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Recycling of Medical Gown Nonwoven Fabric Manufacturing Waste as a Filler for High Density Polyethylene

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Abstract

The objective of this research is to recycle nonwoven fabric waste from medical gown–manufacturing process by using as a filler in high–density polyethylene (HDPE). Before nonwoven fabric waste was mixed with HDPE, this fabric waste was treated with 5, 10 and 15 %w/w of the fabric waste using the treatment time of 2, 3 and 4 hours. The chemical structure of treated fabric waste was confirmed by FT-IR spectroscopy while scanning electron microscopy was used to investigate its surface morphology. The samples were prepared by compression molding using the amount of fabric waste at 5, 10, 15, and 20 %w/w, respectively. After mechanical tests were employed, it was found that the fabric waste content, the amount of maleic anhydride and the treatment time affected the mechanical properties of filled HDPE. Each property was improved when different conditions were used. However, these properties especially impact strength of HDPE filled with modified fabric waste were better than HDPE filled with unmodified one.

Key words: Acid treatment, Maleic anhydride, Nonwoven fabric, High-density polyethylene, Recycle

Introduction

Nowadays, the consumption of synthetic polymers have increased rapidly. This is because these materials have many advantageous properties over other materials including glass, metals, ceramics and woods. For example, they are light-weight, resistant to chemicals and environmental atmosphere. Furthermore, they can be easily processed into desired products by many methods. Therefore, they are used in various applications such as textiles, packaging, automobile parts, etc. It has been known that the waste management for manufacturing wastes and post-consumer products made from these synthetic polymers have dealt with some difficulties. Burning of these wastes and products may result in releasing dangerous gases to the atmosphere while burying them in soil cannot destroy the products because they are slowly biodegradable. Therefore, alternative methods to reduce these wastes and products have been developed.

One commonly used method is to recycle these manufacturing wastes and post-consumer products. Recycling can be divided into two types: chemical recycling and physical recycling. The principle of chemical recycling is to convert high molecular weight polymers into low molecular weight substances via chemical reactions. The obtained substances can be used as the reactants for preparations of other chemicals and polymers.[1-4] In the case of physical recycling, manufacturing wastes and post-consumer products are reprocessed generally into new products using reclaimation process or commingled plastics waste processing.[4-6] Due to its simpler, cheaper and more environmental friendly process, physical recycling is more favorable than chemical recycling.

This research emphasizes on physical recycling of textile manufacturing waste. Possibility of using polyester/cotton (PET/C) nonwoven fabric waste from medical gown manufacturing industry as filler in high-density polyethylene (HDPE) is investigated. Generally, adding hydrophilic filler to hydrophobic matrix requires a surface treatment of one component in order to promote surface adhesion between the filler and the matrix.[7-8] In this case, PET/C nonwoven is modified by esterification with maleic anhydride before compression molding with HDPE. This research also focuses on the effects of the amount of maleic anhydride and the reaction

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time used for treatment and the weight ratio of the fabric waste to HDPE on the mechanical properties of filled HDPE. Tensile, flexural and impact properties of filled HDPEs prepared from various amounts of fabric waste treated at different conditions are compared in order to determine the suitable condition which results in filled HDPE with optimum mechanical properties.

Materials and Experimental Procedures

Materials

Commercial-available high-density polyethylene (HDPE) (H6007 JU-P lot 6A 180315) having melt flow index of 7.5 was supplied by Thai Polyethylene Co., Ltd. Medical gown nonwoven fabric manufacturing waste composing of poly (ethylene terephthalate) and cotton fibers was donated by Mölnycke Health Care (Thailand) Limited. Maleic anhydride, GR grade was purchased from Fluka. Sodium hydroxide, AR grade was purchased from Ajax Fine Chem. 98% Hydrochloric acid, AR grade was purchased from J.T. Baker. All materials were used as obtained without further purification.

