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Evaluation of Rice Straw as Natural Filler for Injection Molded High Density Polyethylene Bio-composite Materials

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Rice straw that left behind during the paddy harvesting process holds immense potential to be used as a renewable resource in the development of eco-friendly polymeric products. Utilisation of rice straw as natural filler in the development of high density polyethylene bio-composite materials by using the injection moulding technique was reported in the present study. The investigation of filler size revealed that the bio-composites with the acceptable tensile strength was achieved when the rice straw with 250 – 300 μm of particle size was used in the composite formulation. By increasing the rice straw content, a decreasing trend was observed in the tensile and flexural strength of the fabricated bio-composites. The tensile and flexural moduli of the bio-composites were enhanced with the increasing of rice straw. The water absorption of the rice straw-based high density polyethylene bio-composites was also significantly increased with the elevation of rice straw content in the composite formulations. The present study provides insights into the underlying behaviours of the rice straw in fabricated high density polyethylene bio-composites, which, in turn, could serve as a reliable guideline for the development of the rice straw for a wide range of eco-friendly products.

1. Introduction

High density polyethylene (HDPE) is a class of petroleum-derived thermoplastic polymer that commonly used in our daily lives. Its applications mainly include packaging materials, storage boxes, household products and corrosion-resistant piping. HDPE exhibits some fascinating characteristics such as good chemical and corrosion resistance, low weight, low cost and ease of processing. Non-biodegradable characteristic of HDPE has stimulated the scientists and researchers to develop a natural filler-based HDPE bio-composite in order to provide a new green material for the fabrication of biodegradable end-use products. Works had been reported on the use of curaua fiber in the development of HDPE bio-composite (Morais et al., 2016). Aldousiri et al. (2013) also tried to formulate a HDPE bio-composite based on the palm fiber in order to increase the biodegradability of the end-used products.

Rice straw is a type of agricultural waste that left behind during the paddy harvesting process. As a natural fibre, rice straw is a potential candidate to be explored in the fabrication of biodegradable polymer composites. By replacing the synthetic filler, rice straw can be used as the natural filler to reinforce the properties of the polymeric products. The fabricated products also possess some degree of biodegradability and make them compatible with the environment. This idea is not only to reduce the solid waste pollution that induced by the non-biodegradable polymeric products, but it also provides an alternative to disposing and reuses the discharged rice straw.

In the previous released reports, the development of rice straw-based HDPE bio-composites had been conducted based on the use of polyethylene wax (El Nemr et al., 2015) in order to study the compatibility between the HDPE and rice straw. Rahman et at. (2009) also reported the used of vinyltrimethoxysilane as coupling agent to improve the surface interaction between rice straw and HDPE. The inclusion of these coupling agents might affect the nature of rice straw and hinder the understanding of the natural interaction between the rice straw and HDPE. The aim of this study is to explore the fabrication of pristine rice straw-based HDPE bio-composites (without using any coupling agent) by using the injection moulding technique, which is currently underexplored. The effect of rice straw particle size and content on the mechanical performance (tensile and flexural properties) and water absorption of the resulting HDPE bio-composites are investigated and reported in the present study. This study is expected to provide insight into the pristine bio-composites whose properties and characteristics are totally constituted by the intrinsic properties of rice straw and HDPE. The collected findings also provide a clear understanding of the synergistic effect between the natural rice straw and HDPE (without surface modification), which, in turns, serves as a reliable guideline to enable the researcher to apply the adaptive method to tailor the fabricated bio-composites in order to achieve the desired properties as well as to facilitates the future development of rice straw as natural filler in HDPE bio-composites.

