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Analysis of Tensile Strength and Water Absorption Properties of Glass-Ramie Hybrid Laminated Composite

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Abstract
Hybrid layered composites (HLC), combining natural and synthetic fibers, are mainly used in the automotive composite industry. The factor determining the inter-mechanical bond between layers impacts the mechanical strength.. Ramie fibers were immersed in a 5 wt.% NaOH solution for 2 hours to remove lignin and hemicellulose content in the fiber surface. Alkali treatment increases the adhesion bond between cellulose and the polyester matrix. The treated ramie fibers to be weaved by traditional machine to produce the woven ramie. The three-layer fibers are manufactured by press mold with a 2-bar pressure. The characterization of HLC for tensile strength according to ASTM D638 and water absorption refers to ASTM D570. The excellent tensile strength and elastic modulus of HLC have a stacking sequence of woven ramie-unidirectional glass-woven ramie (WR-UG-WR) by 150 MPa and 24.1 GPa, respectively, and its lowest water absorption by 3.31%.

INTRODUCTION

The use of ramie fiber as a composite reinforcement has been developed. The hydrophilic properties of natural fiber are the problem when used as reinforcement combined with a polyester matrix with hydrophobic properties. Water content founded in the hemicellulose and lignin structures in the natural fiber. The alkalization using 5 wt.% NaOH at room temperature for 2 hours has effectively removed it. (Ikramullah et al., 2018; Marsyahyo et al., 2008).

Ramie fiber is a fiber with high cellulose content and low hemicellulose and lignin content, so it has the potential to be developed as reinforcement in layered composite products. However, natural fiber composites still have problems with low mechanical strength compared to synthetic fibers, so combining the two types of fibers is necessary. A hybrid composite is a combination of two or more different fiber types. Synthetic and natural fibers can be expected to provide excellent properties of each fiber (Li et al. 2016). Table 1 shows the chemical structure composition of ramie fibers.

Table 1. Chemical composition of raw ramie fibers (Li, et al. 2016)

Ingredients	wax	Water content	Hemicellulose	lignin	Cellulose
Content (%)	1-2	5-8	14-16	0.8-1.5	68-75

HLC with high tensile strength and modulus of elasticity could be applied to several composite products of automotive body panels (Figure 1). Figure 2 is another application of HLC for prostheses generally made from synthetic fibers. For example, the prostheses are made from three layers combine of ramie and glass fibers. It is to minimize the skin-intolerant problem by synthetic material like glass fiber. Besides that, it could be an alternative to the decreased production cost of prostheses (Quintero-Quiroz & Perez, 2019). Figure 3 shows a composite of two layers of jute fiber fabrics to construct a traditional hull boat in Brazil, namely, MIRITI. The

BKI (*Biro Klasifikasi Indonesia*) suggests an allowable material hull boat has a minimum tensile strength by 85 MPA.

Natural fibers have several advantages; cheap, renewable, easy to decompose, and have good ductility properties. In contrast, synthetic fibers have high mechanical properties, but their price is relatively high, and not biodegradable. This study investigates the effect of using fiber architecture of glass fibers in the middle layer on tensile strength and water absorption properties of HLC panel.

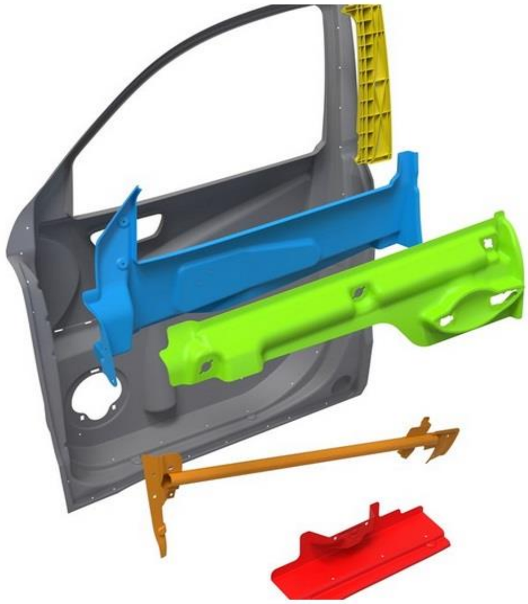

Figure 1. Panel inside door using hybrid glass and carbon fiber (https://www.compositesworld.com/articles/thermoplastic-door-a-first-for-automotive-composites)

