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Effect of Fabric Orientations on Mechanical Properties of Hybrid Jute-Ramie Reinforced Unsaturated Polyester Composites

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Abstract. Jute and ramie fibre received significant attention from the researcher around the globe due to the excellent performance as reinforcement materials for the composite. The present work study the influence of the fabric orientation and layering sequence on the hybrid woven jute-ramie reinforced unsaturated polyester resin (UPE) on mechanical properties (tensile, flexural and impact). The composite sample was prepared via a hand lay-up method with a compression machine. Four (4) different orientation ready for the composite sample consists of 0 laminate, [0°/0°/0°/0°], cross-ply [0°/90°/90°/0]° laminate, angle-ply laminate [45°/-45°/45°/-45°] and quasi-isotropic laminate [0°/45°/-45°/90°]. Based on the finding on the current research, the effect of orientation for hybrid woven jute-ramie is apparent on the tensile testing — nonetheless, the influence of the woven orientation for flexural testing and charpy impact testing. Based on the tensile testing, the composite with the woven orientation of cross-ply yield the highest average tensile strength compared to the other composite. In the case of tensile modulus, the composite sample becoming more ductile when arranged to the orientation of angle-ply laminate and quasi-isotropic laminate. For the flexural testing and charpy impact testing, the entire composite yield almost similar value regardless of the type of woven arrangement.

1. Introduction

The potential of natural fibres as a reinforcement material has becoming a spotlight in the recent year, especially in automotive and structural applications. A natural fibre that used as reinforcement materials exists in the variable of forms such as filler, short fibre, long continuous fibre, bi-directional woven, non-woven and mats. Among all the structure of the reinforcement material, woven fabric is

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extensively applied by the researcher in their study. The number of advantages of woven fabric when used as reinforcement materials such as high impact resistance, excellent strength to weight ratio, high flexibility and good damping properties, simple processing and inexpensive cost [1, 2]. Unlike another form of reinforcement materials such as unidirectional fibre, the woven fabric comprises of made of by interlace yarn fibre in the direction of warp and weft. Therefore, the woven fabric provides more balance properties and less fibre pull-out due to the tightly attached yarn fibre.

The woven fabric that stacked into several layers with similar layer is called lamina. In the case of woven fabric arranged with different fabric orientation, it is known as laminated. The performance for laminated composite depended on the number of parameters from woven parameter and laminated parameter. The weave parameter consists of the woven architecture or weaves geometry, yarn crimp, yarn size, and yarn spacing [3]. On the other hand, the laminated parameter is included in several layering sequences, stacking sequence, volume/weight fraction and woven orientation [3].

The previous study of laminated composite, weave parameter has been performed by the researcher. The influence of different weave geometry, which consists of plain, twill and satin has been shown [4, 5]. The recent trend had shown that the plain woven are the most selected fabric architecture. As addressed by [5], plain weave claims the higher strength of tensile due to the efficacy of uniform stress transfer. Also, the presence of transverse fibres constrained the fibres displacement in the longitudinal directional. Moreover, the plain weave architecture was related to the highest frequency of yarn interlacing that promoting stress distribution uniformly and can withstand high tension due to the less slippage in the structure [6]. Influence of another weave parameter also highlighted by the researcher. Goutianos and team [7] highlighted one of the essential keys in developing the textile composite involve the optimisation of the yarn parameter that is twisted degree. For a composite application, a low level of twist is necessary to improve the impregnation of the polymer resin. Similar findings were found by [8] regarding the effect of the twist angle. To obtain better penetrated of resin, the low twist is acquired. The effect of yarn crimps on the laminated composite shown by [9] which suggested that the crimp percentage is related to the energy dissipation. The higher crimp percentage is indicating that the better energy dissipation due to the increased elongation. However, the crimp percentage is valid when the volume fraction of the matrix polymer is higher than the woven fabric.

The effect of the laminated parameter also has been addressed by the researcher [4, 10, 11]. As discussed by [4] agreed that the relationship between the mechanical properties and the number of plies layer to be linear. The higher number of layering size offers higher breaking resistance in the laminated composite [10]. However, the thickness and weight of a composite also grow definitely. The mechanical properties can be altered by changing the sequence layup. Another critical parameter is fabric orientation. The orthotropic effect of fabric orientation for the unidirectional fibres and woven fabric are different. The mechanical behaviour of the woven laminated composite highly depends on the orientation of the lamina.

Nevertheless, it is very challenging to control the alignment of the fibres to acquire optimum mechanical performance [12]. In the common practice, the plies are limited to several orientation angles which are at 0°, –45°, 45°, and 90° sequences or in a 0°, –60°, and 60° [11, 13]. Most of the laminated design was limited to only three fabric orientation angles because the use of more orientation does not improve the design. The use of more fabric angle is impractical since the manufacturing cost increases as the number of layer increases.

Most of previous study applies the rule of mixture for predicting stress on the unidirectional fibre reinforced composite. Similar rule of mixture cannot be applied directly to the woven laminated composite. Unlike unidirectional, the woven fabrics content of continuous fibre in the direction of warp and weft that experience different fibre tensions during the weaving process. Moreover, the warp and weft also have a different fibre distribution and bundle geometry. Modified rule of mixture for the woven laminated composite have been by proposed [14].

