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MECHANICAL CHARACTERIZATION AND IMPACT RESISTANCE OF A NOVEL HYBRID COMPOSITE BASED ON SALVADORA PERSICA ROOTS AND GLASS FIBERS

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The observation of fibers in salvadora persica roots inspired us to consider the idea of using them as reinforcement to create an innovative composite. The current work focuses on the volumetric mass density, extraction, molding, and mechanical testing of composites and hybrid composites made from salvadora persica roots and glass fibers reinforced with two types of polyester matrix, chosen due their characteristics suitable for use in different orientations. Various extraction and combination methods have been used to identify an optimal approach for obtaining fibers from salvadora persica roots, considering its chemical composition (hemicellulose, pectin, and lignin). In this investigation, the hand lay-up method was used to mold specimens with different geometries. The composite and hybrid composite were combined with a polyester matrix and subjected to various mechanical tests namely; tensile, impact resistance, and water absorption. The results indicate that reinforcing polyester resins with SP fibers, whether long or short, enhances the overall mechanical properties of the composite. Additionally, improved adhesion between salvadora persica roots fibers and resin was observed.

Keywords: hybrid composites, natural fiber, glass fibers, tensile strength, impact resistance.

1. Introduction

Natural fiber-based polymer composites find extensive applications in advanced structural systems, owing to their performance and significant potential for reducing composite weight, cost, and enabling recycling [1-5]. Hybridization is a promising strategy for enhancing the mechanical properties of composite materials when used in conjunction with components [6].

A short time ago, some researchers started to investigate SP powder as reinforcement for composites [6-8]. Many extraction methods were followed [9-11] with several authors have attempted to define composites made from flax, Hemp, Palmyra, Cactus, Date Palm, Washingtonia filifera and Luffa Cylindrical [12-28] , and hybrid composites using fiber glass with Coir, Bamboo, Kenaf, Sisal, Jute, Raffia, Stalk, banana, Coconut Coir, Sugar Palm and Talc [29-55].

The economic objective of utilizing the residual parts from the production of SP roots post-extraction is to create a more cost-effective composite. Hybridization involves incorporating the remaining glass fiber

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from used mats to enhance mechanical properties and broaden technology applications [56]. Concerning the affinity of resin/fiber, cost considerations, and specific application requirements, various extraction methods were employed to preserve the mechanical characteristics of natural fibers. The following description outlines the investigation method for extracting fibers from SP roots to manufacture composites and hybrid composites.

Hybridization involves combining these fibers with glass fibers reinforced polyester resin to undergo tests for volumetric mass density, tensile strength, impact resistance, and water absorption. These tests aim to enhance the mechanical properties of the composites and assess their suitability in aqueous environments. All obtained results were subjected to analysis using the ANOVA method to discern the significance of differences between SP composite and hybrid composites.

2. Experimental study

2.1. Materials and methods

Fiber extraction: Cellulose extraction for composite production has been carried out by researchers using various methods [57–59]. The extraction process includes peeling, laminating, immersing in a 5% NaOH solution for 48 hours, washing with water, and cleaning/bleaching by immersing in an H_2O_2 solution for 0.5 hours. solution for 0.5 hours. Subsequently, the material is washed with water and dried under sunlight (Fig.1).

Fig.1. Extraction process: (a, b) Roots, (c) NaOH, (d) H_2O_2, (e) extracted fibers.

Material processing: In this study, SP and glass fibers are employed to fabricate various composite and hybrid composite specimens. The SP roots are procured from TYBAH SEWAK in Saudi Arabia, while the glass fiber is either extracted or cut from E-glass mat $450\,g\,/\,m^2$. Polyester resin types 3402-TA-H30 and TP200TICO, along with an appropriate catalyst in a 1.5% ratio, are obtained from a local supplier. The molding process involves the use of POLYVAKS Max-9 mold release wax.