Methods

The fabric waste was cut into small pieces and then weighed in order to calculate the amounts of sodium hydroxide and maleic anhydride which should be used (NaOH:MA = 2.2:1 in molar proportion). Aqueous solution of sodium hydroxide was prepared in a 5,000 cm^3 beaker. The cut fabric waste was put and stirred in this solution at speed of 1100 rpm at 50°C and maintained for 30 minutes. Maleic anhydride was then slowly added and the mixture was stirred at 60°C. In order to study the effects of treatment conditions on mechanical properties of filled HDPE, the amount of maleic anhydride was varied from 5, 10 to 15 %w/w of the fabric waste and the treatment time was varied from 2, 3 to 4 hours. The mixture was neutralized with hydrochloric acid solution. After that, the fabric waste was collected, rinsed with distilled water and dried at 70°C for 24 hours. The chemical structures and the surfaces of treated and untreated fabric wastes were identified using a Perkin Elmer System 2000 FT-IR spectrometer and JSM-6400 scanning electron microscope, respectively.

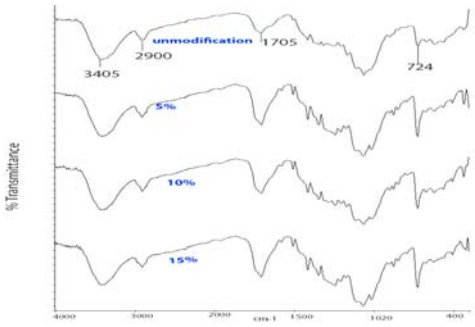
Treated and untreated fabric wastes were mixed with HDPE using fabric waste 5, 10, 15, and 20%, respectively. The variation was done in order to study the effect of the amount of fabric waste on mechanical properties of filled HDPE. Each mixture was placed in a steel mold whose dimension is 150 mm x 150 mm x 4 mm. It was then compressed using compression molding machine with a pressure of 100 MPa at 190°C for 5 minutes. Finally, the compressed sheet was allowed to cool down at room temperature for 30 minutes. The product was cut by cutting machine and it was ground into smaller size by grinding machine. The ground product was then recompressed using the same compression molding machine and compression condition. Finally, the compressed sheet was allowed to cool down at room temperature for 30 minutes. The final product was cut into the standard specimens according to ASTM test methods.

Tensile properties including tensile strength, %elongation at break and Young's modulus of HDPE filled with treated and untreated fabric wastes were determined based on ASTM D638-90 while their flexural properties including flexural strength and flexural modulus were determined based on ASTM D790-81 and impact strength were determined based on ASTM D256-90b.

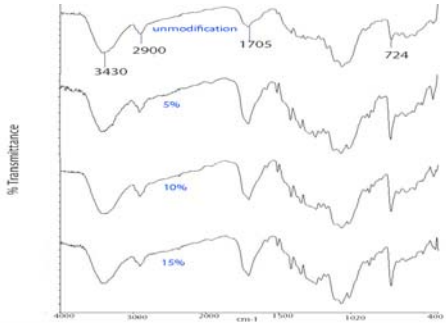
Results and Discussion

All spectra of untreated fabric waste shown in Figure 1 exhibit the characteristic peaks of polyester and cotton fibers which are the components of medical gown nonwoven fabric. The characteristic broad peak between 958-1190 cm^{-1} is attributed to C-O stretching of ether bond. Another strong broad peak corresponding to O-H stretching hydroxyl group of cotton appears at 3000-3600 cm^{-1}. Small peak at 1705 cm^{-1} corresponds to C=O stretching of carbonyl group of polyester.

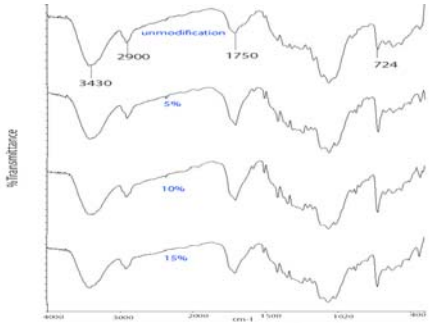
From Figure 1, it can be seen that all spectra of maleic anhydride-treated fabric waste show an increase in intensity of the peak corresponding to carbonyl bond stretching at 1705 cm^{-1} and the appearance of the peak attributed to H-C=C-H bending at 724 cm^{-1}. This observation is a result of the incorporation of maleic anhydride segment to cellulose via esterification as shown below.



