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Enhancement of Mechanical Properties in Glass-Fiber Woven Reinforced Hybrid Composites for Aerospace Applications: An Empirical Investigation

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ABSTRACT

This experimental study aims to create innovative hybrid composites (HCs) for aerospace applications using the hand lay-up technique. Different volume fractions (V_f%) of distinctive natural (white clay (W) and red clay (R)) and synthetic (alumina (A) and woven glass fibers (E-GFW) reinforcing unsaturated polyester (UP). The mechanical and physical characterizations of these innovative HCs were estimated according to the American Society for Testing and Materials (ASTM) standards. The findings show that adding more white clay, red clay, and alumina to the HCs makes a big difference in improving their mechanical properties, such as Hardness Shore D (H_{SD}), True Tensile Strength ($T_{t\sigma}$), Impact Strength (i_σ), and Fracture Toughness (K_c). Analysis of variance (ANOVA) revealed noteworthy variations in the assessed parameters, emphasizing the potential suitability of these materials for aeronautical applications. This research contributes to the ongoing progress in material engineering, specifically in enhancing the mechanical resilience of composites utilized in the aerospace industry.

1. INTRODUCTION

In the realms of aerospace engineering, the National Aeronautics and Space Administration (NASA) has pioneered the development of lightweight composite materials for high-temperature use in aircraft structures [1, 2]. These new composites represent a significant advancement because they combine the best characteristics of polymer matrix (PM) composites, such as high fracture toughness, fatigue resistance, wear resistance, low density, and creep resistance, with the best characteristics of ceramic matrix composites, which are known for their high strength and durability modulus [3, 4]. At the same time, ceramics integrated into structural parts find use in high-wear-resistance situations, where their extraordinary hardness is used to minimise the inherent fragility and dependability difficulties associated with monolithic ceramics [5]. Advanced composites were applied to 50% of aircraft structures, such as brakes and food trays, etc. [6, 7] (Figure 1).

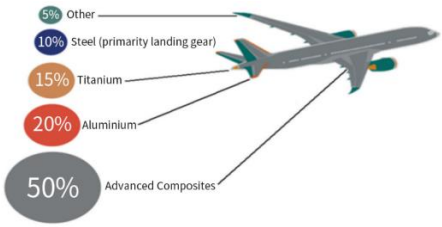

Figure 1. Composite materials used in civilian aircraft (Boeing 787) [8]

Unsaturated polyester resin (UPR) is a popular choice due to its inexpensive cost, ease of handling, corrosion resistance, flexibility, rigidity, weather resistance, and flame retardancy. It is one of the most often used PMs in sophisticated composite applications around the world, where it is mixed with reinforcing fibres, particles, and other materials [9]. Worldwide, more than 2 million tons of UPR are used to make a variety of goods, including gratings, pipelines, tanks, sanitary ware, and high-performance parts for marine and automotive industries [10]. UPR is created chemically by combining alcohols and saturated and unsaturated di-carboxylic acids. When cross-linked with a vinyl reactive monomer, it produces extremely strong structures and coatings [11] (Figure 2). The properties of the final UPR composite are determined by the exact types and quantities of acids and glycols utilized [12].

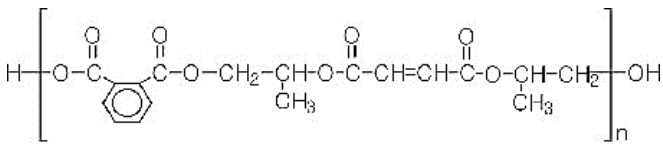

Figure 2. Chemical structure of UPR [12]

Given their affordability and desirable mechanical properties, glass fiber (GF) materials are the most often utilized reinforcements with plastic binders [13]. Glass fibre (GF) materials are the most often utilised reinforcements due to their affordability and good mechanical qualities. Due to its

