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U.V light effect on the mechanical behaviour of HDPE/Carbon black composites

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Abstract. Energy is one of the most essential parts of our universe. Energy has come to be known as a 'strategic commodity' and any uncertainty about its supply can threaten the functioning of the entire economy. Sun is the plentiful source of energy freely & enormously available throughout the world. Solar energy is considered to be one of the more encouraging energy alternatives due to its ubiquity and sustainability. In solar energy floating solar power system is a revolutionary step as it can solve the perennial problem of land. In floating solar structure, floats made of HDPE material are used. The Ultra Violet (UV) rays present in the natural environment degrades HDPE materials. In the present study, the composite of HDPE material with concentration of 1%, 2% & 3% carbon black is used for making composites. The carbon black acts as UV stabilizer. The mechanical behaviour of the HDPE/Carbon black composite floats are analysed before and after U.V exposure. Properties like Tensile Strength, Breakpoint, Flexural Strength, Flexural Modulus, Impact Resistance, Hardness, are evaluated with different percentage of loadings. Incorporation of carbon does not show any major effect in the properties before and after U.V exposure, but a significant effect is observed at 2% loading of carbon black while compared to 1% and 3%. Further increase in carbon black percentage (more than 3%) will reduce the mechanical properties due to the development of stress concentration and crack propagation.

Keywords. Photo voltaic system; HDPE material, Carbon black, Mechanical property.

1. Introduction

The demand of energy is increasing very rapidly and at the same time the fossil fuels are continuously diminishing due to which world is concentrating on sustainable energy sources which are unlimited and are also eco-friendly for the environment [1,2]. The generation of electricity from solar energy has numerous advantages over other forms of energy generation; but it requires huge land for its installation, which is not freely available in the world [3]. An innovative way of using solar power, Floating solar power plants is an emerging solar power generation system which address the issue of land scarcity. This floating solar plant can be installed in any water bodies which will intensify the amount of power generation because of the cooling effect of water and at the same time eliminate the need for costly land.



The floating structures should have nontoxic, resistant to salt water and alkalis acids, UV resistant, recyclable, and be able to withstand temperatures from - 60°C to 80°C for a long time when used in contact with water, without declining in their mechanical properties [4]. Plastic float elements and stainless-steel elements are the main materials which can be used for making structures. Since the metals are expensive, less corrosion & chemical resistance, the plastics float is found better choice due to their easily manufacturing, light weight, good strength, corrosion resistance & chemically inert properties. The density of polyolefin is less than 1, hence it floats in water. In polyolefin family, HDPE material is the most commonly used material for the floating solar systems [5]. The density of HDPE material is 0.940-0.965 g/cm³. The mechanical properties of HDPE material are found to be good and are not affected much when it is used in natural weathering condition for a prolonged time, hence it is ideal for making floats of floating solar panel structure [6].

When polymeric material is exposed to ultraviolet (U.V) light, it degrades losing its mechanical properties. Due to the chain scission or chemical cross-linking, the mechanical properties of the polymer changes when subjected to UV radiations, which cause the photo-degradation of the polymer, hence a solution to overcome this problem is needed. Carbon black acts as stabilizer, which has been found to be the most effective stabilizer for polyethylene plastic with respect to degradation due to light and weathering [7]. The stability is very important when the material is subjected to exposure to sunlight and weathering over long periods of time [8]. Carbon black absorbs light from the entire range of the solar spectrum and protects the interior of the plastic from the penetration of high energy photons. To study the stability over a period a study of the interrelation between the polymeric material and the carbon black surface is important [9, 10]. The particle size of carbon black used and its type determines the resistance to degradation of plastic floats. The resistance against UV radiation also depends upon the scattering of the carbon black in the base matrix and its concentration in resisting [11]. Earlier researchers have reported the evaluation of mechanical and electrical properties of carbon filled polymeric materials [12] like PVC and CB [13], PP and CB [14], and PE and CB [15].

When carbon black is mixed with the polymer lattice, it results in an increase in the mechanical properties like tensile and flexural strength, however, the impact strength of the composite was observed to be decreased [16, 17]. The density difference of the fillers, their morphology, geometrical parameters and the interfacial adhesion between the matrix and the filler are main causes for change in mechanical properties [18].