(a)

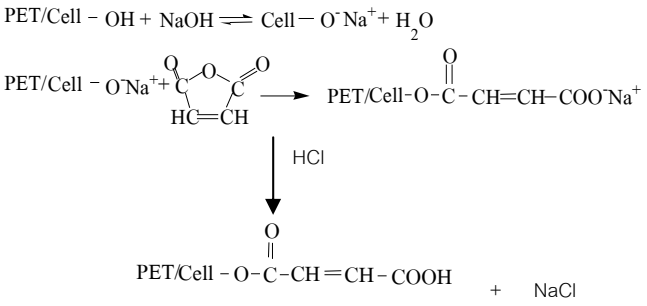


(b)



(c)

Figure 1. FT-IR spectra of untreated fabric waste and fabric wastes treated with maleic anhydride 5, 10 and 15%w/w using treatment times of (a) 2, (b) 3 and (c) 4 hours.



At 1000X magnification, the SEM micrograph in Figure 2 shows a smooth fiber surface of untreated fabric waste. On the other hand, the fiber surfaces of some examples of the treated fabric wastes shown in Figure 3 are rougher and disoriented caused by the incorporation of maleic anhydride segments. However, there are pores in some areas and some parts of the fiber are missing. These indicate the degradation of the fiber. This degradation was possibly caused by acid hydrolysis of cellulose[9] which competed with esterification during the treatment. As the amount of maleic anhydride and/or reaction time increase, the degradation of the fiber increase. This suggests that increasing the amount of maleic ahnydride and/or reaction time favors the degradation reaction.

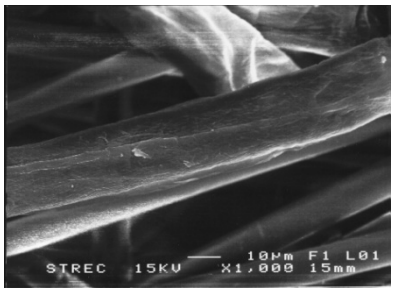


Figure 2. SEM micrograph of the fiber surface of untreated fabric waste.

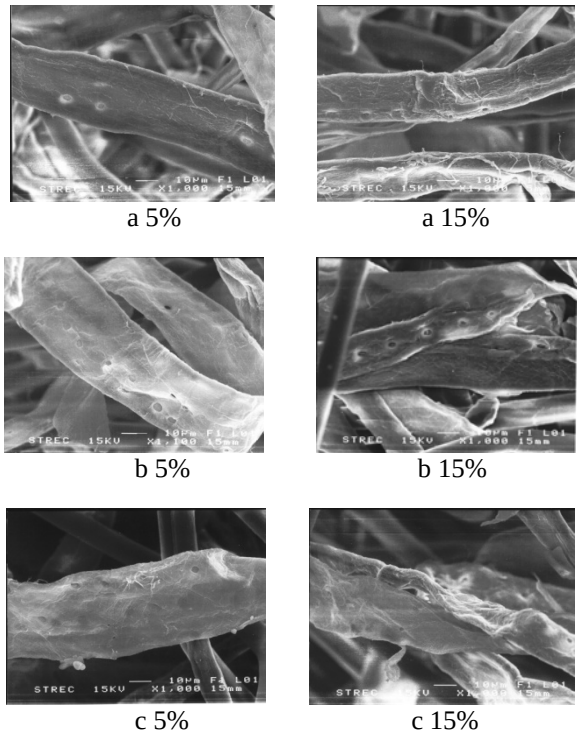
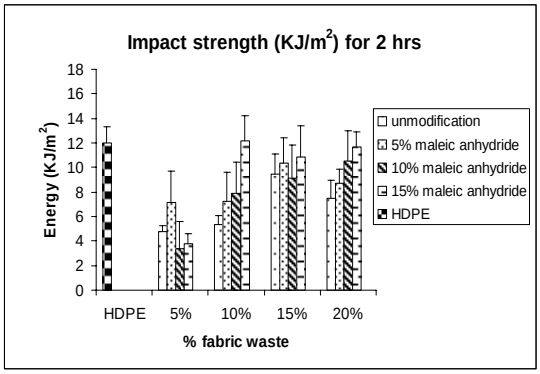


Figure 3. SEM micrographs of the fiber surfaces of fabric wastes treated with maleic anhydride 5 and 15%w/w using treatment time of (a) 2, (b) 3 and (c) 4 hours.