lightweight nature, vibration absorption, corrosion resistance, impact resistance, cost-effectiveness, and ease of repair and production, GF plays an important part in the manufacturing of power and sail-driven racing vessels [14, 15]. Thermoset composites made of e-GF offer good physio-mechanical characteristics. The e-GFs made of silica ($54.3SiO_2$-$15.2Al_2O_3$-17.2CaO-4.7MgO-8.0BO-$0.6Na_2O$) are particularly popular due to their affordable, easily accessible, and have excellent insulating properties up to 815°C. In the realm of improving the mechanical properties of thermoplastics, e-GF reinforcements are a viable alternative when surface-treated fibers are employed because of their high mechanical qualities and enhanced fiber–PM adhesion [16]. Furthermore, kaolin clay, which is mostly constituted of hydrated aluminium silicate minerals (primarily kaolinite) with trace amounts of other oxides, is an important filler material in composite applications [17-20]. Another notable innovation is hybrid composites (HCs), which combine various reinforcing types within the same matrix to synergize composite features [21]. HC materials have a high strength to weight ratio, low cost, and ease of manufacture with incorporation of a proportion of one or two (reinforcement, matrix) elements of lesser quality to achieve the desired qualities, which lowers the overall costs of composite production. Furthermore, HCs have adequate toughness, strength, stiffness, and other qualities to be used in a wide range of technical applications [22]. Kaolin clay is mostly used in the construction and refractory industries [23], but it also works well as a filler material in composite applications. Lee et al. [24] created red clay composites by combining them with aqueous solutions of polyvinyl pyrrolidone, carboxymethyl cellulose (CMC), and polyvinyl alcohol (PVA). The effect of polymeric (PVA) binder additions on compressive strength was investigated. The addition of 1.5 wt% PVA to red clay (R)/polymer composites increased compressive and flexural strength as well as water resistance. The current study's findings show that PVA F-24 may be successfully used as a binder in the production of bricks and tiles. Al-Asade and Al-Murshdy [25] studied the mechanical characteristics of unsaturated polyester (UP) with 3%, 5%, 7%, and 9% kaolin. Flexural modulus, impact strength (i_σ), and hardness were all raised. At low kaolin concentrations, kaolin acted as a binder and particle-reinforcing ingredient, improving the mechanical properties of UP. Eddres et al. [26] determined the hardness, i, and toughness of polymeric composites containing 6, 12, and 18 wt.%. UP with chopped Al_2O_3 (A) fiber reinforcement. With 18 wt.% cut, the investigated qualities improved. A UP with fiber reinforcement. Adnan Abd [27] investigated the thermal conductivity, Shore hardness (HSD), compression strength, porosity (P%), and density of cast-molding polymeric insulators with 5, 10, 15, and 20% fillers. Adnan Abd [27] investigated the thermal conductivity, Shore hardness (HSD), compression strength, porosity (P%), and density of cast-molding polymeric insulators with 5, 10, 15, and 20% fillers. Thermal conductivity and hardness exhibited minimal values with an increase in kaolin content of up to 20 vol.%. The thermal isolation enhanced with the increase in P% and density filler content. The 5% kaolin sample, on the other hand, provided the highest compression strength. The results showed that the increase in the amount of kaolin additives reduced the glass transition temperature, melting point, and crystallization temperature. Kumar et al. [28] investigated woven of glass fiber type E (e-GFW) fabric reinforcement material with 60%, 65%, and 70% V_f of e-GFW, and polyester resin was used as a matrix material by conventional hand lay-up technique. Tensile, hardness, and i_σ were characterized in accordance with ASTM standards. Obtained results showed that 70% woven roving mat (e-GFW) had good mechanical characteristics in comparison with the reinforced PM composite with a V_f% up to 60%. Meanwhile, Islam et al. [29] fabricated 5–50 wt.% e-GFW fabric reinforcement material. Hand lay-up was used to create the reinforced UPR-based composites. This experimental effort addresses the research gap identified by the literacy survey by improving the characteristics of HCs by an increase in e-GF content, making them appropriate for high-temperature applications and structural components in aeroplanes. CMCs are intriguing structural materials, but their applications are limited because to a lack of adequate reinforcing elements, production problems, lifespan, and cost. Thus, this study objective to produce novel materials, such as hybrid composites or specific filler materials like white clay, red clay (local materials), A, and GF materials, new HC materials are being developed to improve the performance of composite materials for airosspace application as blades, fins, tail, and other aircraft structures. This article also seeks to improve manufacturing practices by identifying more efficient and cost-effective methods for producing composite materials, which may result in reduced airplane production costs.

2. PREPARATION Of HCS

To increase the final performance of HC materials, this study used novel starting materials with UPR and MEKP hardener. The UP and MEKP hardener were supplied by (Turkey) company, alumina (A), red kaolin (R), and white kaolin (W) were provided by Iraqi Western Desert and they were crushed and milled to be used as reinforcing powder materials, and the e-GFW material was offered by Thomas Baker (India). The chemical composition of the materials was analyzed (Table 1).

Figure 3 indicates the kaolinite structure drawn with VESTA software. The blue sheet represented the tetrahedral silica layer and the gray sheet the octahedral alumina layer. When used as a filler in composite materials, kaolinite clay is known for its environmental friendliness and unique structure, which makes it very compatible with matrix materials like UP. Furthermore, the unique structure provides great insulating qualities, making it an excellent choice for high-temperature applications, notably in aircraft. Furthermore, the addition of Kaolinite powders contributes to the overall improvement of hybrid composite materials.

