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Tensile and Bending Strength Analysis of Ramie Fiber and Woven Ramie Reinforced Epoxy Composite

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ABSTRACT
This study aims to analyze the effect of the number of woven ramie layers (plies) and ramie fiber weight as reinforcement of composite on the tensile strength and bending strength. The woven ramie reinforced composites are divided into five types including 1, 2, 3, 4, and 5 layers (plies). For ramie fiber, it is divided also into five types based on the weight of fibers as reinforcement: A, B, C, D, and E. The weight of ramie fiber types was adapted by the weight of woven ramie fiber types. All composite types were evaluated by tensile and bending test. Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopes (SEM) were used to analyze the chemical change in the composite and fractural tensile morphology of composite, respectively. The results show that the number of woven ramie layers and the ramie fiber weight in the composite greatly affects the tensile strength and bending strength of the composite. The highest tensile and bending strengths were found in five layers (plies) of woven ramie composite, while for ramie fiber in the composite the highest tensile and bending strengths were found in E type.

KEYWORDS
Ply; natural fiber composite; ramie fiber; woven ramie; tensile strength; bending strength

关键词
使用; 天然纤维复合材料; 苎麻纤维; 苎麻机织物; 拉伸强度; 弯曲强度

摘要
研究了苎麻编织层数和苎麻纤维质量对复合材料拉伸强度和弯曲强度的影响. 苎麻机织增强复合材料可分为1、2、3、4、5层（层）. 苎麻纤维按纤维重量分为A、B、C、D、E五类. 苎麻纤维类型的重量由机织苎麻纤维类型的重量决定. 通过拉伸和弯曲试验对所有类型的复合材料进行评估. 采用傅立叶变换红外光谱（FTIR）和扫描电子显微镜（SEM）分别分析了复合材料的化学变化和复合材料的断裂拉伸形貌. 结果表明，苎麻编织层数和苎麻纤维质量对复合材料的拉伸强度和弯曲强度有较大影响. 苎麻机织复合材料的5层（层）具有最高的拉伸和弯曲强度，苎麻纤维的5层（层）具有最高的拉伸和弯曲强度.

Introduction

The development of materials, in the polymer composite materials, has been continuing to grow in many applications like in automotive, structure, and aerospace. Initially, the composite materials were developed in the aerospace industry, but, over time, natural fiber composites can also be found in the automotive applications with high performance and durability. Natural fiber composites can also be applied in building materials, hulls, and military products with certain criteria (Lee 1993). Natural polymer composites have been more attention in the last decades due to their potential to change synthetic fiber-reinforced polymer composite. The use of natural fiber as a composite reinforcement has many advantages, such as the replacement of synthetic fibers, low

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price, capable to absorption of sound, environmentally friendly, low density, and high mechanical ability, which can meet the needs of industry (Gu et al. (2014) and Pickering, Efendy, and Le (2016)). Some natural fibers have been used as reinforcement of composite like ramie, jute, coir, kenaf, etc.

One of the natural fibers has been developed to reinforce composite is ramie fiber. Ramie fiber in composite and textile field has a good prospect for the future. Its tensile strength is about 400–1586 MPa (Paiva Júnior et al. (2004), Goda et al. (2006) and Marsyahyo, Soekrisno, and Jamasri (2008)) which is higher than flax and jute fiber (Yu et al. 2010). Some studies of ramie fiber-reinforced composite have been conducted by researchers. Paiva Júnior et al. (2004) investigated ramie fiber composition in the composite on the tensile strength. The composition of 45% volume fraction of ramie fiber in the composite has higher tensile strength than other composition and neat resin polyester. Then, surface treatment with alkali and silane of ramie fiber influenced the mechanical properties of ramie fiber-reinforced poly(lactic acid) (PLA). The improvement of mechanical properties and thermo-mechanical properties of ramie fiber-reinforced PLA composite takes place after alkali and silane treatment of ramie fiber because of good adhesion between fiber and PLA matrix (Yu et al. 2010). PLA composite with ramie fiber as reinforcement was also studied by (Debeli, Qin, and Guo 2018). The best properties of the composite were obtained with volume fraction of fiber and matrix 4:6, 175^{0}C molding temperature, and 7 MPa molding pressure for 8 min molding time. In addition, ramie fiber and ramie fabric (woven) as reinforcement of composite have been studied by Chen, Li, and Ren (2010) related to sound absorption behavior of composite. The sound absorption behavior of short ramie fiber composites was found to better behavior than the ramie fabric reinforced poly(l-lactic acid) (PLLA) composites. The epoxy composite with reinforcing ramie fiber has been evaluated by Margem et al. (2010) where 30% volume fraction of fiber in the composite showed higher the storage modulus compared to other volume fractions. Ramie fiber-reinforced epoxy composite was also studied by Kumar and Anand (2019). The best mechanical behaviors including tensile, bending, and impact strength are obtained in 30% weight of ramie fiber in the composite. Meanwhile, the use of polypropylene as a matrix in ramie fiber composite has been investigated by Feng et al. (2011). Composite with 30% volume fraction of fiber has a higher tensile and bending strength than other volume fractions (10% and 20%).

