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Some Mechanical Properties of SiC-Treated Recycled HDPE

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Abstract This paper reports the mechanical properties of recycled High Density Polyethylene (reHDPE) blended with silicon carbide (SiC). Composite of SiC-reHDPE were prepared by blending SiC powder with reHDPE in a laboratory-sized mixer (Brabender Plasticorder 350E). Blend ratio of SiC/reHDPE was varied from 0/100, 5/95, 10/90 and 15/85. After mixing, some of the samples were shaped in a compression mould for tensile test specimens while other were extruded to diameter 15 mm rods from which Izod impact test specimens were machined. The prepared samples were then tested for tensile and impact strength. Results obtained show that the addition of SiC to reHDPE gives rise to improved tensile and impact strength, greater modulus of elasticity and increased stiffness. The brittleness however increased and ductility reduced. It was concluded that addition of SiC in the proportion of 5% to 15% improved some mechanical properties of reHDPE.

Keywords HDPE, Strain, Strength, Stress

1. Introduction

Although many types of plastics may appear more expensive than some traditional materials, when the overall costs of production and accompanying properties are put into consideration, plastics are usually preferable. For these and other reasons, plastics are widely utilized and accepted among the basic engineering materials[1]. Plastics are generally strong, light, highly dielectric, workable, corrosion and chemical resistant, and durable. In addition, although the absolute mechanical property values of plastics are less than those for metals, the low density of plastics means that their specific properties compare very favourably with other materials[2]. Plastic and plastic-based composites are at the centre of the search for alternative decking materials. Plastics abundance, ease of processing, and ability to mix with a wide variety of fillers along with a reasonable price make it a well suited material to replace pressure treated materials. Also, plastic-based replacement products are claimed to withstand temperature and moisture changes, insects and fungi attacks, and not to crack or splinter[3-5]

Polyethylene is made by the polymerization of ethene/ethylene ($CH_2 = CH_2$)[6]. The chemical notation for the polymerization of ethylene indicates a simple reaction:

$$n(CH_2 = CH_2) \rightarrow (-CH_2\text{-}CH_2\text{-})_n \qquad (1)$$

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The properties and applications of this polymer vary over wide ranges depending on the molecular weight, the method of manufacture, and differences in structure and density[7]. Ethylenes are of two basic forms, Low density polyethylene (LDPE) and High density polyethylene (HDPE). They both have the same chemical formulas but differ in the density of their molecular chains due to the manner they are formed. In LDPE the chains have multiple branches, which interfere with a neatly organized packing of chains. This occupies more space and thus results in a lower density. HDPE chain however, comprises essentially of one long continuous chain which allows the strands to fold back upon one another and densely occupy space. HDPE has good chemical resistance, impact resistance, high tensile strength and very low moisture absorption capacity. It is stiffer, stronger, and less translucent than low-density polyethylene and is formed into grocery bags, car fuel tanks, packaging, and piping[8]. It is used in pipe fittings, wear plates, hinges, cutting boards, and excellent for food related products[9].

For the purpose of facilitating materials supply and alleviating resources depletion and also for conservation of energy, recycling of materials has become integral part of materials industry. The main goal of combining two or more polymers is to obtain a material with appropriate features and conditions for processing. Post-use polymers are mixed in order to recycle such materials, and to reduce the environmental impact generated by these solid residues. Plastics represent a serious environmental problem when they become waste at the end of their useful lifetimes[10].

However, recycling causes deterioration of polymer mechanical properties resulting in product of lower quality and subsequently less valuable[11]. Comparison of blends of recycled high-density polyethylene (reHDPE) with 25 and 35 wt % expanded polystyrene (EPS) and blends of a virgin high-denisty polyethylene resin (VHDPE) shows that the crystallinity of reHDPE is significantly lower than that of VHDPE[12]. Hence, filler materials are added to polymers to improve their mechanical properties, dimensional and thermal stability[13]. The use of natural organic fillers in addition to recycled polymers provides advantages in terms of cost, aesthetic properties and environmental impact [14-27]. The addition of polar copolymers (ethylene-co-acrylic acid, ethylene-vinyl acetate) and a maleic anhydride-grafted-grafted polyethylene has led to improved mechanical properties[24]. The thermal conductivity and diffusivity of composite materials obtained by mixing HDPE with sufficient contents of metal powders (copper, iron, bronze, and zinc) has been reported to be superior to that of unfilled HDPE. For filler concentrations above 16%, the thermal conductivity of the composite materials increases with the increase in metal powder content[25]. It has also, been reported that innovative waste composite containing recycled HDPE strips could be used as a fracture-resistant material in civil engineering construction [26].

