Mechanical, Thermal and Instrumented Impact Properties of Bamboo Fabric-Reinforced Polypropylene Composites

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SUMMARY

Many automotive companies are experimenting with natural fibres as a substitute for glass fibres in polymer composites, especially polypropylene (PP) based composites. PP composites reinforced by plain woven bamboo fabric have recently been widely investigated. Bamboo in woven fabric form embedded in the polymer results in easier material handling during production and reduction in the manufacturing cost of the composites. In the current study, the performance of twill-weave bamboo fabric-reinforced PP composites, which were fabricated using a compression moulding method, was evaluated. The mechanical, thermal and impact performances of the bamboo fabric-reinforced PP (BPP) composites were evaluated in comparison to those of PP, at various bamboo contents and stacking sequences. The incorporation of bamboo fabric resulted in the improvement of tensile strength, tensile modulus, flexural strength, flexural modulus and Charpy impact strength of PP by 238%, 110%, 180%, 170% and 160%, respectively. The integration of bamboo fabric slightly increased the melting temperature and the degree of crystallinity of the composites. A 40% decrease in the heat of fusion of the composites was observed compared to that of PP. Impact tests were also conducted using an instrumented drop weight impact test system. The perforation impact energy, peak load and energy absorbed of the composites increased when the bamboo content was increased. The perforation impact energy was at 55 J for the BPP50% composite, compared to that of neat PP at 20 J. The crack damage in the composites was also reduced with the presence of fabric reinforcement. These results indicate that bamboo fabric is truly a new contender for developing excellent and economical light-weight composites as interior components in automobiles.

Keywords: Bamboo fabric, Twill-weave, Polypropylene, Compression moulding, Mechanical properties, Thermal properties, Instrumented drop weight impact

1. INTRODUCTION

Natural fibre reinforced composites (NFRCs) based on fabric reinforcement are popular because of their superior strength and stiffness to weight ratio[1]. When compared to the unidirectional composites, these composites also have more balanced properties in the fabric plane and higher impact resistance[2,3]. These composites are primarily used in the aerospace, marine, defence, land transportation, construction, and power generation sectors[4] as load bearing materials. Furthermore, fabric reinforcements have strength and stiffness, good extensibility, easy manufacture-ability, better energy absorption ability that exceeds those of conventional short fibres thus proving its suitability for the manufacture of structural parts[5,6]. Woven fabric also allows the control of fibre orientation and quality, good reproducibility and high productivity[7]. Past studies usually focus on the use of common natural fabric such as flax, hemp, and jute as reinforcement materials in composites. Several researchers have reported an improvement in mechanical properties, compared to neat matrix with the addition of natural fabric[6,8-15]. These investigations are motivated by the high demand of composites in various applications[16].

Apart from these common natural fibre materials, bamboo has recently emerged as a source of natural fibre with great potential to be used in the manufacture of NFRC[17]. Bamboo fibres have been used in diverse industries such as textiles, paper, furniture and construction[18]. It is believed that bamboo in the fabric form will be able to compete with other more common natural fibres like flax, hemp, jute, sisal and kenaf in automotive industry in the coming years. The research to date

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has tended to focus on short bamboo fibres than fabric in the NFRC, in terms of their mechanical properties, the interface behaviour, composite processing, surface modification and hybridisation with synthetic fibres[19]. So far, however, there has been little discussion about the usage of bamboo fabric as reinforcement. Apart from few researchers[20-24] reported earlier, there is a general lack of research in bamboo fabric composites and the literature that is available has been limited to plain weave.

This research focuses on the significance of twill woven bamboo fabric as reinforcement in terms of mechanical performance, impact resistance and energy absorption ability. The aim of this research is therefore trying and establishing an evaluation towards potential of BPP composites in automotive interior parts. The influence of bamboo weight content and stacking sequence on mechanical performance, thermal and instrumented impact resistance of the BPP composites are investigated. This research should make an important contribution to the field of bamboo fabric as an alternative reinforcement in NFRC.

2. MATERIALS AND METHODS

The raw materials used to fabricate the BPP composites in this work are polypropylene and woven bamboo fabric. The matrix used was polypropylene (PP) random copolymer, Moplen RP241G, manufactured by Lyondell Basell Industries and supplied by Field International Ltd., Auckland, New Zealand. The PP sheets have a nominal thickness of 0.38 and 0.58 mm. 100% bamboo fabric twill-woven was obtained from Xinchang Textiles Co. Ltd, Guangzhou, China. The bamboo fabrics with a width of 1500 mm and weight of 220 gsm were used, having specification of 20*20 tex and 108*58 per square inch for yarn count and density, respectively.

2.1 Fabrication of Composites

The compression moulding process was used in this research to produce composite laminates. The closed mould was heated until the required temperature of 185 °C was reached. The ply stack that had been dried earlier was placed in the mould cavity for pre heating, and the loaded mould was continuously heated for about five minutes without pressure to allow the polypropylene to start melting and percolating through the fibres. At this point, the consolidation pressure of 0.80 MPa was applied and held steady for five minutes. During this impregnation stage, pressure was applied to force the molten polymer into the fabrics while removing the excess air and volatiles. During the cooling period, the pressure applied was maintained until the temperature of the mould cavity dropped down to 40 °C or lower when the laminate could be removed from the mould. The effects of processing parameters such as consolidation temperature, consolidation pressure and fibre weight fraction, used for manufacturing the composites, were optimised in the previous reported work[24]. The optimisation stage was carried out with the use of Taguchi method in order to improve the quality of the composites. Three main configurations were manufactured to investigate the effects of the bamboo content in the mechanical, thermal and impact properties, as shown in **Table 1**. The arrangements of the bamboo fabric and PP sheets in ply stacking are shown in **Figure 1**. The BPP composites with various bamboo contents were stacked in all warp direction.

