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Utilizing Discarded Plastic Bags as Matrix Material for Composites Reinforced with Chicken Feathers

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ABSTRACT: High- density polyethylene (HDPE) in used plastic bags was reinforced with chicken feathers to develop composites in an effort to add value and reduce the amount of the plastics and feathers disposed in landfills. Feathers are biodegradable, derived from renewable resource, and are inexpensive and HDPE in plastic bags is mostly discarded in landfills. Utilizing feathers as reinforcement for HDPE composites will provide an opportunity to develop environmentally friendly composites. In this research, HDPE plastic bags were reinforced with chicken feathers and the flexural, tensile and acoustic properties were studied. It was found that incorporating feathers substantially improved the flexural properties and tensile modulus. At the optimum condition, the HDPE-feather (50/50) composites had flexural strength of 13.9 MPa and stiffness of 0.45 N/mm compared to 9.8 MPa and 0.29 N/mm for 100% HDPE. The 50/50 HDPE-feather composite had similar tensile strength but more than twice the tensile modulus of neat HDPE. © 2013 Wiley Periodicals, Inc. J. Appl. Polym. Sci. 130: 307–312, 2013

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INTRODUCTION

Enormous amounts of plastics are disposed in landfills every year across the globe. Despite efforts to promote recycling and reuse, less than 50% of the plastics are recycled or reused.[1] Plastic shopping bags account for a major part of the consumable plastics.[2] It has been reported that more than 500 billion plastic bags are consumed every year in the United States and less than 20% of the plastic bags are recycled or reused. Disposing plastic bags not only causes environmental pollution but is also a waste of valuable resources generated from nonrenewable petroleum resources. Utilizing the discarded plastic bags for high value applications could help to reduce the amount of plastic disposed in landfills and also promote recycling or reuse. Some efforts have been made to study the potential of using waste plastics as reinforcement for composites. HDPE from Kerbside collection and plastics from Kerbside waste I and Kerbside waste II and janotorial waste were melt blended with *Pinus radiata* wood fibers and injection molded to form composites.[3] In another report waste plastics were blended with Harakeke fiber and composites developed by screwless extrusion and then injection molding.[4] Similarly, recycled HDPE, polypropylene and old news paper were combined with a coupling agent and composite panels were formed through air-forming and hot pressing.[5]

Similar to plastics, more than 4 billion pounds of poultry feathers are disposed in landfills in the United States. Feathers are inevitably generated when rearing poultry, have some distinctive properties such as low density and unique structural arrangement unlike any other natural polymers and are also biodegradable, renewable, and inexpensive.[6] Therefore, considerable attempts have been made to utilize feathers for various applications.[7–11] However, unlike plastics, feathers are nonthermoplastic that restrics the use of feathers for industrial applications. Feathers have to be chemically modified to make them thermoplastic. However, chemical modifications add cost and may not be environmentally friendly and could also reduce the degradability of the feathers. Therefore, it is advantageous to use feathers without chemical modifications.

Because of their low density and unique structural arrangement, feathers are preferred as reinforcement, especially for lightweight composites. Several reports are available on using poultry feathers as reinforcement for composites. Most of the reports have used commercially available feather fibers or feather quills as reinforcement with various types of matrix materials. It has been shown that feather fibers and powdered feather quills can provide similar flexural and tensile properties to light-weight composites compared with using natural cellulose fibers such as jute as reinforcement.[10,11] However, it has been reported that feathers in their native form can provide better properties to light-weight composites compared with using feather fibers or powdered feather quills as reinforcement.[19] Feather fibers were also mixed with cellulose fiber as reinforcement and polypropylene as matrix to develop composites.[9] Similarly, feather fibers were used as reinforcement and soybean oil based resin as matrix to develop completely biodegradable composites.[20] In all the reports on utilizing feathers for composites, the matrix materials such as polyethylene or polypropylene have been used in their pristine form. There are no reports on using feathers as reinforcement and recycled synthetic materials as matrix.