For the first case, which involves an orthotropic SP composite, short fibers ranging from $0.5\,cm$ to $1.5\,cm$ are utilized. The hybrid composite is formed by integrating dismantled remains of E-glass mat $450\,g\,/\,m^2$. In the second case, long fibers are employed for the unidirectional composite, and a hybrid composite is created by adding two mats cut to the dimensions of the specimens. These mats reinforce the lateral sides with the aim of reducing water absorption and improving mechanical properties.

Volumetric mass density: The density of SP fiber was determined following the ASTM D792 standard [60] utilizing an electronic analytical balance model FA2004B with a precision of $0.0001\,g$ to measure the mass m and a graduated beaker of $50\,mL$ to measure the volume v based on Archimedes' principle under room conditions. After testing 6 bundles of SP fibers, the volumetric mass density, as calculated using equation (2.1), is $0.94\ g / cm^3$. This value is comparatively lower than those reported in the literature (Table 1).

$$\rho\left(g / cm^3\right) = m / v \tag{2.1}$$

were m and v represent the mass and volume of the fiber bundle.

Table 1. Volumetric mass density of plant and synthetic fibers [64].

Fiber	Ramie	Flax	Hemp	Jute	Sisal	Cotton	Coir	E-glass	Carbon
Density (g/cc)	*1.5*	*1.5*	*1.5*	*1.3-1.5*	*1.3-1.5*	*1.5-1.6*	*1.2*	*2.5*	*1.4-1.8*

Molding: There are several standardized molding methods used to pull-out specimens, The technique utilized for preparing all types of specimens involves machining steel plates, where metal is removed from the middle steel plates using a CNC Laser cutting machine, following the dimensions outlined in ASTM D638 [61], ASTM D6110 [62] and ASTM D570 [63], Two lateral plates are employed to control the thickness of the specimens (Fig.2). The preparation process involves mixing all components as per Table 2 and pouring the mixture into the mold for short fibers. For long fibers, the resin is poured both before and after inserting the fibers into specimen grooves already immersed in resin. A paddle roller is utilized to remove air bubbles before sealing the mold.

Fig.2. Method of molding the tensile, impact and water absorption test specimens.

Table 2. Samples components of composite and hybrid composite.

	Simple	SP weight (%)	GF weight (%)
Short fiber	POLYPOL	0	0
	SP10	10	0
	SP7.5GF2.5	7,5	2,5
	SP5GF5	5,0	5,0
	SP2.5GF7.5	2,5	7,5
Long fibers	TP200	0	0
	SP7	7	0
	SP7GF14	7	14

2.2. Mechanical tests

Tensile test: The composite and hybrid composite material was molded and tested following the specified dimensions for test specimen type IV of ASTM D638. The testing process involves placing the specimen in the MTS C 43.504 machine (Fig. 3a) and applying traction until it breaks. Approximately 20 specimens were tested for each of the 8 different types, as outlined in Table 2, except the polyester specimens are *10* each.

Impact Resistance test: According to ASTM D6110 standard *8* samples of each composite and hybrid composite specimen (as per Table 1) were molded and manually notched for testing using the KARL FRANK GMBH impact resistance machine, model *53 565*, with a pendulum capacity of 6 joules (Fig. 3b). The average impact resistance (AIR) of the specimen set was calculated using equation (2.2):

$$AIR\left(j\right)=\sum E/n. \tag{2.2}$$

where E is the individual impact resistance value and n is the number of set specimens.

Water absorption test: To determine the water absorption rate following the ASTM D570 standard, three specimens, shaped as disks with a diameter of $50.8\,mm$ and a thickness of $3.2\,mm$, were conditioned at room temperature. Weight measurements were taken after $0.5, 2, 24, 48$ hours, one week, and every two weeks, adhering to the procedure of placing and removing all specimens simultaneously and wiping them with a dry cloth. An electronic analytical balance model FA2004B, capable of reading $0.0001g$, was used until saturation for each set of composite and hybrid composite (Fig.3c).

