abundantly available in nature, possess low-cost materials, and are environment friendly; these natural fibers have opened the door for scientists and engineers to investigate their potentials to utilize them in diverse fields especially in the composite engineering.

Organic agricultural biomass such as wheat, rice, coconut husks, sugarcane bagasse, pineapple and banana leaves, and many more are primary sources of lignocellulosic fiber.[3] Sugarcane/bagasse is the remainder of sugarcane stalk once the juice is extracted from it by milling process. Sugarcane/bagasse mainly contains cellulose, hemicellulose, and lignin.[4] This large amount of produced byproduct was considered as waste with few applications. It was mainly used by sugar industries as fuel for boilers.[5]

Polymeric products are found everywhere in our daily life. Polypropylene (PP) is a widely used polymer. Thermoplastic PP is a low-cost material. Natural fiber–reinforced polymer composite is gaining increasing interest among the researchers. Good numbers of articles are published related to bagasse–PP composites. It is reported that natural fiber does not interact well with polymer. Lignocellulosic natural fibers are hydrophilic in nature whereas polymers exhibit hydrophobic characteristics.[6] To increase the adhesion between fibers and polymeric matrices, surface modifications of natural fibers are carried out. In order to enhance the adhesion between the filler and matrix, alkali treatment is regarded as an effective method.[7] Alexandre Gomes et al.[8] treated curaua fiber alkali solution and concluded that the mechanical properties of the fiber-reinforced composite can be improved considerably with proper alkali treatment. Arrakhiz et al.[9] used alkali to modify the surface of alfa, coir, and bagasse fiber and then these fibers were used as reinforcement with PP, thus the resulting mechanical properties of the composites were found to be far better than standalone PP. The recent study reported by Oladele[10] also found the better performance in adding bagasse fiber. There have been numerous studies on this topic as reported previously.[1–16] However, this study also aims to identify the optimization of fiber loading, whether the amount of fiber has correlation with the strength of developed composites or not. The beauty of this study lies in the fact that it also tries to study the effect of hot press technique in improving the composite quality. It is worth to highlight that the composite blends were hot pressed at 200°C for 10 min and then at 230°C for 15 min under 5 MPa pressure in order to produce better mechanical properties. The results of hardness are also reported. This study also agreed well with other works giving confidence that the local Malaysian sugarcane bagasse have the same quality as the other bagasse from other places.

## Materials and method

### Materials

The sugarcane bagasse used in this work was collected from a juice maker from a local market in Malaysia. For the purpose of alkalization, NaOH of commercial grade was applied. PP of pellet form was utilized for this work.

### Pretreatment of bagasse fiber

Bagasse fibers were cleaned and small pieces were made. A total of 5% NaOH solution was poured into the fibers and it was stirred for 30 min. Alkali solution was drained out from the fiber and was rinsed with distilled water several times to get rid of excess alkali. Chemically treated bagasse fibers were dried in an oven at 108°C for 24 h.

### Specimen preparation

Alkali-treated bagasse fibers were placed in a pulverizer machine followed by a vibratory sieve shaker in order to reduce the size of the fiber. Fibers of 10%, 20%, 30%, and 40% concentrations were blended mechanically with PP. The mixing process took place in an internal/extruder mixer (Haake Polylab OS RheoDrive 16; ThermoFisher, Malaysia Branch). The mixing temperature was 180°C, with the rotor speed of 50 r/min for 10 min. This blend was subjected to crushing in a crusher (TW-SC-400F; CME, China).

The blend was placed separately on the specially designed molds which are capable of fabricating specimens according to the standard size of tensile testing specimen (ASTM D3039), hardness testing specimen (D785), and flexural testing specimen (ASTM 7264). The blends were hot pressed at 200°C for 10 min and then at 230°C for 15 min under 5 MPa pressure.

Specimens were taken out from the mold once it was in room temperature.

### Mechanical characterization

To determine the tensile properties of the bagasse fiber–reinforced PP composites, tensile test was conducted according to the standard of ASTM D3039. The test was carried out in a universal testing machine (Shimadzu AG-1 100 kN; Japan) which is computerized. The length, width, and thickness of the specimens were 250, 25, and 2.5 mm, respectively, wherein the gauge length was 150 mm. The test was carried out in room temperature at a crosshead speed of 2 mm/min.

Flexural tests were conducted on the same machine as tensile test. A three-point bending method was used as per ASTM D7264 standard. The geometry of every specimen was 154 × 13 × 4 $mm^3$. The span length was 128 mm. The crosshead speed of the test was 1 mm/min. The ASTM D785 standard of hardness measurement was followed for the Rockwell hardness test. For this purpose, Mitutoyo Wizhard Rockwell hardness tester; INNOVATEST Japan, was used having a steel ball indenter with 12.7 mm in diameter (Rockwell R scale).

### *Scanning electron microscopy*

Fracture surface of the composites was studied using scanning electron microscopy (SEM). The micrographs were taken by JSM-5310; JEOL, USA. Before the samples were investigated, the fracture surfaces were mounted on conductive adhesive tape and then sputter coated with gold.