Ramie fiber was used as reinforcement of composite with hybridization of Kevlar fiber for armor materials (Ali et al. 2011); meanwhile, the woven fiber composite has been evaluated by Marsyahyo, Rochardjo, and Soekrisno (2009) for armor materials. Woven fiber as a reinforcement composite has influenced the mechanical properties of composite. Woven flax fiber can improve the fracture toughness of composite (Liu and Hughes 2008). Then, the number of woven kenaf layers in the composite improved the tensile strength of composite although it is not significant (Ismail and Che Abdul Aziz 2015).

The woven ramie and ramie fiber as reinforcement in the composite was studied in this paper. In this study, the effect of the number of woven ramie layer and ramie fiber weight as reinforcement composite on the tensile strength and the bending strength was conducted. FTIR and SEM results of composite are also analyzed.

Materials and methods

Materials

Ramie fiber and woven ramie fiber were obtained from Garut area, West Java – Indonesia. The ramie fiber was processed by cutting the stem of the ramie plant. Ramie fiber was extracted from the stem with a decorticator. Ramie fiber then was washed and soaked in the water. After soaking, the ramie

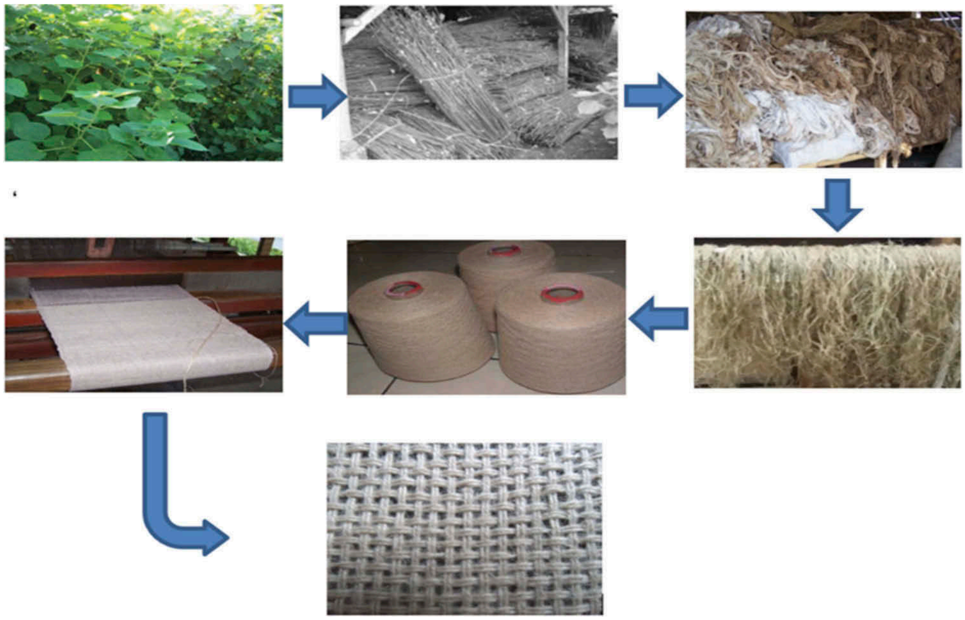

Figure 1. The process of ramie fiber into woven ramie.

fiber was dried. This fiber is used for reinforcement of composite. For woven ramie, the extracted fiber from the stem of ramie plant was then continued by the degumming process to remove the impurities (like gum and pectin) in the fiber. The ramie fiber was then spun into yarn and then processed through a weaving machine to produce ramie woven. Figure 1 shows the flowchart of the process of ramie stem into fibers and woven ramie.

The epoxy used as a matrix in the composite is epoxy resin A (*Bisphenol A-epichlorohydrin*) and epoxy hardener B (Polyaminoamide).

