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Enhancing Mechanical Properties of Polyvinyl Alcohol Fiber Reinforced High Density Polyethylene Composites

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Abstract. In this work, high density polyethylene (HDPE)/polyvinyl alcohol (PVA) fiber composites have been fabricated via melt compounding by employing a twin-screw extruder. The resulted composites samples of four different PVA loadings (i.e. 0, 5, 10, 20 wt%) were then characterized via tensile test to investigate the effect of PVA loadings on their mechanical properties (i.e. modulus elasticity, tensile strength, toughness, and strain at break). Additionally, the surface morphologies of the composites (i.e. cryo-fractured and tensile fractured samples) were also studied by using a scanning electron microscopy (SEM). The SEM micrographs on the cryo-fractured sample showed that PVA fibers were perfectly embedded and well blended in HDPE matrix. Whereas, the SEM images of tensile-fractured samples showed that there was a fibrillation effect on the neat HDPE, while in the composites sample, there was an evident of broken fibers. Additionally, from the tensile test results, the modulus elasticity of the composites has increased by approximately 16, 39, and 81% (as compared to the neat HDPE) for PVAC-5, PVAC-10, and PVAC-20, respectively. Whereas, the toughness and strain at break of the composites have decreased.

Introduction

High density polyethylene (HDPE) is a type of thermoplastic polymers that has been extensively used due to its versatility and low cost. Additionally, it has also good mechanical properties and processability [1]. This thermoplastic has been utilized in numerous applications, e.g. food packaging. Unfortunately, there has been a growing concern on the use of such non-biodegradable plastic to the environment. Therefore, there has also been a growing interest among researchers to improve biodegradability of non-biodegradable plastic like HDPE by blending it with biodegradable polymer such as polylactic acid (PLA) [2] and polyvinyl alcohol (PVA) [3]. For the PVA, apart from its biodegradability, PVA fiber has also been utilized as reinforcing material for plastic for long time. PVA fiber has good mechanical properties, highly chemical resistance toward acids and alkalis, and also high resistance to abrasion, fatigue, and natural exposure (e.g. UV light), etc [4]. Beside their good properties, PVA fiber has also a wide availabillity and competitive price in the plastic market, which make the PVA fiber become a promising reinforcing material for many applications. There are numerous literatures that reported the use of PVA fiber as filler in engineered cementitious composites for construction application, e.g. concrete, where the cement was used as the matrix [4-6]. To the best of our knowledge, there are still limited investigation reports about the use of PVA fiber as filler in the fabrication of polymer composites. Therefore, in the present work we have prepared high density polyethylene (HDPE)/polyvinyl alcohol (PVA) fiber composites via melt blending by employing a twin-screw extruder. The resulted composites samples were then characterized for their mechanical properties.

Experimental

Materials and composites preparation. In the present study, high density polyethylene (HDPE)/polyvinyl alcohol (PVA) fiber composites have been fabricated. The HDPE (product name: M300054) was obtained from SABIC, Saudi Arabia. The HDPE has melt flow index (MFI) of 30 g/10 min, which means it has low melt viscosity. Whereas, the PVA fiber (product name: RECS15) was obtained from Kuraray, Japan. Figures 1a, 1b, and 1c show the photographs of HDPE pellets, PVA fiber, and SEM image of single PVA fiber, respectively. The HDPE/PVA fiber composites were prepared at four different PVA loadings (i.e. 0, 5, 10, and 20 wt%), which referred to as PVAC-0, PVAC-5, PVAC-10, and PVAC-20, respectively. The composites were prepared via melt compounding by employing a twin-screw extruder (TSE), Farrel FTX-20 at 17 rpm screw speed and inlet temperature of 180°C and die temperature of 200°C. The molten polymer composites from the die were quenched/cooled in a water bath, dried (with air), and cutted into pellets. The composites pellets were put in the oven at 70° for 1 day to eliminate the remaining water/moisture. After dried, the pellets were fed into an injection molding machine, Super Master Series SM 120, China to make a set of ASTM (American Society for Testing and Materials) standard samples for further characterization purpose, i.e. morphological analysis, tensile test.