## Results and discussion

### *Tensile properties*

The results of tensile tests are illustrated in Figure 1. It is seen that pure PP had highest yield strength compared to other PP–bagasse compositions. The data showed that for 10% filler added to PP matrix, it gave an yield strength of 13.80 MPa, and the addition of the filler percentage decreased the yield strength for 20% filler and increased for 30% and 40% composition. As the yield strength for 10% and 40% filler in PP composition has the same value, that is, 13.8 MPa, it was concluded that both the compositions have the greatest yield strength among other compositions.

At the same time, it is also observed that pure PP has the highest tensile strength, which is 19.60 MPa. Whereas the 30 wt% filler-added PP composite has the second highest tensile strength, followed by 40 wt% filler-added PP composites which are 15.10 and 14.90 MPa, respectively. The 10 wt% filler reinforced has 14.60 MPa of tensile strength while the 20 wt% filler reinforced has the lowest tensile strength which is 13.50 MPa. The tensile strength is the maximum stress that a material can withstand while being stretched before necking. Pure PP has the highest tensile strength, which means that it can withstand the highest stress while being pulled before it starts necking. The findings also agreed as reported in Oladele.[10] This suggests that the bagasse fiber is not strong enough to be the reinforced fiber and the PP matrix itself has higher bonds. The composites become brittle and less ductile.

### *Flexural properties*

After being subjected to bending force, the reinforced PPs with 10%, 20%, and 30% filler were fractured while the standalone PP and PP with 40% did not show any sign of fracture. The fractured surfaces for all those three specimens were almost the same which give brittle surface fracture. The flexural properties of the composites are represented in Figure 2. Figure 2(a) shows the effect of fiber content on the flexural strength of specimens. The highest flexural strength obtained was 57 MPa which is PP with 10 wt% of the filler; meanwhile, pure PP has 56.25 MPa flexural strength. The flexural strength then decreases with increasing filler addition which is 52 MPa for PP with 20 wt% filler, 50.63 MPa for PP with 30 wt% filler, and the lowest was 44.44 MPa for PP with 40 wt% filler.

Figure 2(b) shows that the flexural modulus has improved with the addition of the filler. However, the flexural modulus decreased with the increase in percent of the filler. The highest flexural modulus obtained was PP with 10 wt% filler which is 25.4206 MPa, hence becomes the stiffest compared to PP with 20, 30, and 40 wt% filler. Yet, PPs with 20%, 30%, and 40% filler still have better flexural modulus than pure PP. The findings also agreed as reported in Haque et al.,[6] Cao et al.,[7] Gomes et al.,[8] Arrakhiz et al.,[9] and Oladele.[10] It

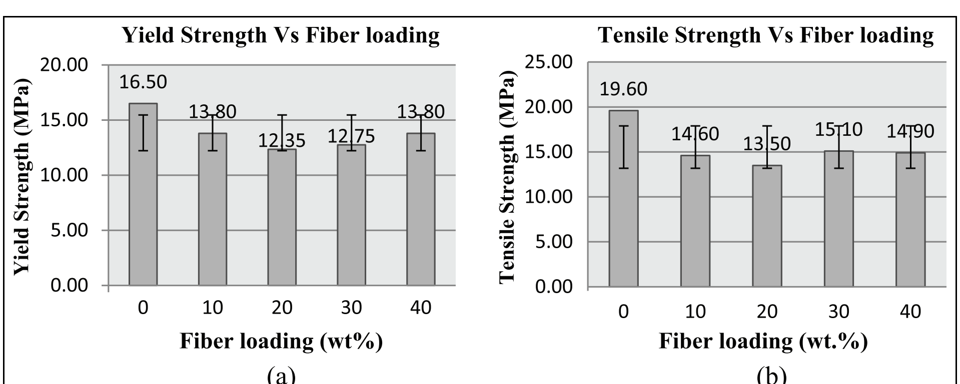


**Figure 1.** Effect of bagasse fiber loading on (a) yield strength and (b) tensile strength of bagasse fiber–reinforced polypropylene composite.

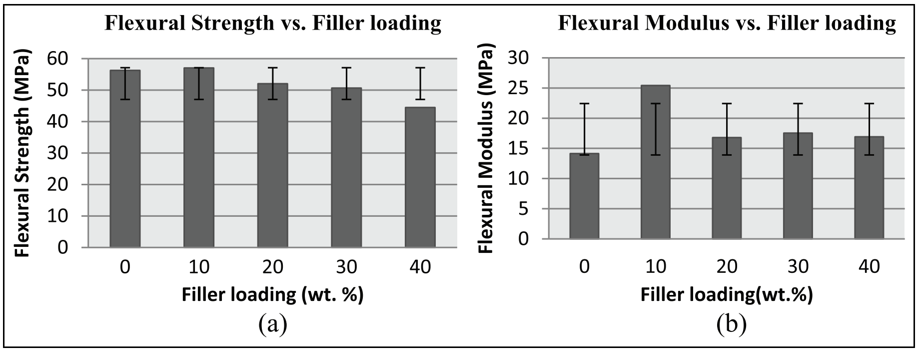


**Figure 2.** Flexural properties of the composites: (a) flexural strength and (b) flexural modulus with increasing fiber loading.