Fabrication of composite

The fabrication of composite used molding tool from steel plate with a size of 250 mm × 250 mm. The compression molding method was used to produce a composite. The compression duration is about 6–8 h for all variations of composite (Djafar et al. 2015). Reinforcement of composite is classified into ramie fiber and woven ramie based on the weight of fiber. Woven ramie as reinforcement in the composite is divided into five types based on the number of layers: 1, 2, 3, 4, and 5 layers (Table 1). The weight of all woven layer types can be seen in Table 1. For ramie fiber, it is divided

Table 1. Woven ramie and ramie fiber based on the weight.

Number of woven ramie layers	Ramie fiber	Weight of woven ramie and ramie fiber (gr)
1	A	18.65
2	B	36.82
3	C	54.66
4	D	73.75
5	E	92.52

also into five types based on the weight of fibers as reinforcement: A, B, C, D, and E. The weight of ramie fiber types was adapted by weight of woven ramie fiber types (Table 1).

Moisture content of composite

The water content of fiber is expressed in percentage (%) called moisture content (MC). Moisture content in fiber was calculated as Equation (1) based on ASTM D629-02

$$\text{Moisture Content}, \% = ((W_o - W_t)/W_o) \ * \ 100\% \tag{1}$$

where W_o is the weight of fiber before dry (gr), and W_t is the weight after dry fiber (gr).

Tensile testing

The tensile specimen was adjusted to ASTM D638-02 with use type I. Tensile specimen is five pieces. Tensile strength is calculated as per Equation (2) based on ASTM D638-02

$$\sigma = F_{max}/A_0 \tag{2}$$

where σ is the tensile strength (MPa), F_{max} is the maximum load (N), and A_0 is a cross-sectional area (mm^2).

Bending testing

Bending testing and preparation of specimen were conducted based on ASTM D790-02. The number of specimen bending test is five pieces. The machine specification used for bending test is the universal tensile machine with the 25 kN Galdabini machine.

The bending strength of a material can be calculated by the following equation

$$\sigma_b = \frac{3PL}{2bd^2} \tag{3}$$

where σ_b is the bending strength (MPa), P is the Load (N), L is the length span (mm), b is the bar width (mm), and d is the thickness of specimen (mm).

Fourier transform infrared spectroscopy (FTIR)

FTIR SHIMADZU Prestige 21 was used in this study to identify the chemical change in the composite with different layers of woven ramie and weight of ramie fiber types. The wavenumber was set up ranged from 500–4000/cm with 2/cm resolution.

Scanning electron microscopes (SEM)

SEM JEOL JSM-6510LA was used in this study to analyze the morphology of fractural tensile test. The composite specimens of SEM analysis were made with a dimension of about 0.5 × 0.5 cm, then followed by a coating process using gold (Au) for 120 s at 20 kV with 500 times magnification.

Results and discussion

Moisture content

Figures 2 and 3 present the analysis of moisture content of woven ramie and ramie fiber. Figure 2 and Table 2 show the relation of the number of woven ramie layers to the percentage of moisture

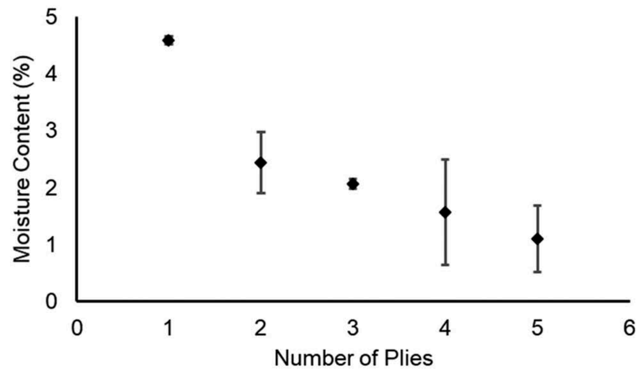

Figure 2. Relationship between the numbers of woven ramie layers (plies) and the percentage of moisture content.

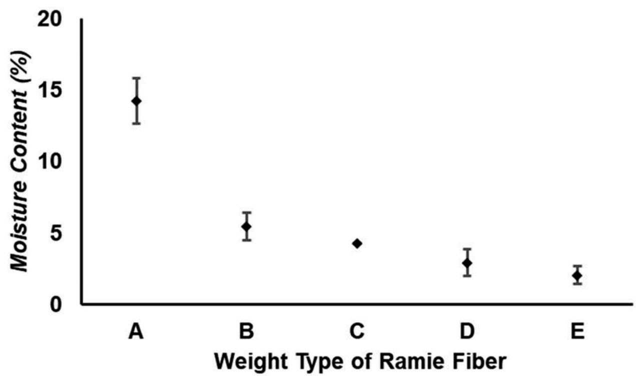

Figure 3. Relationship between ramie fiber weight types and percentage of moisture content.