Figure 2. Foot Prosthesis from glass fiber (http://www.kakipalsuunik.com)

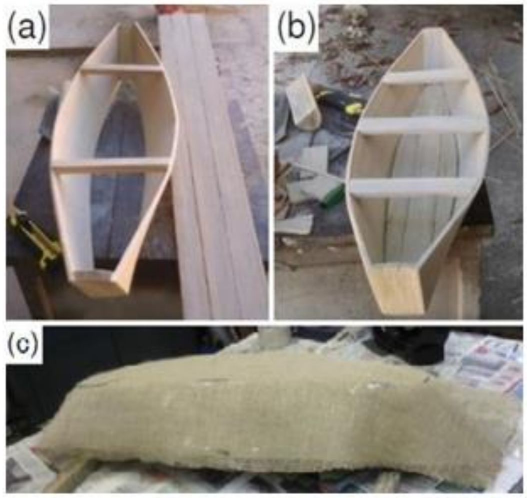

Figure 3. Prototype manufacturing of boat hull (a) molding the boat, (b) finishing boat hull, (c) laminated the boat with jute treated fiber (Carvalho, et al. 2017)

MATERIALS AND METHOD

Ramie fiber was obtained from BALITTAS (Balai Penelitian Tanaman Pemanis dan Serat), Malang, Indonesia. Sodium hydroxide (NaOH), with a purity of 98% obtained from CV. Brata Chemical, Yogyakarta. The unsaturated polyester resin (UPR) BQTN 157-EX and hardener MEKPO (*Methyl Ethyl Ketone Peroxide*).

The ramie fibers are treated with an alkalization 5 wt.% NaOH solution for 2 hours at room temperature. It aims to remove the lignin and hemicellulose in the fiber to obtain good roughness on the surfaces of fiber (Gassan & Bledzki, 1999; Yudhanto & Wisnujati, 2016).

Several kinds of glass fiber are used, namely randomly chopped strand mats glass fibers CSM 200 (RG), woven roving mat WRM 200 (WR), and unidirectional fiber (UG), as shown in Figure 5. The glass fibers obtained from PT. Justus Kimia Raya-Semarang, Indonesia.

Stacking Sequence of HLC

The HLC consists of three layers (woven ramie-glass fiber orientation-woven ramie). The stacking sequences are shown on Figure 4; WR-RG-WR; WR-WG-WR; WR-UG-WR; and WR-URG-WG. The volume fraction fiber (V_f) is 25%. The glass fibers used are randomly chopped strand mat, woven, and unidirectional fibers (Figure 5). The HLC with three layers which used for this research will be applied on automotive body panel product. Figure 6 shows that fibers weaving machine on craft center in Gamplong Village, Bantul, Yogyakarta, Indonesia. The ramie fibers are arranged horizontally and vertically on the loom to produce the woven mat with a dimension of 1 m^2. The molding used steel plate with dimension 400 x 400 mm, in length and width, and it press on two-bar pressure.