Table 1. Chemical analysis of R and W

Oxides	Compositions	
	R	W
SiO_2	40.54	49.13
Al_2O_3	7.55	35.08
Fe_2O_3	5.73	1.45
TiO_2	0.53	1.50
CaO	21.87	0.17
MgO	4.65	0.41
Na_2O	1.03	0.15
K_2O_3	1.50	0.37
Loss On Ignition (LOI)	16.35	11.69

Table 2. Code and compositions of samples

Samples	Compositions in Volume Fraction (V_f%)				
	UPR	R	W	A	E-GFW
H_o	100	0	0	0	0
H_1	70	10	10	0	10
H_2	70	0	10	10	10
H_3	70	10	0	10	10
H_4	60	10	10	10	10

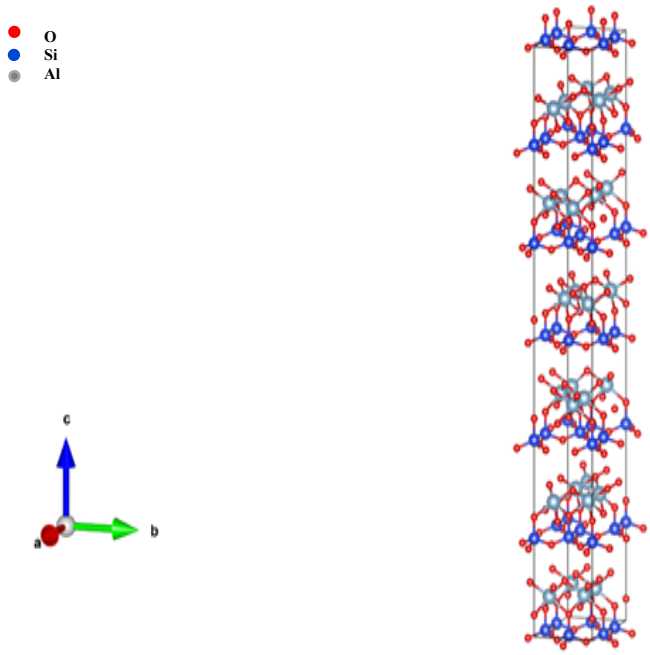

Figure 3. Kaolinite structure ($Al_2H_4O_9Si_2$) drawn with VESTA software ver.3.5.8, 2021

Table 2 provides the mixtures of HCs.

Because of the cost effectiveness, materials placement, and stringent quality control of preparing HCs with the hand-layup method. As seen in the HCs composition, five layers of e-GFW were employed material with a V_f% of 10%, as observed in the composition of HCs. The first step involved the continuous and careful mixing of UP with the hardener at room temperature at a 1:50 ratio using a glass rod to prevent bubble formation. The second step consisted of the addition and combination of reinforcing ingredients (Table 2) and mixing of the mixture for 10 min to achieve homogeneity. In the third step, the mixture was poured into a mold, followed by the insertion of the e-GFW material into the standard mold. The mixture was further poured until the woven material was completely covered. The fourth stage involved pressing the mixture with a suitable weight of 200 g. In the fifth step, to finish the hardening process, we kept the woven material in the mold for 24h at room temperature. Finally, the HC samples were dried at 60°C for 4h after they were poured. Drying is a crucial step in obtaining the optimal cross-linking between polymeric chains, removing tensions created by the preparation procedure, and completing the full hardening of the samples.

3. PHYSICAL INVESTIGATIONS OF HCS

Physical investigations of hybrid composite materials (HCS) play an important part in our study, with the primary goal of elucidating the material's fundamental features and performance properties. It concentrated on three key tests: True density (T_ρ), porosity percentage (P%), and water absorption (W_A) of HCs, a cylindrical sample with a diameter of 40 mm and a thickness of 5 mm was employed according to the ASTM C 373 standard. These experiments were carried out with the overriding purpose of understanding how HCs reacts to various environmental situations and how it may be fine-tuned to thrive in a variety of applications. The test was carried out in accordance with ASTM C 373 [30], with three times repeated for each HC sample. After preparing cylindrical HCs samples, the procedure began with dried in a 100°C oven. The dried HC samples were then weighed. After that, they were submerged in water for 24 hours. The HCs were then withdrawn from the water and blotted dry. Then they were weighed again following the immersion procedure and measured according to Eq. (1), Eq. (2), and Eq. (3).

$$T_p = \frac{W_1}{W_1 - W_2} * \rho L \tag{1}$$

$$P\% = \left(\frac{W_2 - W_1}{W_2}\right) * 100 \tag{2}$$

$$W_A = \left(\frac{W_2 - W_1}{W_1}\right) * 100 \tag{3}$$

where, W_1: dry weight of UP and HC samples (g), W_2: immersed weight of UP and HC samples (g), and ρL: density of distill water ($1\ \frac{g}{cm^3}$) [27, 31].