The blend of HDPE with natural rubber powder (NRP) revealed that viscosity of resulting thermoplastic natural rubber (TPNR) increases continuously with increasing NRP content[27]. Blends of HDPE with recycled thermosetting filler, urea-formaldehyde grit (UFG), showed improved mechanical properties[28]. The tensile yield strength and tensile fracture strength of composite of HDPE-mica was found to increase nonlinearly, while flexural strength and flexural modulus increase linearly with increase in weight fraction of mica[16]. The inclusion of HDPE as fibers in a granular soil chemically stabilized with cement and fly ash was reported to have significantly enhances the overall toughness of the composite[22].

Binary and ternary blends of the high viscosity recycled high-density polyethylene (reHDPE) from milk bottles, containing either homopolymer polypropylene (PP) or copolymer polypropylene (COPP), showed very good mechanical properties, particularly high strength while engendering lower viscosity than reHDPE[29]. The mechanical and rheological data showed that low-density polyethylene (LDPE) is a better modifier for reHDPE than linear-low-density polyethylene (LLDPE)[30].

Other filler materials applicable for polymers among others include wood flour, fibre glass and talc. Although silicon carbide (SiC) has found application in reinforcement of metals, its abrasive properties makes it a good candidate material for use in polymers[6]. It is a chemical compound that forms extremely hard, dark, iridescent crystals which are insoluble in water and other common solvents[31]. For this reason, this study is set out to access the effect of SiC on tensile properties and impact strength of reHDPE.

2. Experimental Method

Materials used were reHDPE granules obtained from post-consumer packaging materials with melt flow index 0.88 g/10 min, density 0.96 g/cm^3 and thermal conductivity 0.505 W/m·K; and SiC powder with the maximum particle dimension of 100 µm. The composite of SiC-reHDPE were prepared by blending SiC powder with reHDPE in a laboratory-sized mixer (Brabender Plasticorder 350E). Blend ratio of SiC/reHDPE was varied from 0/100, 5/95, 10/90 and 15/85. The mixing conditions were set as follows: fill factor = 0.8, intial chamber temperature = 130°C, rotor speed = 40 rpm and mixing time = 15 min. After mixing, some of the samples were shaped in a compression mould that has the shape of tensile test specimen shown in Figure 1 at 160°C. The resulting composites were preheated in the mould for 4 min, then pressed for 5 min and finally cooled down. Necessary finishing was made and the samples were tested for tensile properties using Monsanto Tensometer machine.

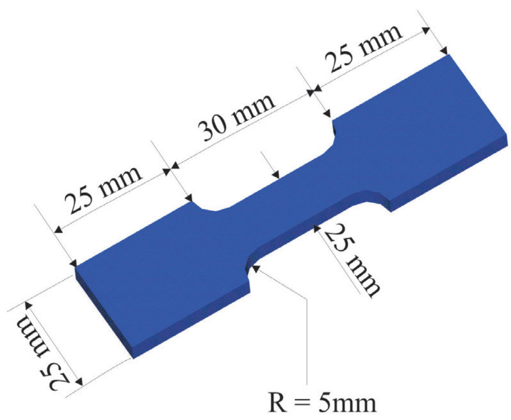

Figure 1. Dimension flat test specimen

The remaining samples after mixing were extruded to diameter 15 mm rods from which impact test samples were machined. The impact test samples were prepared according to Izod specimen (Figure 2). The Izod specimen has a round cross-section with a V-shaped notch. The depth of the notch is 3.3 mm and included angle is 45°.