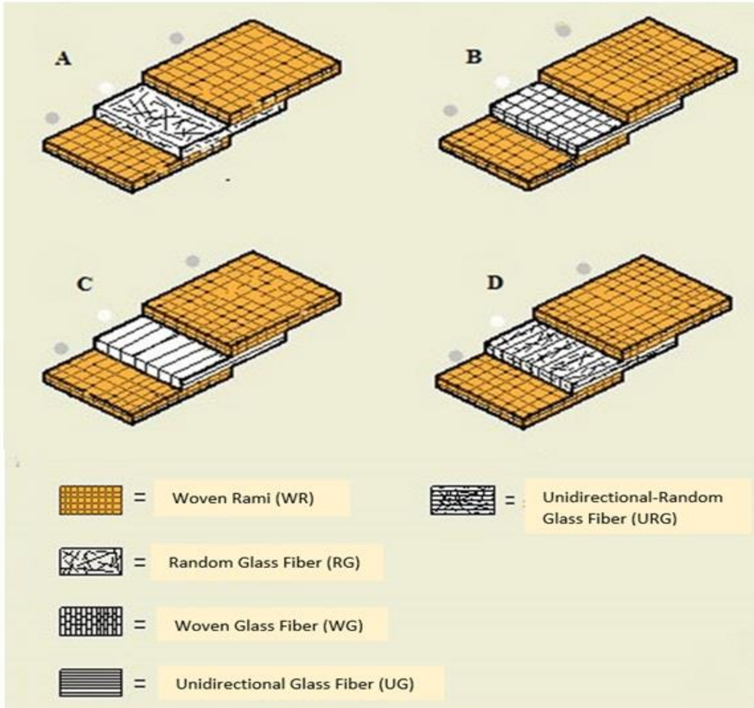

Figure 4. Scheme of stacking sequence of three plies of HLC: (a) WR-RG-WR, (B) WR-WG-WR, (C) WR-UG-WR, (D) WR-URG-WR

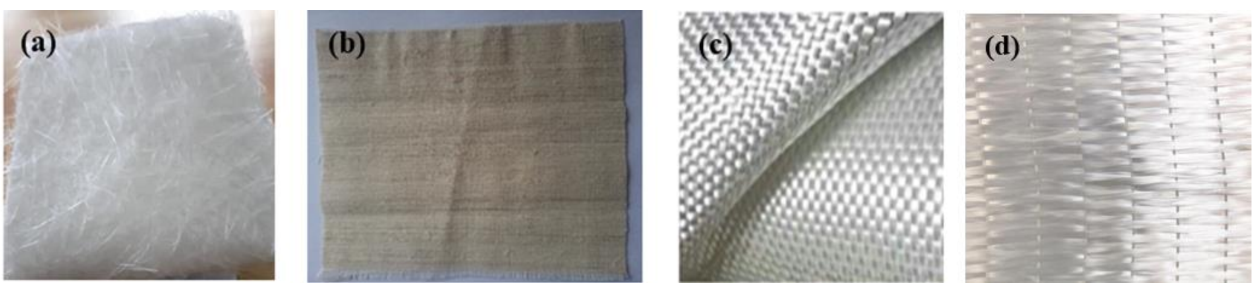

Figure 5. The materials of HLC; (a) Randomly chopped strand mat glass fiber (RG), (b) Woven ramie (WR), (c) Woven Glass fiber (WG), (d) Unidirectional Glass fiber (UG)

Figure 6. The traditional of fiber weaving machine

Tensile Test

The HLC sample was tested using a UTM (universal testing machine) Servopulser. Five specimens for each variation have been used for the tensile test. The test specimens refer to the ASTM D638 test standard with dimensions that can be seen in Figure 7. The tensile speed of the crosshead is 2 mm/minute. The total volume fraction of fibers in the HLC can be calculated by equation 1,

$$V_f = \frac{\left(\frac{W_r}{\rho_r}\right) + \left(\frac{W_g}{\rho_g}\right)}{\left(\frac{W_c}{\rho_c}\right)} \qquad (1)$$

Where V_f is volume fraction of fibers (%), ρ_r is density of ramie fiber, ρ_g is density of glass fiber, ρ_c is density of composite. The density of ramie and glass fibers are 1.6 g/cm^3 (ρ_r) and 2,6 g/cm^3 (ρ_g), respectively. W_c is weight of composite panel, W_r is weight of ramie fiber, W_g is weight of glass fiber.

Figure 7 shows the ASTM (American Standard Testing and Material) D638 is specific for testing the tensile strength of plastics and other resin materials.

