Effects of Natural Fillers on Some Properties of Polystyrene

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Abstract- The effects of some animal materials, viz feather, hide and hoof, as fillers for polystyrene were investigated. Composites of varying weight percentages of fillers in fixed weight of the polymer resins were produced for each filler type by the injection moulding technique. The physico-mechanical and thermal properties of the composites prepared showed variations in the properties such as, tensile strength, elongation at break, compressive strength, flexural strength, surface hardness and melting and crystallization temperatures. These materials of animal origin can be used as fillers and mainly as biodegradable fillers for polymer resins and form bio-plastics.

Index Terms- Feather, hide, hoof, mechanical properties and polystyrene.

I. INTRODUCTION

The ever increasing rise of thermoplastics has led to the production of many viable goods that can serve man in several ways. In fact, people have used polymers for far longer than metals; from the earliest times, wood, leather, wool and cotton have been in use for various purposes [1]. This is because of their inherent properties which include corrosion resistance; resistance to water and chemicals, high dielectric constant, toughness, high strength, enhanced abrasion resistance, flex and moderate-to-high creep resistance and moderate temperature moulding characteristics. Most materials of commerce though identified as single materials by their generic names are actually not mono-materials. Many additives are usually incorporated to impart desired physico-mechanical/chemical properties on the finished products. These additives (compounding agents) are carefully selected based on the desired performance target [2].

Fillers are additives widely used for thermoplastics, thermosets and elastomers. They may be inert materials that serve to reduce resin cost and, to a lesser extent, improve processability [3]. Fillers are used in polymers for a variety of reasons; cost reduction, improved processing, density control, optical effects, thermal conductivity, control of thermal expansion, electrical properties, magnetic properties, flame-retardancy and improved mechanical properties such as hardness and tear resistance [4]. Thus, some animal materials such as feather, hide and hoof were used as fillers and incorporated into the polymer resins of common utility. These animal materials like feather and hide are naturally fibrous, tough and light due to high keratin content. Hoof, from physical observation, is tough and coarse. They are used to enhance the mechanical properties of polystyrene and also to see produce green composites of polystyrene.

Polymer Matrix

This is the base polymer which may be either thermoplastic or thermoset. Virtually all polymers have at one time or the other served as matrix for some form of composites because of their low strength and usual ductility or toughness in comparison with the reinforcing materials which are strong, stiff and brittle and with low density [5]. Polymer matrix supports the fillers and transfers the external loading to them by shear of the filler/matrix interface. In addition, matrix provides protection for the filler surface and minimizes diffusion of species such as oxygen or moisture which can degrade the mechanical properties of filler during manufacturing or service life of the composites. It prevents the propagation of cracks in the filler and usually provides the major control of electrical, chemical and thermal properties of the composites.

II. MATERIALS AND METHOD

Materials

General purpose polystyrene was used. Polystyrene is a thermoplastic and aromatic polymer made from the aromatic monomer styrene, a liquid hydrocarbon that is commercially manufactured from petroleum by the chemical industry. It has many desirable properties and one of the most widely used kind of plastic. Polystyrene is outstandingly easy to process. Its stability and flow makes it an ideal polymer for injection moulding technique.

The samples feather, hide and hoof from chicken and cow respectively, were used as the fillers. They were collected, washed and dried for two weeks. The dried samples were sieved and mesh sizes of 200µm were used.

Method

i.) Polymer Composite Production

Pellets of polystyrene resins were mixed with each of the fillers at varying percentages. These were extruded as strands and made into small granules. This was done to ensure a homogenous mixing of the fillers and the polymer resins. Later, each composition was fed into the hopper of an injection moulding machine(TL-120-8.50 Model, Made in China),fixed with a rectangular shaped die(with the dimensions of 146mm in length,40mm in width and 5mm in thickness). After melting and compounding, the mixture was injected into the rectangular die and rectangular polymer composite test bars were produced.

ii.) Mechanical Properties Measurement of the polymer composites

The tensile properties of the filled polymer composites of polystyrene were measured using the Instron Universal Testing Machine. The compressive and flexural strengths were also measured using the Compressive Strength Testing machine of Model Cat G 43/2 and Flexural Strength testing machine of Model Cat L 18/D and Make Controls, Mikano, Italy, respectively. The readings were automatically recorded and the values computed.