The water absorption percentage, indicating the increase in weight during immersion, was calculated to the nearest 0.01% using equation (2.3):

$$W_t\left(\%\right)=\left(W_{wet}-W_{in}\right)/W_{in} \tag{2.3}$$

where: W_t represents the increase in percentage, W_{wet} is the wet weight after water absorption for a specific period, and W_{in} is the initial mass before immersion.

Fig.3. Experiments of: (a) Tensile, (b) Impact and (c) water absorption tests.

3. Results and discussions

3.1. Mechanical characterization of Novel Hybrid Composite (SPR/GF)

The stress-strain curves of the SP roots/glass fibers composite and hybrid composites, considering both short and long fibers, represent an advancement over the previous experimental process. This improvement is evident in Fig. 4, illustrating the behavior, and is substantiated by the increased Young's modulus values reported in Tables 3 and 4. The rise in glass fiber content, regardless of the mode, method, or length employed, contributes to this enhancement.

Comparison of the tensile strengths and strains at break for SP roots/glass fibers composite and hybrid composites (Tables 2, 3, and Fig. 2) reveals a reduction of approximately 2/3 in the case of short fibers when compared to SP10. Upon initiating hybridization with 2.5% glass fibers (SP7.5GF2.5), this reduction is halved. However, with further increments in the percentage of glass fiber, the tensile strengths continue to double.
For long fibers, there is a six fold increase in tensile strength compared to SP7, and this increases to two-thirds after hybridization (SP7GF14).

Table 3. Short fibers – Tensile Young modulus.

Simple	POLYPOL	SP10	SP7.5GF2.5	SP5GF5	SP2.5GF7.5
Young modulus (MPa)	*2001,5*	*2291,72*	*2343,04*	*2502,88*	*2791,04*
Tensile strenght (MPa)	*47,72*	*32,75*	*26,85*	*34,52*	*58.80*
Strain at break (%)	*1,48*	*0,81*	*0,63*	*0,77*	*1,82*

Table 4. Long fibers – Tensile Young modulus.

Simple	TP200	SP7	SP7GF14
Young modulus (MPa)	*1856,57*	*2318,85*	*3039,03*
Tensile strenght (MPa)	*27,85*	*32,85*	*40,79*
Strain at break (%)	*0,84*	*0,81*	*0,75*

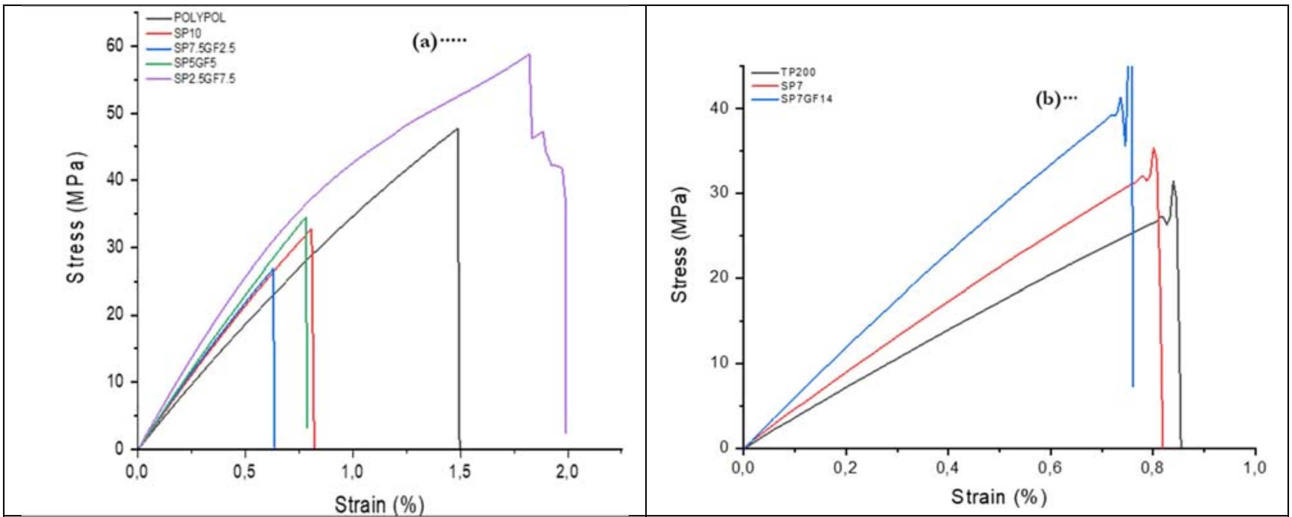

Fig.4. Mechanical behavior of SPR/GF hybrid composite with (a) Short Fiber (b) Long Fiber