Table 2. Moisture content of woven ramie.

Number of woven ramie layers	Average weight preheat (gr)	Average weight after preheat (gr)	Moisture content (%)
1	18.65	17.79	4.59 ± 0.07
2	36.82	35.92	2.44 ± 0.53
3	54.66	53.52	2.07 ± 0.09
4	73.75	72.59	1.57 ± 0.92
5	92.52	91.51	1.10 ± 0.59

content. The highest percentage of moisture content was obtained in 1 layer (ply) of 4.59 ± 0.07%, while the lowest percentage of moisture content is found in 5 plies amounts of 1.10 ± 0.59%. These results suggest that the water content contained in the woven 1 ply is greater than others, it may affect the mechanical strength of the composite. High water content tends to weaken the mechanical strength of the composite material.

Figure 3 and Table 3 show the relationship between various types of ramie fiber weight toward the percentage of moisture content. The highest percentage of moisture content is found in the A type of fiber weight with 14.24 ± 1.59%, while the lowest percentage of moisture content is on the E type of fiber weight with the value is 2.07 ± 0.64%. It identifies that the moisture content contained in A type ramie fiber is larger than other types so that it may affect the mechanical strength of the composite. High moisture content tends to weaken the mechanical strength of a composite material (Moudood

Table 3. Moisture content of ramie fiber.

Ramie fiber	Average weight preheat (gr)	Average weight after preheat (gr)	Moisture content (%)
A	18.65	15.99	14.24 ± 1.59
B	36.82	34.80	5.48 ± 0.97
C	54.66	52.32	4.27 ± 0.03
D	73.75	71.59	2.93 ± 0.92
E	92.52	90.60	2.07 ± 0.64

et al. 2017). To minimize its existence in the fiber, the drying process was conducted by using an oven to reduce the moisture content.

These results suggest that moisture content in ramie fiber and woven ramie has a tendency to decrease with the increase in the number of woven ramie layers and ramie fiber weight. It may influence the mechanical strength of ramie fiber-reinforced composite or woven ramie fiber-reinforced composite. Saw et al. (2014) studied jute fiber and coir hybrid composites that moisture content fibers influenced the physical and mechanical properties of the composite. If higher moisture content in the fiber, interfacial adhesion of fiber-matrix is poor consequently influence to mechanical properties of the composite.

Tensile strength

Tensile strength of woven ramie reinforced composite related to the number of woven ramie layers is shown in Figure 4. It can be seen that tensile strength tends to increase with increasing the number of woven layers. The woven ramie composite has the highest tensile strength with 5 layers of plies about of 99.04 ± 2.85 MPa (Table 4). Otherwise, the lowest tensile strength is the 1 layer (ply) in the composite of 85.04 ± 1.54 MPa. It is identified that the number of woven ramie layers in the composite can affect the tensile strength of the composite where the increasing amount of woven layers in the composite tends to increase the tensile strength of the composite material. These results in line with the study of Ismail and Che Abdul Aziz (2015) where the number of woven kenaf layers in composite influenced the increase in tensile strength even though it is not significant. In addition, the layer number in carbon fiber composite also affected tensile strength where carbon fiber composite with 5 layers of plies has greater strength compared to 3 layers of plies (Rahmani, Najafi, and Ashori 2014).

Figure 5 shows the relationship between the ramie fiber weight types and the tensile strength of the ramie fiber composite. The ramie fiber weight influenced the tensile strength of the composite. The highest tensile strength of the composite is an E specimen with 138.84 ± 8.35 MPa (Table 4),

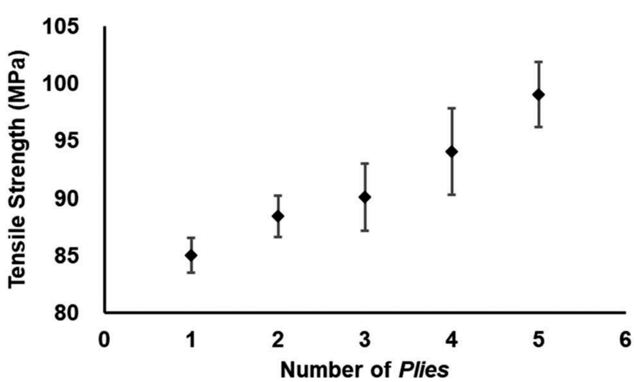

Figure 4. Relationship between the numbers of woven ramie layers (plies) and tensile strength of the composites.

Table 4. Tensile and bending strength of woven ramie and ramie fiber-reinforced composite.