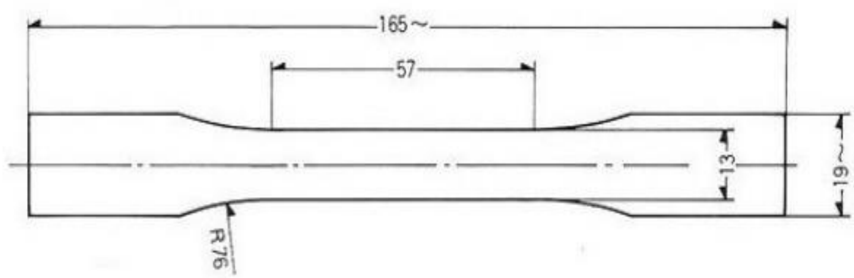

Figure 7. Tensile test specimen standard of ASTM D638

Density of HLC

The HLC density test was carried out using a digital weighing device. The dimension of density test is 20 x 20 mm in length and width. The specimens were dried in an oven at a temperature of 105°C for one hour, after that the specimen was put in a desiccator for 24 hours.

$$e = \frac{mass}{volume}\ ; (\text{g/cm}^3) \qquad (2)$$

Water Absorption

Prepare the composite specimens by 20 x 20 mm, in length and width, and then it was dried in an oven at 110°C for 1 hour, and then the weight was record as dry weight (W_{dry}). Composite samples were then immersed in distilled water for 24 hours and recorded as (W_{wet}). The percentage of water absorption has been calculated by equation 3,

$$w_{absorbtion} = \frac{w_{wet} - w_{dry}}{w_{wet}}\ ; (\%) \qquad (3)$$

$W_{absorption}$ is the ratio of the increase in weight value due to the sample being immersed in the water for 24 hours with the sample's weight after drying in an oven and desiccator.

RESULTS AND DISCUSSION

Alkali Treated of Ramie Fiber Mat

The crystallinity index of raw ramie fiber of 61.8% caused the cellulose to be covered by lignin and hemicellulose (amorphous content), as shown in Figure 8 (a). The alkalization on the ramie fiber increases crystallinity index to 66.3% by XRD (x-ray diffraction) test (Jamasri & Yudhanto, 2022). It indicates the lignin and hemicellulose removal from surfaces of the fiber. The cellulose microfibril could be seen in Figure 8 (b).

Alkaline treatment with high concentrations more than 5 wt.% NaOH with a longer soaking time can damage the cellulose crystalline structure. The damaged cellulose crystal structure affected decreasing the tensile strength properties of the fiber. The selection of the concentration of 5 wt.% NaOH for 2 hours ramie fiber immersion in this study is based on the previous research by Jamasri and Yudhanto (2022), the effect of alkaline immersion on the crystallinity index and tensile strength of ramie fibers. The parameter alkaline with 5 wt.% NaOH for 2 hours was affected to good surface roughness of the fibers.

The alkaline treatment of the ramie fiber can increase the mechanical bond between the fiber and the polyester matrix. Ramie fiber immersed in 2 wt.% sodium hydroxide (NaOH) for two hours at a temperature of 90°C, It has been investigated by Fatkhurrohman et al. (2020). The results obtained the crystallinity index of ramie fiber increases from 80.7% to 85.2%. It indicates that the cellulose content of fiber increases caused by removing the hemicellulose and lignin composition.

Cai et al. (2016) investigated the physical properties of the abaca fiber obtained from the philippine. It was immersed in an aqueous NaOH solution with a concentration of 5 wt.% for 2 hours at room temperature. As a result, the crystallinity index of abaca fiber increases from 52% to 58%, and it causes the tensile strength raises from 717 MPa to 773 MPa and the modulus of elasticity from 18.6 Gpa to 25.3 GPa.