It can be seen from Figure 4 that impact strength of HDPEs filled with treated fabric wastes are generally higher than those of HDPEs filled with untreated fabric waste and it is clearly seen that impact strength of both HDPEs generally increases with increasing filler content from 5 to 20%. At the treatment time of 2 hours and the same amount of fabric waste content, impact strength of filled HDPEs shows tendency to increase as the degree of treatment increases as shown in Figure 4a. This may be caused by higher interfacial adhesion between the fabric and HDPE due to the reaction that possibly occurred as shown below. Therefore, the impact load transfer between the two components was enhanced. When the treatment time was increased to 3 hours, it can be seen that the impact strength increases as shown in Figure 4b. On the other hand, when the treatment time of 4 hours was used, the impact strength of filled HDPEs prepared from the fabric treated with 15% maleic anhydride was lower than those of filled HDPEs prepared from the fabric treated with 10% maleic anhydride as shown in Figure 4c. This may be a result of the degradation of cellulose fibers caused by acid hydrolysis which is favorable at high amount of maleic anhydride and long reaction time as was previously discussed.



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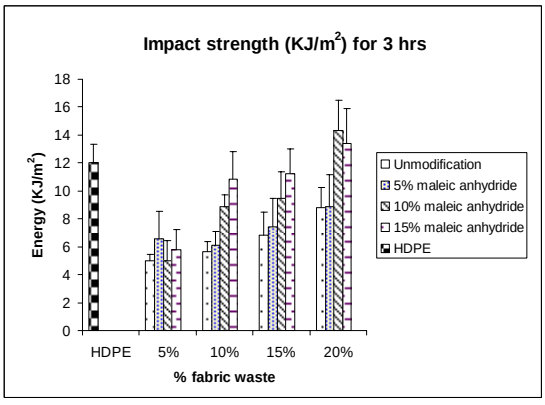

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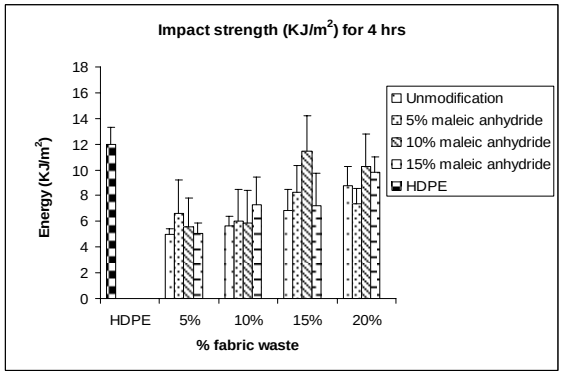

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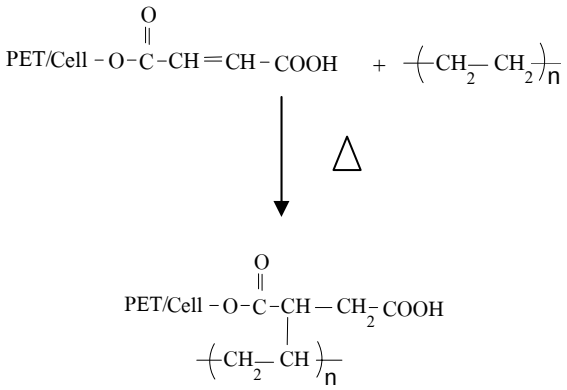
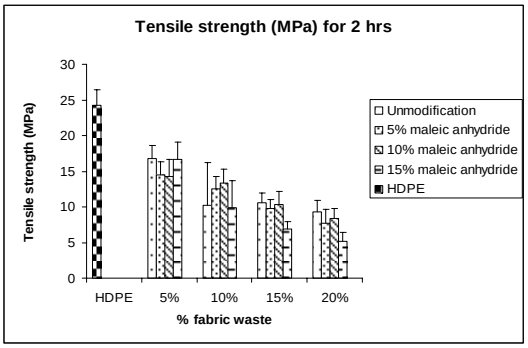
Figure 4. Impact strength of HDPEs filled with untreated fabric waste and fabric wastes treated with maleic anhydride 5, 10 and 15%w/w using treatment times of (a) 2, (b) 3 and (c) 4 hours.



