JURNAL rekayasa mesin
ISSN 2477-6041 articles 15, pp. 909 – 925, 2023
Vol. 14. No.3

PHYSICAL-MECHANICAL PROPERTIES OF PINEAPPLE LEAF FIBRE REINFORCED IN UNSATURATED POLYESTER RESIN FILLED WITH CALCIUM CARBONATE

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Abstract

Using natural fibres is often recommended as polymer composite materials owing to their potential to reduce the pollution of synthetic material waste. This study aimed to obtain the physical properties of unsaturated polyester resin matrix composite containing calcium carbonate fillers of 15 and 30 parts per hundred weights of the resin and natural pineapple leaf fibre of the amount 20% and 30% of the composite weight. The composite samples were three millimetres thick, with the pineapple leaf fibres arranged in one longitudinal direction. Some parameters observed included density, water absorption, response to fire, hardness, tensile strength, modulus of elasticity, and impact strength. The results showed that adding calcium carbonate filler into the matrix increased the density, water absorption, hardness, and modulus of elasticity of the composite. However, it reduced the flame propagation rate, tensile strength, and impact strength. Also, the use of pineapple leaf fibre contributed to increased water absorption, rate of flame propagation, tensile strength, modulus of elasticity, and impact strength of the composite, but it reduced the density and hardness. As these samples use economical materials, they are likely valuable for building materials that do not require high mechanical properties, especially guttering materials.

Keywords: *Characterization, Calcium Carbonate, Pineapple Leaf Fibre, Unsaturated Polyester Resin.*

1. INTRODUCTION

Polymer matrix composites (PMC) are commercially made from synthetic materials. Gutters made of PMC are commonly used in Indonesia. The material used is a matrix of unsaturated polyester resin filled with calcium carbonate filler and reinforcement using E-glasses chopped strand mat and woven roving with usually three millimeters composite thickness [1]. However, when these synthetic materials are not used, or their life cycle has run out, they are difficult to decompose naturally, which will likely pollute the envi-ronment if not controlled [2,3,4].

One alternative that can help prevent environmental pollution is using natural materials, namely pineapple leaves. With numerous pineapple plantations in Indonesia, these pineapple leaves, though often considered wastage, can serve as potential raw materials to replace

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Received on : 2022-12-21
Revised on : 2023-09-20
Accepted on : 2023-10-11

DOI: 10.21776/jrm.v14i3.1451

synthetic materials. The utilisation of pineapple leaf fibre as the reinforcing fibre in PMC can provide high added value [5,6].

Natural fibres are more advantageous in that the latter is abundant, cheap, renewable, and easily degradable in the soil when not used. Nevertheless, natural fibres do have some drawbacks. One drawback is the presence of wax/cellulose, which can reduce the adherability to the matrix [7,9]. Another property is that natural fibres are hydrophilic, quickly absorbing water and reducing the interfacial bond between the fibre and the matrix. Also, the tensile strength of natural fibres is not as high as that of synthetic fibres. That said, through proper engineering, natural fibres like pineapple leaf fibre can still be used as PMC reinforcement [10,11].

Daud et al. reported that pineapple leaf fibre filled with polypropylene as a matrix with a fibre weight fraction of 40 percent could produce superior composite material properties [12]. Gaba et al. made an alkaline treatment of pineapple leaf fibre with a 6% NaOH solution by weight in water. The pineapple leaf fibre experienced suitable lignin and hemicellulose removal, increasing its tensile strength from 1090 MPa to 1620 MPa [13]. Zeleke et al. have made PMC from unsaturated polyester resin (UPR) reinforced with pineapple leaf fibre with a weight ratio of 70% and 30%. It was observed that the tensile strength, compressive strengths, and water absorption were 43.13 MPa, 39.78 MPa, and 2.52%, respectively [14]. Another study by Reddy et al., through a finite element analysis, demonstrated the success of using pineapple leaf fibre with epoxy resin and graphite filler as PMC materials [15]. Hestiawan et al. Investigate the effect of alkali treatment on the physical and mechanical properties of lantung fibers. with an alkali treatment process using 4% and 6% natrium hydroxide (NaOH) solutions and immersion time of 1 and 2 hours, at room temperature. The results of XRD and fiber tensile test showed that alkali treated lantung fibers were effective in increasing the crystallization index (CI) value and fiber tensile strength. The highest CI values and fiber tensile strength were obtained at alkali treatment of 4% NaOH for 2 hours, respectively 85.42% and 228.5 MPa [16].

In addition to pineapple leaf fibre, the economy of the PMC materials can be enhanced through UPR and calcium carbonate (CC) filler with bamboo fibre reinforcement, as revealed by Sugiman et al. and Rahman et al. [17,18]. In their studies, two kinds of material composition were used: immature bamboo fibre and old bamboo fibre with an arrangement of 1% wt., 3% wt., and 5% wt. of Nano Calcium Carbonate (NCC). The findings showed that the second component of the old bamboo composite exhibited better tensile and flexural strength than the first composition of the immature bamboo. composite exhibited better tensile and flexural strength than the first composition of the immature bamboo.

Given the economic and environmentally friendly nature of these PMC materials, their utility for building materials that do not require high physical properties, for example, a guttering material, is worth further investigation. UPR can serve as a suitable constituent material for general applications and is a relatively cheap resin. In contrast, pineapple leaf fibre can function as an ecologically friendly, abundant, and inexpensive material for PMC reinforcement. Furthermore, the mixture of CC filler into the UPR will increase the economy of the PMC materials. However, the information on the physical properties of the PMC materials composed of UPR, CC filler, and reinforcing fibre from pineapple leaf fibre with a thickness of three millimetres is relatively scarce. This study aimed to characterise the physical and mechanical properties of three millimetres thickness PMC material using 15 and 30 parts per hundred weight of the resin (PHR) with CC fillers as a matrix, as well as reinforcement from pineapple leaf fibre of 20% and 30 % wt. The physical-mechanical properties were based on the ASTM D3841 standard [19], with several parameters observed, including density, maximum water absorption, response to fire, hardness, tensile strength, modulus of elasticity, and impact strength. The fracture morphology of the sample from the

impact test was observed with a scanning electron microscope (SEM). Eventually, the insights into the physical-mechanical properties of the three millimetres thickness PMC materials in this study can provide some consideration for their application as a substitute for conventional materials for guttering and other building materials. The physical-mechanical properties of GFRP material required for the construction of gutters are a maximum specific density of 2.5, a minimum Barcol hardness of 40, a minimum impact strength of 40 kJ/m2, a minimum tensile strength of 50 MPa, and a minimum modulus of elasticity of 2000 MPa [1]. This study aimed to determine the physical and mechanical properties of the unsaturated polyester resin matrix composite material, which was given filler CaCO3 15 and 30 parts per hundred by weight of resin with pineapple leaf fiber reinforcement of 20% and 30% of the weight of the composite. The motivation for this research is the possibility of this material being used for making gutters, fishing boat bodies, anti-riot shields for security forces, and other applications.