Liu and Horrocks described the effect of carbon black master batch on the surface of 75 mm LLDPE extruded film when exposed to artificial weathering condition. The author used different particle size, concentration and structure of carbon black master batch for the exposure of the sample to UVA and UVB lamps, under specified temperature and relative humidity. The variation in mechanical properties was studied during exposures when tested by a universal testing machine. The result shows that the strength of UV resistance increases as the concentration of carbon black increased from 1.5% to 3.5% w/w for the films blend with carbon black. The composite LLDPE/carbon black film show more elongation against the UV radiation when reinforced with an average particle size of carbon than larger one [19].

Parvin et al. studied the effect of inorganic filler like talc (T) and Organic filler like carbon black separately loaded in high-density polyethylene (HDPE) with 0, 0.5, 1.0, 10, 20 and 40 wt %. The compression moulding machine was used to prepare the specimens at a temperature of 160° C, and to compare and characterize their morphology and evaluation of mechanical properties. The carbon black mixture with HDPE material encourages the crystallinity and crystalline size more than the incorporation of talc. The increase of carbon black and talc mixture increases the material stiffness by 350%. The flexural strength decreased as the percentage of talc increased but it shows a gain while there is an increase in carbon black content. The increment in the hardness was also observed for both the fillers; nevertheless it was 80% higher for carbon black mixture blend than that of talc when it is loaded with 40% of the filler content. The concluded the strong recommendation that HDPE material simpatico with carbon black rather than talc [20].

Liang et al. selected the weight fractions of the Carbon black as 0, 3%, 5% and 8 % to examine the Mechanical Properties of HDPE material mixed with Carbon Black Antistatic Composites. They have a surface treated the carbon black by the silane coupling agent. The various mechanical properties like flexural modulus, yield strength, the flexural strength of the composite material were analysed under different carbon black concentration. All the properties show a positive hike as the concentration of carbon black increased. The value of elongation at break was increased upto when the concentration of carbon black reaches to 5% [21].

Jassim et al. studied and compare the effect of U. V radiation by evaluating the alteration in tensile strength on the pipe made from MDPE material mix with carbon black and without carbon black. The results bespeak that tensile strength at breakpoints higher for MDPE pipe with carbon black (160.7 kg/cm²) than that of virgin MDPE (137 kg/cm²). Also, the carbon black act as a U. V stabilizer, so there is no change observed in the value of tensile strength at the break after exposed to U.V light (i.e., 160.7 kg/cm²) [22].

After reviewing several literatures with respect to the effect of U.V rays on properties of HDPE material, some of the authors have found that HDPE material is losing its mechanical properties when it is in contact with U.V rays, while the incorporation of carbon black may alter the properties. In addition, thermal degradation studies like FTIR and Thermal aging (like DSC) are not evident.

In this work, HDPE is proposed as a material to make a floating structure for installing the solar panel. This study aims

- To assess the mechanical properties e.g. Hardness, Tensile Strength, Impact strength, Elongation at break, Flexural Modulus, & Flexural Strength, at a different percentage of carbon black loadings.
- To study the effect of the U.V rays on HDPE/Carbon black floating structure at different loadings (1%, 2%, and 3%).

2. Experimental

2.1. Raw materials

HDPE plastic material is supposed to be used for making a structure for floating PV installation. The HDPE material will be exposed to sunlight and will be under the influence of U.V rays. In this work, the Carbon Black having density 2,500 kg/m³ and mesh number 800 is used as a filler and a High-Density Poly Ethylene material having grade HDPE B6401, by Haldia Petrochemical Limited (HPL), India is utilized for the base matrix, with Melt Flow Index 0.884 (g/10 min) at 2.16 kg, 190 °C and density 948 kg/m³.

2.2. Preparation of HDPE/carbon black composite floats

The filler is amalgamated with HDPE material using a high-speed blender for at least 5 min in a concentration of 1%, 2%, and 3% by weight. Then the mixture so formed is processed in a twin-screw extruder to produce granulated composites. The specified specimens are prepared in an injection molding machine (JIT make, the Philippines, 80 T capacities) for testing of various mechanical properties. The Mechanical properties like Flexural moduli, Impact strength, Hardness, Elongation at brake, Tensile and Flexural strength are determined by international standards such as ASTM D 790,256,2240,638,638 and 790 respectively [23].