Employing a digital microscope with a magnification of 1600X and varying exposure settings for the analysis of fracture surfaces, Fig. 6a reveals an improvement in fiber-matrix adhesion in the isotropic SP composite. However, Fig.5a, depicting the orthotropic SP composite, illustrates diminished fiber-matrix adhesion due to the orientation, accumulation, and crossing of short fibers. Hybridization, as outlined in Table

3 and Table 4 and presented in Fig.5b-d and Fig.6b, indicates a discernible pull-out of resin with fiber. Notably, the greater pull-out lengths of glass fibers compared to SP fibers are clearly visible.

3.2. Impact resistance of SPR/GF composite

To assess the resistance to breakage of the SP root/glass fiber composite and hybrid composites under flexural shock, along with the corresponding energy required for fracture, the values presented in Table 5, Table 6, and Fig. 7 are crucial. These data highlight that the energy absorbed by the orthotropic SP10 composite is approximately 10 times that of 3402-TA-H30 resin. Moreover, the introduction of glass fiber increases the absorbed energy significantly, as seen in the case of SP2.5GF7.5, providing 23 times the energy absorption of 3402-TA-H30 resin and 2.5 times that of SP10. Conversely, for the isotropic composite, the energy absorption is around 4 times for SP7 and 7 times after hybridization compared to TP200TICO resin.