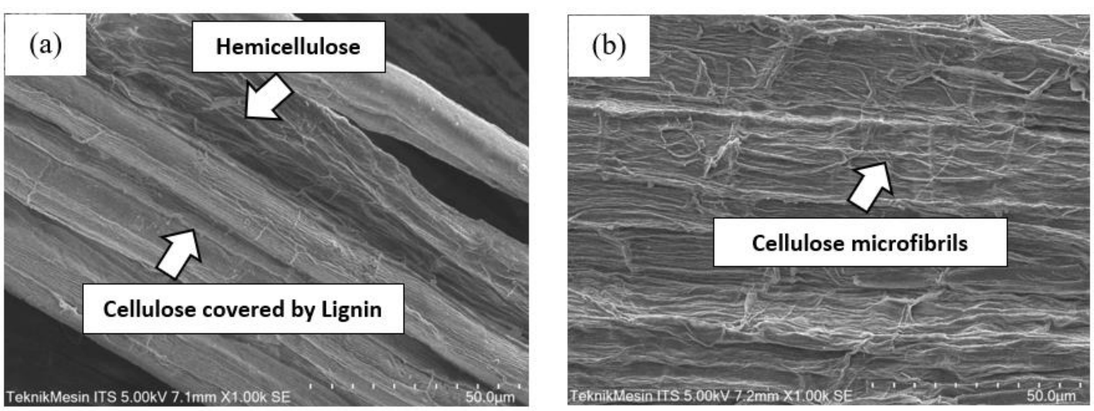

Figure 8. Photo SEM of (a) raw ramie fibers; (b) after alkalization 5 wt.% NaOH for 2 hours

Tensile Properties of HLC

HLC with the WR-UG-WR variation obtains a highest tensile strength and modulus of elasticity by 150 MPa and 24.1 GPa, respectively. This type of HLC has an arrangement of glass fibers in the direction of the tensile force in the middle of the layer, flanked by two layers of woven ramie fibers. The second-best variation is the

WR-WG-WR variation with tensile strength and modulus of elasticity by 105 MPa and 16.8 GPa, respectively. Figure 9 shows the results of all interpretation tensile test of HLC. The variation of the WR-URG-WR and WR-RG-WR have low tensile strength and modulus. It causes the woven roving ramie fibers can't bind perfectly to a non-uniform orientation and randomly arrangement of glass fibers. The resin difficult wetting well in the randomly orientation of glass fibers.

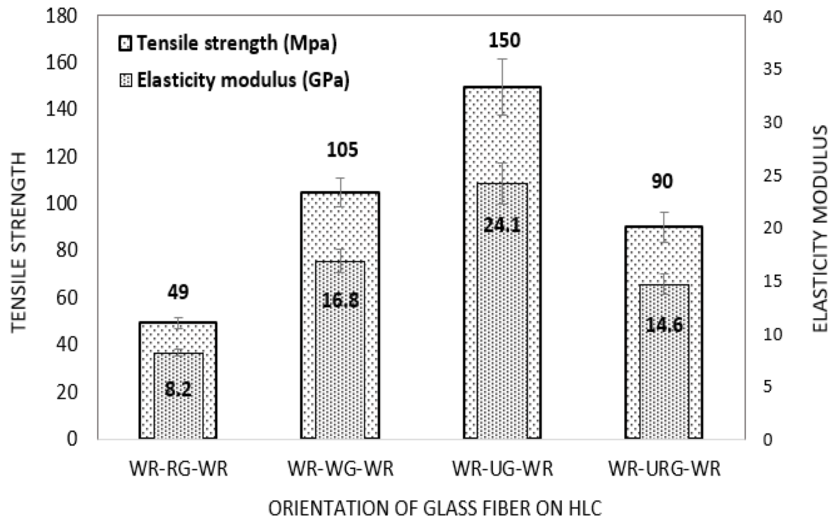

Figure 9. Tensile strength and modulus of elasticity HLC

Previous research on HLC using Agave sisalana fiber and glass fiber has also been conducted by the same researcher, Yudhanto et al (2016). The HLC used three layers of woven fibers. The variations used are variations in different fiber arrangements. The S-FG-S arrangement (S = Sisal and FG = Fiber Glass) has a tensile strength value of 68 MPa and an modulus of elasticity by 6.74 GPa. It is lower than those of the WR-WG-WR (WR = Woven Ramie, WG = Woven Glass fibers) variation in this study with a tensile strength of 105 MPa and an modulus of elasticity by 16.8 GPa.