In this research, we have developed composites utilizing discarded plastic bags as matrix and feather fibers as reinforcement. The effect of the ratio of feathers in the composite and the time and temperature of fabricating the composite on the flexural and tensile properties have been studied. Acoustic properties and morphology of the composites have also been investigated to evaluate the potential of using the composites for automotive and other applications requiring light-weight composites.

MATERIALS AND METHODS

Materials

Poultry feathers containing quills and barbs were supplied by Feather Fiber Corporation, Nixa, MO. The feathers were cleaned and had feathers fibers with length ranging from 60 μm to 1 mm and width ranging from 4 to 10 μm.[10] The feathers were used as received. Plastic bags made from High Density Polyethylene (HDPE) used as reinforcement were collected from the recycling program of a major retail grocery store.

Thermal Analysis

The HDPE plastic bags were tested to determine their melting point using a differential scanning calorimetry (DSC). About 8 mg of the plastic bag was placed in aluminum pans and the DSC (Mettler Toledo D822^e) was operated at a heating rate of 20°C/min from 50°C to 200°C under nitrogen atmosphere. The DSC thermogram obtained was analyzed to determine the melting temperature of HDPE.

Fabricating the Composites

Plastic bags were cut to dimensions of $25 \times 30\,\text{cm}^2$. A total weight of 130 g of the reinforcing and matrix materials was used to fabricate the composites. On the basis of the ratio of feather to plastic bags, the required plastic bags and feathers were divided into three to five parts. It was ensured that layers of plastic bags separated the feathers to create a sandwich structure with enough plastic bags at the top and bottom of the composites. The stacked plastic bags and feathers were weighed before compression to ensure that the same weight was used for different replications. Proportion (w/w) of the feathers to plastic was varied from 40/60 to 70/30. Stacked layers were placed between the platens of a Carver press (Carver, Wabash, IN) that was preset to the desired temperature 170–193°C (340–380°F). The plastic and feathers were compression molded for 2–5 min at a particular temperature at a pressure of ~17 MPa. After compression, the press was cooled by running cold water and the samples were removed. To understand the effect of feathers on the composite properties, the plastic bags were compression molded without feathers.

Testing the Composites

Composites developed were conditioned at 21°C and 65% relative humidity for at least 24 h before being tested for their flexural, tensile, and acoustic properties. Flexural tests were done according to ASTM standard D790-03 on samples measuring 7.6 cm × 20.3 cm with 15.2 cm support length and crosshead speed was 1 cm/min on a MTS tensile tester (Model Q test 10, MTS Corporation, Eden Prairie, MN). The stiffness values obtained were multiplied by 10 and the modulus of elasticity values by 0.01 to be able to fit the flexural properties into one graph. Tensile tests were performed using dog bone-shaped specimens according to ASTM standard D638-03 on the MTS tensile tester. Crosshead speed was 5 mm/min and gauge length was 11.5 cm. At least six samples collected from three different composites were tested for flexural and tensile properties. Sound absorption of the composites was tested based on ASTM standard C423-99A using a Bruel and Kjaer small size impedance tube. Sound absorption was measured in terms of sound absorption coefficient at various frequencies as an average of three samples taken from three different composites.

Morphology

The morphology of the composites was observed using Scanning Electron Microscope (SEM, Hitachi Model S3000N). Samples were cut from the center of the composites using a blade and coated with gold palladium and placed on adhesive tapes for observation at an accelerating voltage of 25 kV.

Statistical Analysis

The flexural and tensile properties of the composites were analyzed for statistical significance by a *t*-test using a SAS program. Statistical significance was considered if the P value was <0.05.

RESULTS AND DISCUSSION

Thermal Behavior of HDPE

Figure 1 shows the DSC curve for the HDPE plastic bags. The HDPE in the plastic bags had a melting temperature of about 130°C. Although the HDPE melted at 130°C, we used compression temperatures ranging from 171 to 193°C (340–380°F) to ensure that the HDPE melted and was able to flow through the layers of feathers.