4. MECHANICAL INVESTIGATIONS OF HCS

It is critical for determining the hardness, tensile strength, bending strength, and impact strength of HCs in order to determine their quality, safety, and suitability for aeronautical applications. These experiments were carried out at room temperature repeated three times for each HC sample for each of the properties listed below.

4.1 Hardness shore D (H_{SD}) test

Following the ASTM DI-2240 standard a cylindrical sample with a diameter of 40 mm and a thickness of 5 mm was used for the shore hardness test of HCs [32]. This test is performed by placing the durometer perpendicular to the sample on the material's surface. Apply a certain force (4.5 N) for a predetermined amount of time (usually 15 seconds).

4.2 Tensile test

ASTM D638 is critical for quality control and design considerations in industries that rely on plastic materials for testing the tensile qualities of HCs with overall lengths of 165 mm and widths of 13 mm, with a gauge length of 50 mm. This test includes producing specific-shaped specimens and exposing them to controlled strain until they fracture. The tensile test was performed at room temperature with an applied load of 10 KN and a strain rate of 0.5 mm/min using a certain machine type, in accordance with ASTM (D638) [33] (WDW-200E, China).

4.3 Bending test

The test was performed with samples measuring 191 mm × 13 mm × 5 mm, according to ASTM D790 [34]. After placing them horizontally between two supports and applying force to a specific location, inducing maximum bending or maybe fractures and calculated the bending values according to Eq. (4).

$$E = (\frac{M_* g_* L^3}{48_* I_* S}) * 100 \quad (4)$$

where, E: modulus of elasticity (MPa), M: maximum bending moment, g: acceleration due to gravity ($\frac{m}{s^2}$), L: span length between the two supports (m), I: moment of inertia of the specimen's cross-sectional for rectangular cross-section (m^4), and S: maximum deflection of the samples (m) [35].

4.4 Impact and fracture strength tests

These tests are critical for determining the feasibility of composite materials in applications requiring high impact resistance, such as automotive, aerospace, and construction. The capacity of samples to withstand abrupt, high-velocity hits using a pendulum-type impact tester, as well as the energy absorbed during specimen fracture, were examined, yielding impact strength, material ductility, toughness, and sensitivity to sudden stress. This test was carried out with dimension (55*10*10) mm accordance with ISO-179-1 [36], and the fracture toughness and impact resistance of hybrid and UP samples were determined according to Eq. (5) and fracture toughness (Kc) was calculated from Impact test according to Eq. (6).

$$Gc = \frac{Uc}{A} \quad (5)$$

$$K_c = \sqrt{G_c E} \quad (6)$$

where: Uc fracture energy (J), A: cross section area (m^2), and Kc: fracture toughness (MPa$\sqrt{m}$) [31].

5. RESULTS AND DISCUSSION

5.1 Physical investigations

As more reinforcement material contents with greater densities than the matrix was used, the densities of all HC samples were higher than those of pure polyester samples (UP). The T_ρ values were lower compared with the theoretical density (Th_ρ) values, which can be due to the existence of certain flaws (pores or voids) formed during the manufacturing process. The hybrid composite type (H_4) samples showed a higher density because they contained 60% unsaturated polyester (UP) + 10% alumina (A) and 10% red clay (R) + 10% white clay (W) + 10% glass fiber type E-woven (e-GFW). Thus, the presence of A and two types of kaolin influenced the densities of the HCs (Table 3).

Previous research [27] found that the highest density of reinforced UP with 20 wt. kaolin was less than 1.36 $\frac{g}{cm^3}$.

Table 4 demonstrates the P% and W_A of HC and UP samples, respectively (3.4). Given that this hybrid had more reinforcing additives (10%A 10%R + 10%W +10% e-GFW) than other samples, H_4 showed lower P% and W_A. Another factor was that W and R had lower P% and W_A due to the increased presence of A (Table 1) [37]. According to the study [24], the increase in W_A values as compared to prior study was around 28.3% using 85 wt.% clay type R, 14.25 wt.% water, and 0.75 wt.% polyvinyl alcohol 0.75 (PVP). The application of 20 wt.% kaolin, on the other hand, raised the P% to 20% [27]. While the current experiment demonstrated a decrease in P% values with greater utilization of all content reinforcing materials.