Number of woven ramie layers	σ (MPa)	σ_b (MPa)
1	85.04 ± 1.54	79.08 ± 6.49
2	88.45 ± 1.79	85.48 ± 6.21
3	90.11 ± 2.91	91.81 ± 5.20
4	94.08 ± 3.77	94.33 ± 13.82
5	99.04 ± 2.85	98.73 ± 5.98
Type of ramie fiber weight		
A	89.97 ± 5.96	97.88 ± 18.25
B	97.01 ± 6.58	105.41 ± 11.64
C	97.86 ± 10.37	109.81 ± 8.58
D	119.70 ± 19.52	113.19 ± 11.54
E	121.85 ± 8.35	138.84 ± 15.60

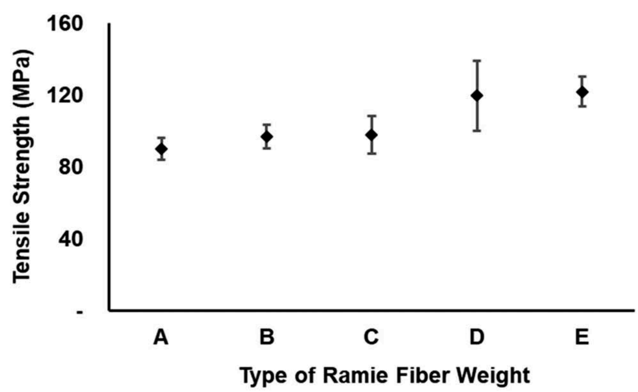

Figure 5. Relationship between ramie fiber weight types and tensile strength of the composites.

while the lowest tensile strength is A specimen of 89.97 ± 5.96 MPa. It can infer that there is a tendency to increase tensile strength with increasing ramie fiber weight.

Bending strength

The bending test is conducted to determine the bending strength of the composite. Figure 6 shows the relationship between the bending strength and the number of woven ramie layers in the

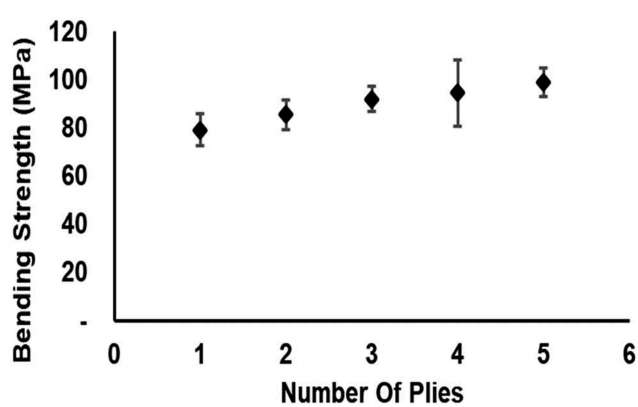

Figure 6. The relation between numbers of woven ramie layers (plies) and the bending strength woven ramie of the composites.

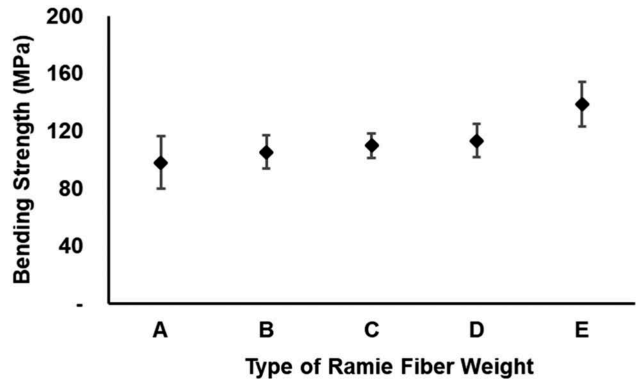

Figure 7. Relationship between the ramie fiber weight types and bending strength of the composite.

composite. The 1 woven ramie layer in the composite has the lowest bending strength of 79.08 ± 6.49 MPa (Table 4), while the composite with 5 woven ramie layers has the highest bending strength of 98.73 ± 5.98 MPa. The bending strength of composite with 5 woven ramie layers increases about 25% to the 1 woven ramie layer. The increasing of bending strength in composite with 5 woven ramie layers may be caused by improvement interfacial adhesion between woven ramie and matrix and also improvement stiffness of the composite. This identifies that the amount of woven ramie layers can affect the bending strength of the composite. With the increasing number of layers of woven ramie in the composite tends to increase the bending strength of the composite.