2. MATERIAL AND METHOD

2.1. Constituent Materials

The constituent materials for making the PMC material samples consisted of resin, catalyst, filler, and natural fibre from pineapple leaves. The resin was UPR type SHCP 2668W-NC-HLU (PT SHCP Indonesia, Indonesia). The catalyst for the curing process was one per cent of the resin volume using methyl ethyl ketone peroxide (MEKP) MEPOXE S (PT Kawaguchi Kimia Raya, Indonesia). The CC fillers used the Jia Dah Chemical Industrial Co. brand. from Taiwan. Finally, the dried pineapple leaf fibres were extracted by farmers from the Cikadu-Cijambe-Subang village, West Java, Indonesia. The density of these constituent materials was 1100 kg/m^3, 2600 kg/m^3, and 1070 kg/m^3 for UPR, CC, and pineapple leaf fibre, respectively. Six samples of PMC material were obtained, with each three millimetres thick. The details of these six samples are shown in Table 1.

Tabel 1. Material samples of pineapple leaf fibre PMC

SAMPLES	MATRIX (WF)		PMC (WF)		THICKNESS
	UPR	CC	FIBRE	MATRIX	
CC00F20	100	0	20	80	3 mm
CC00F30	100	0	30	70	3 mm
CC15F20	100	15	20	80	3 mm
CC15F30	100	15	30	70	3 mm
CC30F20	100	30	20	80	3 mm
CC30F30	100	0	30	70	3 mm

2.2. Preparation of PMC Composite Samples

We carry out the detailed steps of the research stages as shown in Fig. 1. The preparation began with washing the dried pineapple leaf fibres using water to remove any impurities aside from the fibres. The pineapple leaf fibres were then soaked in a solution of 6% NaOH and purified water at room temperature for one hour. These fibres were soaked in pure water for 30 minutes to be rinsed and subsequently dried at room temperature for 48 hours. The

samples with a size of 300 mm × 300 mm × 3 mm, whose fibre direction was arranged in the same order, were prepared with the hand lay-up technique, as shown in Fig. 2. The resin and filler were mixed using a 3000-rpm rotary stirrer for five minutes, and the mixture was then left to stand for 10 minutes, during which the air bubbles would naturally disappear. The PMC matrix was obtained by mixing a 1% volume of catalyst with a mixture of resin and filler using a wooden stick stirrer. The pineapple leaf fibres in the mould, whose direction was in the same order, were then moistened with a matrix and rotated with a steel roller to minimise voids. The last step was to cut the specimens from each sample into a specific size.

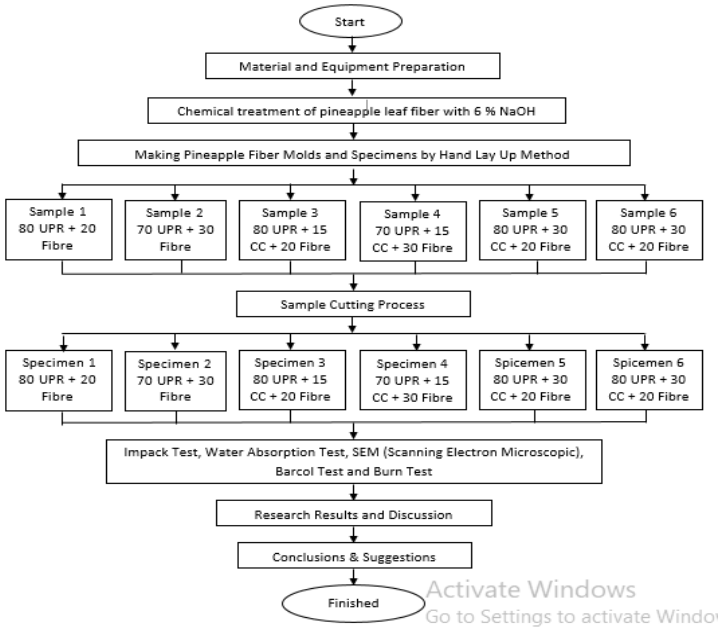

Fig. 1. Flow chart research

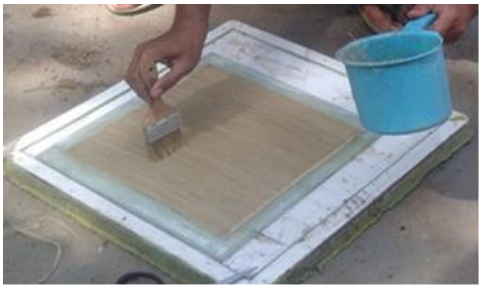

Fig. 2. Making samples of pineapple leaf fibre PMC with hand lay-up.

2.3. Physical Properties

The physical properties observed in this study were density, maximum water absorption, response to fire, hardness, tensile strength, modulus of elasticity and impact strength.

The density of the material samples was measured using the ASTM D792 [20] standard. The measurement results are the average density measurements of five specimens, whose size was 30 mm × 30 mm × 3 mm as shown in Fig. 3. According to the ASTM D792 standard, the density is measured by weighing the specimen in the open air and immersing it in pure water at 23 OC. Eq. (1) and (2) calculate specific gravity and density.

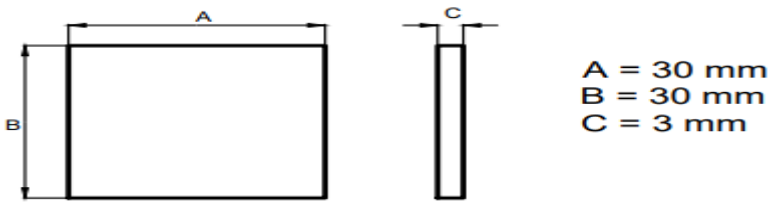

Fig.3. Specimen of density test

$$\text{Specific grafity} = \frac{a}{[(a+w)-b]} \quad (1)$$

$$\text{Density (kg/m}^3\text{)} = \text{specific gravity} \times 997.6 \quad (2)$$

In Eq (1), a is the actual mass of the specimen, without sinker and wire, in the air, b is the apparent mass of specimen (and of sinker and wire, if used) completely immersed and that of the wire partially immersed in liquid, and w is the apparent mass of the totally immersed sinker (if used) and that of the partially immersed wire.

The water absorption of all five specimens of each material was assessed based on the ASTM D570 standard [21]. The measurement results were the average of the measurement results of the five specimens, whose size was 76.2 mm × 25.4 mm × 3 mm as shown in Fig. 4. First, all samples were dried in an oven at a temperature of 60 OC for one hour, after which the mass was weighed. Next, all specimens were immersed in pure water at room temperature for 45 days. Every 24 hours for the first two weeks, the mass of all specimens was recorded, which was the additional mass of water absorbed by the composite.

