface adhesion for [C-2G-C] configuration with 109 MPa. Resulting crack propagation inevitably leads to abrupt brittle fracture.

For hybrid composite with combination H3 Figure 9, it was clearly that there is good bonding between

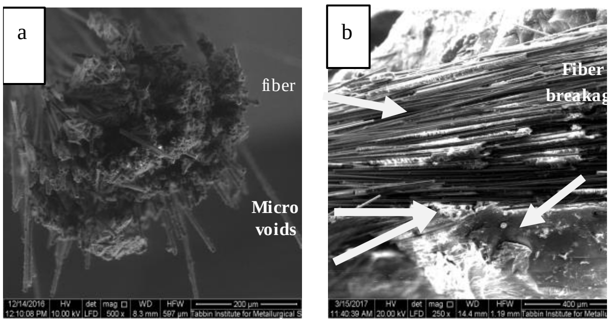

Figure 8. Fracture surface of the hybrid composites with combinations a) H5 [C-G-C-G] and b) H6 [G-C-G-C]

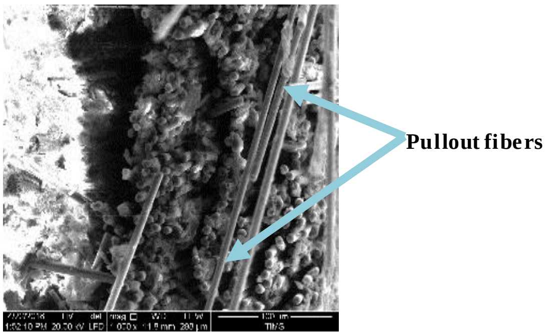

Figure 9. Fracture surface of the hybrid composites with combinations H3 [C-G-G-C]

carbon and glass fibers and matrix phase. In addition, many factors such as the bond strength between matrix, fibers, and fabrics type, volume fraction of fibers are affected on the fracture mechanism.

In addition, minimum degree of fiber pull-out may be noted. In this case, stable and homogenous by distributes voids are created upon fiber-matrix debonding under state loading. Dues stable void formation varies the plastic deformation of the surrounding matrix. Homogenous distributions of debonding can his places the fine polymer ligaments between the debonded fibers under conditions of plane shear, promising shear yielding of the matrix. This is turn explain the incurves in ILSS of the combinations H1, H3 as compared with combination H6.

4. CONCLUSIONS

In this work, the evaluation of moisture absorption, mechanical behavior, and dielectric properties of hybrid and non-hybrid polymeric composites is carried out. Hybrid polymeric composites with different fiber configurations of carbon-E-glass/ polyester hybrid composites laminates samples have been prepared by the hand layup procedure at room temperatures. Based on the present result, the following points can be concluded:

- Non-hybrid (E-glass/ polyester) composites with stacking sequences [4G] exhibited maximum moisture ratio of 3 % with immersion time for 264 hour compared to the other stacking sequences.
- Good mechanical properties were of the hybrid composite with combination [C-2G-C].
- For the combination [C-G-C-G] hybrid composites, the carbon fibers were pull-out, rapture and delamination in warp direction.
- The non-hybrid carbon composite [4C] exhibits maximum dielectric constant while non-hybrid (E-glass/ polyester) exhibits minimum dielectric constant.
- The dielectric constant value of hybrid composites is located between value of non-hybrid carbon composite [4C] and non-hybrid (E-glass/ polyester).
- The value of frequency exponent (n) for different stacking sequence is located in range between 0.3775 and 0.5332 with highest value for stacking sequence [C-2G-C] hybrid composite.

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Dielectric Constant

چکیده

در این مقاله جذب رطوبت، رفتار مکانیکی و عملکرد دی الکتریک کامپوزیت‌های پلیمری ترکیبی و غیرترکیبی بررسی شده است. روش کپی دست برای پردازش کربن، کامپوزیت رزین پلی‌استر تقویت‌شده شیشه (غیرترکیبی) و کامپوزیت هیبرید کربن شیشه‌ای/پلی‌استر با تنظیمات فیبرهای مختلف استفاده شد. حداکثر مقاومت در برابر جذب آب برای کامپوزیت‌های هیبریدی با ترکیب [2C-2G]، که در آن نسبت جذب آب به ۱٪ رسید، به دست آمد. علاوه بر این، حداکثر کشش، مقاومت خمشی و ILSS این ترکیب به ترتیب ۱۲۳ مگاپاسکال، ۱۳۹۷ مگاپاسکال و ۲۲/۳۵ مگاپاسکال بود. این به علت استحکام کششی ماتریس پلی‌استر و چسبندگی خوب بین شیشه و کربن پارچه با ماتریس پلی‌استر است. ثابت دی الکتریک کامپوزیت غیرهیبریدی با کد [C] بالاتر از کامپوزیت غیرترکیبی با کدهای [G] و ثابت دی الکتریک برای تمام کامپوزیت‌های هیبریدی بین کامپوزیت‌های غیرترکیبی بوده است.

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