It can be seen from Figure 5 that the tensile strength of HDPEs filled with untreated and treated fabric waste generally decreases with increasing the filler content from 5 to 20%. At the same treatment time and the same amount of fabric waste content, the tensile strength of all HDPEs was almost comparable. The effect of the degree of treatment was not clearly observed since the destruction of the samples did not occur between interface of fabric waste and HDPE matrix but occurred at fabric waste. Since nonwoven fabric waste is easily to tear apart, the areas containing only the fabric waste were the defects of the samples which can be easily destroyed as tensile load was applied. When considering the effect of reaction time on this property, as same as the effect of degree of treatment, it was not clearly shown due to the same reason. %Elongation and Young's modulus of unfilled and filled HDPEs were shown in Figures 6 and 7. The effects of the amount of maleic anhydride and the reaction time were not also clearly seen resulted from the destruction at fabric waste as previously discussed.



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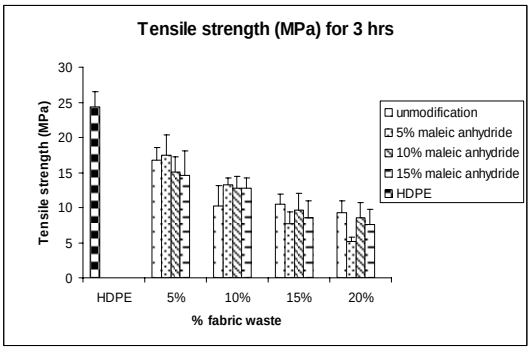

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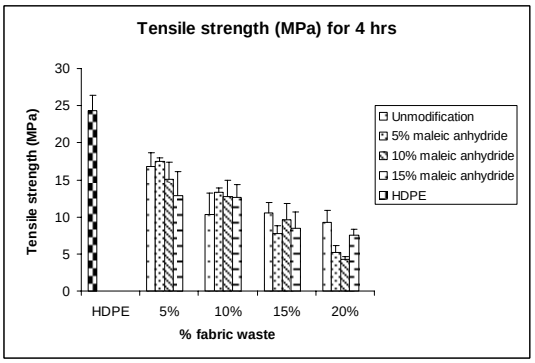

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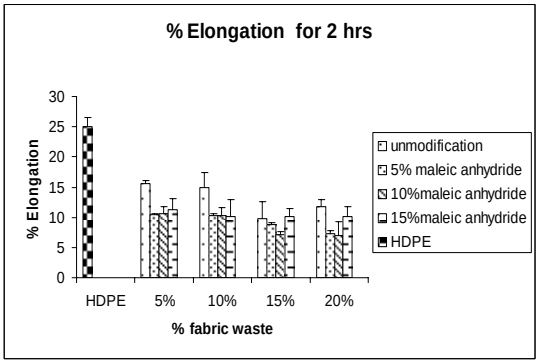
Figure 5. Tensile strength of HDPEs filled with untreated fabric waste and fabric wastes treated with maleic anhydride 5, 10 and 15%w/w using treatment times of (a) 2, (b) 3 and (c) 4 hours.



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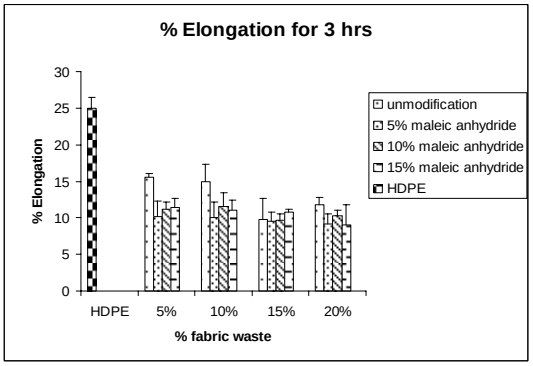