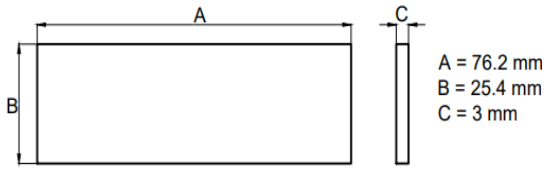

Fig.4. Specimen of water absorption test

Furthermore, the recording mass of all specimens was done once a week. The graph of water absorption as a function of time for each specimen uses Eq. (3). In this case, Mt refers to the percentage of additional weight as a function of time, Ww the wet weights and Wd the dry materials' weights.

$$Mt(\%) = \frac{Ww - Wd}{Wd} x100\% \quad (3)$$

The response to fire of all composite samples was assessed using the ASTM D635 [22] standard. Flames of methane gas of 37 MJ/m^3 hit the free end for 30 seconds on the test specimen with one end clamped. The dimension of the specimens was 125 mm × 13 mm × 3 mm and was horizontal with an inclination of 45 degrees. The flame propagation rate was based on the average of five test specimens from each sample. The test carried out is a horizontal burning test. The first test is to get the flame time on the specimen placed horizontally on a clamp. The specimen starts burning at the end side in a tilted position at an angle of 45 degrees to the specimen; after the flame appears, the burner is turned off, and the time needed to ignite the flame on the specimen for 30 seconds at intervals of 0 to 25 mm. The value of the propagation rate is obtained when the first time the flame is ignited at a distance of 25 mm to 100 mm. The Rate of Burning value is obtained from a distance of 75

mm. The rate of fire propagation is based on the average of 5 test objects for each sample. Specimens are categorized in the HB class.

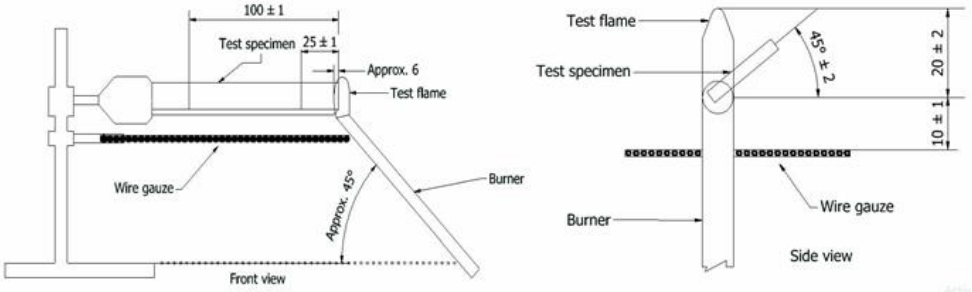

Fig. 5. Testing the flame propagation rate in the horizontal direction [21].

The hardness of the material was measured using a Barcol impressor according to the ASTM D2583 [23] standard. According to the Barcol scale, hardness values range from 0 to 100, and perfectly polymerised thermoset resins typically have Barcol hardness values on a scale of 35 to 45. The hardness measurements of each sample were carried out at twenty different points. The ten-best data, namely data from ten points whose values are close together, were selected to obtain the average value.

The tensile properties were assessed using a specimen of type IV measuring 115 mm × 19 mm × 3 mm according to the ASTM D638 [24] standard. Fig. 6 illustrates the size of the tensile test specimen. Tensile testing will produce a graph of the stress-strain relationship. A straight or elastic curve, according to the Hooke's law, will create a modulus of elasticity in the elastic or linear region. Eq. (4) is the formula to calculate the modulus of elasticity (E, MPa), which is the difference in stress (ΔO̊, MPa) divided by the difference in strain (ΔƐ).

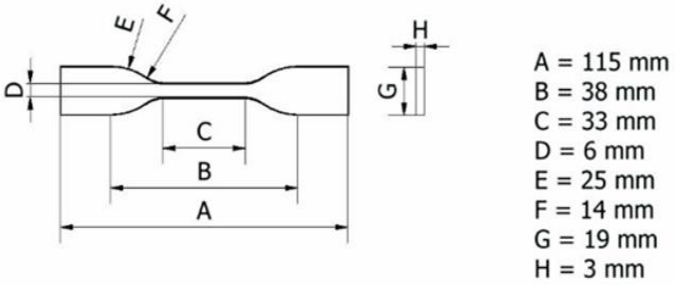

Fig. 6. Type IV tensile test specimen according to the ASTM D638 standard [24].

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} \tag{4}$$

Finally, the impact testing of all samples was intended to determine the toughness of the five specimens measuring 127 mm × 10 mm × 3 mm. The final result of the impact strength was the average of the five-test data. As per the ASTM D6110 [25] standard, the Charpy method was selected, in which the specimen does not need to be indented. The test method used in ASTM D6110 has a pendulum-type hammer test tool that loads the specimen horizontally with the notch facing the direction of the pendulum speed. The specimen is placed in a secure position at each end. The pendulum is pulled up and then released. The hammer hit the notch and broke the specimen in half. Due to the impact, the pendulum loses energy. The lost energy is the energy required to break the specimen.

2.4. Morphology of Composite Microstructure

The observation of tensile test specimen fractures using a scanning electron microscope (SEM) revealed the morphology of the material's microstructure. This morphology supports the explanations related to the physical properties of each composite material sample. The fracture surface of the tensile test specimen was first coated with a thin layer of gold palladium in a vacuum to allow for conductivity prior to the examination. The observation used an acceleration voltage of 10 kV with a working distance of 10 mm.[11]

3. RESULTS AND DISCCUSSIONS

Table 2 and Figs. 7 to 13 present the measurement results of density, water absorp-tion, flame propagation/burning rates, hardness, tensile strength, modulus of elasticity, and impact strength.

Table 2. Physical properties of the pineapple leaf fibre PMC samples.

Samples	Specific Gravity	Density (kg/m^3)	Maximum Moisture Content (%)	Rate of Burning (mm/min)	Barcol Hardness (1–100)	Tensile Strength (MPa)	Modulus of Elasticity (MPa)	Impact Strength (kJ/m^2)
C00F20	1.009 ± 0.01	1007 ± 10	2.50 ±0.55	30.50 ± 0.32	34.1 ± 3.9	73 ± 7.07	2182.7 ± 180.6	61.61 ± 7.10
C00F30	0.997 ± 0.012	995 ± 12	3.05 ±0.46	36.58 ± 0.95	32.2 ± 2.29	75.5 ± 10.43	2383.9 ± 213.2	67.33 ± 6.18
C15F20	1.020 ± 0.013	1018 ± 13	2.87 ±0.59	29.49 ± 0.74	38.8 ± 3.08	65.5 ± 3.53	2543.4 ± 149.8	52.99 ± 7.10
C15F30	1.015 ± 0.035	1013 ± 35	3.24 ±0.47	30.30 ± 0.98	34.9 ± 4.67	72.5 ± 4.94	2690.4 ± 192.4	56.46 ± 6.00
C30F20	1.024 ± 0.019	1022 ± 19	3.18 ±0.49	26.30 ± 0.19	49.4 ± 3.43	57.5 ± 0.70	2822.2 ± 90.5	48.17 ± 7.84
C30F30	1.022 ± 0.011	1020 ± 11	3.59 ±0.64	28.15 ± 0.84	41.9 ± 2.42	60 ± 8.48	2958.2 ± 260.7	52.54 ± 5.21