Table 3. Th_ρ and T_ρ of HCs

Samples	Th_ρ ($\frac{g}{cm^3}$)	T_ρ ($\frac{g}{cm^3}$)
H_o	1.24	1.27
H_1	1.29	1.33
H_2	1.31	1.35
H_3	1.35	1.31
H_4	1.37	1.39

Table 4. P% and W_A of samples

Samples	P%	W_A
H_o	2.8	1.8
H_1	2.7	1.4
H_2	2.4	1.2
H_3	2.2	0.7
H_4	1.8	0.2

5.2 Mechanical investigations

5.2.1 Hardness shore D (H_{SD}) test

Table 2 and Figure 3 show the hardness values of HCs and UP samples. The hardness of HC samples was higher than that of UP samples due to the addition of reinforcement materials (powders of W, R, and A and layers of e-GFW material), which can raise the material hardness to further increase the material resistance against plastic deformation [38]. The elevated hardness levels were attributed to the increased cross-linking and stacking, which reduced the movement of polymer molecules [39]. Moreover, the hardness of H_4 was higher than those hybrid composite types (H_1, H_2, and H_3) because of its higher reinforcement contents (Table 5).

According to prior research [27], the values of H_{SD} decreased with increasing kaolin content to UP to 20 wt.%. In the current investigation, increased reinforcing to UP resulted in an increase in H_{SD} values.

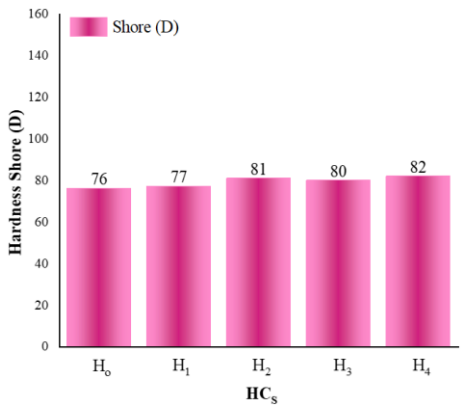

Figure 4. Relationship between HC and UP in hardness test

Table 5. H_{SD} of hybrid and non-reinforced UP samples

Samples	H_{SD}
H_o	76
H_1	77
H_2	81
H_3	80
H_4	82

5.2.2 Tensile investigation (True tensile strength ($T_{t\sigma}$))

Table 6 and Figure 4 show the results of $T_{t\sigma}$ of HC and UP samples. The tensile strengths of HCs were higher than those of UP samples due to existence of e-GFW material in the five layers, which showed positive effects on strength and toughness (resistance to crack propagation) of the samples [40]. The H_4 obtained higher $T_{t\sigma}$ than other samples (UP, H_1, H_2, and H_4) because of its higher contents of reinforcement filler. In addition, H_1 and H_2 showed decreased tensile strength because of the presence of kaolin, which contained a high alumina content; they were characterized by high hardness in addition to the presence of alumina filler in their contents, which decreased the $T_{t\sigma}$ [41].

Table 6. $T_{t\sigma}$ of HCs and non-reinforced UP samples measured at 10 KN

Samples	$T_{t\sigma}$ (MPa)
H_o	5.2
H_1	2.5
H_2	5.5
H_3	7.92
H_4	10.57

According to prior research [28], the greatest tensile strength using 70% e-GFW reinforced polyester resin was 306 MPa. And reached less than 89 MPa [29] with 50 wt. % of e-GFW The highest value reached 10.57 MPa throughout the current work.

5.2.3 Investigation of bending modulus

Table 4 and Figure 5 show the modulus of elasticity (M_ε) of HC and UP samples. The results reveal that the moduli of elasticity of HC samples were higher than those of pure polyester samples, which can be due to the presence of e-GFW material, which can impart great stiffness to the UP [42]. In addition, the modulus of elasticity of sample H_4 was lower than those of other samples due to the reinforcement by A, R, and W, which increased the hardness of hybrid samples.

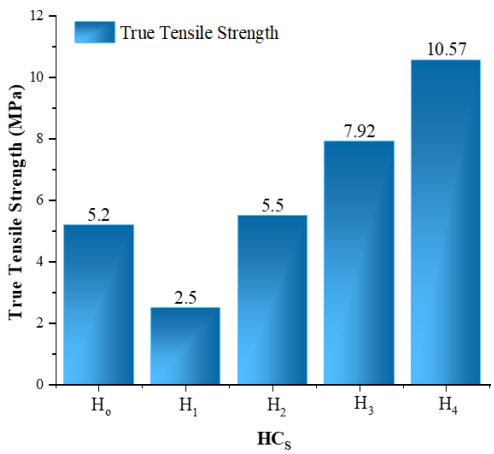

Figure 5. Relationship between HC and UP and their $T_{t\sigma}$

5.2.4 Bending investigation

Table 7 and Figure 6 display the results of iσ and fracture toughness of HC and UP samples. The iσ of HC samples were enhanced compared with that of pure polyester because the kaolin particles acted as crack initiators.