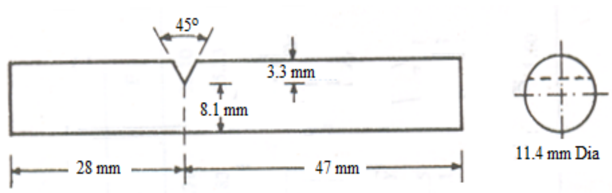

Figure 2. Notched Izod specimen

3. Results and Discussion

3.1. Results

The average of three readings for various parameters taken during the tensile tests for the prepared samples are presented in Table 1, the stress – strain relationships are presented in Figure 3. The changes in UTS and modulus of elasticity with changes in SiC content are presented in Figures 4 and 5 respectively while the percentage elongation and impact strength results are presented in Figures 6 and 7 respectively.

3.2. Discussion of Results

Plastic is preferable in recycling process as it uses less energy and fewer resources. However, as earlier mentioned, recycling causes deterioration of polymer mechanical properties resulting into products of lower quality and less valuable[11]. This is also evident from the various tensile and ductility test obtained (Figures 3 – 7). In all cases the reHDPE to which nothing was added (with zero per cent SiC) shows inferior properties.

Table 1. Average measured values for various parameters of tensile test specimens

Sample	SiC (%)	[1] L_0 (mm)	[2] L_f (mm)	[3] ΔL (mm)	[4] t (mm)	[5] W (mm)	[6] A_0 (mm^2)
HDPE 1	0.00	73.35	73.82	0.47	5.50	13.40	73.69
HDPE 2	5.00	72.10	72.48	0.38	5.87	12.60	73.91
HDPE 3	10.00	72.90	73.22	0.32	5.58	12.73	71.03
HDPE 4	15.00	73.10	74.33	0.24	5.47	12.97	70.82

1. Intial guage length 2. Length at fracture 3. Elongation
4. Thickness 5. Width 6. Original cross-sectional area

The results of the tensile tests showed that the greater the proportion of SiC powder in the blend, the higher the load required in fracturing the sample (Figure 3). Similarly, the stress required to produce a given magnitude of deformation increases as the SiC contents in the reHDPE increases (Figure 3). In the elastic region of the stress – strain curve, a specimen returns to its original length if the load is removed prior to reaching the elastic limit[32]. This implies that all the samples produced deform elastically (Figures 3), just like many plastics do[6].The rate of deformation, however, varies according to SiC content i.e. the higher the SiC content, the higher the deformation rate. Equilibrium separation distance between molecules change during elastic deformation but since the atoms retain the same nearest neighbours during elastic deformation, there were no major changes in the shape of the specimen[32]. Accordingly, this is more pronounced in the samples with higher SiC content.

The tensile strength of the reHDPE is also noted to increase as the SiC content increases (Figure 4). Since the condition under which they are produced are the same, the observed difference in the response to externally applied load can only be attributed to SiC powder added. From Figure 4, it is derived that for every 1.00% addition of SiC to the reHDPE, its strength is raised by 0.038 N/mm^2. Increase in the tensile upon the addition of SiC may be attributed to SiC acting as an additive in the reHDPE matrix which reinforces the HDPE matrix. For this reason the tensile strength of the reHDPE increases as the SiC content also increases (Figure 4).