Effect of Proportion of Feathers and Plastic

The proportion of feathers in the composites affected all the flexural properties as seen from Figure 2. Without reinforcement, the 100% HDPE had considerably low flexural strength and modulus of elasticity (MOE) compared with the properties of the HDPE-feather composites reinforced with 50 and 60% feathers. Composites with low (40%) and high (70%) proportion of feathers, did not have any statistically significant difference in flexural properties compared with the compression molded 100% HDPE. Increasing the concentration of feathers

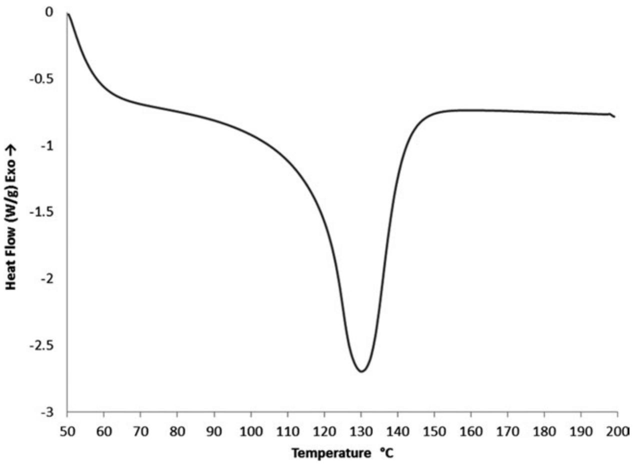

Figure 1. DSC thermogram showed a melting temperature of 130°C for the HDPE plastic bags.

to 50 and 60% substantially improved the flexural properties. Flexural strength of the 50 and 60% feather composites was about 43% and 62% higher than the flexural strength of 100% HDPE. However, incorporating feathers into HDPE made the composites stiffer as seen from the higher stiffness and MOE values. Further increase in the concentration of feathers to 70% decreased the stiffness, flexural strength, and MOE. Increasing concentration of feathers increased the reinforcing ability and therefore the flexural properties improved. As seen from Figure 3, composites containing 60% feather had an alternate thick layer of matrix and feathers and some of the matrix should have penetrated into the feathers providing relatively higher flexural strength to the composites. Although the layers of plastic bags melt, the HDPE is unable to penetrate through the feathers. Composites containing 40% feathers are compact than the 60% feather composites. HDPE in the 40% feather composite melts but is also unable to penetrate into the feathers as seen from Figure 4, most likely due to the lower temperature and shorter time used for compression. Considerable numbers of voids were also seen in both the 40 and 60% feather composites that lead to lower flexural properties.

In previous studies, it was also observed that increasing proportion of feathers used as reinforcement increased the mechanical properties up to a certain optimum level. Adding up to 20–30% feather fibers substantially increased the offset yield, stiffness and maximum load but the properties did not increase upon increase in feather fiber concentration above 30% because there was insufficient matrix material to bind the feather fibers.[11] A similar effect was also observed when polypropylene was reinforced with feather quills.[10] Since the flexural properties of the composites with 50 and 60% feather were similar, we choose to optimize other composite fabrication conditions with 50% feather to increase the proportion of plastic waste in the composites.

Effect of Compression Time

Increasing compression time from 2 to 4 min did not show any major changes in the flexural properties except for MOE as seen from Figure 5. The offset yield load and stiffness showed relatively less change with increase in time from 2 to 4 min but decreased considerably when the compression time was 5 min. Flexural strength showed significant difference only when the compression time was 5 min. Composites compression molded at 2 min had significantly lower MOE than those compression molded at longer times. However, there was no difference in MOE for the samples compression molded at 3, 4, and 5 min. Sufficient time was necessary for the HDPE to melt and bind the feathers together. Therefore, the increase in flexural properties at longer compression times should be due to better binding between the reinforcing feathers and HDPE matrix.As seen from Figure 6, composites made at 5 min were compact with few voids and showed good binding between the feather and HDPE layers. However, prolonged compression time will damage the feathers and HDPE leading to decrease in flexural properties as seen for the offset yield load and stiffness when the compression time was increased from 4 to 5 min. MOE was mainly dependent on the flexibility of the matrix and