The effect of the orientation for the hybrid jute-ramie composite is entirely new in the fields of the research fields. Also, hybrid jute-ramie composite possesses a unique trait that can be applied to meet the design requirement for mechanical properties. Through combining the jute and fibre in appropriate order can significantly reduce the cost while attaining good mechanical performance. Nevertheless, the performance of the hybrid jute-ramie, especially in-plane strength and stiffness high depended on the fabric orientation of the reinforcement. The research work aims to determine the performance of the hybrid woven jute-ramie under the influence of the different fabric orientation setup and layering sequence. In the same time, the fracture surface of the composite sample with different layering sequence and fabric orientation was investigated.

2. Methodology

2.1. Materials

In the study, the 1/1 plain woven fabric of the jute and ramie have been selected as the primary reinforcement. Woven jute and ramie are each labelled as (J) and (R). The woven fabric was prepared with width and length of 300 mm × 300 mm (Figure 1). The details for the woven fabric of jute and ramie, which obtained from the preliminary study is presented in Table 1. Unsaturated polyester (UPE) resin has been selected as the primary matrix phase. A catalyst of methyl ethyl ketone peroxide (MEKP) was mix to the UPE resin.

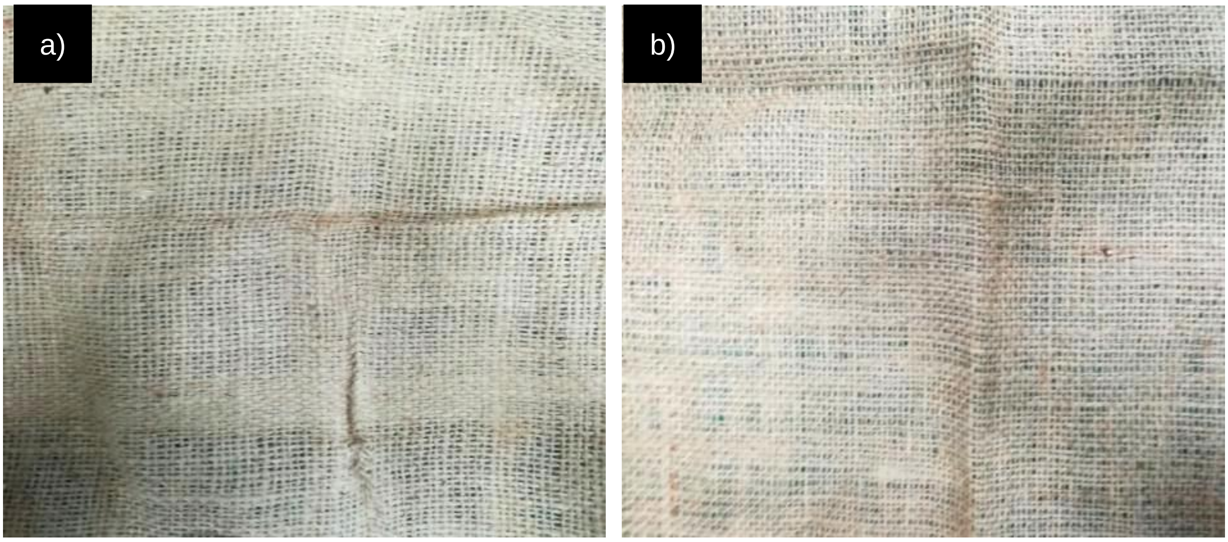

Figure 1. The woven fabric: a) jute b) ramie.

Table 1. Detail for the woven fabric of jute and ramie.

Parameter / Type of fabric		Jute	Ramie
Fabric count	Warp direction (ends per 2 cm)	10	10
	Weft direction (ends per 2 cm)	10	10
Cover factor	Warp direction	0.67	0.65
	Weft direction	0.66	0.77
Fabric cover factor		0.89	0.92

2.2. Fabrication of laminate composite

The woven jute and ramie were arranged based on the stacking sequence and orientation, as displayed in Table 2. The laminated composited fabricated with 4-layers of woven fabric. Based on the previous research work, the effect of layering size on tensile strength is significant when apply three or more layers [15]. The type of angle condition is applied which include 0º laminate (0°/0°/0°/0°), cross-ply laminate (0°/90°/90°/0°), angle-ply laminate (0°/45°/45°/0°), and quasi-isotropic laminate (0°/45°/-45°/90°).

The composite sample was prepared according to the hand lay-up techniques followed by the compression press. The aluminium mould with a dimension of 300 mm × 300 mm × 3 mm was used for the sample fabrication. Two configurations have been used to arrange the woven fabric. The first configuration is denoted as 0°-ply, which refer to woven fabric with yarn in the warp direction on the horizontal axis. Meanwhile, for 45°-ply mean yarn in the warp direction rotates about 45° from the horizontal axis. The average total weight fraction of the fibre on composite sample is 29.31% ± 0.717.