Fig. 1. Photograph of **a)** HDPE pellets; **b)** PVA fiber; and **c)** SEM image of single PVA fiber

Composites characterization. The surface morphology of the HDPE/PVA fiber composites was inivestigated using a Scanning Electron Microscopy (SEM), JEOL JSM-6360A, Japan. The object of SEM analysis was the cross-section surface of cryo-fractured composites sample. The SEM analysis was carried out at 15 kV and magnification of 200X. Prior to the analysis the sample was coated with a thin layer of gold using coater machine, JEOL JFC-1600, Japan. Additionally, the composites were also characterized for their mechanical properties via tensile test. The tensile test was carried out using universal testing machine, model H100 KS (Hounsfield Instrument, USA) with ASTM D-638 as our guidelines. For this test, dumbbell-shape tensile bars obtained from the injection molding were used. The test was carried out at room temperature and cross-head speed of 50 mm/min. The displacement was measured from the cross-head position. The tensile properties values such as tensile modulus, tensile strength, tensile energy to break (toughness), and strain at break were determined by analyzing the stress-strain curves generated from the test.

Results and Discussion

The morphological study of the HDPE/PVA composites was investigated by using Scanning Electron Microscopy (SEM). The SEM micrographs of the surface of cryo-fractured composites samples, i.e. PVAC-0 and PVAC-15 are exhibited in Figs. 2a and 2b, respectively. As seen in Fig. 2b, the PVA fibers were perfectly embedded and well blended in HDPE matrix, which were shown by the arrows.

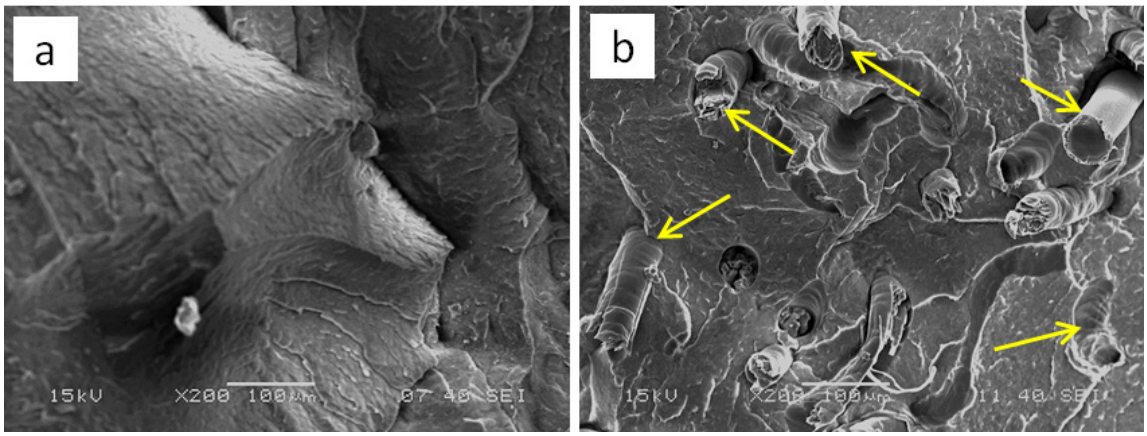

Fig. 2. SEM images of cryo-fractured surface of a) Neat HDPE; and b) PVAC-15 composites

Additionally, the mechanical properties of the HDPE/PVA fiber composites were also characterized via tensile test. Figure 3 shows the result of tensile test for neat HDPE and its composites in the form of stress vs %strain curve. As seen in the figure, the slope of the curve at lower %strain of the composties were higher or steeper as compared to the neat HDPE. This slope (at lower %strain) is attributed to the modulus elasticity. Other mechanical properties, i.e. tensile strength, toughness, and strain at break can also be derived from the curve in Fig. 3. All these mechanical properties are summarized in Table 1.