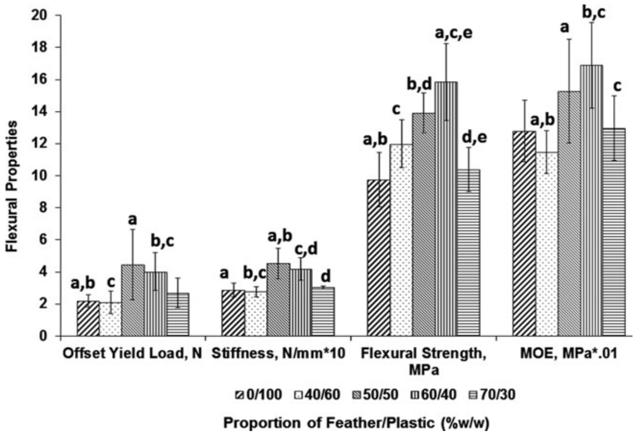

Figure 2. Flexural properties of the HDPE-feather composite at various ratios of feather and HDPE and fabricated at 182°C and 2 min. For each property, data points with the same alphabets indicate statistically significant difference.

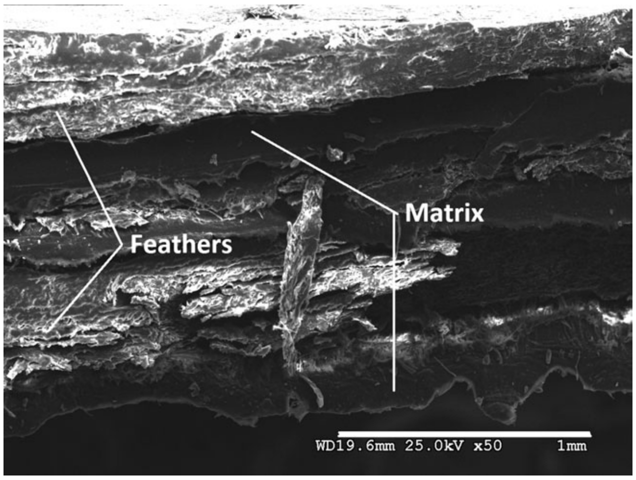

Figure 3. SEM image of the crossection of a composite containing 60% feather and 40% HDPE.

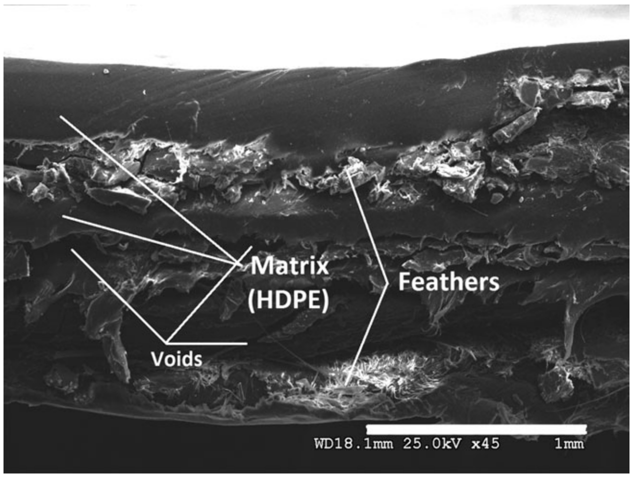

Figure 4. SEM image of the crossection of a composite containing 40% feather and 60% HDPE with fewer voids than the composites with 60% feathers.