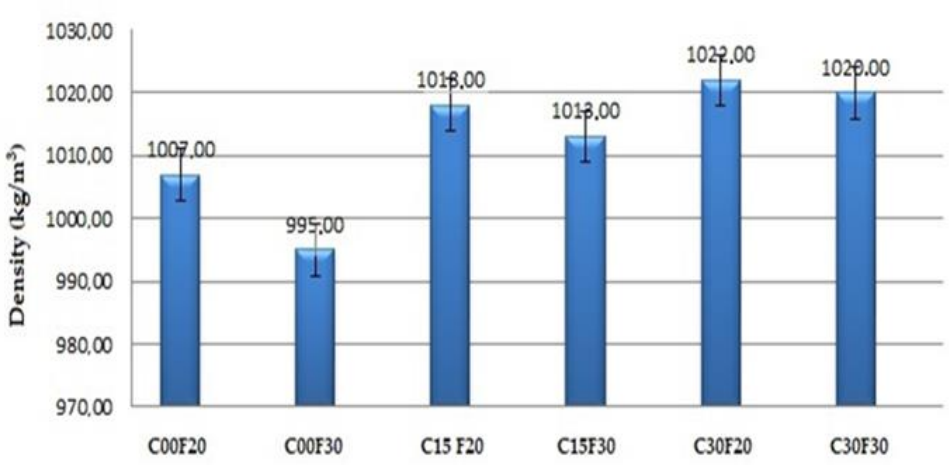

Fig. 7. Density of the composite samples.

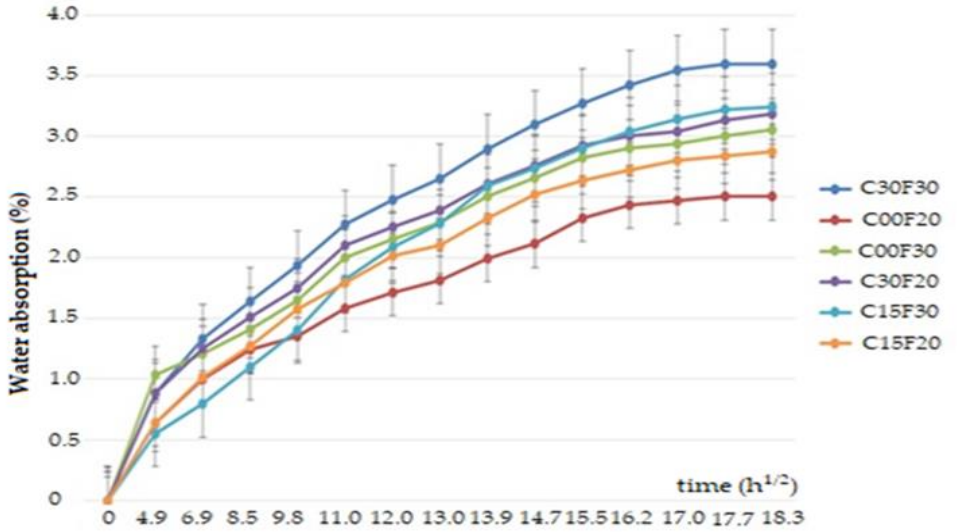

Fig. 8. Water absorption of the composite samples

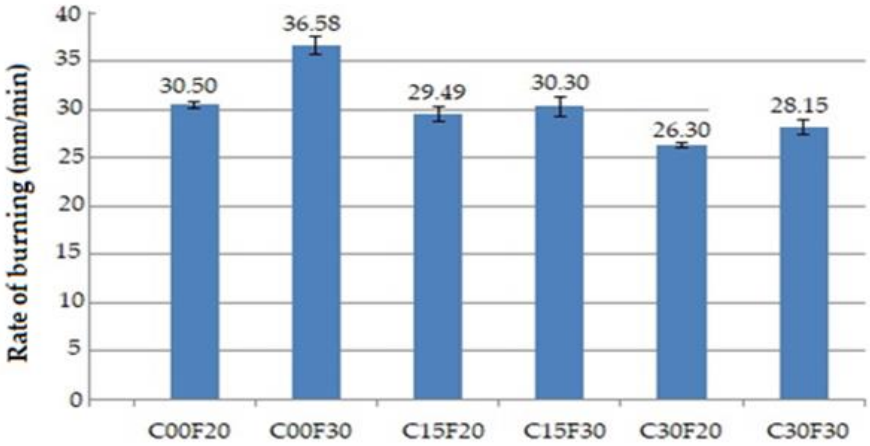

Fig. 9. Flame propagation/burning rate of the composite samples in a horizontal direction.

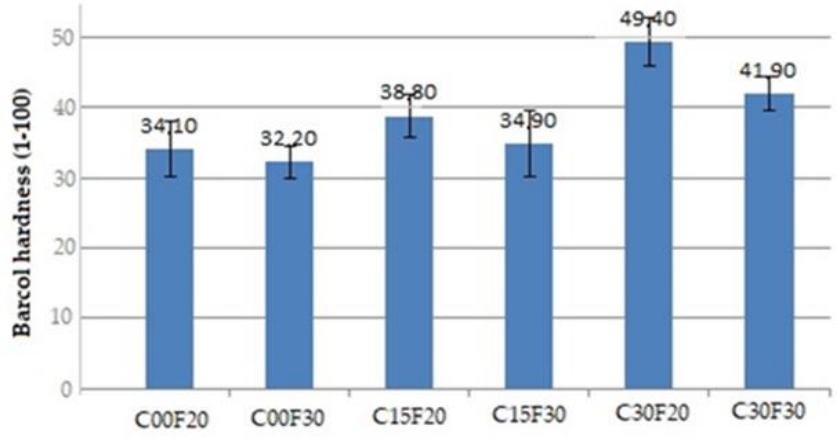

Fig. 10. Barcol hardness of the composite samples

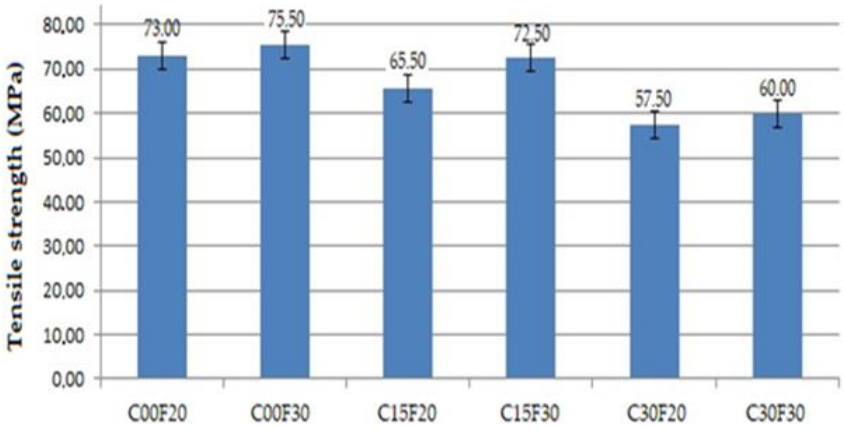

Fig. 11. Tensile strength of the composite samples.