2.3. U.V exposure test of samples

According to standard ASTM G 154-16 [24], the test samples were placed under fluorescent lamps in a QUV test chamber that provides a radiation spectrum cantered in the ultraviolet wavelengths. A cycle of 192 hours is chosen for conditioning the samples at 23± 2oC and relative humidity of 50 ± 5% for further test.

2.4. Evaluation of mechanical properties

2.4.1. Tensile strength & break point. The testing of HDPE/carbon black composite samples was done using Universal Testing Machine (Shimadzu make, Japan, 100 KN capacities). The test speed and gauge length are selected as 50 mm/min and 100 mm respectively as according to ASTM D638 [25] at a temperature of 23 ± 2 °C and relative humidity of 50 ± 5 %. The average values are reported among the 5 tested specimens.

2.4.2. Flexural strength & flexural modulus. The test is conducted on Universal Testing Machine (Shimadzu Make, Japan, 100 KN capacity) according to ASTM D 790 [26] at a strain of 1 % at a specified temperature and humid conditions. The average values are reported among the 5 tested specimens.

2.4.3. Impact strength. A notched Izod impact test is conducted on an Impact testing machine (Tinius Olsen, USA make, Model-IT 104) using hammer energy of 2.7641 J at a specified temperature and humid condition as per ASTM D256 [27]. The average values are reported among the 5 tested specimens.

2.4.4. Hardness. Durometer by CASA Make is used to measure the shore D hardness of the prepared specimen at the specified temperature and humid condition according to ASTM D 2240 [28]. The average values are reported among the 5 tested specimens.

3. Results and discussion

3.1. Analysis of mechanical properties

3.1.1. Tensile strength and break point. The tensile strength test was conducted to measure the effect of U. V radiation on the composite so formed. Figure 1 and figure 2 represent the change in tensile strength and breaking point before and after carbon black loading under the same weathering conditions. The value of tensile strength increases significantly upto 2% loading of carbon black which confirms uniform dispersion of carbon black and good interfacial adhesion with HDPE matrix. The increase in tensile strength results because of the load employed is expeditiously transferred to the filler.

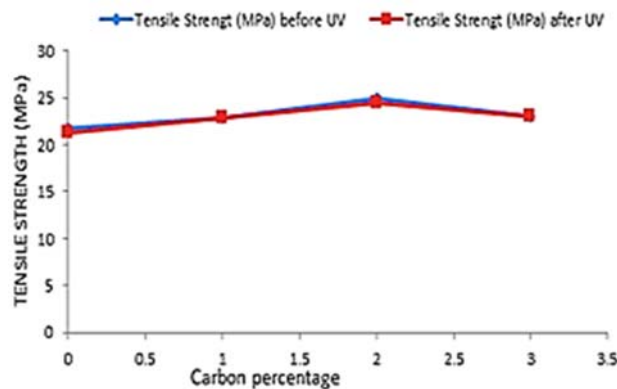


Figure 1. The variation of tensile strength w.r.t carbon % (before and after U.V).

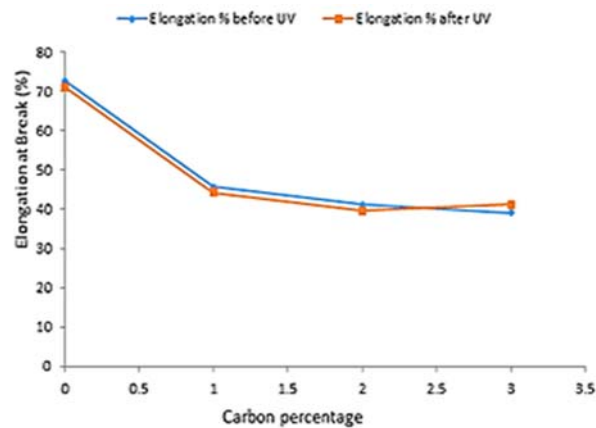


Figure 2. The variation of elongation at break w.r.t carbon % (before and after U.V).

Since the chain mobility of the polymer decreased due to the presence of filler which results in lower deformability of the composites because of the polymer-filler interaction resulting in diminution of the breakpoint [15]. The values at 2% loading of carbon black show a good combination of tensile strength and breaking point. Also, these values are not affected by exposure to U.V environment as carbon black act as a perfect light stabilizer at all wavelength. The inflexibility of the composites rest on the uniformity of the distribution of filler particle in the base material and the interfacial adhesion between the filler particle and the base material [30].