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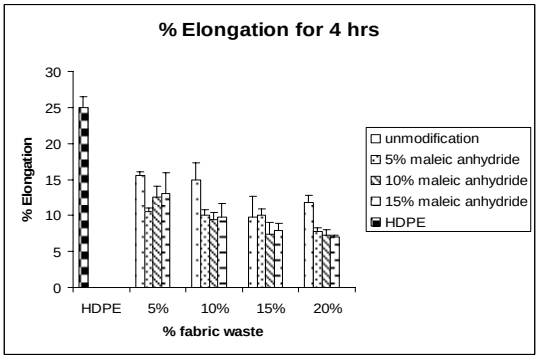

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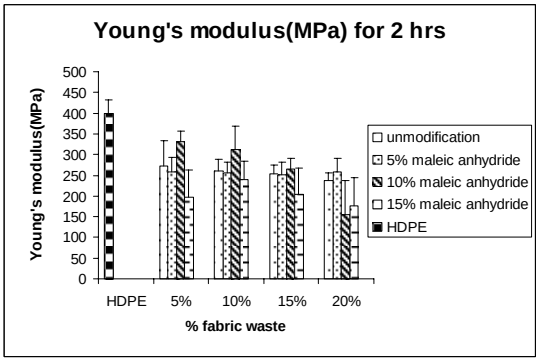
Figure 6. %Elongation of HDPEs filled with untreated fabric waste and fabric wastes treated with maleic anhydride 5, 10 and 15%w/w using treatment times of (a) 2, (b) 3 and (c) 4 hours.



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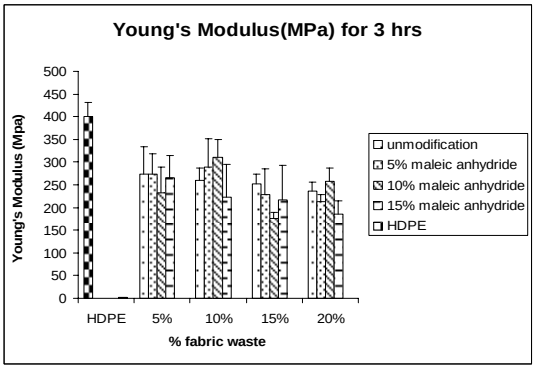

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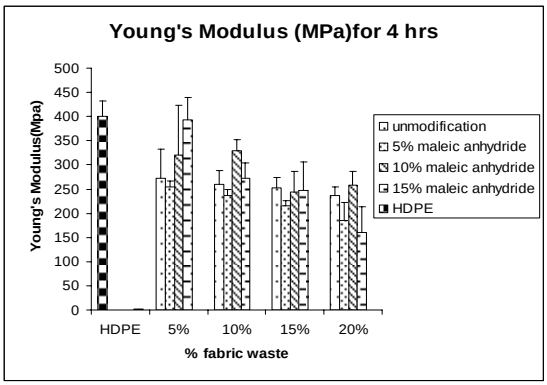

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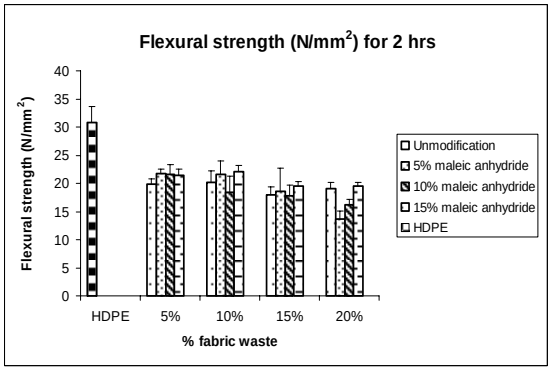
Figure 7. Young's Modulus of HDPEs filled with untreated fabric waste and fabric wastes treated with maleic anhydride 5, 10 and 15%w/w using treatment times of (a) 2, (b) 3 and (c) 4 hours.