Figure 7 shows the effect of the ramie fiber weight in composite on the bending strength. The higher the fiber content (fiber weight) in the composite, the higher the bending strength. The lowest ramie fiber weight in the composite is expressed by A type which has the lowest bending strength of 97.88 ± 18.25 MPa (Table 4), while the composites with E type of fiber weight have the highest bending strength of 138.84 ± 15.60 MPa. This shows that the weight of ramie fibers can affect the bending strength of the composite. With the increasing weight of ramie fiber in the composite tends to increase the bending strength of a composite material. This is supported by Lei, Lei, and Ren (2006) study which states that the bending strength increases with an increase in ramie fiber content in composite.

Fourier transformation infrared (FTIR) analysis

Fourier Transformation Infrared (FTIR) analysis of the composite is shown in Figures 8 and 9. Figure 8 shows the FTIR analysis of woven ramie reinforced composite. It shows that the absorption area 2200–2400 cm^{-1} formed nitrile functional group (C ≡ N) which is a sharp peak physical appearance and medium intensity of 2368.59 cm^{-1} with an intensity of 19.574% T. In the area of 3300–3500 cm^{-1}, O-H group is formed with strong intensity and wide peak physical appearance (Fan, Dai, and Huang 2012). The wide peak and strong intensity identify the material which tends to easily absorb water which can then affect the mechanical strength of a composite material. The widest peak shape is displayed by 2 plies woven ramie composite which has a peak value of 3410.15 cm^{-1} and an intensity of 5.103% T. Figure 8 also shows that the highest intensity occurs in woven ramie composite with five layers of plies with an intensity of 25.148% T at peak 1851.66 cm^{-1} which indicates the presence of CO group with acyl halide compound.

In Figure 9, FTIR analysis shows several absorption areas including the 2200–2400 cm^{-1} which is sharp and clear which indicates FTIR analysis for ramie fiber composites based on the weight of type A to type E. Figure 9 shows that the highest intensity occurs in ramie fiber composites with C type with an intensity value of 34.983% at peak 1851.66 cm^{-1} which indicates the presence of

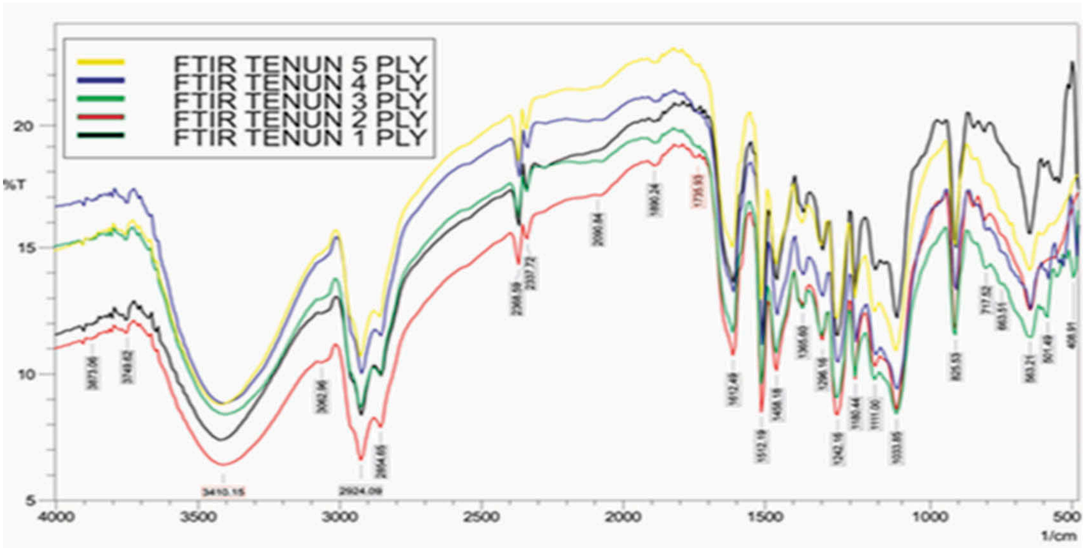

Figure 8. The FTIR analysis of woven ramie composite with 1 layer to 5 layers (plies).