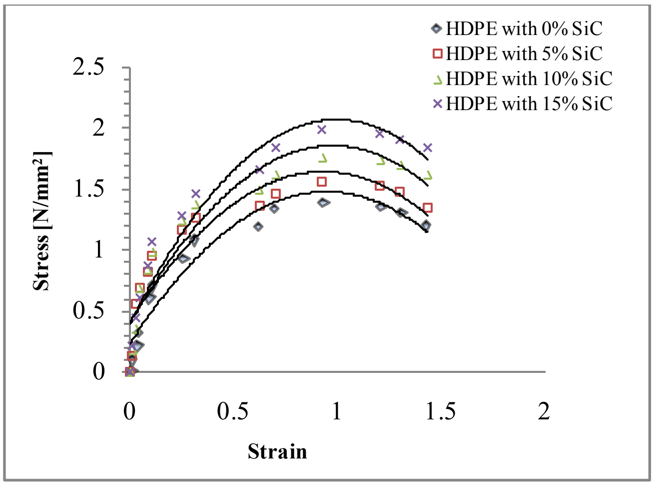

Figure 3. Stress-strain curve for recycled HDPE containing different SiC content

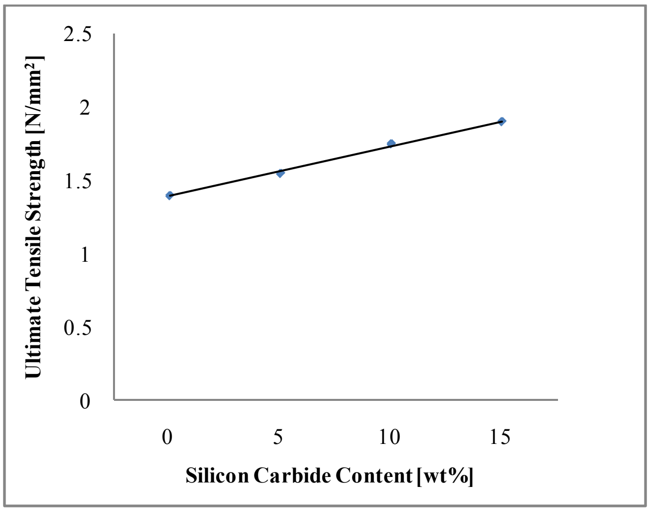

Figure 4. Changes in ultimate tensile strength with increasing SiC content

From the slope of the stress-strain curve of the reHDPE (Figure 3), the modulus of elasticity is produced. The slope of each curve is very steep and becomes steeper as the SiC content increases. The slope of the curve in Figure 5 is about 24.70 $N/mm^2/\%$, showing that increasing SiC content in reHDPE leads to an increase in the modulus of elasticity. The observed increment in modulus of elasticity may be as a result of change in the nature of bonding system of HDPE. The blend of HDPE with SiC possibly results in polymer-matrix composite (PMC) in which HDPE is the matrix and SiC reinforcement. At the interface, this may have produced an interfacial bonding due to the adhesion between the reinforcement and the matrix[33]. Consequently, a chemical bond is formed between the chemical grouping on the reinforcement surface (SiC) and a compatible chemical group in the matrix (HDPE). A range of active functional groups like $–CO_2H$, –C–OH and C=O can be produced at this interface[34]. Since bonding in SiC is covalent and we would therefore expect the strong bonding like this to give high strength with a high modulus.

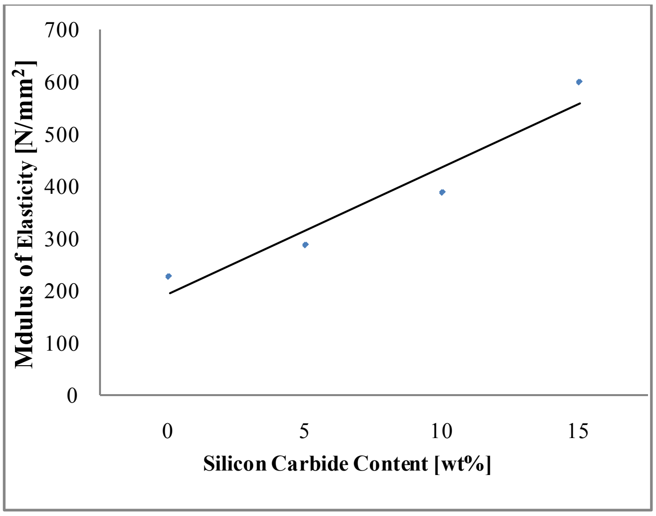

Figure 5. Changes in modulus of elasticity of recycled HDPE wih increasing SiC content