2. Methodology

Rice straw was grounded and sieved into a particle size of 250 – 300 μm, 125 – 250 μm and 75 – 125 μm. After that, the ground rice straw was dried in a bench-top oven at 105 °C for 24 h. To investigate the effect of rice straw particle size on the bio-composites, the rice straw and HDPE (30 : 70) as well as the dispersing agent lubricant (Ultra-Plast TP01) and binding agent (Ultra-Plast TP10) were mixed in a high-speed mixer and then melt compounded using a co-rotating and intermeshing twin screw extruder at temperature of 180 – 190 °C. The pelletised compound was then injection molded into ASTM standard specimens for characterisation. The same procedures were repeated to fabricate the HDPE bio-composites with different rice straw content (10 %, 20 %, 30 %, 40 % and 50 %) in order to study the effect of filler loading.
The fabricated rice straw-based HDPE bio-composites were characterised in terms of tensile properties, flexural properties, water absorption and scanning electron microscopy analysis. The tensile and flexural properties of the bio-composites were evaluated according to the ASTM D 638 and ASTM D 790. The water absorption of the HDPE bio-composites was measured according to the ASTM D 570. The fracture surface of the bio-composites was subjected to the scanning electron micrographic analysis using a JEOL JSM6390LV scanning electron microscope in order to examine the interaction between the rice straw and HDPE.

3. Results and discussion

Chapter 2 Figure 1 shows the tensile strength of the HDPE bio-composites fabricated at different rice straw particle size. The bio-composites achieve the highest tensile strength at the particle size of 250 – 300 μm. Even though the tensile strength of the bio-composites that consist of the rice straw at 125 – 250 μm is not much different from the one that was fabricated at 250 – 300 μm, however, the standard deviation reflects the fluctuation range of the tensile strength is broader than the latter one, and thus, reduces the consistency of the fabricated materials. This finding is supported by the reduction in the tensile strength of the HDPE bio-composites when the particle size of 75 – 125 μm was used in the formulation. This phenomenon is attributed to the decreasing of the aspect ratio (length/diameter) due to the decreasing of the length of the rice straw which leads to less stress dispersion between the filler and polymer chain.

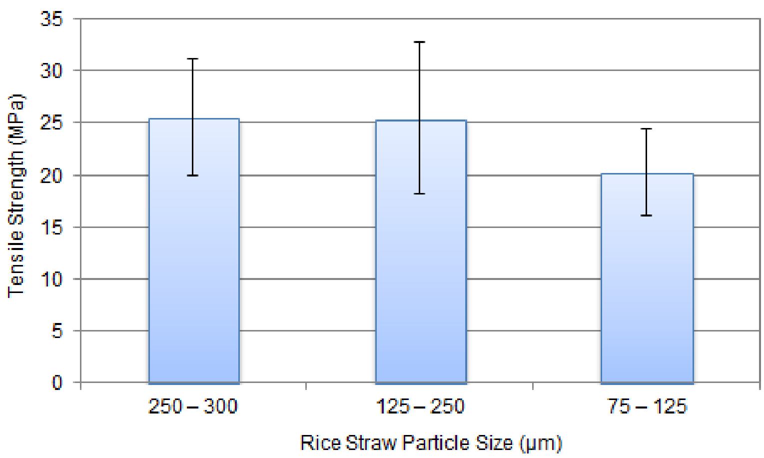


Figure 1: Tensile strength of the HDPE bio-composites fabricated at different of rice straw particle size (the symbol "I" indicates the error bar)

The rice straw filler with a particle size of 250 – 300 μm is selected for the subsequent studies in order to examine the effect of filler loading on the fabricated HDPE bio-composites.

The effect of the rice straw content on the tensile property of the fabricated HDPE bio-composites is illustrated in Figure 2. The tensile strength of the bio-composites decreased with the increasing of rice straw content. This observation is rationalised by the poor surface interaction between the hydrophilic rice straw and hydrophobic polymer chain. The hydrophilic rice straw cannot firmly adhere to the surface of the polymer chain and tend to agglomerate to each other at higher content. Consequently, the contact surface area between the rice straw and polymer chain is reduced, which, in turns, impairs the stress propagation as well as the tensile strength of the bio-composites. The tensile moduli of the rice straw-based HDPE bio-composites exhibit an increasing trend with the elevation of rice straw content. This simply indicates the stiffness of the resulting HDPE bio-composites is enhanced due to the intrinsic rigidity of the rice straw. In the present study, the maximum composition of the bio-composites was found at 50 % of rice straw content. Beyond that, the rice straw-based HDPE compounds were unable to be processed (under the applied processing parameters in the current study) by using the injection moulding technique. This indicates the rice straw content must be maintained at/below 50 % in the formulation in order that the designed bio-composites can be fabricated by using the conventional injection moulding process.