For the study of stacking sequences, the weight fractions of the composites were kept constant at about 50 wt.%. During the overlapping of the fabric pieces, the warp ends or weft picks in each layer were kept parallel to each other. Four types of stacking sequences were manufactured namely; www for all warp direction, fff for all weft direction, wfw for $(\text{warp/weft/warp})_s$ and fwf for $(\text{weft/warp/weft})_s$ respectively as tabulated in **Table 2**. The schematic diagram of the composites is shown in **Figure 2**.

2.2 Tensile, Flexural and Impact Testing

The tensile properties of the composite samples were obtained using an Instron 5567 testing machine with a 30 kN loading capacity according to ASTM 3039. A crosshead speed of 2 mm/

Figure 1. Schematic diagram of the stacking for BPP composites (a) BPP30%, (b) BPP40% and (c) BPP50%

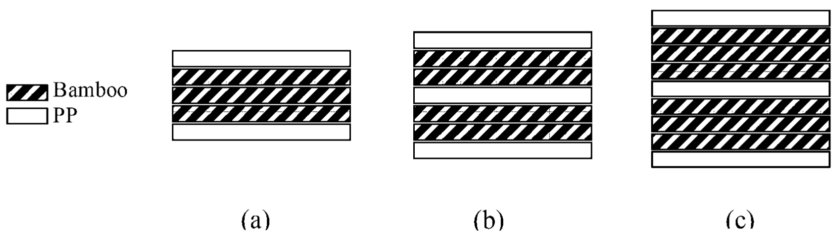


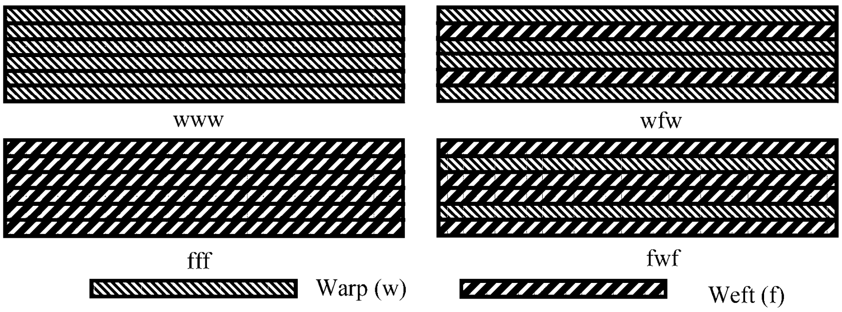
Table 1. Compositions of the BPP composites fabricated

Composite	Bamboo fabric		Polypropylene (PP)	
	W_f (%)	V_f (%)	W_f (%)	V_f (%)
BPP30%	30.0	22.6	70.0	77.4
BPP40%	40.0	29.0	60.0	71.0
BPP50%	50.0	39.1	50.0	60.9

Table 2. Sample code and its stacking sequence for the BPP composites fabricated

No.	Sample code	Bamboo fabric stacking sequence lay-up
1	www	PP/www/PP/www/PP
2	fff	PP/fff/PP/fff/PP
3	wfw	PP/wfw/PP/wfw/PP
4	fwf	PP/fwf/PP/fwf/PP
w: Warp direction , f:Weft direction, PP: Polypropylene		

Figure 2. Schematic diagram of the BPP composites with different stacking sequences



min was used. Seven specimens were prepared for each sample and were tested in order to obtain at least five legitimate test data. The flexural properties of composite samples were obtained according to ASTM 790-10 Procedure B using an Instron 5567. The test with a loading span of 80 mm and a crosshead speed of 10 mm/min, were carried out on seven specimens to acquire average test data. To determine the impact resistance of the composites, tests were performed according to ASTM D6110 (Charpy Pendulum Impact Tester, CEAST) using an impact hammer of 5.5 J. Seven specimens were prepared for each sample and were tested in order to obtain at least five legitimate test data.

2.3 Differential Scanning Calorimetry (DSC)

Differential scanning calorimetry (DSC) analysis was performed to determine the melting point and crystallinity of the PP and composite sheets using DSC Q1000. The samples were cut from the cross-sectional area of the composite laminates to ensure the samples taken consisting of both fibres and matrix. The measurement was conducted on a 9 mg sample in an open aluminium pan under nitrogen atmosphere at 45 ml/min flow rate in a heating range and rate of 20 – 250 °C and 10 °C/min, respectively. The degree of crystallinity can be determined from the heating fusion of normalised to that of PP using to the following equation:

$$X_c = \frac{\Delta H_m}{\Delta H * \left(1 - W_f\right)} x100\% \tag{1}$$

where ΔH_m is the heat of fusion of the samples, ΔH is the heat of fusion of a 100% crystalline PP is 207 J/g and W_f is the weight fraction of the bamboo fabric in the composites.

2.4 Instrumented Drop Weight Impact Test

Impact test was also conducted using an instrumented drop weight impact test system (DYNATUP 8250) on samples size of 150 x 100 mm. The test was performed using a drop weight with a steel (Thyrodur 2550) hemispherical striker tip of 16 mm diameter. Different impact energies of 20, 25, 35, 45 and 55 J were applied to the composites. The energy was obtained by changing the drop height, with constant impactor mass of 9.745 kg. For every type of laminate three specimens were tested. The specimen was tested using a test rig with a 40 mm diameter ring clamp. The impact data was generated by the data system in terms of force-time, energy-time, force-displacement graphs which was displayed from the output, along with the computed values of input energy, impact velocity, peak load, total energy, maximum energy at peak load, etc.

3. RESULTS AND DISCUSSION

3.1 Mechanical Properties

Figure 3 compares the results obtained from the tensile test of BPP composites (with stacking sequence of www). A clear pattern of increasing of both tensile strength and its modulus of the neat PP after reinforcing with bamboo fabric can be seen. When increasing the fabric content from 30 wt.% to 50 wt.%, the tensile strength increases linearly, however, there are not much changes in the tensile modulus, when compared between the BPP composites. Interestingly, there is a significant increment at the 50 wt.% of bamboo content, where the tensile strength and its modulus were increased 238% and 110% compared to neat PP, respectively.