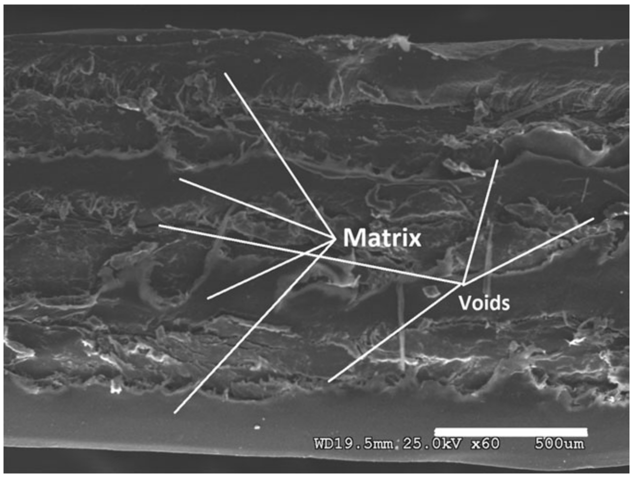

Figure 6. HDPE-feather (50/50) composite fabricated at 182°C for 5 min had very few voids.

reinforcing materials whereas the offset load, stiffness, and flexural strength were mainly dependent on the properties of the reinforcing materials. The higher decrease in the offset load, stiffness, and flexural strength suggests that the feathers were probably damaged to a greater extent than HDPE at a compression time of 5 min.

Effect of Compression Temperature

Increasing temperature from 170°C up to 188°C did not have any major influence on the flexural properties but compression molding at 193°C decreased the flexural properties except MOE as seen from Figure 7. The offset yield load, stiffness, and flexural strength were considerably lower at 193°C. There was no significant difference in the MOE of the composites when compression molded at any of the compression temperatures studied. As with compression time, sufficient temperature was necessary to melt the HDPE and bind the feathers together. At low compression temperatures, the presence of layers of feathers prevented the HDPE to penetrate and adequately bind the feathers leading to inferior flexural properties. As seen from Figure 8, compression at 193°C better facilitates the HDPE to have enough viscosity to penetrate and bind the feathers. The composites are compact with HDPE covering most of the feathers. However, excessively high temperature damaged the feathers and therefore decreased the tensile properties. Discoloration of the feathers was seen in composites fabricated at 193°C. Temperature and time of compression complement each other and high temperature and shorter compressing time or lower temperature and longer compression times could be selected to prevent the thermal damage to feathers.

Tensile Properties

Table I provides a comparison of the tensile strength and modulus of the feather-HDPE composites at various composite fabrication conditions. A compression time of 2 min provided the composites better strength although there was no particular

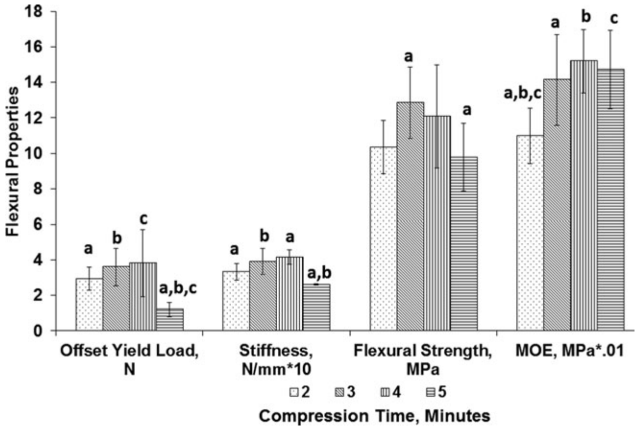

Figure 5. Flexural properties of the HDPE-feather (50/50) composite fabricated at 182°C and different compression times. For each property, data points with the same alphabets indicate statistically significant difference.