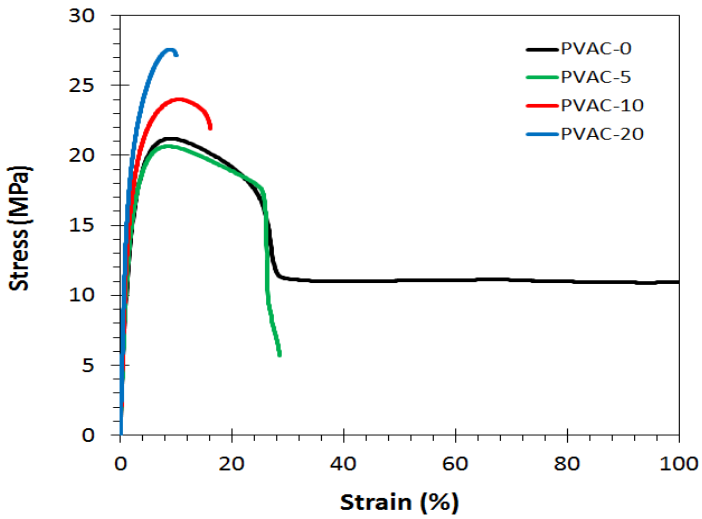

Fig. 3. Stress-strain curve of HDPE/PVA fiber composites

As seen in Table 1, the modulus elasticity of the composites were all higher than that of neat HDPE and increased with increasing PVA fiber loadings. The improvement of the modulus elasticity was approximately 16, 39, and 81% (as compared to the neat HDPE) for PVAC-5, PVAC-10, and PVAC-20, respectively. This can be attributed to the presence of PVA fiber and its interaction with the HDPE matrix. Additionally, the tensile strength of composites significantly increased with PVA fiber loading starting from 10 to 20 wt%, in which the improvement was approximately 115 and 120% (as compared to the neat HDPE) for PVA loadings of 10 and 20 wt%, respectively. This could be attributed to the fact that during the tension process, both the formation of the new fracture surface and pulling out the PVA fiber from the matrix will absorb the energy, so the composites showed higher tensile strength [7]. However, at 5 wt% PVA fiber loading the tensile strength decreased. It can be explained that on the low PVA loading, the interfacial binding between the fiber and the polymer matrix was still poor, which caused the stress was hardly transferred from the matrix to the fiber.

Table 1. Summary of mechanical properties of HDPE/PVA fiber composites

Sample	Modulus Elasticity (Mpa)	Tensile strength (Mpa)	Toughness (MJ/m3)	Strain at break ± 2 %
PVAC-0	929.29	10.30	13.30	100.00
PVAC-5	1078.60	5.66	5.14	28.52
PVAC-10	1290.10	22.19	3.37	16.17
PVAC-20	1678.50	22.63	2.53	10.00

In the other hand, there was a decrease in the toughness as well as the strain at break of the composites. The toughness of material is related to the strain at break, the higher the strain at break, the more area under the stress vs %strain curve, hence the toughness also higher. Figure 5 shows the SEM micrographs of tensile fractured surface of the composites at different PVA loadings. Whereas, Fig. 5 shows the photograph of tensile fractured samples of HDPE/PVA fiber composites. As seen in Fig. 5, the neat HDPE sample stretched more than to the composites (shown by dashed-line), which correspond to higher strain at break. The stretching effect was due to the fibrillation of the HDPE material, which was shown in Fig. 4a. As seen in Table 1, with increasing PVA fiber loading, the composites exhibited a decrease of toughness, which means more brittle. It can be attributed to the effect of brittleness nature of PVA fiber. The more the PVA fiber loading, the more brittle effect given to the PVA fiber-HDP matrix system. The brittleness of the PVA fiber was shown in Figs. 4a-4c, as indicated by the broken fiber (shown by arrows). This explanation can also be proven by the difficulty to extrude composites with 30 wt% of PVA fiber by TSE machine in this work, which was due to the highly brittle 30 wt% PVA fiber loading that hindered the extrusion process [8].