Table 7. M_ε of HCs and UP samples.

Samples	M_ε (GPa)
H_o	40
H_1	974
H_2	141
H_3	134
H_4	125

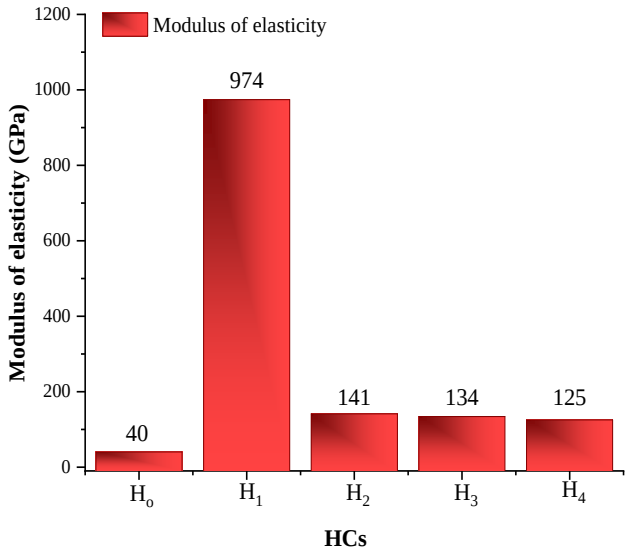

Figure 6. Relationship between (HC and UP) and modulus of elasticity M_ε

The M_ε values with attained 70% e-GFW were 7550 MPa [28] and with 50 wt. % of e-GFW reinforced UP was less than 4000 MPa [29], however in the current study the greatest M_ε value was 974000 MPa with sample type (H_1). And increasing the reinforcing content dropped the value to 125000 MPa. Figure 7 displays the iσ of HCs was greater than that of UP samples, with the lower fracture toughness of H_1 than other HC samples. This result was due to the increased additions of R and W with alumina fillers content in particle form, which functioned as sites for localized stress concentration, in which failure occurred. It may also aid in the reduction of material elasticity and lowering the absorbed energy matrix, which reduced the toughness [43], as seen in Table 8. According to the study [25], an increase in iσ value was detected when compared to literates' survey. The greatest value was 2080 J/m^2 with 9 wt.% of kaolin filler UP. The same behavior was seen in the study [28], with 70% of e-GFW reinforced UP. While the present work obtained 11196.89 J/m^2 with sample type (H_1). Furthermore, an improved increase in K_c values was found in this work when compared to the greatest K_c value [26], which was around 86.7 $MPa.m^{1/2}$ with 18 wt.% of (A) reinforced UP. While the current study displayed maximum K_c was 374*103 $MPa.m^{1/2}$ with H_1 sample.

Thus, according to the results of the physical and mechanical properties. This work suggests the benefit of novelly prepared HCs with natural and synthesized ceramic oxide Al_2O_3 and e-GFW to be used in fuselage blades, vertical fins, tail assemblies, and other aircraft structures.

Table 8. iσ investigation in hybrid and non-reinforced UP samples

Samples	iσ (J/m^2)	Kc ($MPa.m^{1/2}$)
H_o	125	8.866
H_1	11196.89	$374 * 10^3$
H_2	10635.31	$321 * 10^3$
H_3	3057.72	$207 * 10^3$
H_4	1564.42	$145 * 10^3$