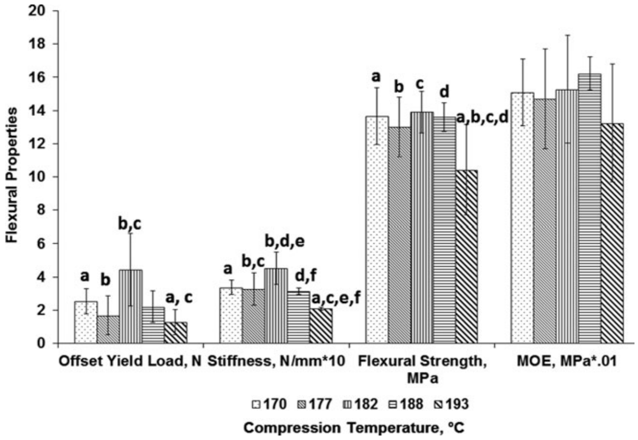

Figure 7. Flexural properties of the HDPE-feather (50/50) composite fabricated at different compression temperatures and compressed for 2 min. For each property, data points with the same alphabets indicate statistically significant difference.

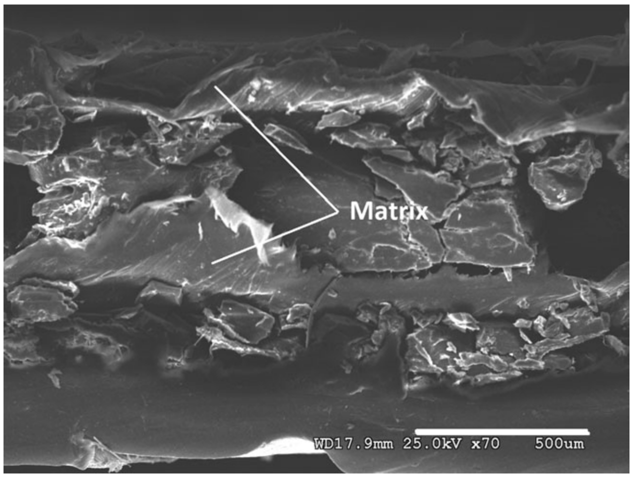

Figure 8. SEM image of the HDPE-feather (50/50) composite fabricated at 193°C and 2 min shows that the HDPE melts and penetrates through the feathers.

trend in the strength of the composites with increasing compression time. However, the tensile strength decreased when compression molded for 5 min. No significant difference was observed in the tensile modulus of the composites molded at different compression times. At long compression time, the feathers could be damaged due to prolonged exposure to heat resulting in a decrease in the tensile strength which was also observed for the flexural strength.

Table I. Comparison of the Tensile Strength and Modulus of the HDPE-Feather Composites at Various Composite Fabrication Conditions

	Tensile strength, MPa	Modulus, GPa
Time, minutes		
2	$15.2 \pm 0.4^{a,b}$	1.4 ± 0.03
3	12.3 ± 2.6^{a}	1.2 ± 0.20
4	13.0 ± 2.6^{c}	1.3 ± 0.31
5	$10.2 \pm 2.0^{b,c}$	1.2 ± 0.17
Proportion, %(w/w)		
100/0	$14.9 \pm 0.9^{a,b}$	$1.2 \pm 0.10^{a,b,c,d}$
60/40	13.7 ± 1.9^{c}	$1.4 \pm 0.03^{a,e,f,g}$
50/50	15.2 ± 0.4^{e}	$1.4 \pm 0.12^{b,e}$
40/60	$12.5 \pm 1.3^{d,f}$	$1.3 \pm 0.14^{c,f}$
30/70	$7.3 \pm 0.9^{b,c,e,f}$	$0.6 \pm 0.06^{d,g}$
Temperature, °C		
170	11.4 ± 1.7^{a}	$1.2 \pm 0.14^{a,b,c}$
177	12.5 ± 2.1^{b}	1.2 ± 0.25
182	$15.2 \pm 0.4^{a,b,c}$	1.4 ± 0.03^{a}
188	13.2 ± 1.7^{d}	1.4 ± 0.11^{b}
193	$12.6 \pm 2.6^{c,d}$	1.4 ± 0.08^{c}

Effect of time was studied using 50/50 ratio of feathers/plastic bags at 182°C. Effect of proportion of feathers was studied at a temperature of 182°C and compression molded for 2 min. Effect of temperature on the tensile properties was studied using 50/50 ratio of feathers/plastic bags and compression molded for 2 min.