Firstly, the inner surface was coating by bee wax to ensure the composite sample easily removed after the curing. The woven fabric was placed on the surface of the mould up to four maximum layers. The resin was poured to reinforcement and rolled evenly to remove entrapped air. The mould closed tightly and compression by compression machine with a pressure of 50-60 bar. Then, the mould left for 5 hours at room temperature (25-27 ºC). Lastly, the composite plate was cut based on the standard required for mechanical testing.

Table 2. Formulation for the composite sample.

	Stacking sequence	Lay-up angle	Weight of material fibre jute (g)	Weight of material fibre ramie (g)	Total weight of the fibre (g)	Total weight of UPE resin (g)	The total weight fraction of the fibre (w/w)	The weight fraction of the UPE resin (w/w)
1	JJJJ	[0°/0°/0°/0°]	82.12	0	82.12	200	29.11	70.89
2	JJJJ	[0°/90°/90°/0°]	81.32	0	81.32	200	28.90	71.09
3	JJJJ	[+45°/-45°/-45°/+45°]	83.48	0	83.48	200	29.45	70.55
4	JJJJ	[0°/+-45°/90°]	80.76	0	80.76	200	28.76	71.23
5	RRRR	[0°/0°/0°/0°]	0	84.39	84.39	200	29.67	70.33
6	RRRR	[0°/90°/90°/0°]	0	89.36	89.36	200	30.88	69.12
7	RRRR	[+45°/-45°/-45°/+45°]	0	90.68	90.68	200	31.20	68.80
8	RRRR	[0°/+-45°/90°]	0	83.52	83.52	200	29.46	70.54
9	JRRJ	[0°/0°/0°/0°]	36.34	42.34	78.68	200	28.23	71.77
10	JRRJ	[0°/90°/90°/0°]	42.4	41.76	84.16	200	29.62	70.38
11	JRRJ	[+45°/-45°/-45°/+45°]	42.22	44.6	86.82	200	30.27	69.73
12	JRRJ	[0°/+-45°/90°]	41.35	42.45	83.8	200	29.58	70.47
13	RJJR	[0°/0°/0°/0°]	38.23	42.21	80.44	200	28.68	71.32
14	RJJR	[0°/90°/90°/0°]	39.34	40.46	79.8	200	28.52	71.48
15	RJJR	[+45°/-45°/-45°/+45°]	39.5	44.32	83.82	200	29.53	70.47
16	RJJR	[0°/+-45°/90°]	40.38	41.87	82.25	200	29.14	70.86
17	JJRR	[0°/0°/0°/0°]	35.79	43.71	79.5	200	28.44	71.56
18	JJRR	[0°/90°/90°/0°]	41.32	41.69	83.01	200	29.33	70.67
19	JJRR	[+45°/-45°/-45°/+45°]	38.86	40.91	79.77	200	28.51	71.49
20	JJRR	[0°/+-45°/90°]	40.68	41.85	82.53	200	29.21	70.79
21	JRJR	[0°/0°/0°/0°]	37.61	44.87	82.48	200	29.20	70.80
22	JRJR	[0°/90°/90°/0°]	40.46	41.49	81.95	200	29.06	70.93
23	JRJR	[+45°/-45°/-	41.78	40.07	81.85	200	29.04	70.96

		45°/+45°]						
24	JRJR	[0°/+-45°/90°]	42.56	42.11	84.67	200	29.74	70.26

2.3. Mechanical testing

2.3.1. Tensile test
The composite sample was prepared according to the ASTM 3039 via Universal tensile testing (UTM) (INSTRON 5582). The crosshead speed used for tensile testing is 1 mm/min. The test will be replicate about five (5) times for each group of composite samples. The value obtained for tensile strength and tensile modulus will be averaged.

2.3.2. Flexural testing
The flexural testing was performed via ASTM D790 at room temperature. The similar machine UTM, as mentioned on the tensile testing, is applied for the flexural test. The crosshead speed is fixed to 2 mm/min. Each type of composite sample was tested about five (5) times. The data obtained for flexural strength and flexural modulus were statistically averaged.

2.3.3. Impact testing
The purpose of impact testing is to access the amount of energy absorbed by the composite sample during fracture occur. The composite sample for the Charpy impact testing was prepared according to the ASTMD-256. The testing was performed by using Izod Impact tester with room temperature at 25± 2 °C. The composite sample has a V-shape notch which was prepared by using the notch cutter with the constant speed during the operation. The notch has an angle of 45° with radius of curvature at the apex about 0.25mm. The test was replicated about 5 times. The result obtained for impact strength was statistical analysis.

2.4. Scanning electron microscopy (SEM)
Scanning electron microscopy (SEM) machine was used to study the surface morphology the woven hybrid natural fibre and the composites. The specimens were sputter-coated with a thin layer of palladium to avoid electrostatic charging during sample examination and observed at a variable magnification ranging from 100 to 1000.