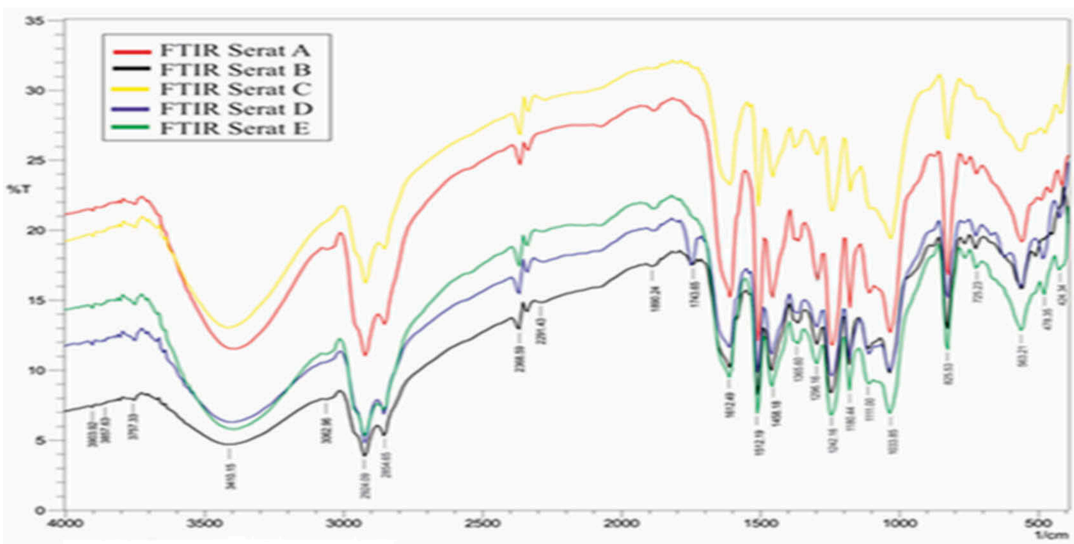

Figure 9. FTIR analysis of ramie fiber composites with different fiber weight.

clusters >CO with Acyl Halide compound. Meanwhile, the lowest intensity value is found in the B type with an intensity value of 3.868% and a peak value of 2924.09 cm^{-1} which indicates the presence of CH group with Alkane compound in it (Fan, Dai, and Huang 2012).

Scanning electron microscopes (SEM) analysis

Figure 10 shows SEM analysis for composite with reinforcement of woven ramie of 1, 2, 3, 4, and 5 plies (layers). Figure 10a shows the fracture occurs in the composite with 1 woven ramie layer (ply)

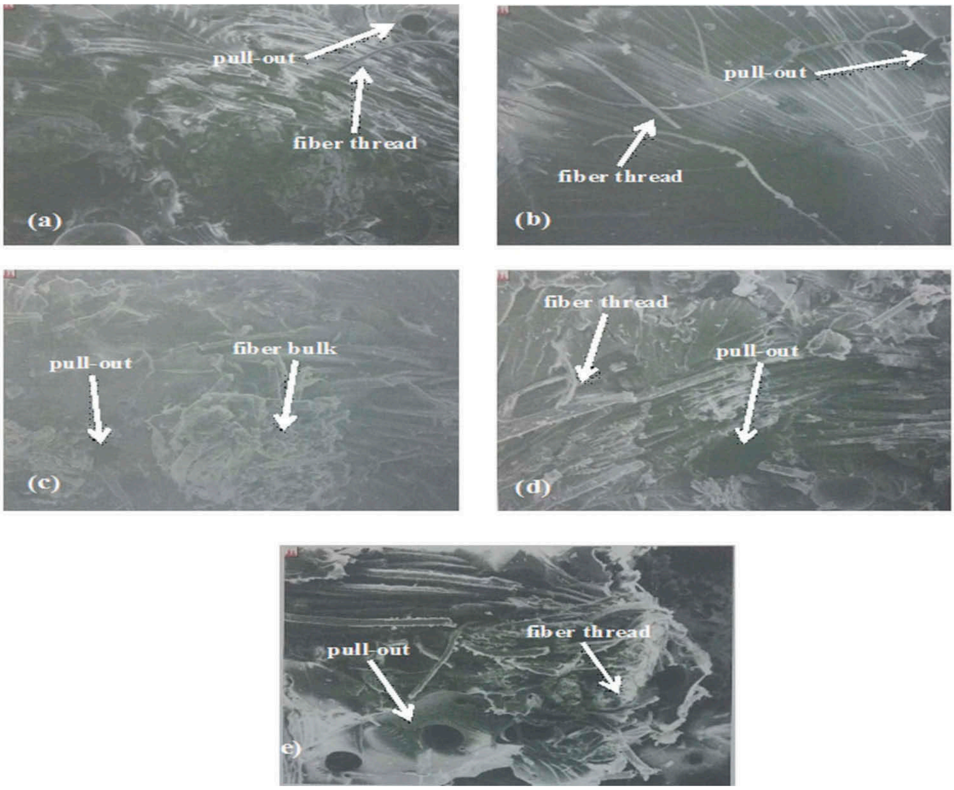

Figure 10. SEM image on woven ramie composite with variation in a number of layers (a) 1-ply, (b) 2-ply, (c) 3-ply, (d) 4-ply, and (e) 5-ply.

where the fracture surface appears brittle due to the less woven ramie fiber to withstand fracture. The same situation in Figure 10b of 2 layers in composite shows that the fibers are slightly higher than the 1 layer (ply) for withstanding the fracture of the composite. Figure 10(c–e) depicts the woven ramie layers (3, 4, and 5 layers, respectively) in the composite give more tighten than 1 and 2 layers in composite. This case may improve the strength of composite. An increase in the number of woven ramie layers in the composite indicates an increase in strength on the composite material.