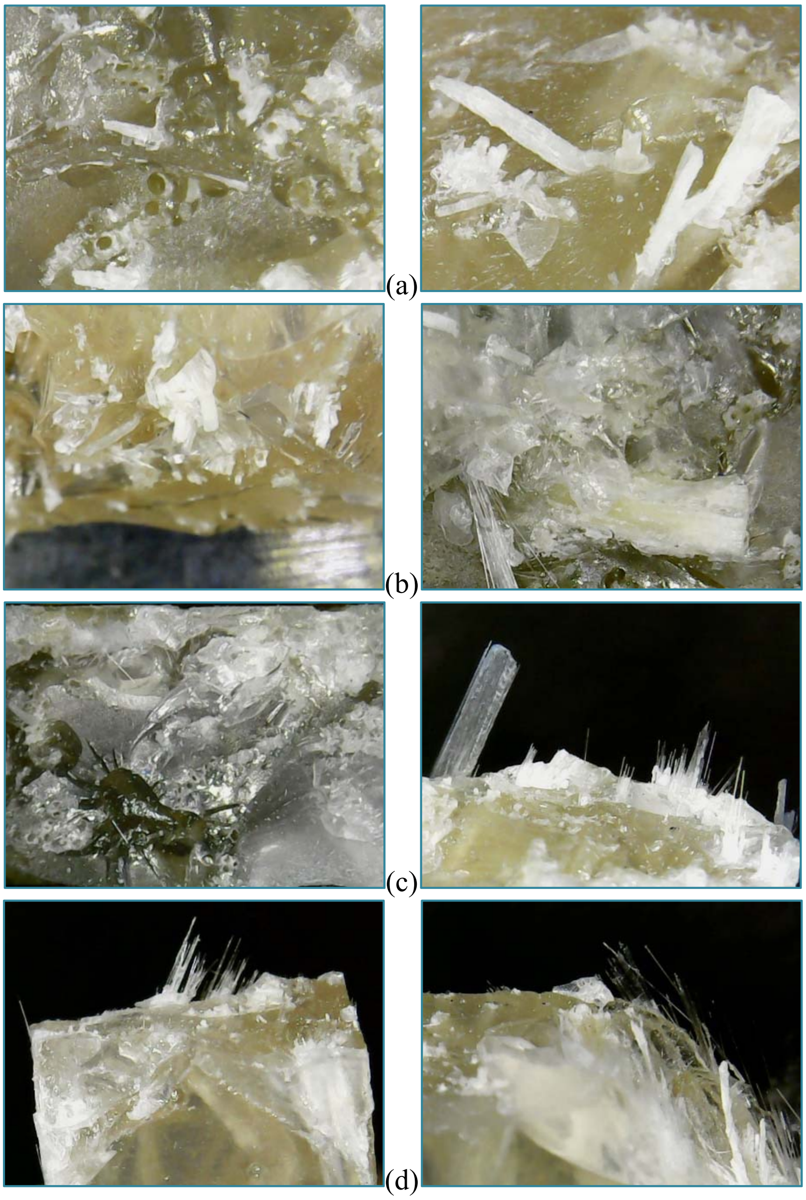

Fig.5. Digital microscope inspections of the tensile fractured specimens with short fibers (a) SP10 (b) SP7.5GF2.5 (c) SP5GF5 (d) SP2.5GF7.5.

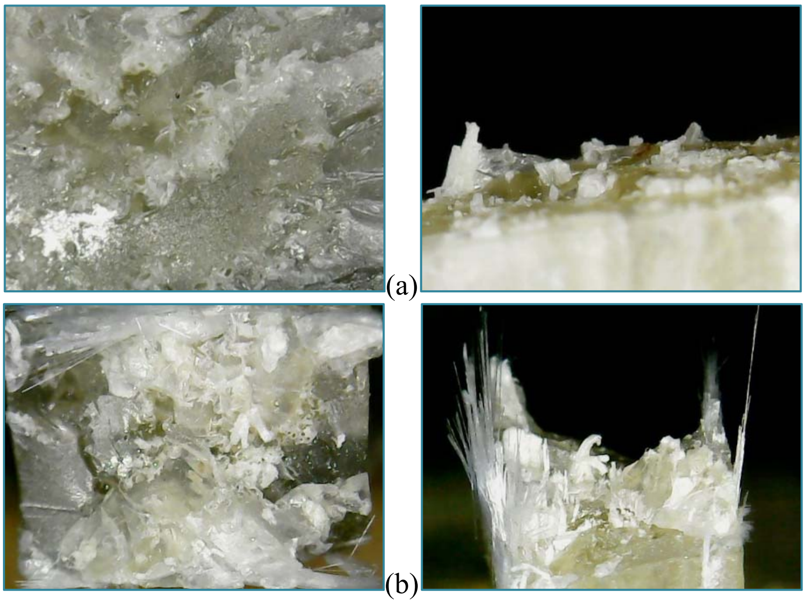

Fig.6. Digital microscope inspections of the tensile fractured specimens with long fibers (a) SP7 (b) SP7.5GF14