The effects of bamboo content as fabric reinforcement in neat PP were determined. This study found that the tensile properties increased with the increasing of the bamboo content. This finding is in agreement with findings of Porras *et al.* and Rawi *et al.*[20-22]. The result in this study can be explained by the fact that the addition of fabric increases the tensile strength and modulus of the composites because a uniform stress distribution from the polypropylene is transferred to the bamboo fabric. The modulus of the composites is strongly dependant on the modulus of the fibre and the matrix, the fibre content and orientation. The tensile properties of BPP30% in this study were compared with the work on cotton fabric[25] and jute fabric[12]. It was found that the tensile strength in this study was higher than those of cotton and jute fabric PP composites, approximately at 42% and 25% increment, respectively. At the 40 wt.% fibre loading, the BPP40% exhibited about 30% higher improvement of tensile strength compared to the flax fabric PP composites observed by Kannan *et al.*[14].

The effects of different lay-up of stacking sequence of the bamboo fabric on the mechanical properties of the BPP composites are presented in **Figure 4**. The figure shows that the mechanical properties of BPP composites are superior to neat PP regardless of the stacking sequence. The tensile strength and modulus of www were 238% and 110% higher than those of neat PP. The BPP composite with fff stacking sequence showed the least improvement in tensile strength and modulus at 119% and 60%, respectively. However, the tensile properties of fwf and wfw stacking sequences were close to each other. The tensile properties of the wfw stacking sequences were almost similar to the www. Thus it can be concluded that the www, all warp stacking sequence would be a better choice to reinforce the composites. However, further research on this factor should be undertaken to examine the effect of different linear densities and weave type (such as plain or satin weave) of bamboo fabric, before the association between the fabric characteristics and tensile properties is more clearly understood.

The effects of bamboo content on the flexural properties were studied. **Figure 5** provides the flexural properties for the BPP composites (with stacking sequence of www). These results show a similar pattern to those for tensile properties. There was a positive increment of flexural strength and modulus of neat PP after reinforcement with at least 30 wt.%

Figure 3. Tensile properties of PP and the BPP composites (with stacking sequence of www) with different bamboo content (wt.%): a) tensile strength and b) tensile modulus

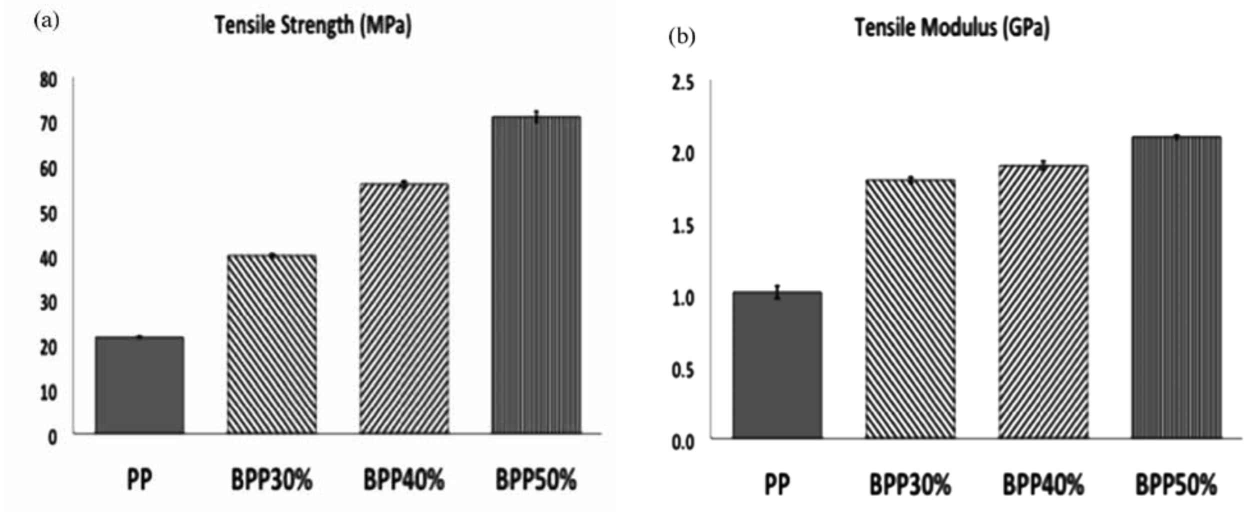
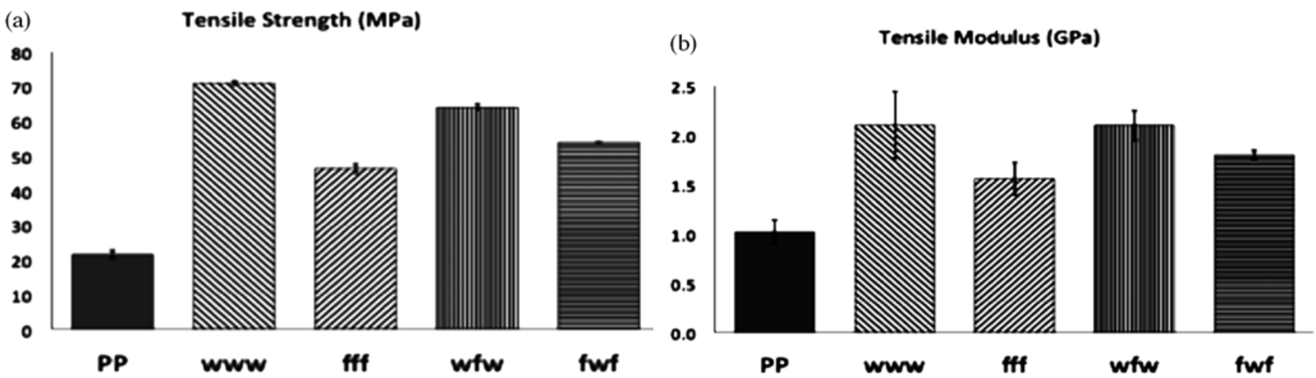


Figure 4. Tensile properties of PP and the BPP50% composites at different stacking sequences a) tensile strength and b) tensile modulus



of bamboo. An improvement of 100% was observed for BPP30% compared to neat PP. Upon increasing the bamboo content up to 50 wt.%, the flexural strength and modulus sharply rose to 70 MPa and 2.7 GPa, respectively. A 180% increase of strength over the neat PP. The highest bamboo content has a remarkable effect on the flexural properties.