The surface hardness of the polymer composites were determined by means of the Avery Hardness Testing machine, Type 6406, Number E65226, manufactured by Avery Birmingham, England.

iii) Determination of the thermal properties of the composites

The thermal properties of the polymer composites were determined by the means of the Differential Scanning Calorimeter, (DSC), of Model DSC Jade and Make Perkin Elmer.

The melting and crystallization behaviour of polymer composites were examined by differential scanning calorimeter (DSC). This method is suitable for the determination of the melting and crystallization temperature of plastics (PE, PP and PS). By heating the samples in a DSC at a constant heating rate, cooling at constant rate and reheating at a constant heating rate, the melting and crystallization temperatures with their corresponding enthalpies of reactions were determined separately and recorded.

III. RESULTS AND DISCUSSIONS

3.1. Mechanical Properties Tests

i) Analysis of Tensile Strength

This is the stress at which the specimen breaks or ruptures, as measured in MPa. This stress at failure is called the ‘ultimate stress’. It results from large and irreversible deformation, which is a sample rather than material property and is strongly influenced by sample defects and processing history. Tensile strength is the most common of the mechanical properties of polymers [6].

Table 1: Values of tensile strength of PS composites

Polymer Composites	Tensile strength (MPa)	Elongation (mm)	Elongation (%)	Break load (KN)
0% PS	4	10.55	6.35	0.81
1% Feather	5	7.14	4.79	0.99
5% Feather	4	11.79	7.86	0.65
1% Hide	8	14.87	9.98	1.53
5% Hide	7	51.97	35.6	0.27
1% Hoof	3	16.44	10.96	0.47
5% Hoof	2	0.86	0.57	0.46

The two fillers, feather and hide, enhanced the tensile strength of the polystyrene composites while hoof filler decreased it below the value of the unfilled specimen. Hide filled composite has the highest value, followed by feather and they decreased their effects as the filler loading increased to 5%.

Hide, it should be recalled that is, elastic, fibrous and collagenous, while feather is fibrous and very rich in keratin (98%) and hoof rich in calcium and coarse in nature.

The variations in the values of the tensile strength of the composites observed may be linked with the degree of adherence of the fillers to the polymer matrix as explained by Bueche [7] and Flemmert [8]. These authors believe that the filler particles tie polymer chain bundles together by filling interstitial voids, thereby restricting molecular slippage on application of tensile force. At the same time, the filler particles assist in distributing any induced stress more equitably. This also reduces the chances of “break or craze ” to propagate along the molecular chain, leading to mechanical failure. By the same mechanism, elongation should be hindered, especially with increasing filler loading [9]. This fact was also confirmed from this work and some other works [10, 11], as elongation at break decreased with increased filler loading in all the polymer composites characterized.

Table 2: Values of compressive strength of PS composites

Polymer Composites	Test force (KN)	Compressive strength (N/mm^2)
0% PS	152.40	47.60
1% Feather	270.20	84.40
5% Feather	218.70	68.40
1% hide	240.80	75.30
5% Hide	254.80	79.60
1% Hoof	246.10	76.90
5% Hoof	275.80	86.20

The addition of these fillers into polystyrene matrix increased the compressive strengths. This tremendous increase in the compressive strengths of polystyrene composites could be attributed to better polymer-filler interaction and adhesion which results in the stiffening of the polystyrene chain and thus exhibited a resistance to compression under applied strain. These fillers hoof and hide can be used to enhance the compressive strength of polystyrene.

The keratin content of feather and hoof filled composites proved their increased strengths to the composites, while hide filler depicted an improvement on the compressive strength of polystyrene.