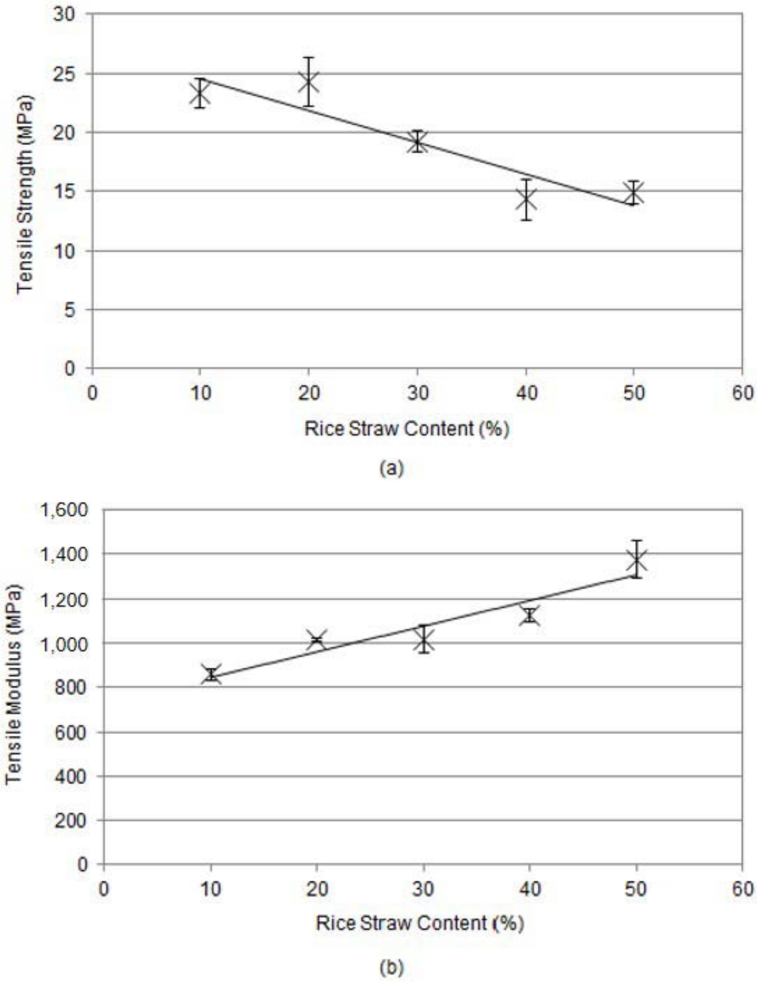
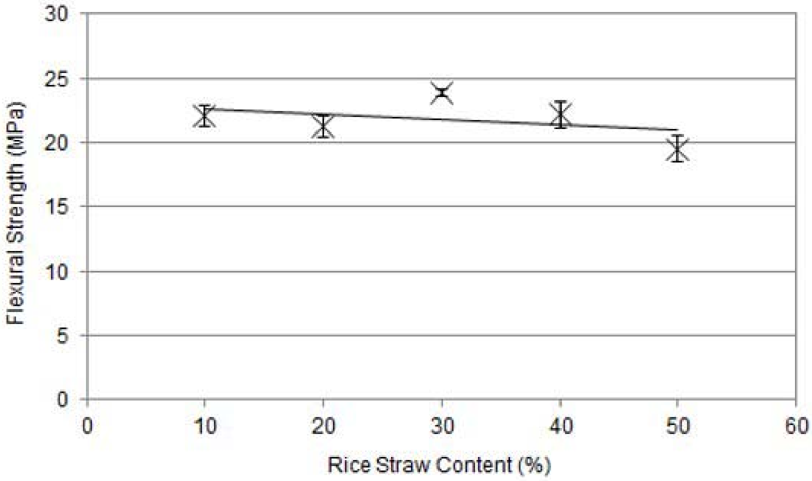
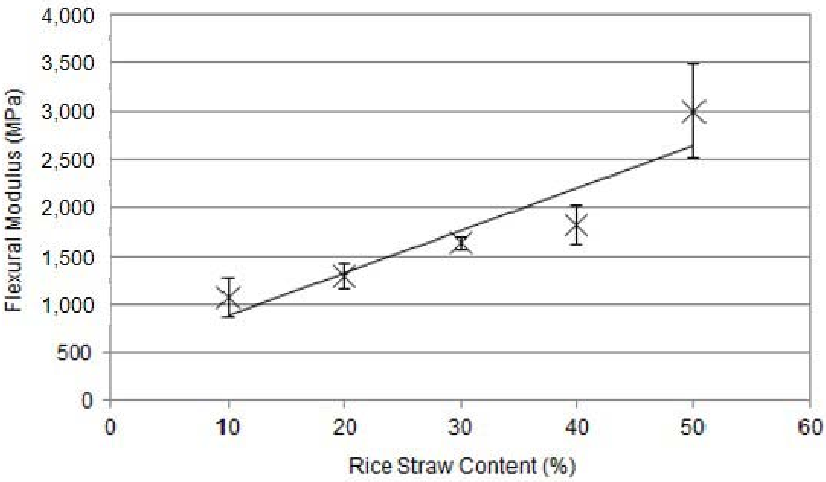