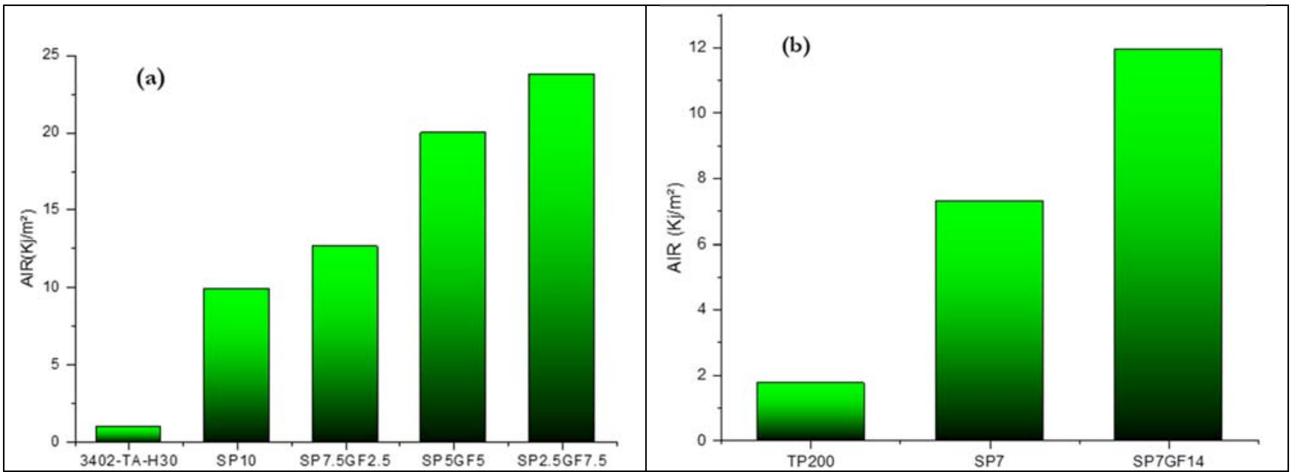

Fig.7. Average Impact Resistance: (a) Short fibers, (b) Long fibers.

Table 5. Impact Energy and Average impact resistance of short fibers.

Simple	POLYPOL	SP10	SP7.5GF2.5	SP5GF5	SP2.5GF7.5
Impact Energy (J)	*0,15*	*1,43*	*1,82*	*2,88*	*3,43*
Average Impact resistance (KJ/m2)	*1,04*	*9,93*	*12,64*	*20*	*23,82*

The average impact resistance, calculated for SP roots/glass fibers composite and hybrid composites with both short and long fibers, further underscores the improvements achieved through the experimental process. This is evident in Fig.7 and detailed in Table 5 and Table 6, emphasizing the increased impact resistance with the addition of glass fibers, regardless of the mode, method, or lengths employed.

Table 6. Impact Energy and Average impact resistance of Long fibers.

Simple	TP200	SP7	SP7GF14
Impact Energy (J)	*0,25*	*1,05*	*1,72*
Average Impact resistance (KJ/m2)	*1,74*	*7,29*	*11,94*