Figure 6 shows a comparison of flexural properties with different stacking sequences. The www stacking sequence showed the highest performance. Interestingly, the pattern was exactly the same as the tensile properties. The flexural strength and modulus of neat PP were increased by 180% and 160% for the www stacking sequences, respectively. The flexural strength and modulus of the www stacking sequences were 70 MPa and 2.7 GPa respectively. The stacking sequence of the fff showed the least improvement of flexural strength and modulus, 128% and 97%, when compared to pure PP.

Flexural properties are defined as a material's ability to resist deformation under load. The findings of the current study are consistent with those Rukmini *et al.*[25] who found a remarkable improvement of flexural properties of cotton fabric reinforced PP over the neat polymer used. These results may be due to the fabric reinforcement restricting the bending movement of the PP matrix. The flexural strength and modulus increased with an increase in bamboo fabric loading. These results also agreed well with those observed in the literature using jute fabric PP[13]. A similar trend was observed for flexural properties with that of tensile properties. These results demonstrate the advantages of using of bamboo fabric.

The effect of bamboo fabric content (with stacking sequence of www) on the impact property is presented in **Figure 7**. It is observed that the addition of the bamboo fabric increased the impact energy of the neat PP, by 54% with at least 30 wt.% of bamboo

Figure 5. Flexural properties of PP and the BPP50% composites (with stacking sequence of www) with different bamboo content (wt.%): a) flexural strength and b) flexural modulus

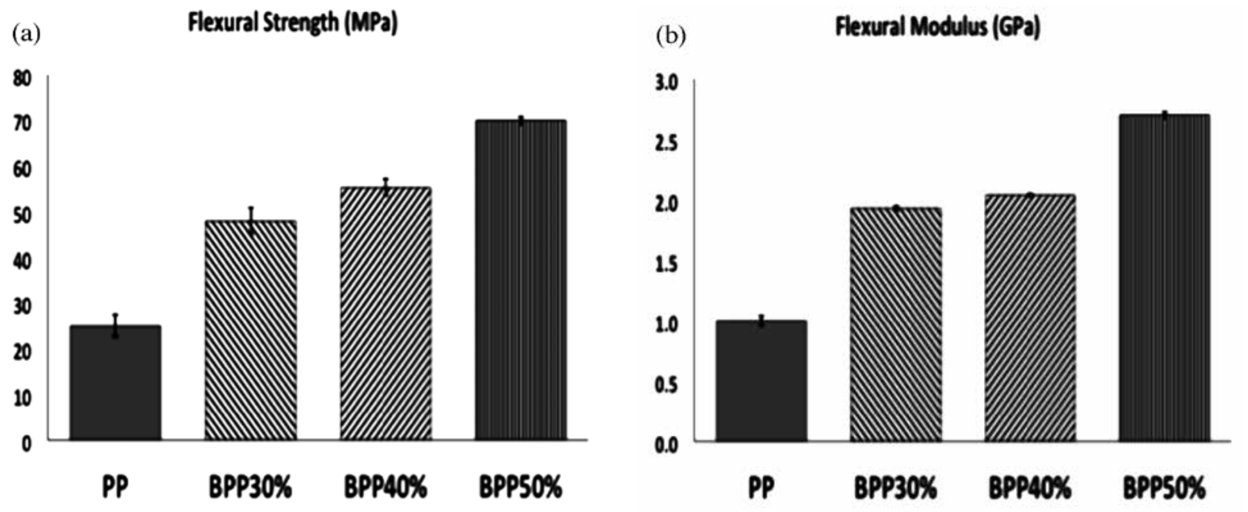
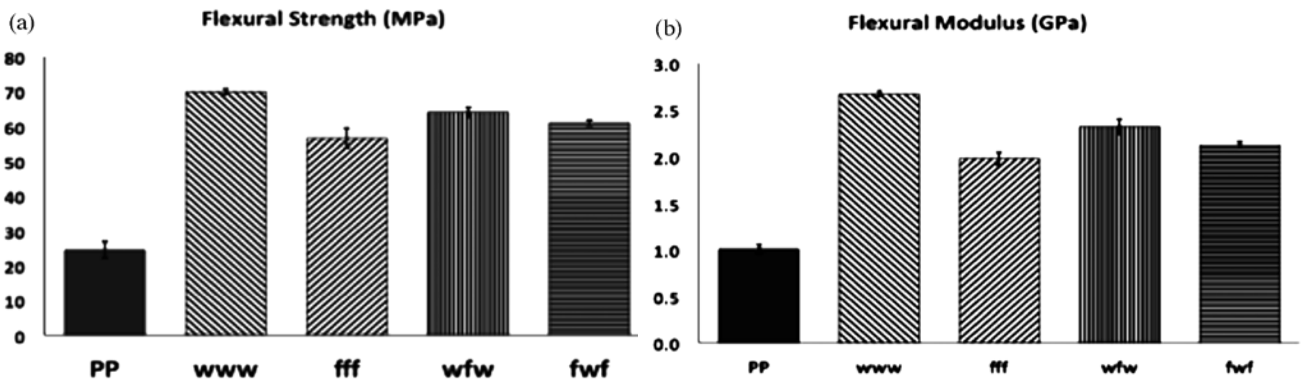


Figure 6. Flexural properties of PP and the BPP50% composites (with stacking sequence of www) at different stacking sequences: a) flexural strength and b) flexural modulus



reinforced. Thus, it was further increased by 160% with addition of 50 wt.% bamboo. The impact energy improves with the increasing bamboo content. A similar pattern was observed with as the results of the tensile and flexural properties.