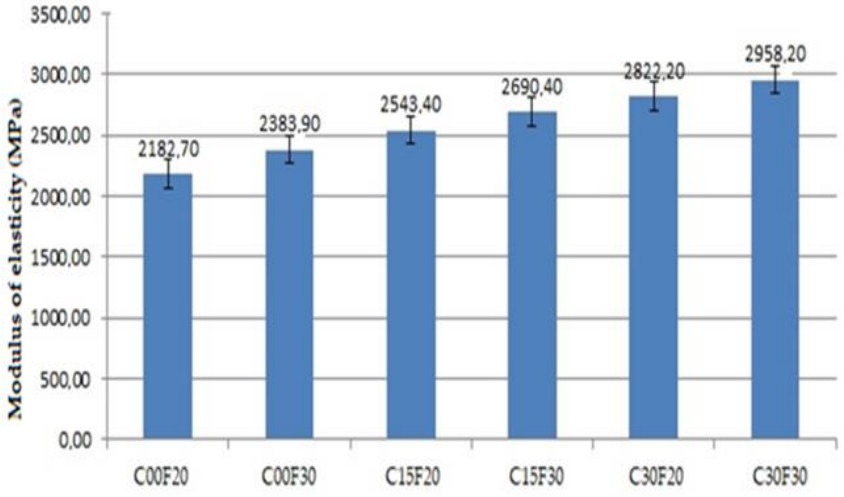

Fig. 12. Modulus of elasticity of the composite samples

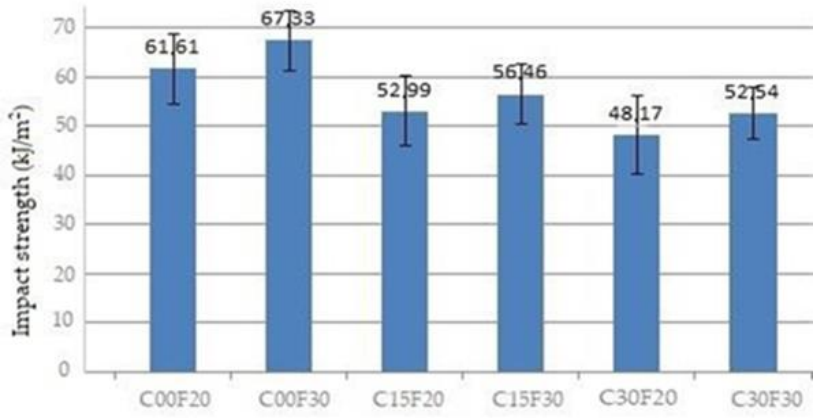

Fig. 13. Impact strength of composite samples.

3.1. Effect of Filler and Fibre on the Density

Fig. 7 depicts the effect of adding CC filler into the UPR and pineapple leaf fibre on the composite's density, as presented in Table 2. It shows that adding CC filler into the UPR increases the density of the matrix. The composite matrix consisted of pure UPR without filler and UPR mixed with 15 and 30 PHR CC fillers. The density of CC is 2600 kg/m^3, while the density of UPR is 1100 kg/m^3. It indicates that the greater the amount of CC filler, the greater the density of the matrix, which means that the density of the composite will likewise increase. It is clearly seen that the density of C30F20 > C15F20 > C00F20 and C30F30 > C15F30 > C00F30. The findings are in line with the results of earlier studies [26].

The density of the pineapple leaf fibre is 1070 kg/m3. The density is lower than that of the three types of matrices. Mixing fibre with matrix will result in a lower density of the composite than that of the matrix. The higher the number of fibres, the less the density of the composite. It is illustrated in Fig. 7, where the density is C00F30 < C00F20, C15F30 < C15F20, and C30F30 < C30F20. These findings conform to those of previous studies [26].

The lowest and highest density of all samples is 995 kg/m^3 and 1022 kg/m^3. The density of all composite samples is even lower than that of each constituent material that makes up the composite. The specific gravity of the constituent materials of the composites - UPR, CC, and Pineapple Leaf Fibre - is 1100 kg/m^3, 2710 kg/m^3, and 1070 kg/m^3, re-spectively. It is due to the voids in the composite, which likely appeared during the hand lay-up process. As evident from the SEM images, the presence of these voids in all composite samples leads to a decrease in the composite's density, meaning that as the composite's volume increases, its mass decreases.

3.2. Effect of Filler and Fibre on the Water Absorption

Fig. 8 shows the effect of the addition of CC filler into the UPR and pineapple leaf fibre on the composite's water absorption rate. The ordinate indicates the percentage of water absorption, while the abscissa indicates the root of time. The curve depicts the relationship between the water absorption rate (Mt) and the square root of time (t1/2) of the samples immersed in water.

In all samples, the water absorption is observed to be linear at first, slow down, and saturate as the time increases; however, each sample exhibits different characteristics of water absorption behaviour. The composite sample with the most CC filler and pineapple leaf fibre, sample C30F30, has the highest water absorption of 3.59%, while the lowest, 2.5%, is found in sample C00F20, a sample with no CC filler and little pineapple leaf fibre

content. Between these two extremes are variations in the number of CC 20 and 30 PHR fillers and the amount of pineapple leaf fibre of 20% and 30% of the composite's weight.

This observation indicates that both CC filler and the natural pineapple leaf fibre are hydrophilic in nature, that is, water-absorbent. These findings are in line with those of previous studies [17,26,28]. It should be noted that the nature of polymer composites that absorb or contain water can influence their mechanical properties. The water that fills the voids in the composite can reduce the bond between the fibres and the matrix, resulting in the decreasing interfacial bonding between the fibres and the matrix. This is why the mechanical properties of the composite can decrease when it contains water [17,26,28].

3.3. Effect of Filler and Fibre on the Flame Propagation

Fig. 9 depicts the effect of adding CC filler into the UPR and pineapple leaf fibre on the composites' flame propagation/burning rate in a horizontal direction as per the ASTM D635 standard.