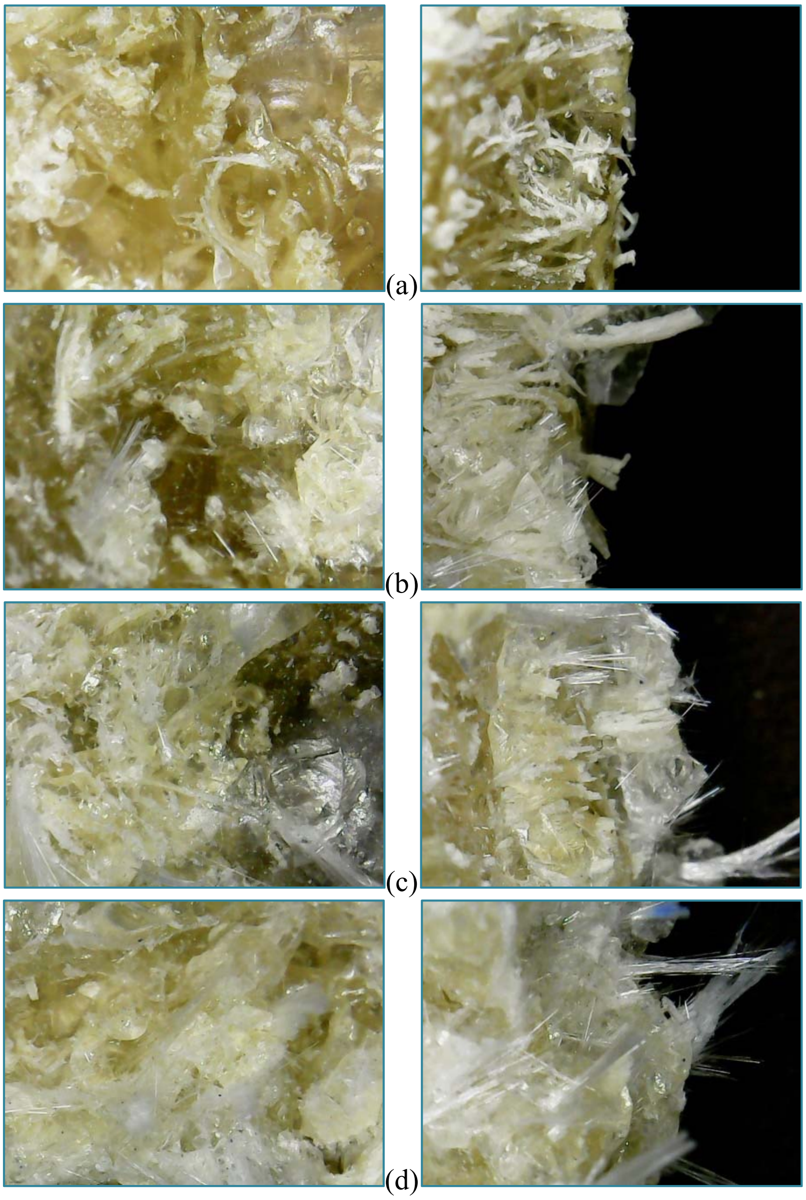

Fig.8. Digital microscope inspections of the impact fractured specimens with short fibers (a) SP10, (b) SP7.5GF2.5, (c) SP5GF5, (d) SP2.5GF7.5.

Using the same digital microscope to analyze the Charpy fracture surfaces, Fig.8a illustrates that the pull-out fiber lengths of the isotropic SP composite are greater than those of the orthotropic SP composite, as shown in Fig.9a. Hybridization, as outlined in Table 2 and presented in Fig.8b-d and Fig.9b, reveals instances of breakage due to the pull-out of fibers.

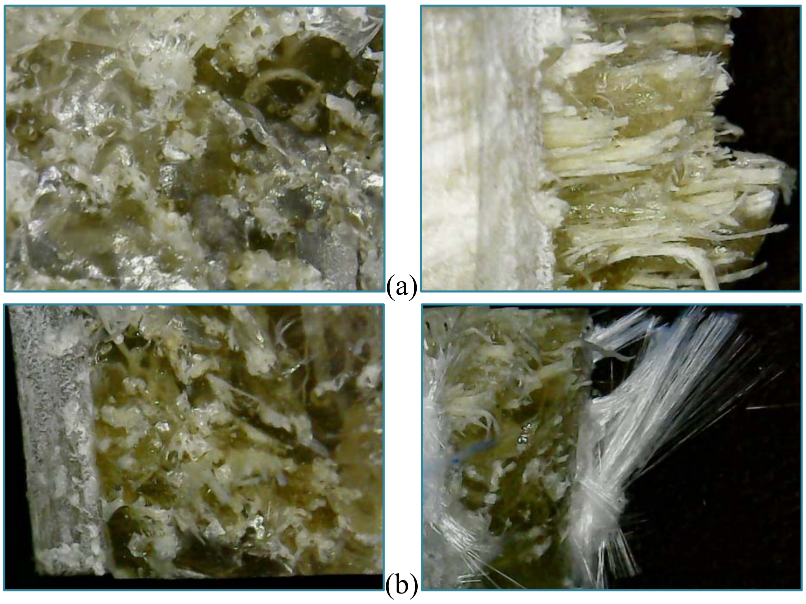

Fig.9. Digital microscope inspections of the impact fractured specimens with short fibers (a) SP7, (b) SP7.5GF14.

3.3. Water absorption

The saturation curves for the SP roots/glass fibers composite and hybrid composites, including both short and long fibers, are illustrated in Fig.10. These curves exhibit a continuous decline, representing a decreasing inclination that signifies the absorption rate leading to saturation stabilities. Tables 7 and 8 provide information indicating that water absorption, after approximately two months of immersion, initially occurs rapidly within the first week and then gradually slows down until reaching saturation. The increase in the percentage of glass fiber in the orthotropic composite and hybrid composite results in a reduction in water absorption over time, as evidenced by a decrease in saturation weight percentage by 1/3 for SP7.5GF2.5, 1/2 for SP5GF5, and 2/3 for SP2.5GF7.5. Additionally, the saturation weight percentage decreases by 1/3 after the hybridization of the isotropic composite.