3. Result and Discussion

3.1. Tensile properties
The result of tensile strength and tensile modulus obtained for the composite sample of with 4 layers consisted of different layering sequence such as JJJJ, RRRR, JRRJ, RJJR, and JRJR are shown in Figure 2 and Figure 3. As mentioned by [16], when the higher strength of materials applied as skin that the tensile strength of the laminated composite greater. Nevertheless, as found in the current study, the effect of layering sequence on the composite sample not dominance in the tensile testing. In the current study, the tensile stress produced via hybrid jute-ramie is almost similar regardless the stacking sequences. Nevertheless, the composite with higher jute content produced higher tensile stress. The composite with the higher content of ramie is becoming stiffer which limit the stress distribution.

The composite sample was arranged with fibre orientation of [0°/0°/0°/0°], [0°/45°/-45°/90°], [0°/90°/90°/0°] and [45°/-45°/-45°/45°]. Changing the fibre orientation produce different value for the tensile strength, which indicates the unfavorable anisotropic properties of the woven laminated composite. This is because when changing the fabric orientation will affect the initiation and propagation of damage.

Based on the testing performed on the composite samples, the highest tensile strength for produced for composite JJJJ, JJRR, JRJR, JRRJ, RJJR and RRRR is 40.98 MPa, 38.43 MPa, 36.34 MPa, 34.25

MPa, 36.72 and 33.14 MPa respectively. The data shown that the maximum tensile strength obtained from the composite sample with 0° and cross ply laminated arrangement. High tensile strength in the direction of 0° laminate and cross-ply laminate due to the arrangement of fibre align to the main load-carrying direction that capable of strengthening the composites [17]. The cross-ply composite produces higher tensile strength than 0° laminate due to the different strength of yarn in warp and weft direction. In this study, the yarn in the direction of weft is required more force to break. Also, the yarn crimps in the weft direction are higher than the warp direction. Therefore, crimped yarn fibre in the weft direction can extend more make it efficiently propagate the high stress in the matrix. The tensile strength becomes lesser when oriented to the 45° in the specific test directions.

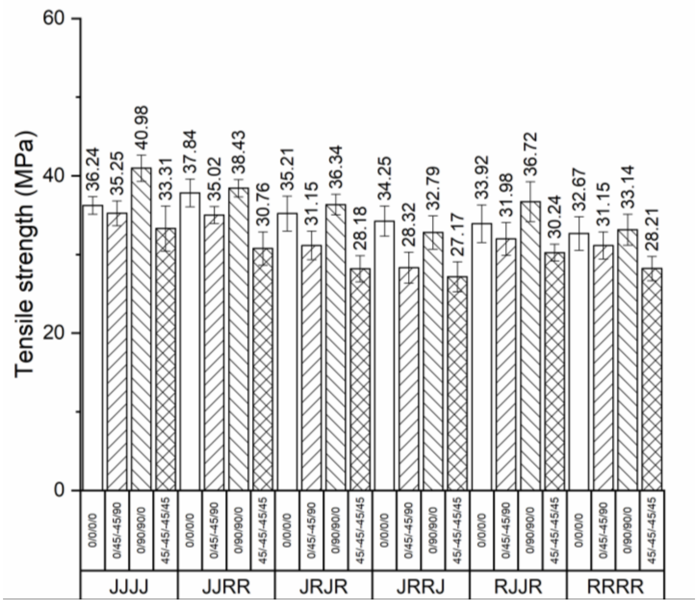

Figure 2. Effect of fabric orientations on tensile strength of jute/ramie composites.

Figure 3 shows that the tensile modulus obtained from the composite with different layering sequence and fabric orientation for monolithic and hybrid composite. The modulus for the composite is altered when arranging with different fabric orientation due to the anisotropic properties. Therefore, the tensile modulus is different in each direction (E0°≠E45°≠E90°). The composite with 0° laminate and cross-ply setting produce excellent tensile modulus compared to the composite with the arrangement of quasi-isotropic and angle-ply laminate. The composite sample becomes stiffer when arranging in the direction parallel to the applied load [18].

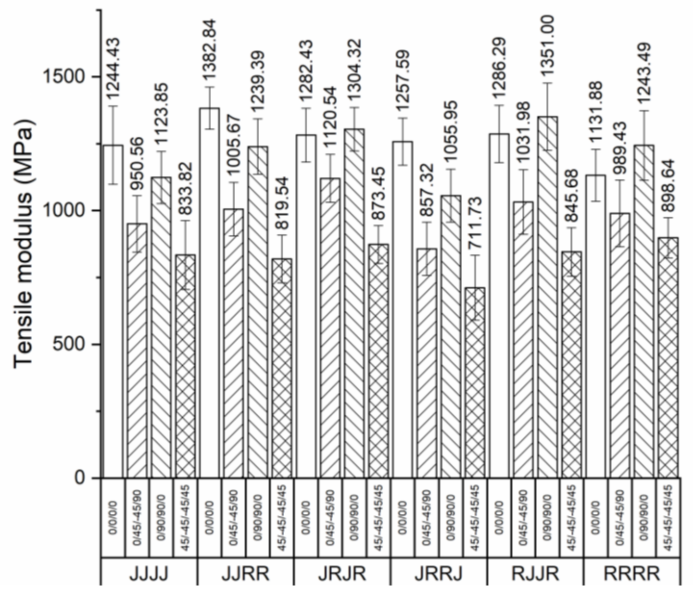

Figure 3. Effect of fabric orientations on tensile modulus of jute/ramie composites.