[a,b,c,d,e,f,g] For each compression condition data with the same alphabets indicate statistically significant difference.

Reinforcing HDPE with feathers marginally improved the tensile strength but the modulus more than doubled at a HDPE to feather ratio of 50/50. There was no significant change in the strength of the composites when reinforced with 40 or 50% feathers. Increasing the feather concentration to 60 and 70% decreased the tensile strength. The 100% HDPE had considerably low modulus and reinforcing with feathers significantly increased the modulus. However, composites with 50, 60, or 70% feathers did not show any difference in the modulus. The changes in the tensile strength and modulus of the composites with incorporation of feathers into HDPE were mainly dependent on the amount of feathers and the interaction between the feathers and HDPE. The hydrophilic feathers and hydrophobic HDPE will have weak attraction at the interface. Modifying the surface of the feathers and/or adding compatibilizers should help to further improve the tensile properties. In addition, incorporating feathers introduced voids which also decreased the tensile strength of the composites. Compression temperature affected the tensile strength more than the tensile modulus as seen from Table I. The tensile strength at 170°C is ~ 75% of the strength of the composites at the optimum temperature of 182°C. The tensile modulus is also highest at this temperature (182°C). However, increasing temperature above 182–193°C considerably decreased the tensile strength and modulus mainly due to the thermal damage to the feathers.

Sound Absorption

Sound absorption of the composites with feathers (50/50) and 100% HDPE are shown in Figure 9. As seen from the figure, incorporating feathers into HDPE increased the sound absorption by several magnitudes. There are peaks of sound absorption between 2.5–3 kHz and 3.5–4 kHz. Except for sound absorption in the 1–1.5 kHz and 4.3–5 kHz region, the feather composites had much higher sound absorption than HDPE. As seen from the SEM images, incorporating feathers into HDPE introduced voids that act as barriers to sound transmission. In addition, feathers had inherent voids that also assisted in increasing the sound absorption. Such improvement in the sound absorption of composites containing feathers has been reported previously.[10,11]

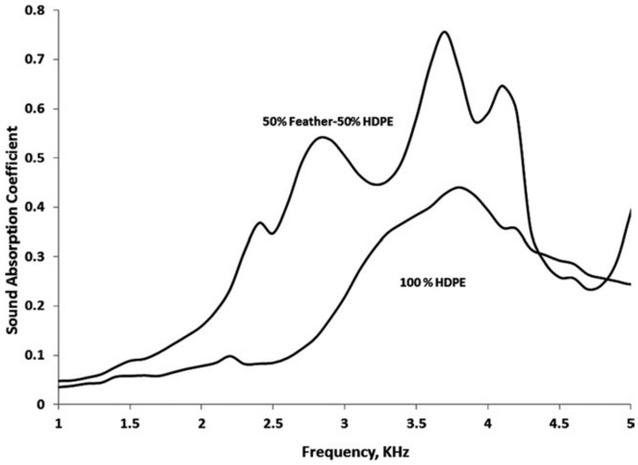

Figure 9. Sound absorption coefficient of 100% HDPE and 50/50 HDPE-feather composite compression molded at 182°C for 2 min.

CONCLUSIONS

This research showed that discarded plastic bags can be used as matrix to develop composites for various applications. Incorporating feathers as reinforcement for HDPE provided much higher flexural strength, tensile modulus and sound absorption than 100% HDPE. The composite fabrication conditions especially the amount of feathers and HDPE influenced the properties of the composites. The individual plastic bags melted and adhered the feathers together but high temperatures or prolonged exposure damaged the feathers and decreased the flexural and tensile properties. A HDPE to feather ratio of 50/50, compression temperature of 182°C and compression time of 2 min was found to provide optimum flexural properties. The inherent voids in the feathers and those between the feather and matrix bags provided substantially higher sound absorption to the composites. Utilizing discarded plastic bags as reinforcement could be a viable approach to add value to the plastic bags and feathers and promote recycling and reuse.

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