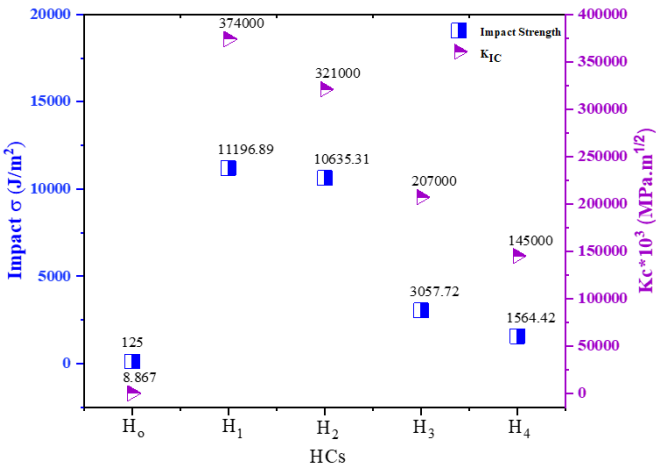

Figure 7. Relationship between (HC and UP) and iσ and K_c

5.3 Analysis of variance (ANOVA)

ANOVA was used in this study to analyze the importance of changes across various parameters with regression models to comprehend and quantify the relationship between variables, especially for predicting or explaining outcomes based on predictor factors. The best fit is determined by statistical indicators such as R-squared, p-values, and model assumptions. So, the major results of experimental parameters, which included H_{SD}, P%, iσ, K_c, and M_ε, were evaluated using ANOVA. Figure 8 shows the association between H_{SD} and P%. According to the regression plot, the change in P% resulted in an increase of 23.51604 in P% and a decrease of approximately 6.35982 in H_{SD} with R^2 = 91%.

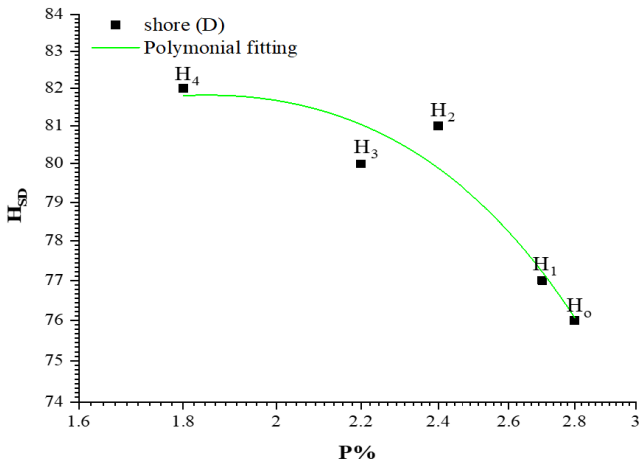

Figure 8. Regression plot between P% and H_{SD} of HCs and UP samples

In addition, according to ANOVA results (Table 9), the regression model was fitted with no independent variables (p-value: 0.08944).

Table 9. ANOVA table

Source	DF	SS	MS	F	P-value
Regression	2	24.40313	12.20157	10.18126	0.08944
Error	2	2.39687	1.19843		
Total	4	26.8			

Moreover, the regression equation was nonlinear, as displayed in Eq. (7).

$$M_\varepsilon = 2000.37 - 514.38759\, T_{t\sigma} + 32.40914\, T_{t\sigma}^{\,2} \quad (7)$$

Figure 9 shows the regression plot between i_σ with K_c, with the change in i_σ indicating an increase of 78.07997% and a decrease of 0.00433% K_c.

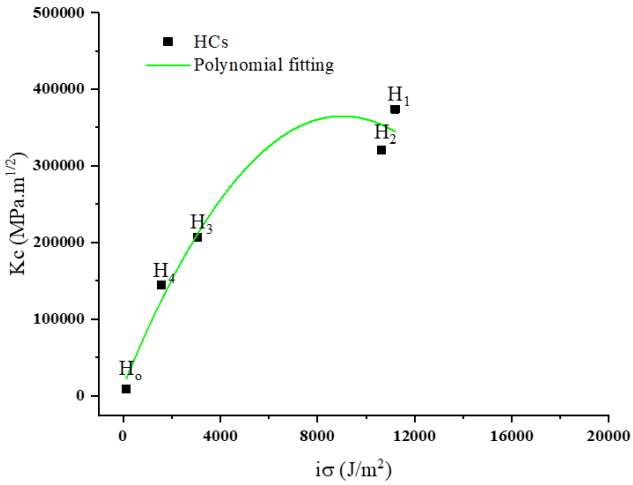

Figure 9. Regression plot between K_c and i_σ of HCs and UP samples

Moreover, a high-fitting regression model was shown by ANOVA (Table 10), with a P-value of 0.03062 and R^2: 96.

$$Kc = 12667.00124 + 78.07997\, i\sigma - 0.00433\, i\sigma^2 \quad (8)$$

Table 10. ANOVA table

Source	DF	SS	MS	F	P-value
Regression	2	8.13304E10	4.06652E10	31.66314	0.03062
Error	2	2.56861E9	1.28431E9		
Total	4	8.3899E10			

Table 11. ANOVA

Source	DF	SS	MS	F	P-value
Regression	2	540266.75653	270133.37826	8.49582	0.10531
Error	2	63592.04347	31796.02174		
Total	4	603858.8			

Furthermore, the as-revealed change in $T_{t\sigma}$ reflected a reduction of 514.38759% and a rise of 32.40914% in M_ε. Table 11 shows the ANOVA results, which indicated a high fit of the regression model between variables with P-value of 0.10531 and R^2 = 89.