3.2. Flexural properties
Result for flexural strength and flexural modulus for all the composite samples were presented in Figure 4 and Figure 5. Based on Figure 4, the result for average flexural strength shown that the monolithic composite for composite ramie is more excellent compared to the monolithic composite for jute composite. On the other hand, the value for hybrid jute-ramie composite is in between of monolithic jute and ramie composite. The influence of the layering sequence prevails in the hybrid composite sample. The result for flexural is depended on the stacking order and type of material reinforced [19]. The flexural strength is better for the composite sample with higher resistance at the outer layers. The fabric at the outer layer is acting as load carrier. In the current study, the woven ramie having is higher strength than woven jute. Therefore, the woven jute in the outer layer will yield more reduced flexural strength. On the other hand, the effect of fabric orientation is minimal on the flexural properties. The following trend is observed from the result of fabric orientation on the flexural strength such as [0°,45°/-45°/90°] > [0°/90°/90°/0°] > [45°/-45°/-45°/45°] > [0°/0°/0°/0°]. The composite with the fabric orientation of [0°,45°/-45°/90°] capable disperse load efficiently in the different directions.

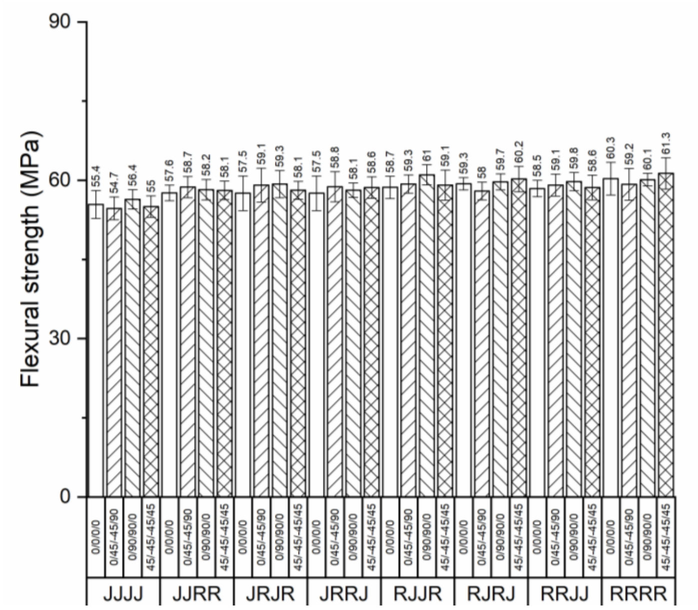

Figure 4. Effect of fabric orientations on flexural strength of jute/ramie composites.

Figure 5 displayed the result for flexural modulus for the composite sample. The high flexural modulus indicated the resistance to deformation of composite in bending. The flexural modulus for the ramie composite is more exceptional than jute composite. Flexural modulus for hybrid jute-ramie almost similar but the value obtained for composite JRJR and JRRJ lower than other types hybrid composite sample due to most massive yield displacement and most moderate maximum load. JRJR and JRRJ composite have good ductility compared to the different hybrid composite samples. In term of fabric orientation, the performance of the flexural modulus increases via following sequence such as [0°/0°/0°/0°] > [0°,45°/-45°/90°] > [0°/90°/90°/0°] > [45°/-45°/-45°/45°].

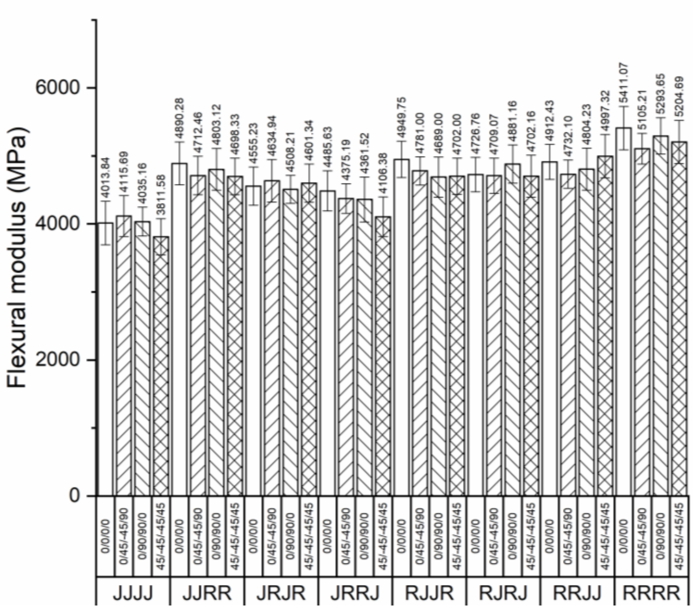

Figure 5. Effect of fabric orientation on the flexural modulus for composite samples.