The SEM analysis on the tensile fracture of the ramie fiber-reinforced composite is shown in Figure 11. Figure 11a shows fiber in A type composite experienced pull-out from the matrix. This may be caused by poor adhesion between fiber and matrix leading to occur fracture in composite and also less tensile strength of composite. Figure 11(b–e) shows that fiber in B, C, D, and E types, respectively, provide more strength to the composite than the A type. While in composites with B, C, D, and E types the number of fibers increases, the number of cracks reduces consequently the strength of composite improves. As the increase of ramie fiber weight in the composite can indicate the increase in strength that occurs on the composite material.

Conclusions

Tensile and bending strengths of the woven ramie and ramie fiber-reinforced composite are influenced by the number of woven ramie layers and ramie fiber weight. The highest tensile strength on woven ramie reinforced composites is 5 layers (plies) in the composite with an average tensile strength of 99.04 ± 2.85 MPa, whereas for ramie fiber-reinforced composites the highest

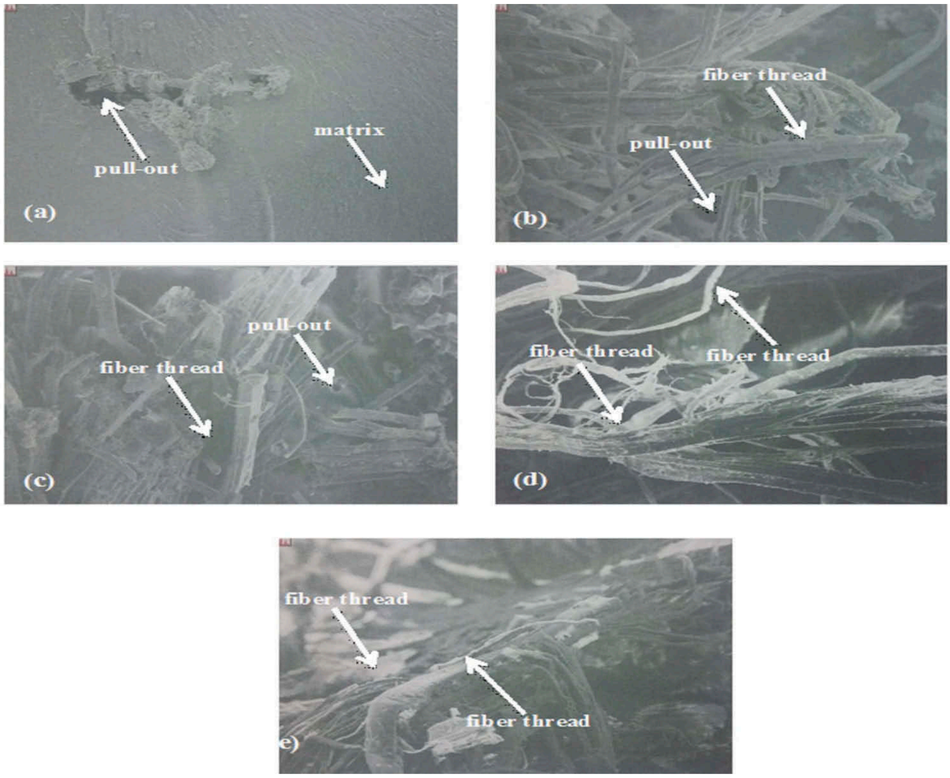

Figure 11. SEM image on ramie fiber composite with variation in type of weight (a) Type A, (b) Type B, (c) Type C, (d) Type D, and (e) Type E.

tensile strength is an E type with an average tensile strength of 121.85 ± 8.35 MPa. Meanwhile, the highest bending strength of woven ramie reinforced composite was obtained in 5 layers (plies) in the composite of 98.73 ± 5.98 MPa, whereas in ramie fiber-reinforced composite which was strengthened by fiber the highest value was in E type of 138.84 ± 15.60 MPa.

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