A similar study by Hossain et al. (2013) used four layers of hemp fiber with an epoxy matrix prepared using the vacuum infusion method. The variations were fiber architecture of the jute fibers to the tensile stress [0/0/0/0], [0/-45/+45/0], and [0/90/90/0]. The best result for tensile strength is variation [0/0/0/0], which is in the same direction by 112 MPa and the lowest by [0/90/90/0] at 42 MPa.

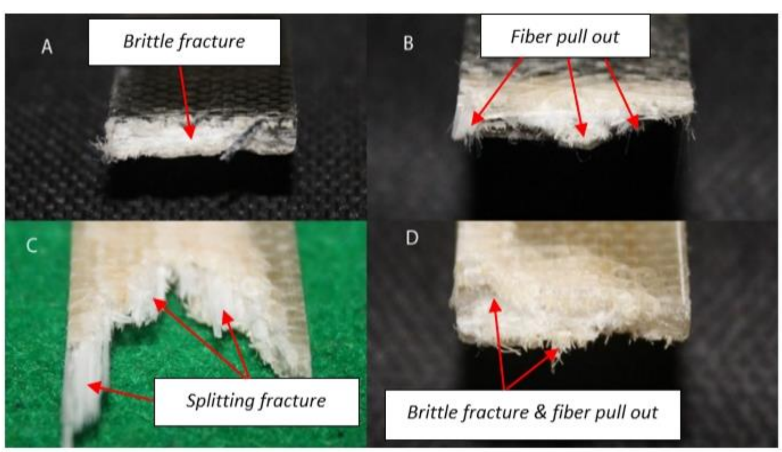

Figure 10. Fracture of (a) WR-RG-WR, (b) WR-WG-WR, (c) WR-UG-WR, (d) WR-URG-WR

Another research on hybrid synthetic fiber composites using an arrangement of five layers of woven glass fiber and carbon was carried out by Shomad et al. (2020). The best results obtained were synthetic HLC in the stacking sequence: CGGGC (C=Carbon & G=Glass fibers) with a tensile strength of 219 MPa and a modulus of elasticity of 6.8 GPa. Some of these studies indicate that the structure of the stacking sequence and the fibers' direction influence tensile strength and elastic modulus.

Figure 10 shows the fractured specimen after the tensile test. Figure 10a shows brittle fracture causes the randomly chopped strand mat to have irregular fibers form. Figure 10b shows the fiber pull out, causing the woven glass fibers to have two orientation directions. Figure 10c shows the splitting fracture, which occurs when the value of stress exceeds the maximum value and then triggers a radial fracture. Finally, fig 10d shows brittle and fiber pull out, which causes the delamination inter-layer in the glass fibers.

Density and Water Absorbtion Analysis

Figure 12 shows the density of HLC related to the results of the water absorption test. The high-density value causes water difficulty entering the HLC panel. High density indicates the resin well covers the glass and ramie fibers.