It can be seen from Figure 8 that the flexural strength of HDPEs filled with untreated and treated fabric waste are comparable even though the filler content increases from 5 to 20 %. This suggests that the amount of fabric does not affect this property; In addition this property is not affect by the degree of treatment. However, it was found that the reaction time shows significant effect on flexural strength. From Figures 8a to 8c, as the reaction time increases from 2 to 4 hours, the flexural strength of all samples generally decreases. This may be a result of the degradation of cellulose fibers caused by acid hydrolysis which is favorable at long reaction time as was previously discussed. This results in lower molecular weight cellulose fibers and also less interfacial adhesion between fabric waste and HDPE matrix. In contrast to flexural strength, the deformation at maximum load of the samples increases with increasing reaction time as shown in Figure 9. This is due to the same reason. Because of less interfacial adhesion between the two components, therefore, it is easier for polymeric molecules to move apart from each other. As a result, flexural modulus of these samples also increases with decreasing the reaction time as shown in Figure 10.

From Figures 4 to 10, it can be seen that most mechanical properties of HDPEs filled with unmodified fabric waste are lower than those of unfilled HDPE. This indicated that the fabric waste cannot improve these properties and acts only as a non-reinforcing filler.[6,10] However, increasing the adhesion between these two components can improve the mechanical properties of filled HDPE to be comparable with unfilled HDPE.



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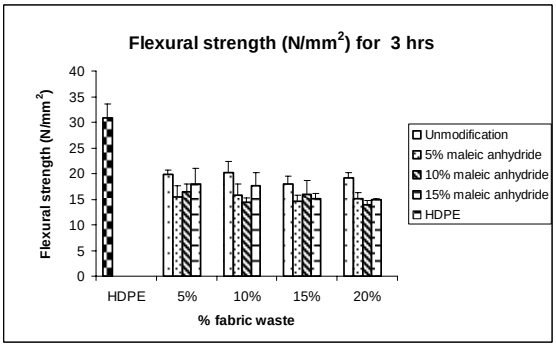

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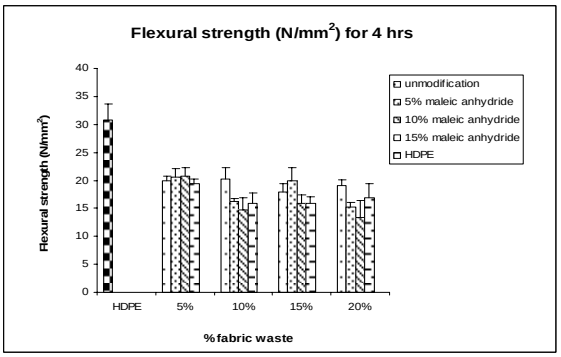

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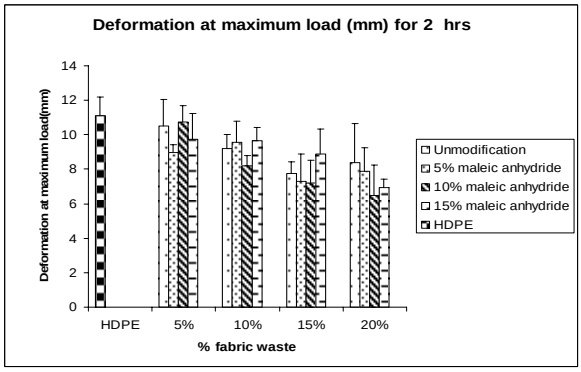
Figure 8. Flexural strength of HDPEs filled with untreated fabric waste and fabric wastes treated with maleic anhydride 5, 10 and 15%w/w using treatment times of (a) 2, (b) 3 and (c) 4 hours.



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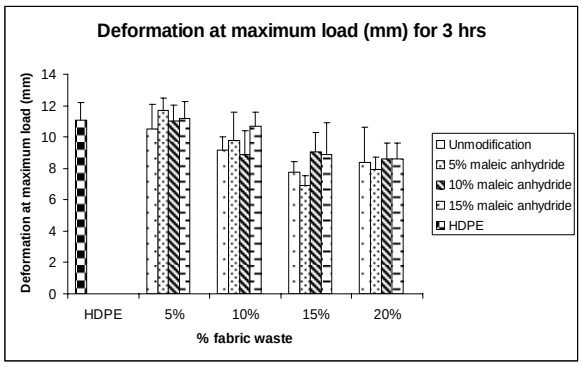