Table 7. Short fibers - Water absorption saturation.

Simple	SP10	SP7.5GF2.5	SP5GF5	SP2.5GF7.5
Saturation Wt (%)	4,31	3,07	2,34	1,48
Saturation time t(h)	1512	2016	2520	2856

Table 8. Long fibers - Water absorption saturation.

Simple	SP7	SP7GF14
Saturation Wt (%)	3,22	2,03
Saturation time t(h)	2520	3528

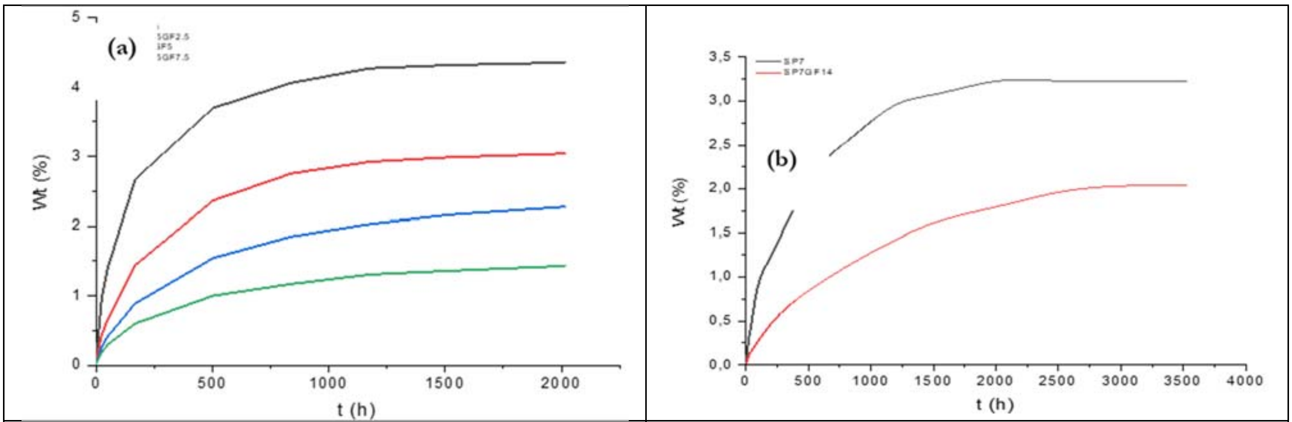

Fig.10. Water absorption behavior: (a) Short fibers, (b) Long fibers.

4. Conclusion

Practically the composites and hybrid composites based on SP roots/glass fibers reinforced Polyester resin have been planned and characterized. The following most important finishes have to mention in this work:

- The fiber extraction process from SP roots was successfully executed, as evidenced by the observed adherence in tensile and impact results.
- The molding method, adhering to specified standards, has validated and strengthened the results by ensuring consistency in quantities and behaviors.
- The reinforcement of polyester resins with SP fiber, whether using long or short fibers, enhances the overall mechanical properties of the composite.
- Increasing the weight percentage of glass fiber through hybridization contributes to the improved mechanical properties of the hybrid composite.
- The water absorption by the composite and hybrid composite is inversely proportional to the weight percentage of glass fiber, resulting in a decrease in weight percentage.
- A notable adherence between SP roots fibers and resin was observed.

Lastly, a significant advantage lies in highlighting the improved density of SP fiber, making it a valuable option for reinforcement in comparison to other composite materials.

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Nomenclature

AIR – Average Impact Resistance
E – Individual Impact Resistance.
GF – glass fiber
m – mass
sp – salvadora persica
W_{in} – initial weight before immersing.
W_t – increased percentage in weight

W_{wet} – reading weight

v – volume

ρ – volumetric mass density

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