The impact properties of BPP composites at different stacking sequences are compared in **Figure 8**. It is interesting to note that there is an improvement in the impact resistance of neat PP, regardless of stacking sequences. There is a similar pattern of improvement in the tensile and flexural properties. There was a significant increase over neat PP after reinforcing it with bamboo fabric. The impact energy value of the www lay-up showed the maximum energy of 530.9 J/m, with all warp stacking sequence. The impact energy of the wfw was approximately of 524.4 J/m, while for the fwf and fff stacking sequences, the figure shows impact energies of 398.2 J/m and 334.3 J/m, respectively. The impact energy increased to 160% of the neat PP for www. However, the impact energy increased to 63% after reinforcing it with the all weft direction.

The impact strength becomes very essential in service conditions, because crack formation due to sudden loads. The impact strength of a composite depends upon many factors such as the toughness of the reinforcement, the nature of the interfacial region, the geometry of the composites, and the test conditions[25]. It is expected that the bamboo fabric improves the impact resistance of the neat PP since the reinforcement plays an important role, acting as a medium for stress transfer during crack formation. There was an improvement in the impact energy of the neat PP with reinforcement because the bamboo fabric helped to absorb energy, which the neat PP did not. These similar trends of impact property were observed in the literature[4,27].

The usage of bamboo fabric as the reinforcement gives more advantages in comparison with the other types of fibre reinforcement. This twill-weave fabric offers superior wet out and drapeability over the plain weave with only a small reduction in stability. The crimp decreases the strength of the yarn and of the fabric[28]. With reduced crimp, the twill-weave fabric in this study also has a smoother surface and slightly higher mechanical properties compared to the plain-weave. It is of interest to highlight another possible explanation for this result as reported by Huang *et al.*[29] that in twill weaves, the yarn interlacing points reduce the tendency of yarns to bend. When the twill-weaved sample is being stretched, the yarn, which is in a relatively straight form in the twill weave, contributes more to bearing the load and thus results in greater tensile strength.

3.2 Thermal Properties

The melting behaviours of composites studied using DSC, can be seen in **Figure 9**. The numerical data for the composites from the DSC curves is summarised in **Table 3**. The melting temperature of PP was about 149.8 °C. The incorporation of bamboo fabric increased the melting temperature of the composites. The melting temperatures of BPP composites were approximately of 154 – 155 °C, slightly increased compared to neat PP. A 40% decrease in the heat of fusion, ΔH_m of the BPP40% and BPP50% composites compared to that of the PP. It decreased with the addition of more

Figure 7. Impact properties of PP and the BPP composites with different bamboo content (wt.%)

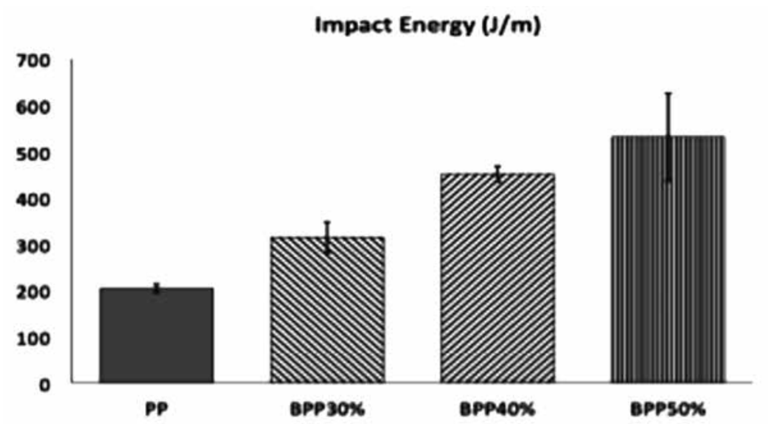
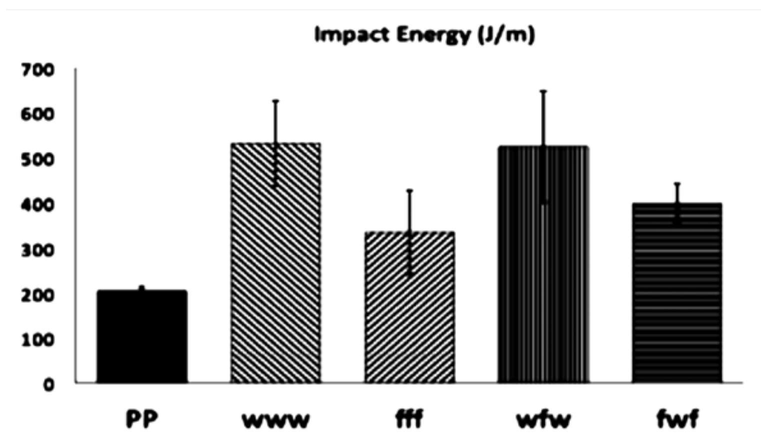


Figure 8. Impact properties of PP and the BPP50% composites at different stacking sequences



bamboo fabric. The results also show that the degree of crystallinity of the BPP composite was slightly increased, relative to that of the PP.

The incorporation of bamboo fabric increased the melting temperature of the composites in this study. The inclusion of these fibres into PP seems to restrict the mobility of the polymer chain, resulting in higher melting temperature[29]. A small weight loss was observed as the moisture content obtained, in agreement with measurement of bamboo fabric's moisture content. In case of BPP composites, a higher thermal stability was displayed compared with PP, which may be due to the increase in the molecular weight by a crosslinking reaction between PP matrix and bamboo fibre or molecular chain extension of the matrix itself.