Figure 2: Tensile properties of the HDPE bio-composites with different rice straw content (the symbols "X" and "I" indicate the findings and error bar)

Figure 3 shows the effect of rice straw content on the flexural properties of the fabricated HDPE bio-composites. Similar to the tensile properties, the addition of rice straw has reduced the flexural strength of the bio-composites. This observation is once again attributed by the incompatibility between the hydrophilic rice straw and hydrophobic polymer chain which hinders the stress transfer, and thus, the flexural strength. In other word, the agglomerated rice straw (especially at higher content) serves as a foreign object instead of reinforcing filler and impairs the flexural strength of the fabricated bio-composites. The rigidity of the rice straw may be elevated due to the agglomeration, which, in turns, exerts a positive effect on the flexural modulus of the fabricated HDPE bio-composites. The similar flexural behaviour had also been reported for the rapeseed flour-based polypropylene bio-composites by Zabihzadeh et al. (2011).



(a)



(b)

Figure 3: Flexural properties of the HDPE bio-composites with different rice straw content (the symbols "X" and "I" indicate the findings and error bar)

The water absorption capability of the rice straw-based HDPE bio-composites is shown in Figure 4. As seen, the percentage of water absorbed by the bio-composites is proportional to the rice straw content. The higher the rice straw content in the bio-composite, the higher is the percentage of water absorption. The water absorption of the bio-composites is relatively low and not much different from the rice straw content of 10 % and 20 %. The noticeable increment of the water absorption is only observed when 50 % of rice straw is applied in the formulation. These findings could be explained by the increasing of free hydroxyl group in the fabricated HDPE bio-composites due to the elevation of rice straw content. The hydrophilic nature of rice straw will tend to attract and form a hydrogen bond with the water molecules. Incompatibility between the rice straw and polymer chain also results in the formation of gap/void at the interface, which, in turns, facilitates the diffusion and permeability of water molecules.

The scanning electron microscopy analysis of the fracture surface confirms the reported findings and justifications. As depicted in the scanning electron micrograph (Figure 5), the fracture surface of the HDPE bio-composites consists of a large number of voids that resulted from the pulling-out of rice straw from the polymer surface. This simply indicates the mechanical failure of the fabricated bio-composites is mainly attributed to the interfacial failure between the rice straw and HDPE. The examination of fracture surface confirms the reported mechanical properties and water absorption as well as the justifications whereby the weak surface interaction between the rice straw and HDPE is the main reason that results in such observations.