The samples with the highest and lowest burning rates were C00F30 and C30F20, namely 36.58 mm/min and 26.30 mm/min, respectively. The lower the burning rate, the better the fire-retardant properties of the composite. These data suggest that the addition of pineapple leaves into composites can increase the burning rate, whereas the addition of CC filler can reduce the burning rate. The different effects of the natural fibres and CC fillers are attributed to their respective properties. The pineapple leaf fibre is made up of cellulose, which can be burned or decomposed by fire. More natural fibre content can consequently increase the burning rate. On the other hand, the reinforcing fibre wrapping matrix is composed of a mixture of resin and filler, namely UPR and CC. The amount of resin, which is a flammable hydrocarbon chain, can drop in conjunction with the addition or mixing of CC filler into the UPR. This means that adding CC filler into the UPR can then reduce the burning rate of the composite. This phenomenon is in line with the findings of earlier studies [26].

3.4. Effect of Filler and Fibre on the Barcol Hardness

The effect of adding CC filler into the UPR and pineapple leaf fibre on the composite hardness according to the Barcol scale, as shown in Fig. 10. The hardness value of the composite sample is measured on a scale of 32.2 to 49.4. This data shows that the resin polymerisation process is generally successful, although there are three samples whose hardness number is slightly below 35.

CC filler is harder and stiffer than UPR and pineapple leaf fibre. CC filler can inhibit deformation and micro-cracks in case the composite receives external loads or forces. The higher the number of CC fillers, the harder the composites [26]. On the other hand, the addition of pineapple leaf fibre decreases the composite hardness [4,13]. One reason is that the hardness of the pineapple leaf fibre is lower than that of CC filler and UPR. Another reason is that adding fibre increases the number of voids, which are noticeable in the morphology using SEM, particularly on the fracture cross-section of the tensile test. The emergence of these voids was also due to the agglomeration of the CC filler [28]. It can be implied that the addition of CC filler increases the hardness of the composite, while the addition of pineapple leaf fibre decreases the hardness.

3.5. Effect of Filler and Fibre on the Tensile Strength and Modulus of Elasticity

Figs. 11 and 12 show the effect of the addition of CC filler into the UPR and pineapple leaf fibre on the composite's tensile strength and modulus of elasticity. The highest tensile

strength is found in sample C00F30, a composite with no CC filler and with fibres making up 30% of the weight of the composite. Meanwhile, the lowest tensile strength is in sample C30F20, a composite containing CC 30 PHR filler with a smaller number of fibres, which is 20% of the weight of the composite. This phenomenon indicates that the addition of filler can cause the tensile strength to decrease, while the addition of pineapple leaf fibre can cause the opposite.

Previous studies have shown that adding CC fillers or other types of fillers up to about 7.5% can still increase the composites' tensile strength. The increase is a consequence of how some micro-fillers mix homogeneously with the resin and expand the contact area between the resin-fibre interface and the fibre-filler. In contrast, the amount of filler of more than 7.5 PHR will cause agglomeration and a reduction in the fibre-matrix interface bond, thereby reducing its tensile strength [17,28]. By comparison, increasing the number of fillers up to 25 PHR can cause an increase in the modulus of elasticity because the filler at this amount still functions to withstand composite deformation due to external loads, whereas the amount of filler that exceeds 25 PHR can result in a decrease in the modulus of elasticity [29,30].

3.6. Effect of Filler and Fibre on the Impact Strength

The effect of the addition of CC filler into the UPR and pineapple leaf fibre on the composite's impact strength is shown in Fig. 13. The composites that do not contain filler but have a lot of fibre, namely C00F30, exhibit the highest impact strength, while the lowest is found in the one with the highest filler content with a low fibre content, namely C30F20. The results indicate that adding 15 PHR and 30 PHR CC fillers into the UPR can reduce the impact strength, which is attributed to the tendency of the fillers in the matrix to agglomerate, reducing the matrix's ability to adhere to the fibre [30]. In other words, adding more filler will make the tendency of the fillers to clump more likely. To minimise the agglomeration, CC fillers can be distributed more homogenously, which is dependent on the quality of the mixture of CC fillers and UPR resin. The agglomeration of this filler is shown in Fig. 14, which depicts the morphology of the fracture of the samples from the tensile test.

Adding pineapple leaf fibre up to 20% and 30% of the weight of the composite can increase the impact strength. The interfacial bond between the pineapple leaf fibres and the matrix either UPR or a mixture of UPR and CC filler can transmit the external force received by the composite through the matrix to the fibres. The better the interfacial bond between the fibre and the matrix and the greater the number of fibres, the higher its ability to absorb the impact energy.

3.7. Scanning Electron Microscopy

Fig. 14 ilustrated the SEM micrographs of the fracture of the samples from the ten-sile test: (a) C00F20, (b) C00F30, (c) C15F20, (d) C15F30, (e) C30F20, and (f) C30F30. The Figure shows that all samples contain voids, which in turn contribute to lowering the physical properties of the composite. In images (c) to (f), which show the CC filler, it is ev-ident that CC filler agglomeration is more common in images (e) and (f). The voids and filler agglomeration in the composite both affect the previously described properties, such as density, water absorption, flame propagation, hardness, tensile, and impact.

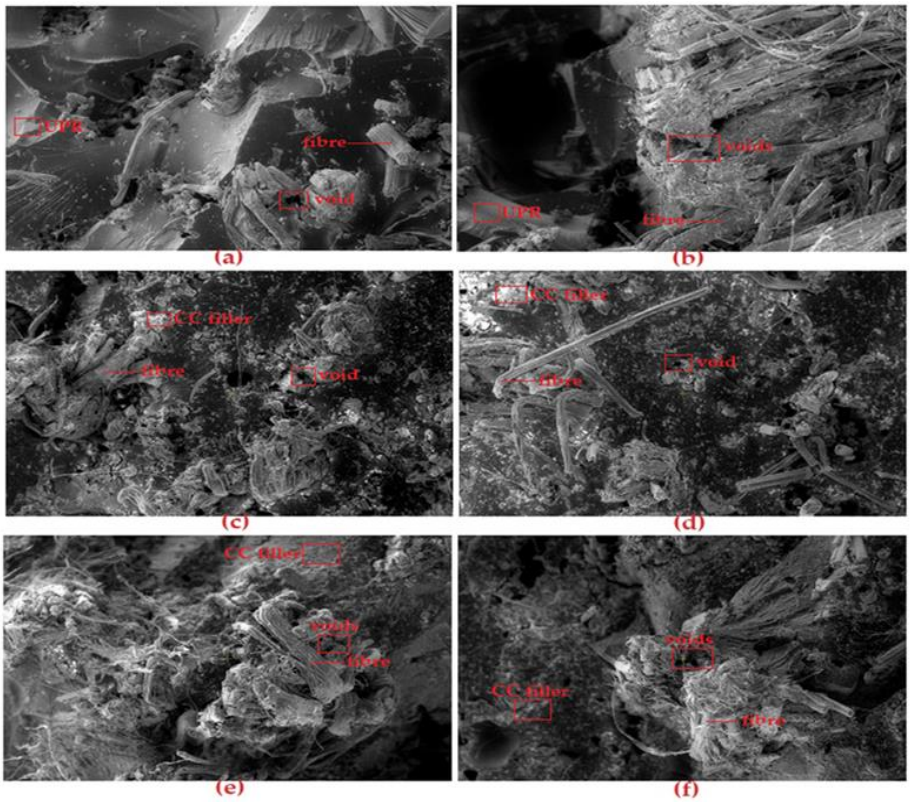

Fig. 14. SEM micrographs of tensile fracture surfaces: (a) C00F20, (b) C00F30, (c) C15F20, (d) C15F30, (e) C30F20, (f) C30F30