3.3. Impact properties

On overall, the impact damage cause complete penetration on the composite samples. On the other hand, Figure 6 shows the effect of different fabric orientation and stacking sequence for monolithic and hybrid composite for jute and ramie on the impact properties. The data obtained from the Charpy impact test give an information about the energy absorption capability of composite samples [20]. The result of the impact testing yields average value of 73 KJ/m ± 1.472. The maximum value obtained from the sample of JRRJ [0°/0°/0°/0°] with value of 75.1 KJ/m meanwhile the minimum value is attained by composite sample of JRJR [0°/45°/-45°/90°].

As seen in Figure 6, the value obtained for impact strength is almost similar regardless the type of woven content, fabric orientation and stacking sequence. Nevertheless, RRRR composite sample produce lower average value of impact strength than JJJJ due to the brittle behavior. Average the value obtained from the orientation angle of [0°/0°/0°/0°] and [0°/90°/90°/0°] are more significant compared to the direction of [0°/45°/-45°/90°] and [45°/-45°/-45°/45°].

The 0° laminate and cross ply have better fibre resistance that restrict the fracture, debonding to occur. The energy dissipates efficiently via fibre pull out from the matrix composite. Number of factor influence the performance of impact strength of the composite sample that include weight/volume fraction, geometry and fibre and fibre orientation [21, 22]. As highlighted by [23], there are two factor which greatly influence impact properties which is interlaminar and interfacial adhesion. The variation of total weight contents in the composite sample altering the result of the impact strength. The appearance of the void content due to poor adhesion between fibre and matrix also deters the performance of hybrid. The void content reduces the resin rich area which limits the energy absorption capability.

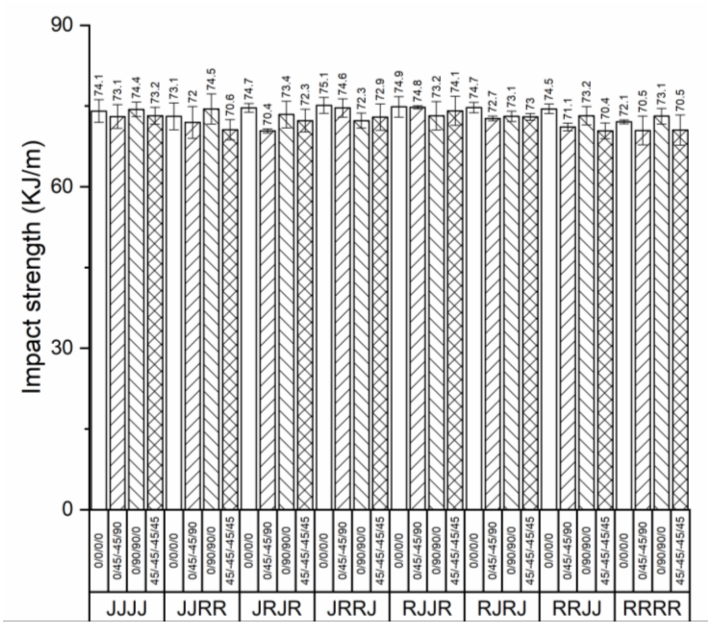

Figure 6. Effect of fabric orientation on the impact strength for composite samples.

3.4. Scanning electron microscopy (SEM)

Scanning electron microscopy (SEM) micrographs the fractured sample of tensile test has shown in Figure 7a – 7d. In most of the cases, impact damage on the composite caused matrix cracking, fibre fracture, and delamination [24]. Image in Figure 7a represent the SEM image for a composite sample of RJJR in the direction of [0°/0°/0°/0°]. In general, all the woven fabric is tightly covered by the UPE, which can hold the fibre in position. As a result, less fibre pulls out present in the surface of the