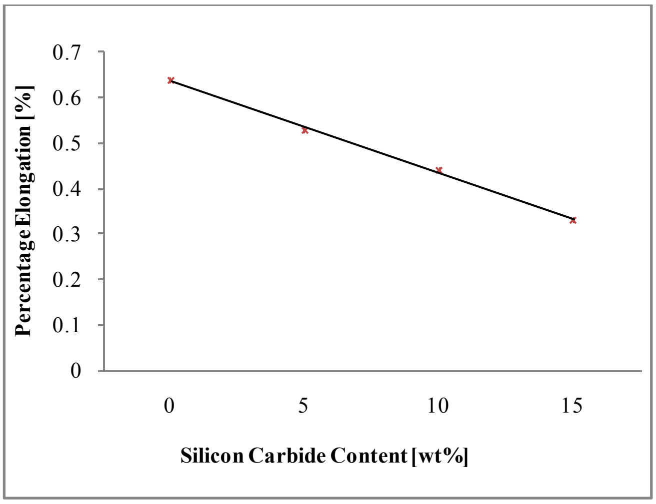

Figure 6. Changes in percentage elongation with increase in the SiC content

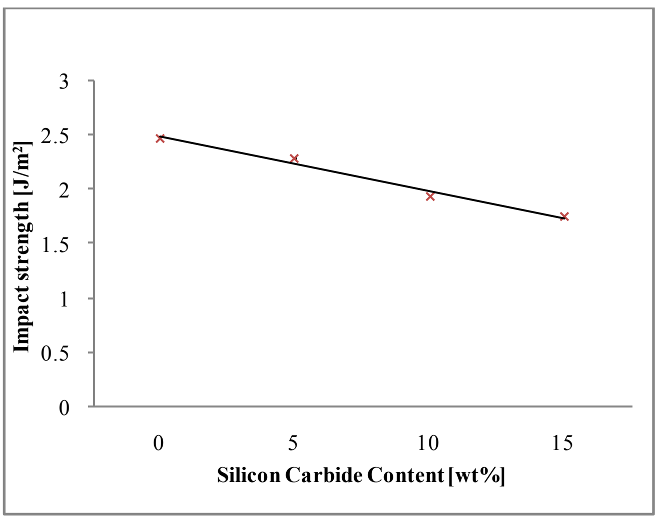

Figure 7. Changes in Impact strength with increase in the SiC content

The implication of the observed increase in the tensile modulus of this material as the silicon carbide content increases is that it develops more resistance to deformation as external load is applied. That is, though the strength increases as SiC content increase, the material is however not readily responsive to deformation been initiated by the externally applied tensile loading. This becomes more obvious when the percentage elongation of the material is considered as the SiC content increases (Figure 6). This implies that the prepared polymers are not readily deformed but provide resistance to deformation as the stress on them increases. Figure 6 reveals that deformation of only 0.02 is accomplished for every 1% addition of SiC before fracture occurs. That is, the reHDPE can only be stretched by 0.02% of its original length before it breaks for every 1 wt.% SiC addition to it. The strength of polymers with a high degree of crystallinity is often limited by the size of voids that develop between neighbouring spherulites during the crystallization process[35]. It is possible that the SiC particles blended in the reHDPE filled such voids during crystallization leading to an increase in strength and stiffness of the sample produced. Also, SiC is a very thin single crystal that have extremely large length-to-diameter ratios[34]. As a consequence of their size, they have a high degree of crystalline perfection and are virtually flaw free, which accounts for their exceptionally high strengths. Increasing value of the modulus of elasticity is an indication of increasing stiffness of the material[13]. This implies that the elastic strain that results from the application of a given stress becomes smaller as the elastic modulus increases due to increasing SiC contents. The addition of SiC therefore improves the stiffness of the reHDPE the extent of which depends on the quantity of the SiC in the recycled HDPE (Figure 6).

The impact test results indicates that the total energy absorbed by reHDPE for fracture to take place decreases as the SiC content in the samples increases (Figure 7). That is, the energy absorbed in breaking the samples with SiC is lower than the samples with 100% recycled HDPE. The above behaviour of the prepared reHDPE shows that they are strong plastics with relatively low impact strength with increase in SiC content. This makes the prepared reHDPE reinforced with SiC a suitable engineering material where high strength and stiffness are required.

4. Conclusions

The addition of SiC to reHDPE at ambient temperature improves its tensile strength while its ductility and impact strength decreases. The increase in strength arises as the SiC content in the reHDPE increases. The ductility and energy absorption capacity of the material however decreases as the SiC content increases. The treated recycled HDPE are said to be strong and stiff plastics the extent of which depends on the quantity of SiC in the HDPE matrix. It can also be inferred that the prepared reHDPE reinforced with SiC is a suitable engineering material for application where high strength and stiffness are required.

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