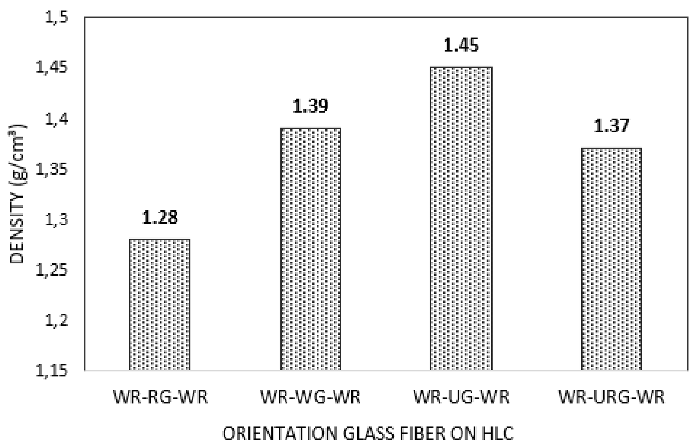

Figure 12. Water absorption of HLC

Figure 13 shows the wide range of water absorption values of the HLC from 3.31 to 11.5%. The high composition of HLC in ramie fiber by 75% (natural) and then the low composition in glass fiber by 25% (synthetic). Therefore, it causes a vast range percentage of water absorption value. On the other hand, the lowest water absorption on the WR-UG-WR, by 3.31%, caused the polyester resin to wet glass fibers excellently, as seen in Figure 14.

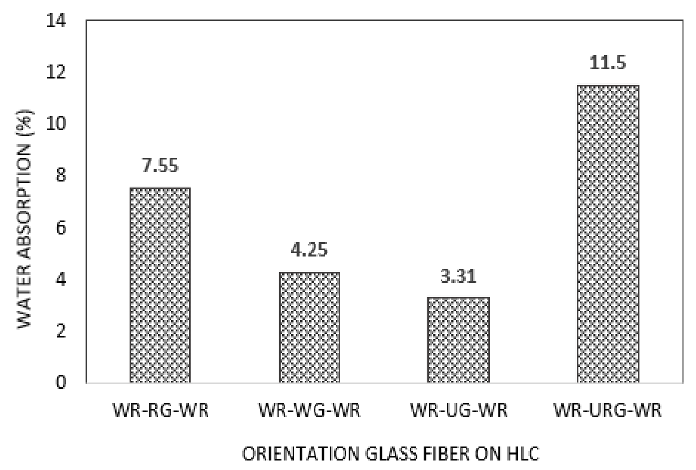

Figure 13. Water absorption of HLC

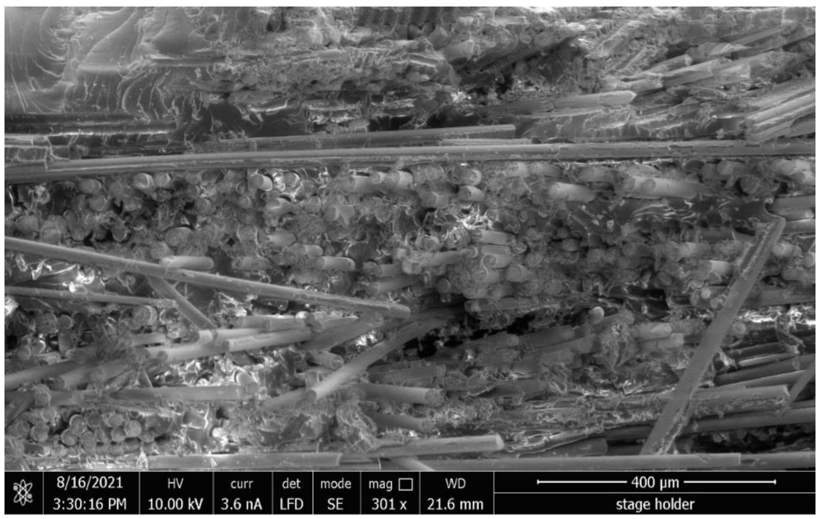

Figure 14. Photo SEM the polyester resin bonded well with the glass fibers

CONCLUSION

HLC panels can be applied to automotive composite products using combined the treated ramie and glass fibers. The treated ramie fibers by 5 wt.%, for two hours could be increased the mechanical properties due to the loss of amorphous materials. The glass fiber architecture in the middle layer impacted the HLC mechanical properties, which is recommended to be applied on the automotive body panel. The excellent tensile strength and modulus of elasticity in the stacking sequence of WR-UG-WR by 150 MPa and 24.1 Gpa, respectively. The water absorption properties is 3.31%. The photo SEM shows unidirectional glass fibers have excellent inter-mechanical bonded with a polyester matrix.

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