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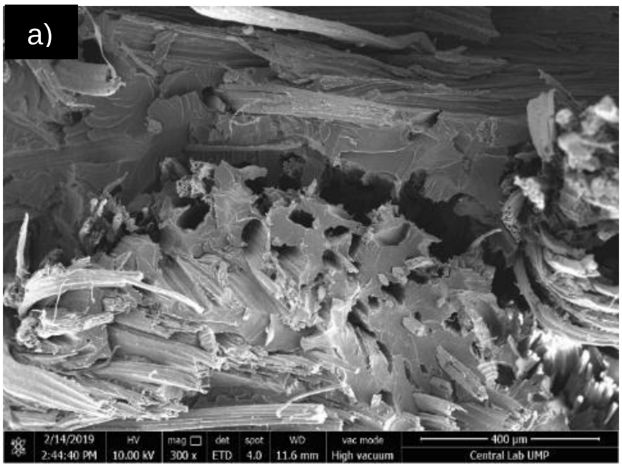
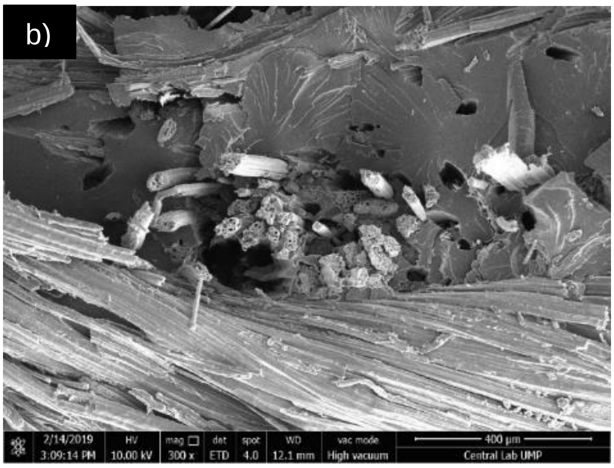
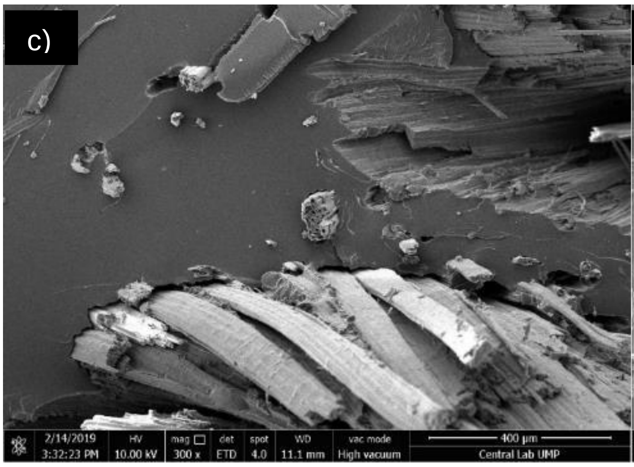
composite, which indicating strong interfacial adhesion between woven fabrics with UPE resin. However, the appearance of hollow still exists as in image 7a and 7b that caused by the separation of the yarn fibre with the UPE resin. As observed from image 7a, RJJR has many perforations, matrix crack and fibre fracture. The similar feature also is seen in image 7b, which represent the composite sample in the direction of [0°/90°/90°/0°]. The debris of resin can be seen on the surface of RJJR and RRRR composite. Unlike image 7a and 7b, the image of 7c, which represents composite JRRJ has a clean surface. Also, no fibre pull-out is visible in image 7c, which is the proof for lesser extensibility for yarn fibre in the woven fabric when the tensile loading is applied. This is proof that the composite of JRRJ is more brittle. Nevertheless, the fractured fibre is seen on the surface. The image 7d is represented composite JJJJ with fabric orientation of [0°/45°/-45°/90°]. Unlike image 7a and 7b, the composite sample of JJJJ is cleaner and less appearance of voids.



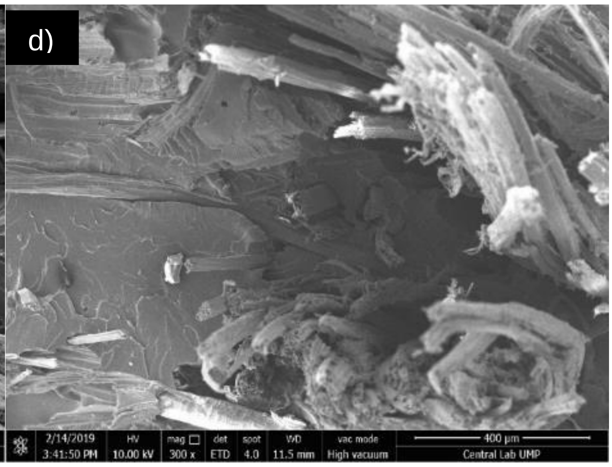
RJJR 0°/0°/0°/0°



RRRR 0°/90°/90°/0°



JRRJ 45°/-45°/-45°/45°



JJJJ 0°/45°/-45°/90°

Figure 7. Fracture surface of tensile test.

4. Conclusion

In the study, the effect orientation and stacking sequence on the tensile, flexural and impact testing for 4 layers woven jute, woven ramie and hybrid woven jute-ramie reinforced UPE resin was discovered. The following key finding was observed in the study.

- The result of the tensile strength and tensile modulus depended on to the orientation. The influence of the stacking sequence on the tensile properties is minimal. Tensile strength is

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excellent when arranged to cross-ply laminated. For the tensile modulus, the value is lower for the composite sample when arranged in the direction of angle-ply and quasi-isotropic.

- The effect of fabric orientation is lesser than the effect of stacking sequences in term of flexural strength. No exact trend for composite sample in the result of flexural modulus. As observed, the value of flexural modulus increases when arranging as the following sequence: angle-ply<cross ply< quasi-isotropic < 0° laminated
- Impact strength of the composite sample exhibit similar behaviour as flexural strength. The impact strength improved significantly when arranged in the orientation of the 0° laminated and cross-ply laminated.

The study about the influence of the layering size, stacking sequence and fabric orientation should be extended to the dynamic mechanical properties.