3.3 Instrumented Impact Testing

Table 4 shows the impact properties of the BPP composites at various bamboo weight fractions when tested using a ring clamp. The perforation impact energy increases when bamboo content is increased. The perforation impact energy for the BPP30%, BPP40% and BPP50% composites are 35 J, 45 J and 55 J respectively. The peak load and energy absorbed by the composites increase when the bamboo content is increased. As the bamboo content increased, the peak force increased; however, there was little difference in the peak force between the BPP40% and BPP50% composites. As the bamboo content increased the amount of energy has absorbed and displacement to achieve maximum load increased up to 40% bamboo content but then decreased at 50% bamboo content. Little difference was observed in the amount of energy absorbed in the BPP40% when compared to BPP50%. **Figure 10** shows the typical impact force *versus* displacement of BPP composites with different bamboo weight fractions. It

Table 3. Comparison of thermal properties of BPP composites and PP from DSC analysis

Samples	Melting temperature (T_m) (°C)	Crystallisation temperature (T_c) (°C)	Heat of fusion ΔH_m (J/g)	Crystallinity (X_c) (%)
PP	150	110	45	22
BPP30%	155	112	39	27
BPP40%	155	112	25	20
BPP50%	156	113	24	24

Table 4. Impact properties of the BPP composites with different bamboo content (wt.%) at different applied energies and tested using the ring clamp

Bamboo contents	Applied energy (J)	Peak load (kN)	Energy absorbed (J)	Displacement to max. load (mm)	Impact responses
BPP30%	35	2.3±0.2	10±1.0	13.1±0.2	Perforation
BPP40%	45	2.6±0.1	15±1.0	15.9±0.1	Perforation
BPP50%	55	2.7±0.9	14±1.0	13.5±0.4	Perforation

Figure 9. DSC thermograms of PP and the BPP composites

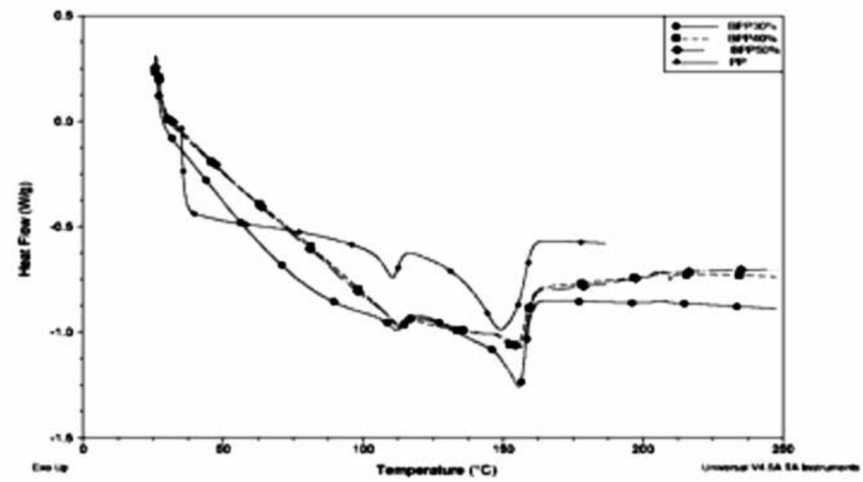


Figure 10. Typical impact force *versus* displacement of the BPP composites at different weight fractions