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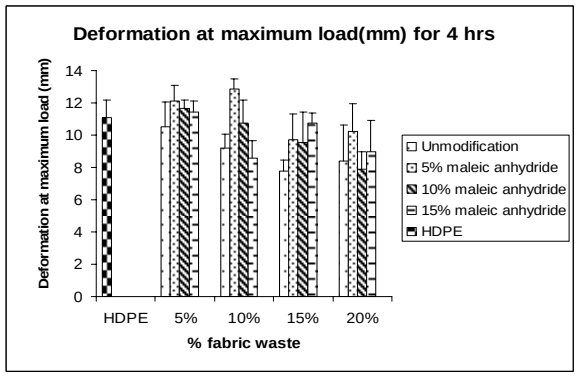

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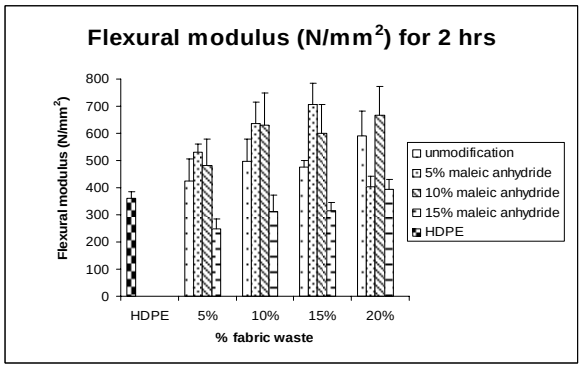
Figure 9. Deformation at maximum load of HDPEs filled with untreated fabric waste and fabric wastes treated with maleic anhydride 5, 10 and 15%w/w using treatment times of (a) 2, (b) 3 and (c) 4 hours.



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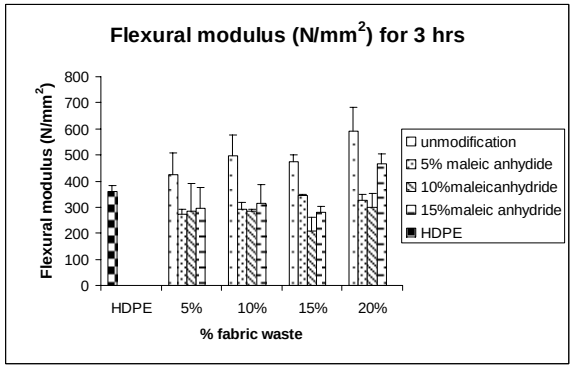

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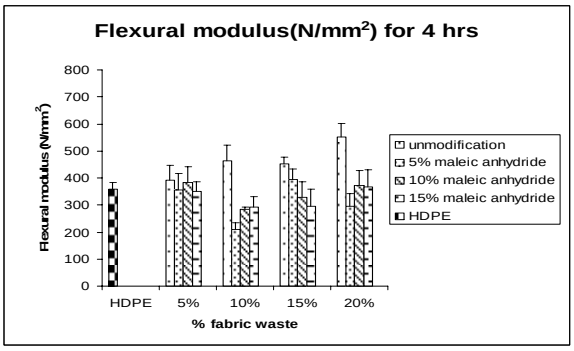

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Figure 10. Flexural modulus of HDPEs filled with untreated fabric waste and fabric wastes treated with maleic anhydride 5, 10 and 15%w/w using treatment times of (a) 2, (b) 3 and (c) 4 hours.

Conclusions

The above results indicated that interfacial adhesion between HDPE matrix and polyester/cotton (PET/C) filler was increased by acid treatment of cotton fibers in the fabric waste with maleic anhydride. Mechanical properties of filled HDPE were affected by the amount of fabric waste, the amount of maleic anhydride and the treatment time. At some treatment conditions, some mechanical properties of filled HDPEs are slightly higher or comparable to those of pure HDPE. This suggests that surface-treated medical gown nonwoven fabric manufacturing waste can be used as a filler for HDPE and by adjusting the treatment condition and the fabric waste content, the desired properties of filled HDPE can be obtained.

Ackhowledgements

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