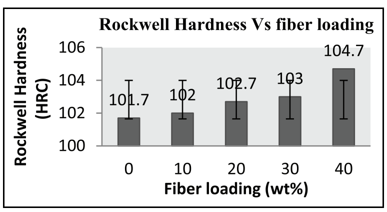


**Figure 3.** Rockwell hardness versus fiber loading in PP composite.

is interesting to note how the reinforced bagasse fiber reacts to the direction on the applied loading. In bending stress, the performance is different from the normal stress applied. The 10% filler gives better resistance to bending and reduces the ductility of PP. This is due to the good bond achieved between the mixture PP and filler.

### *Hardness*

Figure 3 demonstrates the effect of adding sugarcane bagasse on the hardness property of polymer matrix composite. The optimum hardness for PP is obtained at 40 wt% fiber. It can be seen from the result obtained that Rockwell hardness value for the composites increased with increasing fiber loads. The findings also agreed as reported in Cao et al.,[7] Gomes et al.,[8] Arrakhiz et al.,[9] Oladele,[10] Athijayamani et al.,[11] and Simão et al.[12] The hardness increases when the resistance of the materials to the deformation increases. This happens when more filler is added; the composite becomes harder and the materials' hardness improves. The layer of the filler gives better resistance to the plastic deformation in the transverse direction of the filler.

### *SEM*

Bagasse-reinforced PP composite which had undergone tensile testing and has the best and the worst performance was used for SEM analysis. The composition of PP with 30% filler shows the best performance with tensile strength 15.1 MPa, while the composition of PP with 20% filler shows the worst performance with the tensile strength 13.5 MPa.

From Figure 4, it can been seen that small amount of fiber fractures is observed in 30 wt% fiber loads than 20 wt% of fiber loads. Also, the composite specimen with 20 wt% of the filler consists of considerable amount of pores. This porous structures lead to the poor tensile properties of the composites. By investigating the SEM images, it is rational to suggest that 20 wt% fiber-reinforced composite specimen were subjected to poor homogenous mixing as fiber fractures are evident. This phenomenon leads to a decrease in stress transfer capability of the matrix to the reinforcement. As a result, a decrease in tensile strength is observed.

## Conclusion

In this work, the effect of bagasse fiber loading on the mechanical properties of PP–bagasse fiber composites was studied. The micrographs of the fracture surfaces were taken and analyzed. It is to be concluded that

- Composites with 30 wt% of bagasse fiber have the highest tensile strength than the others, but it is lesser than that of standalone PP.
- Rockwell hardness value of the composites increased with increasing fiber content.
- Flexural strength and flexural modulus have increased considerably with the addition of bagasse fiber.
- SEM investigation determined a porous structure and fiber fracture on a composite specimen which is an indication of uneven mixing of the fiber and PP.

Ultimately, the findings of this kind of research give manufactures and engineers a sound basis decision

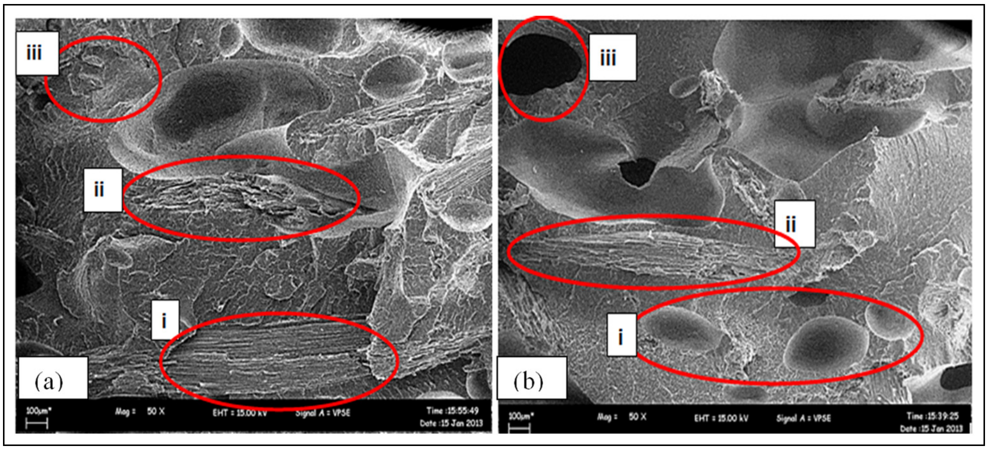

**Figure 4.** SEM micrographs of the fracture surface at (a) 30% filler in PP–bagasse and (b) 20% filler in PP–bagasse. (a): (i) fine fibers attach with matrix, (ii) fracture happened on the fibers, and (iii) matrix; (b): (i, iii) pore and (ii) bagasse fiber.

whether to apply the use of this composite for weight reduction especially in automotive applications or not.

## Declaration of conflicting interests

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