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References

[1] Hamdan M H M, Siregar J P, Cionita T, Jaafar J, Efriyohadi A, Junid R and Kholil A 2019 Water absorption behaviour on the mechanical properties of woven hybrid reinforced polyester composites *Int J Adv Manuf Technol* **104** 1075–86
[2] Khan G M A, Terano M, Gafur M A and Alam MS 2016 Studies on the mechanical properties of woven jute fabric reinforced poly(l-lactic acid) composites *J King Saud Univ - Eng Sci.* **28** (1) 69-74
[3] Bin Saiman M P, Wahab B, Saidin M, Wahit B and Uzir M 2014 The Effect of Alkali Treatment on Impact Strength of Woven Kenaf Reinforced Unsaturated Polyester Composite using Vacuum Infusion Process *Appl. Mech. Mater.* **564** 422-7.
[4] Achukwu E O, Dauda B M and Ishiaku U S 2015 Effects of Fabric Pattern on the Mechanical Properties of Cotton Fabric/Unsaturated Polyester Composites *Br J Appl Sci Technol* **11** 1–11
[5] Alavudeen A, Rajini N, Karthikeyan S, Thiruchitrambalam M and Venkateshwaren N 2015 Mechanical properties of banana/kenaf fiber-reinforced hybrid polyester composites: Effect of woven fabric and random orientation *Mater Des* **66** 246–57
[6] Aisyah H A, Paridah M T, Khalina A, Sapuan S M, Wahab M S, Berkalp O B, Lee C H and Lee S H 2018 Effects of Fabric Counts and Weave Designs on the Properties of Laminated Woven Kenaf/Carbon Fibre Reinforced Epoxy Hybrid Composites *Polymers* **10** 1320
[7] Goutianos S, Peijs T, Nystrom B and Skrifvars M 2006 Development of flax fibre based textile reinforcements for composite applications *Appl Compos Mater* **13** 199–215
[8] Ma H, Li Y and Wang D 2014 Investigations of fiber twist on the mechanical properties of sisal fiber yarns and their composites *J Reinf Plast Compos* **33** 687–96
[9] Misnon M I, Islam M M, Epaarachchi J, Lau K-T and Wang H 2016 Fabric Parameter effect on the mechanical properties of woven hemp fabric reinforced composites as an alternative to wood product *Adv Res Text Eng* **1** (1) 1004
[10] Jayabal S, Natarajan U and Sathiyamurthy S 2011 Effect of glass hybridization and staking sequence on mechanical behaviour of interply coir–glass hybrid laminate *Bull Mater Sci* **34** 293–8
[11] Rama Mohan Rao A and Arvind N 2007 Optimal stacking sequence design of laminate composite structures using tabu embedded simulated annealing *Struct Eng Mech* **25** 239–68
[12] Cherif Z E, Poilâne C, Vivet A, Ben Doudou B and Chen J 2016 About optimal architecture of plant fibre textile composite for mechanical and sorption properties *Compos Struct* **140** 240–51
[13] Mönicke A, Katajisto H, Kere P, Palanterä M and Perillo M 2007 Engineering oriented formulation for laminate lay-up optimization In: *Proc. ETDCM8-8th Semin. Exp. Tech. Des. Compos. Mater*. 3–6

[14] Akkerman R 2005 Laminate mechanics for balanced woven fabrics *Compos Part B Eng* **37** 108–16
[15] Salman S D, Leman Z, Sultan M T H, Ishak M R and Cardona F 2016 The effects of orientation on the mechanical and morphological properties of woven kenaf-reinforced poly vinyl butyral film *BioResources* **11** 1176–88
[16] Almansour F A, Dhakal H N and Zhang Z Y 2018 Investigation into Mode II interlaminar fracture toughness characteristics of flax/basalt reinforced vinyl ester hybrid composites *Compos Sci Technol* **154** 117–27
[17] Ismail A E, Aziz C A and Aswadi M 2015 Tensile strength of woven yarn kenaf fiber reinforced polyester composites *J Mech Eng Sci* **9** 1695–704
[18] Yong C K, Ching Y C, Chuah C H and Liou N-S 2015 Effect of fiber orientation on mechanical properties of kenaf-reinforced polymer composite *BioResources* **10** 2597–608
[19] Tomašić D, Ilinčić P and Pilipović A 2015 Influence of layers lay-up on the mechanical properties of hybrid composites in field of aeronautics *Polimeri* **36** 5–10
[20] Yahaya R, Sapuan S M, Jawaid M, Leman Z and Zainudin E S 2015 Effect of layering sequence and chemical treatment on the mechanical properties of woven kenaf–aramid hybrid laminated composites *Mater Des* **67** 173–9
[21] Chandrasekar M, Ishak M R, Jawaid M, Sapuan S M and Leman Z 2018 Low velocity impact properties of natural fiber-reinforced composite materials for aeronautical applications In: *Sustain. Compos. Aerosp. Appl.* Elsevier pp 293–313
[22] Khalili S M R, Farsani R E and Rafiezadeh S 2011 An experimental study on the behavior of PP/EPDM/JUTE composites in impact, tensile and bending loadings *J Reinf Plast Compos* **30** 1341–7
[23] Yahaya R, Sapuan S M, Jawaid M, Leman Z and Zainudin E S 2016 Effect of fibre orientations on the mechanical properties of kenaf–aramid hybrid composites for spall-liner application *Def Technol* **12** 52–8
[24] Ullah H, Harland A R and Silberschmidt V V 2014 Evolution and interaction of damage modes in fabric-reinforced composites under dynamic flexural loading *Compos Sci Technol* **92** 55–63