3.8. Overall Analysis

The physical-mechanical properties of all samples have been shown in Table 2 and Figs. 7 to 13. The physical properties in Table 2 are specific density, maximum moisture content, and rate of burning in a horizontal direction. All samples produced a specific density around number 1, far below the number 2.5 required as a guttering material. Therefore, all six samples meet the maximum specific density value requirements.

The maximum moisture content of the six samples spread from 2.5% to 3.59%. Moisture content can cause a decrease in the mechanical properties of the composite material. The decline is caused by water filling the voids and reducing the interfacial bond between the fibre and the matrix [31]. Noting that the difference in the maximum moisture content of the six samples is relatively insignificant, it is considered that the six samples are acceptable.

The burning rate of the six samples spread from 26.3 mm/min to 36.8 mm/min. The higher the filler content, the better the flame-retardant properties. The addition of filler results in reducing the percentage of the amount of resin. Resin is a flammable hydrocarbon chain. That is why the composite matrix containing filler adds to its fire resistance property. The two best samples for this property are samples C30F20 and C30F30.

The mechanical properties in Table 2 consist of Barcol hardness, tensile strength, modulus of elasticity, and impact strength. All six material samples have met the minimum tensile strength, minimum modulus of elasticity, and minimum impact strength requirements, which are greater than 50 MPa, 2000 MPa, and 40 kJ/m^2. Meanwhile, material samples with a Barcol hardness greater than or equal to 40 are C30F20 and C30F30. Thus, only two of the six samples met the requirements as gutter material, namely samples C30F20

and C30F30. Based on these considerations, the material samples that meet the requirements as gutter material are C30F20 and C30F30, namely composites with an unsaturated polyester resin matrix using 20-30 PHR filler and reinforced pineapple leaf fibre with a fibre weight percentage of 20- 30 of the composite weight.

4. CONCLUSIONS

This study investigated polymer matrix composite samples whose constituent elements are affordable. The constituent materials included unsaturated polyester resin, calcium carbonate filler, and pineapple leaf fibre. The thickness of the samples was three millimetres, with the pineapple leaf fibre arranged as reinforcement in one longitudinal direction. Some physical-mechanical properties were assessed, namely density, water absorption, fire resistance, hardness, tensile strength, modulus of elasticity, and impact strength.

Sample C00F30 had the lowest density, 995 kg/m^3, while the highest density was 1022 kg/m^3 in sample C30F20. The lowest and highest water absorption of 2.5% and 3.59% occurred in samples C00F20 and C30F30. The lowest and highest combustion rates of 26.30 mm/min and 36.58 mm/min occurred in samples C30F20 and C00F30. The lowest and highest Barcol hardness were samples C00F30 and C30F20, which values were 32.2 and 49.4, respectively. The lowest and highest tensile strengths of 57.5 MPa and 75.5 MPa belong to samples C30F20 and C00F30. The lowest elastic modulus is 2182.7 MPa, and the highest is 2958.2 MPa in samples C00F20 and C30F30. The lowest impact strength of 48.18 kJ/m2 occurred in sample C30F20, and the highest of 67.33 kJ/m^2 occurred in sample C00F30.

The results showed that adding CC filler into the matrix increased the density, water absorption, hardness, and modulus of elasticity of the composite while reducing the rate of flame propagation, tensile strength, and impact strength. Furthermore, the use of pineapple leaf fibre, contributed to increased water absorption, rate of flame propagation, tensile strength, modulus of elasticity, and impact strength of the composite, but it reduced the density and hardness. The physical properties affect the quality of PMC materials. The lighter, the lower to absorption of water, the lower the burning rate, the harder it is, the higher strength and stiffness, and the higher toughness of the PMC composite, which is the expected superior properties.

Material samples that meet the requirements for guttering and others are C30F20 and C30F30, namely composites with an unsaturated polyester resin matrix using 20-30 PHR filler and reinforced pineapple leaf fibre with a fibre weight percentage of 20-30 of the composite weight. Generally, the composites containing 30 PHR of CC filler and 30% by weight of pineapple leaf fibre have desirable physical-mechanical properties, with the composition fulfilling the economic element of raw material prices. The components of the composites are in fact relatively inexpensive: unsaturated polyester resin is a standard thermoset resin that is economical in price, CC filler is a cheap filler, and the natural fibre from pineapple leaves is abundant and is a green material that helps reduce the cost of the composites. These materials offer some potential as building materials especially as guttering application. Further research needs to be done, especially on how the production method by hand lay-up is appropriate to implement this material into gutter and others.

Generally, the composites containing 30 PHR of CC filler and 30% by weight of pineapple leaf fibre have desirable physical-mechanical properties, with the composition fulfilling the economic element of raw material prices. The components of the composites are in fact relatively inexpensive: unsaturated polyester resin is a standard thermoset resin that is economical in price, CC filler is a cheap filler, and the natural fibre from pineapple leaves is abundant and is a green material that helps reduce the cost of the composites. These

materials offer some potential as building materials that do not require high physical-mechanical properties, such as guttering applications.

REFERENCES

[1] PT Intec Persada. Available online: https://intecpersada.com/ accessed on September 2022.

[2] Gopalraj, S.K., Kärki, T. A., "Review on the recycling of waste carbon fibre/glass fibre-reinforced composites: fibre recovery, properties and life-cycle analysis", SN Applied Sciences, v. 2, n. 433, Feb 2020.

[3] Balart, R., Montanes, N. Dominici, F. Boronat, T. Torres-Giner, S. "Environmentally Friendly Polymers and Polymer Composites", Materials, v. 13, n. 4892, Oct. 2020.

[4] Ramesh, M., James, J.D., Kumar, G.S., Vijayan, V, Narayanan, S.R., Teklemariam, "Synthesis and Characterization of Banana and Pineapple Reinforced Hybrid Polymer Composite for Reducing Environmental Pollution" Bioinorganic Chemistry and Applications, v. 2022, May. 2022.

[5] Hoque, M.E., Rayhan, A.M., Shaily, S.I. "Natural Fiber-based Green Composites Processing, Properties and Biomedical Applications", Applied Science and Engineering Progress, v. 14, n. 4, pp. 689-718, Sep 2021.