Table 3: Values of flexural strength of PS composites

Polymer Composites	**Test force (KN)**	**Flexural strength (N/mm^2)**
0% PS	0.30	1.06
1% Feather	0.39	1.37
5% Feather	0.18	0.63
1% hide	0.13	0.46
5% Hide	0.28	0.98
1% Hoof	0.16	0.56
5% Hoof	0.36	1.27

Polystyrene composites filled with feather at 1% and hoof at 5% filler loading respectively increased the flexural strength above that of the unfilled polystyrene Table 3. Feather and hoof fillers interacted well with polystyrene matrix, thereby improving its flexural strength. Hoof filler, in this case increased the flexural strength as the filler loading increased meaning that hoof exhibited good polymer-filler phase interaction and adhesion, thus offering good strength to the polystyrene resin, while feather filled composites decreased the strength as the filler loading increased.

Table 4: Readings of surface hardness of PS composites

S/No	**Specimen**	**Diameter of indentor D, (2mm)**	**Load (5Kg)**	**Diameter of indentation d, (mm)**	**BHN (N/mm^2)**
1	PS 0% Filler	2mm	5kg	0.5	4.1722
2	PS1%Feather	2mm	5kg	0.5	4.1139
3	PS 5% Feather	2mm	5kg	0.6	4.2332
4	PS 1% Hide	2mm	5kg	0.5	4.1722
5	PS 5% Hide	2mm	5kg	0.5	4.1722
6	PS 1% Hoof	2mm	5kg	0.4	4.1139
7	PS 5% Hoof	2mm	5kg	0.5	4.1722

The same similar irregular trend was observed among the three fillers incorporated into polystyrene composites as shown in Table 4. This could be attributed to the fact that the addition of these fillers to the polymer matrices affected the adhesion strength between the polymer and fillers. This can be explained by means of an analysis of polymer-filler interactions. The presence of electrons in the fillers and polymers may have caused repulsion that affected the surface hardness, since there was no donor or acceptor of electrons, thereby reducing crosslinking density and consequently, there was no additional physical crosslinks within the polymer network, Thus, the surface hardness was meaningless [12] or it could mean that the fillers were evenly distributed on the polymer matrix, thereby showing slight surface resistance.

Table 5: DSC Readings for PS composites

Polymer	**Filler**	**Tm (^{O}C)**	**DTm (^{O}C)**	**ΔHM(J/g)**	**DΔH m(J/g)**	**Tc(^{O}C)**	**DTc (^{O}C)**	**ΔHc (J/g)**	**DΔHc (J/g)**
PS	0%	90.59	-	0.59	-	90.24	-	0.88	-
	2%Feather	92.93	2.34	0.47	-0.12	92.95	2.71	1.89	1.01
	2% Hide	91.94	1.35	0.71	0.12	91.51	1.30	1.75	0.87
	2% Hoof	91.90	1.31	0.89	0.31	94.31	4.07	2.84	1.96

In the case of polystyrene composites, the fillers increased both the melting and crystallization temperatures, when compared with the unfilled polymer specimen and unlike its counterparts where an increase in melting temperature and a decrease in crystallization temperature for polyethylene composites and vice versa for polypropylene composites as depicted in Table 5.

This resulting increase for polystyrene composites may be due to the nature of these fillers, polymer-filler phase interaction, strength of the intermolecular forces and sensitivity of the DSC method. The variations in the crystallization temperature,(Tc), as shown by Chemistry, may be due to the interactions of the fillers with the polymer matrix and these depend on the nature of the fillers, time , pressure and purity of the fillers[13].

IV. CONCLUSION

The use of feather, hide and hoof as fillers have embedded some significant properties that are advantageous to polystyrene. Hide filler exhibited better reinforcing performance on the polymer resins, followed by feather and lastly hoof. This could be attributed to the nature of hide and also confirms the good and durable leather product made from hide. The qualities also revealed by feathers showed an interesting value for feathers. This may be due to its high keratin content and other desirable qualities, leading to its increasing demand by researchers to convert feathers into bio-plastics resins and carbon fibers. These fillers are proteinous materials that can decompose and degrade. So the need to use them as biodegradable fillers incorporated into polymers (plastics which litter the environment and seen at landfills) is strong, to help in keeping the environment clean. Also, they can be used to form bio-plastics due to the mechanical strength property, they displayed; thereby reducing dependence on the polymer resins produced from petrol.

Therefore, it is pertinent to channel these fillers into use as fillers for thermoplastic resins and more especially the feathers which are not being used but mainly seen and disposed.

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