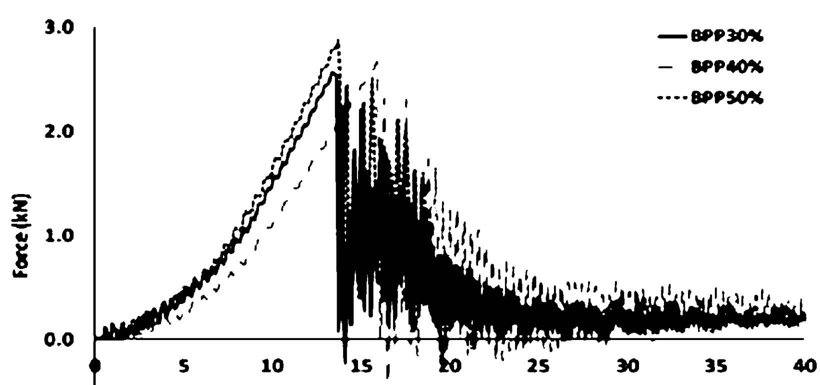


Figure 11. Photos of impact damage in the neat PP impacted at 20 J

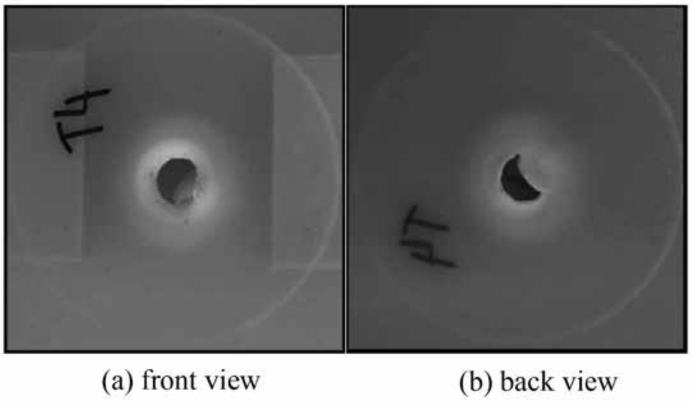
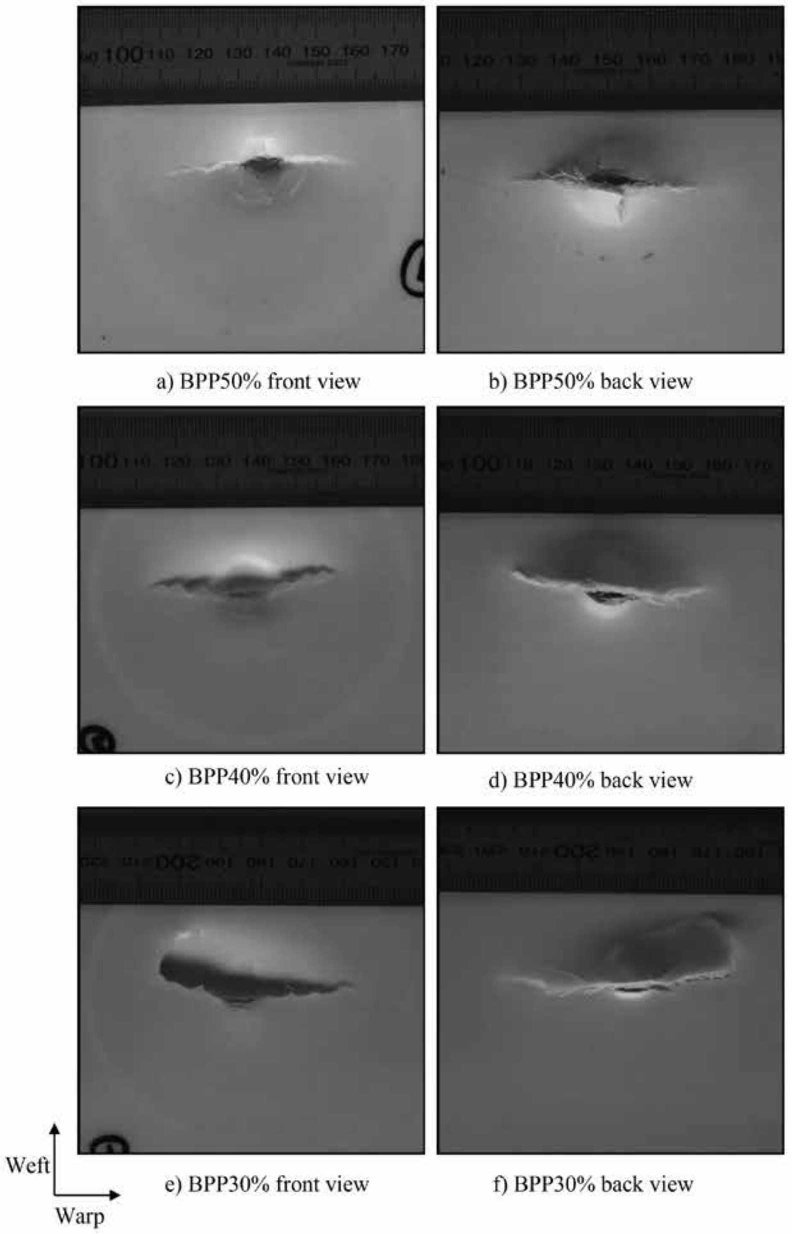


Figure 12. Photos of damage patterns (front and back view) in the BPP composites with different bamboo content (wt.%) impacted at perforation energy



can be seen again that the highest peak is at BPP50%; however more deflection occurred with the BPP40% than that with other composites.

Figure 11 shows the impact damage pattern of a pure PP sample using ring clamp, which was impacted at perforation energy of 20 J. The fracture appearance of the PP sample clearly shows the radial cracks formation. The punched hole has a diameter equal to the diameter of the striker. **Figure 12** shows the damage patterns of BPP composites at different weight fractions. The fracture area of the composites decreased as the bamboo content increased. The fractured area of the BPP30% was larger and has more cracked than the other composites. The damage modes of the BPP composites had fibre breakage and matrix cracks. The impact failure was profound at both sides for all the composites.

The impact resistance of the composites tested using a ring clamp for different stacking sequences are summarised in **Table 5**. A large difference in the impact properties can be seen between the www and wfw stacking sequences of the composites. The peak load and energy absorbed for BPP50% composites was higher when stacking sequences of wfw were used.

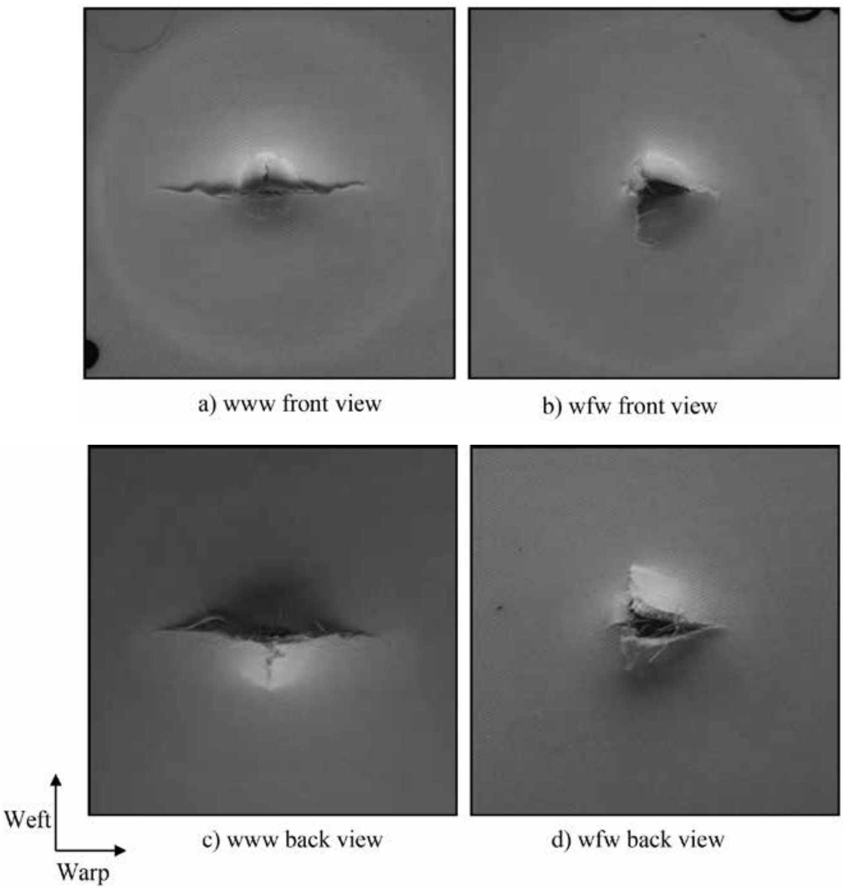
Figure 13 shows the impact damage patterns for the BPP composites, impacted at the perforation energy of 55 J at the www and wfw stacking sequences. There is a clear difference in the damage behaviour between the www and wfw stacking sequences. The damage propagates along the warp direction for the www specimen. The damage for the wfw specimens initiated along the warp direction, then propagated along the weft direction. Less crack propagation occurred in the wfw specimens.