[6] Jain, J., Sinha, S, "Pineapple Leaf Fiber Polymer Composites as a Promising Tool for Sustainable Eco-friendly Composite Material", Review. Journal of Natural Fibers, v. 19, pp. 10031-10052, Oct. 2021.

[7] Hadi, A.E., Siregar, J.P., Cionita, T., Norlaila M.B., Badari M.A.M., Irawan, A.P., Jaafar, J., Rihayat, T., Junid, R., Fitriyana, D.F. "Potentiality of Utilizing Woven Pineapple Leaf Fibre for Polymer Composites Polymers", Polymers 2022, v 14, pp. 2744, Jul. 2022.

[8] Wang, Q., Zhang, Y., Liang, W., Wang, J., Chen, Y., "Effect of silane treatment on mechanical properties and thermal behavior of bamboo fibers reinforced polypropylene composites", Journal of Engineered Fibers and Fabrics, v. 15, pp. 1-10, Sept. 2020.

[9] Triastuti, W.E., "Effect of alkali treatment on processing of pineapple leaf fibers". In: AIP Conference Proceedings 2342, Institut Teknologi Sepuluh Nopember Surabaya East Java, Indonesia, April. 2021.

[10] Anand, P.B., Lakshmikanthan, A., Chandrashekarappa, M.P.C., Selvan, C.P., Pimenov, D.Y., Giasin, K, "Experimental Inves-tigation of Effect of Fiber Length on Mechanical, Wear, and Morphological Behavior of Silane-Treated Pineapple Leaf Fiber Reinforced Polymer Composites", Fibers, v.10, June. 2022.

[11] Kusmono, Hestiawan, H., Jamasri., "The water absorption, mechanical and thermal properties of chemically treated woven fan palm reinforced polyester composites", Journal of Materials Research and Technology, v. 9, pp 4410-4420. Volume 9, June. 2020.

[12] Daud, M.A.M., Ghani. A. F., Zakaria, K. A., Selamat, M. Z., Dharmalingam, S., THIRUKUMARAN, M. "The Effect of Pineapple Leaf Fiber as a Filler in Polymer Matrix Composite for Interior Part in Automotive" International Journal of Nanoelectronics and Materials, v.14, pp. 363-372, Augst 2021.

[13] Gaba, E.W., Asimeng, B.O., Kaufmann, E.E., Katu, S.K., Foster, E.J., Tiburu, E.K. "Mechanical and Structural Characterization of Pineapple Leaf Fiber", Fibers, v.9, Augst. 2021

[14] Zeleke, Y., Feleke, T., Tegegn, W., And Atin, Y., "Design and development of false ceiling board composite material using pineapple leaf Fibre reinforcement in unsaturated polyester matrix", International Journal of Sustainable Engineering, v. 15, n. 1, pp. 146-154, Jul. 2022.

[15] Reddy, M., Adaveesh, B., Mohankumar, T. S., Nagaral, M., "Tensile and flexural behaviour of graphite filler particles and pineapple leaf fiber (PALF) reinforced polymer composites", Metallurgical and Materials EngineeringAssociation of Metallurgical Engineers of Serbia AMES, v. 28, n.1, Marc. 2022.

[16] Hestiawan, H., Ariawan, D., Amri, K., Nuramal, A., Afrizal, A., Sudibyo "Pengaruh Perlakuan Alkali Terhadap Sifat Fisis Dan Mekanis Serat Lantung (Artocarpus Elasticus)", Rekayasa Mesin, v. 13, n. 3, pp. 819 – 826, 2022. Aug. 2022.

[17] Sugiman, S., Setyawan, P.D., Maryudi, M., Madnasri, S. "Water absorption, tensile, flexural and impact properties of aged bamboo fibre/nano CaCO3-modified unsaturated polyester composites", Journal of Applied Science and Engineering, v 24, pp. 239-251. http://dx.doi.org/10.6180/jase.202104_24(2).0013, Apr. 2021.

[18] Rahman, M., Al Mamun, Md.A., Sarker, P., Islam, T., Khan, M.A., "Effect of Initiator Concentration on the Mechanical and Degradation Properties of Bamboo Fabric Reinforced Polyester Resin Composites", Global Journal of Material Science and Engi-neering, v. 02, pp. 10-14, 2020

[19] ASTM D3841 Standard. Available online: https://www.astm.org/d3841-21.html accessed on June 2022.

[20] ASTM D792 Standard. Available online: https://www.astm.org/d0792-20.html accessed on June 2022.

[21] ASTM D570 Standard. Available online: https://www.astm.org/standards/d570 accessed on June 2022.

[22] ASTM D635 Standard. Available online: https://www.astm.org/standards/d635 accessed on June 2022.

[23] ASTM D2583 Standard. Available online: https://www.astm.org/d2583-13a.html accessed on June 2022

[24] ASTM D638 Standard. Available online: https://www.astm.org/d0638-14.html accessed on June 2022.

[25] ASTM D6110 Standard. Available online: https://www.astm.org/d6110-18.html accessed on June 2022

[26] Setyanto, D., Jayatun, Y.A., Basoeki, P.D., De Fretes, A. "Physical Properties of Glass-Fibre-Reinforced Polymer Filled with Alumina Trihydrate and Calcium Carbonate", Polymers, v. 14, pp. 2464, Jun. 2022.

[27] Atiqah, A., Ansari, M.N.M., Kamal, M.S.S., Jalar, A., Afeefah, N.N., Ismail, N. "Mechanical properties of kenaf/polyester composite for plastic encapsulated electronic packaging application", J. Mater. Res. Technol., v. 9, pp. 12899–12906, Dec. 2020.

[28] Badaruzzaman, W.H.W., Dabbagh, N.M.R., Salleh, K.M., Saharuddin, E.N., Radzi, N.F.M., Azham, M.A.A., Sani, S.F.A., Za-Karia, S. "Mechanical Properties and Water Absorption Capacity of Hybrid GFRP Composites", Polymers, v. 14, pp. 1394, Marc 2022

[29] Mahdi, E., Dean, A., "The Effect of Filler Content on the Tensile Behavior of Polypropylene/Cotton Fiber and polyvinyl chloride/Cotton Fiber Composites" Materials (Basel). v.13, n. 3, pp. 753, Feb 2020.

[30] Suarsana, K., Soenoko, R., Putra Negara, Dnk., Sunu P.W., "Characterization of Aluminum Matrix Metal Composite Hybrid Reinforced with SiCw/(Al2O3-Mg) on Thermal Conductivity and Hardness", Rekayasa Mesin, v. 12, n. 1, pp. 159 – 169, May. 2021.

[31] Muttaqii, M., Kurniajaya, F., Hadi, A.E., "Karakteristik Material Komposit Berbasis Batuan Basalt Dan Dross", Rekayasa Mesin, v. 13, n. 3, pp. 819 – 826, Aug. 2022.