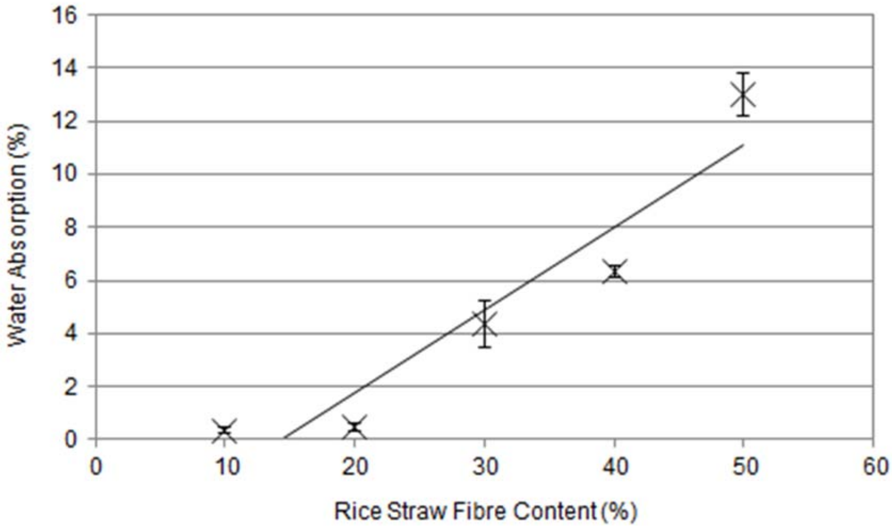


Figure 4: Water absorption of the HDPE bio-composites with different rice straw content (the symbols "X" and "I" indicate the findings and error bar)

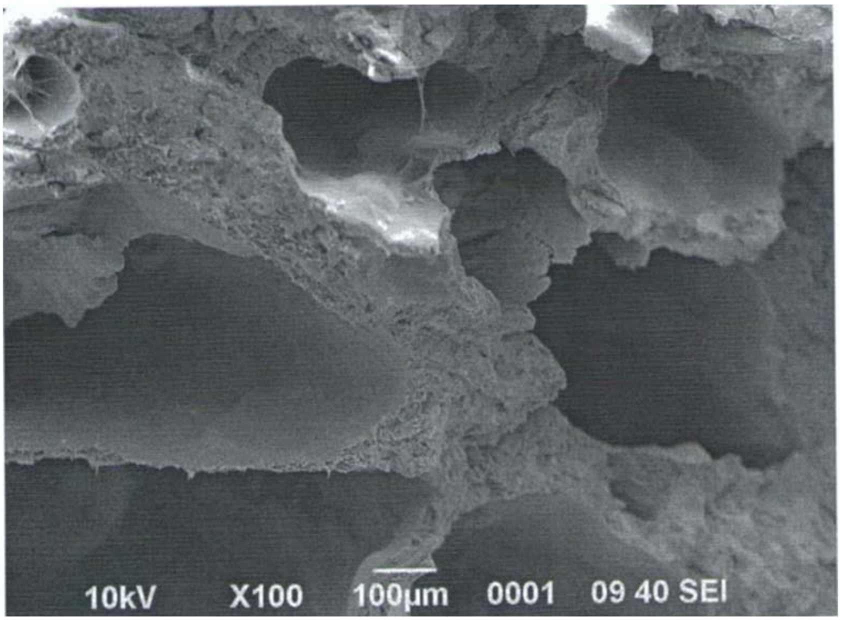


Figure 5: Fracture surface of the rice straw-based HDPE bio-composites

4. Conclusions

In the present study, an injection moulded bio-composite was successfully fabricated by using the natural rice straw and HDPE without the addition of coupling agent. The fabricated bio-composites achieved the highest tensile strength at the particle size of 250 – 300 µm. The addition of rice straw had enhanced the tensile and flexural moduli of the bio-composites. Increasing of rice straw content had reduced the tensile and flexural strength of the HDPE bio-composites due to the incompatibility between the hydrophilic rice straw and hydrophobic polymer chain, as evidenced by the examination of fracture surface. This condition had also induced the water absorption of HDPE bio-composites increased with the elevation of the rice straw content. Rice straw content must be maintained at/below 50 % in the formulation in order to ensure the designed HDPE bio-composites can be fabricated by using the injection molding process. The present study provides the valuable information on the underlying behaviour of the rice straw in the fabricated HDPE bio-composites. These findings enable the researchers to know more about the nature of rice straw, which, in turns, facilitates the future development of the rice straw-based polymeric products.

Acknowledgments

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