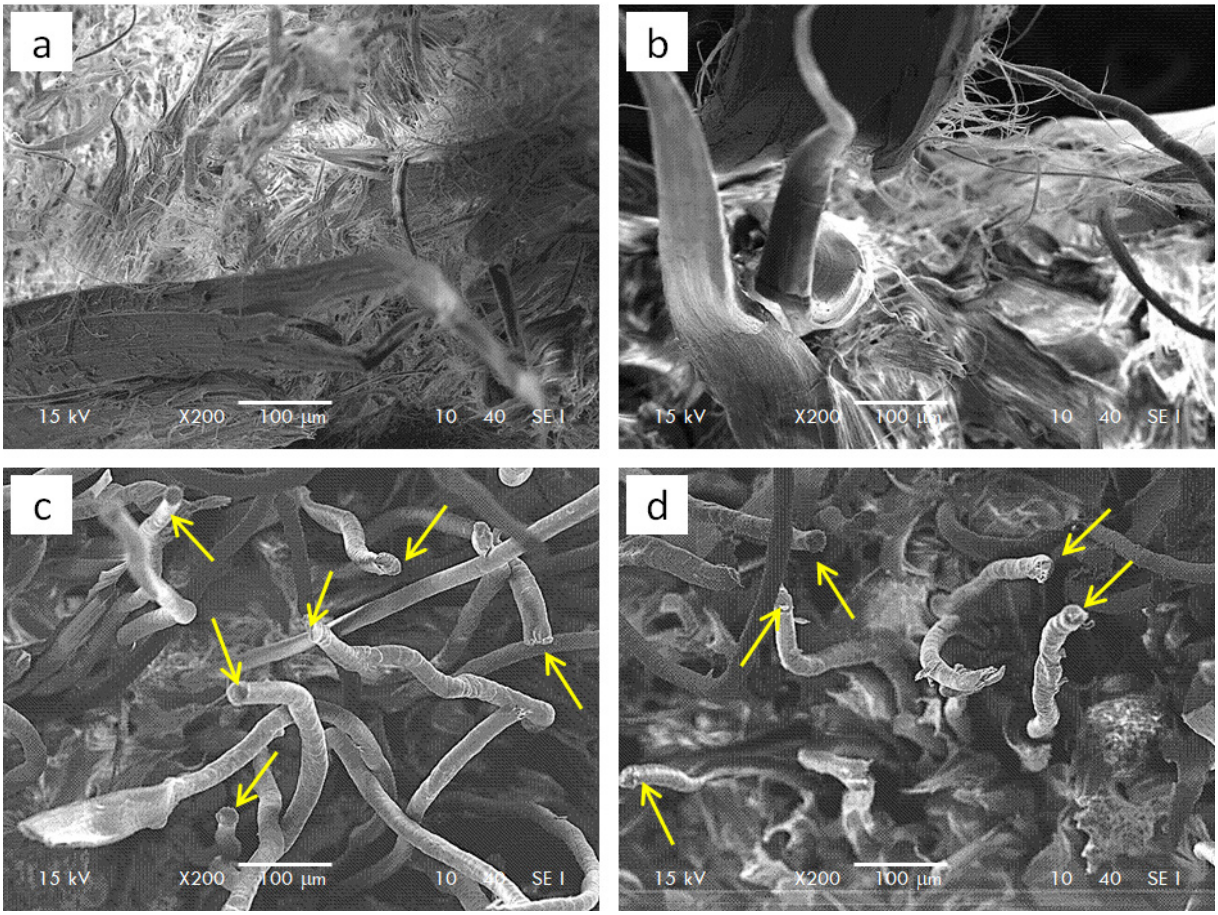

Fig. 4. SEM micrographs of tensile fractured surface of HDPE/PVA fiber composites: **a)** PVAC-0; **b)** PVAC-5; **c)** PVAC-10; and **d)** PVAC-20.

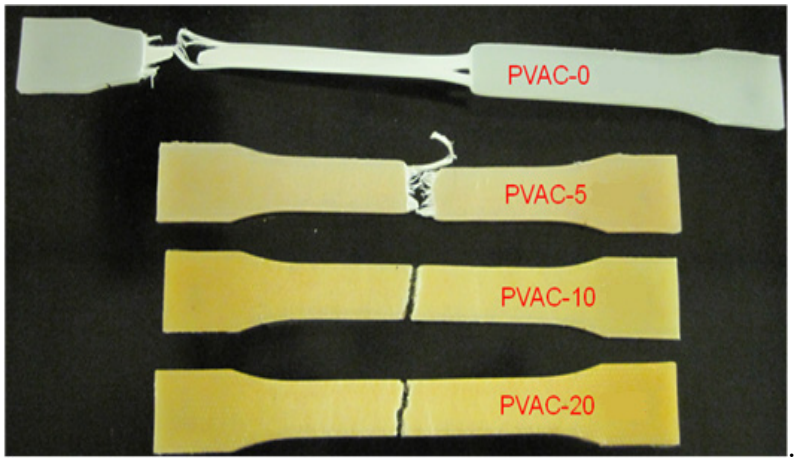

Fig. 5. Photograph of tensile fractured samples of HDPE/PVA fiber composites

Conclusion

In the current study, the effect of PVA fiber loadings (i.e. 0, 5, 10, and 20 wt%) on the mechanical properties of the HDPE/PVA fiber composites have been investigated. From the tensile test result (i.e. stress vs %strain curve), mechanical properties e.g. modulus elasticity, tensile strength, toughness, strain at break of the composites have been determined. The modulus elasticity of the composites increased by approximately 16, 39, and 81% (as compared to the neat HDPE) for PVAC-5, PVAC-10, and PVAC-20, respectively. Whereas, the tensile strength also increased at composites with PVA loadings of 10 and 20 wt%, which were approx. 115 and 120% (as compared to the neat HDPE). In the other hand, there was a decrease in the toughness and strain at break of the composites.

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