Figure 10 depicts the regression plot between tensile strength ($T_{t\sigma}$) and the modulus of elasticity (M_ε). It was observed a polynomial fitting with these studied parameters.

$$M_\varepsilon = 2000.37 - 514.38759\, T_{t\sigma} + 32.40914\, T_{t\sigma}^{\,2} \quad (9)$$

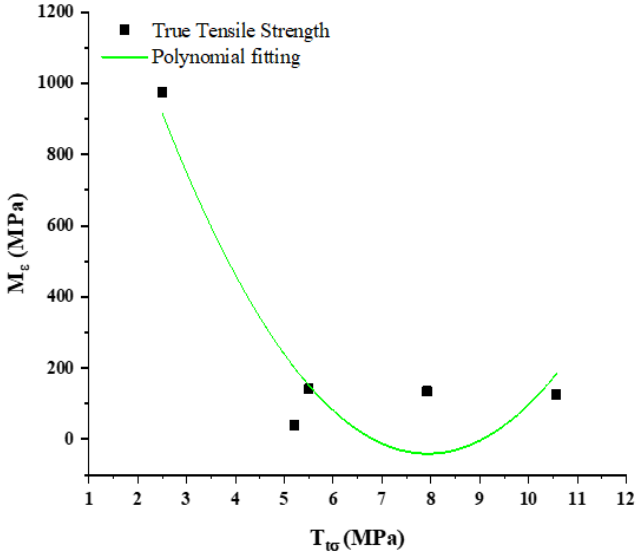

Figure 10. Regression plot between $T_{t\sigma}$ and M_ε of HCs and UP samples

6. CONCLUSIONS

This experimental investigation assessed the physical and mechanical properties of Hybrid Composite (HC) materials. Notably, as an alternative to more expensive industrial production processes, we used a low-cost method, hand lay-up, to create new HC materials. The T_ρ value obtained significant findings found were 1.39 g/cm^3 with H_4 sample as a consequence of the effect of the 60 UP%, 10% R%, 10% W%, 10% A%, and 10% e-GFW%. In comparison to prior work, the P% disclosed dropped with H_4 to 1.8% and 0.2 of WA. The M had the greatest value of 125000 MPa with H_1 sample due to the absence of alumina content as reinforcement material and raised UP percentage to 70% V_f%.

In addition, when compared to pure Unsaturated Polyester (UP) samples and previous published work, H_1 displayed the greatest values for modulus of elasticity (M_ε), impact strength ($i\sigma$), and fracture toughness (K_c), with $i\sigma$ was 2080 J/m^2 with 9 wt.% of kaolin filled UP and K_c obtained 86.7 MPa.m$^{1/2}$ with 18 wt.% of (A) reinforced UP. ANOVA of investigated parameters and regression demonstrated a strong significant correlation association meant a strong and significant correlation between variables. It was indicated that changes in one variable have a predictable impact on changes in another. A model with a high fit between variables explained and predicted the relationship. These findings have practical implications and increase confidence in the findings between the hardness shore D (H_{SD}), P%, M_ε, True Tensile Strength ($T_{t\sigma}$), K_c, and $i\sigma$ of HCs and UP with regression model suggesting a high fit between variables of analyzed associations revealed with high R^2 values of analyzed relationship. It was concluded that with hand lay-up was determined to be a manual composite material preparation procedure that includes mold preparation, material selection, fiber arrangement, resin application, layering, curing, demolding, and finishing. It is used for one-of-a-kind or small-batch objects that require precise attention to detail in order to achieve the desired characteristics and quality. It was decided that the low cost of preparing HCs with unique chemicals by hand made it appropriate for use in aeronautical applications.

7. FUTURE WORK

It is recommended to utilize Kevlar woven as reinforcing materials with the same volume fraction and addition and to assess the same properties in addition to the thermal conductivity and electrical insulator properties.

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NOMENCLATURE

A	Al_2O_3
ASTM	American Society for Testing and Materials
ANOVA	Analysis of variance
e-GFW	E-glass fiber woven
R	Red kaolin
W	White kaolin
K_c	Fracture toughness
HCs	Hybrid composites

Greek symbols

$i\sigma$	Impact strength, $J.m^{-2}$

Subscripts

T_ρ	Trure density
Th_ρ	Theortical density
$T_{t\sigma}$	True tensite strength
P%	Prosity percentage
M_ε	Modulus of elasticity
H_{SD}	Hardness Shore (D)
W_A	Water absorption