High impact resistance and energy absorption capability are important criteria in designing an effective NFRC for automotive interior applications.

Table 5. Impact properties of the composites at perforation energy using the ring clamp for different stacking sequences

Specimens	Stacking sequence code	Peak load (kN)	Energy absorbed (J)	Displacement to max. load (mm)
BPP50%	www	2.7±0.9	14±1.0	13.5±0.4
	wfw	3.3±0.5	18±0.5	15.1±0.2

Figure 13. Photos of damage patterns (front and back view) in BPP composites impacted at 55 J for different bamboo stacking sequences



The study of these properties using drop weight impact testing provided interesting insight into the capability of the BPP composites. The force in the BPP composites increased before dropping off. The gradual dropping off indicated crack propagation occurred and energy was then absorbed by the bamboo fabric. The impactor bounced back at energies lower than 55 J for the composites. Damage in the composites impacted at 25 J to 45 J was limited to small indentations at the point of impact. 55 J was required to perforate the specimens. These results indicate the greater impact load carrying ability of the BPP composites. This is because of greater stiffness and load bearing ability in the bamboo fabric compared to the pure PP. A larger damage area was associated with the increase in the applied energy. This is consistent with the findings elsewhere in the literature[31]. The fracture area of the composites decreased as the weight increased. The ductility of the PP matrix provided a delayed perforation and a plastic deformation occurred. The larger fracture area at the lower bamboo content than that of the higher content indicated the capability of plastic deformation in the crack propagation process was inhibited. The crack damage propagated in the composites was reduced with the presence of fabric reinforcement absorbing energy.

The higher applied impact energy required to perforate the BPP composite can be explained in terms of the fibre toughness. Woven fabric inhibits the initiation of interlaminar cracks. The fabric composites offer excellent resistance to impact damage through the cross-over points, which act as stress distributors. The impact loading applied on the fabric composites beyond the perforation threshold energy level produces crack initiation within the ply in the fabric composites which begins to propagate through the thickness, but has to cut through the fibre. Unless the energy available is high enough to fracture the fibre tow, the crack is arrested[32]. The PP also offers high toughness, enhancing the impact resistance of these composites.

In terms of the effect of various bamboo weight fractions, high impact energy was required to penetrate the composites as the bamboo content increased, showing the good impact resistance of bamboo fabric added to PP. This increase was attributed to the additional energy absorbing mechanism of fibre breakage which occurred in the composites. Yarn crimp may increase the impact resistance of the composites. According to Tan *et al.*[33] who studied the effects of yarn crimp on the impact response of woven fabric, crimping in yarns have an important effect on the fabric deformation to impact loading. When an impact load was applied on the fabric, the initial stage fabric deformation caused crimped yarns to straighten. Minimal resistance was met by the impactor. The fabric only started to resist the impactor when the yarns had straightened and started to stretch. Crimp can give rise to excessive transverse deflection and consequently increased impact resistance.

The highest energy absorbed and displacement occurred at 40 wt.% of bamboo content. Very little difference was observed in the amount of energy absorbed in the BPP40% when compared to BPP50%. It seems that at 40% fibre loading, the composites stored more energy than others. This pattern is in agreement with that Bledzki *et al.*[34] who studied the effect of impact energy at various fibre contents using abaca-PP and flax-PP composites in their research. In addition to the increase in the mechanical performance, it is reported that the energy absorbing capability of the composites increased with the use of fabric. Fabric is effective and widely used in high impact strength components.

4. CONCLUSIONS

The research has given an account of and the reasons for the potential use of bamboo fabric in NFRC. The study was undertaken to evaluate the effect of bamboo content and stacking sequence on the mechanical performance and impact resistance of the BPP composites. The results are significant at the 50 wt.% of bamboo contents, where the tensile strength and its modulus were increased 238% and 100% compared to neat PP, respectively. Similarly, the flexural strength and modulus contributed to about at least 170% increase over the neat PP when it sharply raised to 70 MPa and 2.7 GPa. One of the more significant findings to emerge from this research is that increase of about 40% of energy absorbed with the www compared to the fff composites. The study has demonstrated for the first time that impact damage resistance of bamboo twill-woven fabric composites using the drop weight impact test which also discussed the stacking sequences effect. The perforation impact energy, peak load and energy absorbed of the composites increased when the bamboo content was increased. The perforation impact energy was at 55 J for the BPP composite, compared to that of neat PP, at 20 J. The crack damage in the composites was also reduced with the presence of fabric reinforcement. This evidence suggests that the possibility that bamboo fabric can be potential used alternatively as greater impact resistance and higher energy absorption reinforcement in NFRC automotive interior. This research has been served as a base for future studies especially with regards to the performance after hybridisation with glass fibre as reported in previous author's work[35]. It makes several noteworthy contributions to the usage of bamboo fabric composites as alternative natural reinforcement.

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