3.1.2. Flexural strength and flexural modulus. As indicated by the figure 3 and figure 4, the flexural modulus and strength both are increased after the incorporation of carbon black. The flexural strength is increased because of the strong coalition among the filler particles and polymer chains and/or between particles and particles of the filler and polymer. Also, the stiffness of the composites increased because of the presence of rigid inorganic carbon black particles as the macromolecule in the chain segments become immobile.

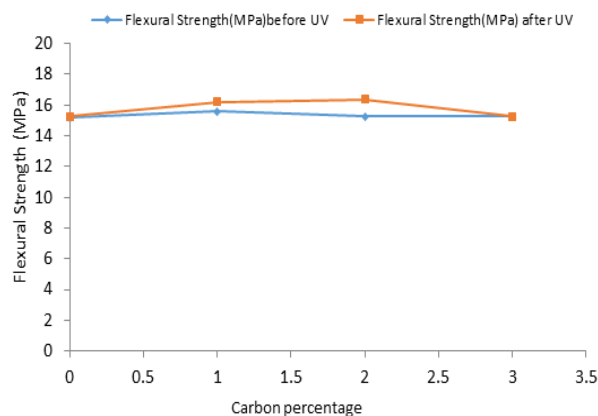


Figure 3. The variation of flexural strength w.r.t carbon % (before and after U.V).

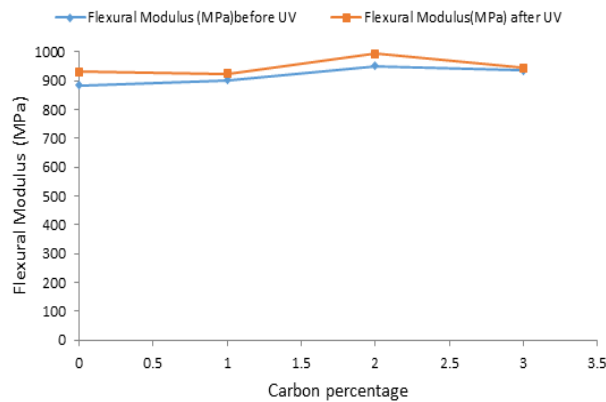


Figure 4. The variation of flexural modulus w.r.t carbon % (before and after U.V).

3.1.3. Impact strength. Figure 5 shows the change in impact strength wrt different carbon percentage. The impact strength of HDPE/carbon black composite decreases sharply with the increase in carbon as a filler percentage. This is because the filler particle blocks the roving of macromolecule chain segment, which limit the ability of the composite to accommodate the contortion and to the speedy crack distribution along with the interface of the filler-matrix [31]. The main reason for the reduction of impact strength is the generation of cracks on the weaker interfacial regions due to the excess of filler content that increase the interfacial regions as the crack propagation does not resist by interfacial regions more effectively as the polymer matrix can [32]. The exposure to U.V light does not show any effect on the impact strength. The change in mechanical properties before and after U V stabilization for different loading conditions can be best viewed through the graphs shown in figure 6.

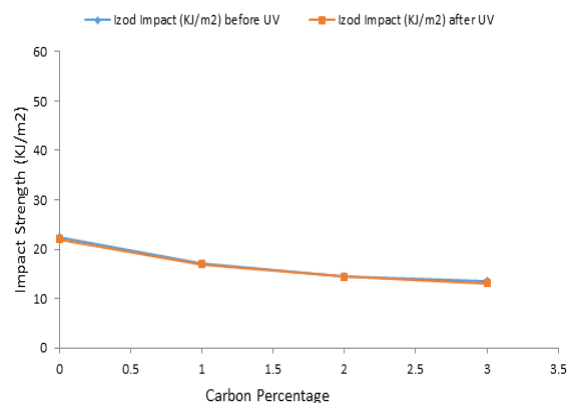


Figure 5. The variation of Impact strength w.r.t carbon % (before and after U.V).

3.1.4. Hardness. The percentage of carbon shows a negligible effect on the hardness before, and after U.V. A slight variation occurs due to the molecules of the filler and polymer are closely packed at the macroscopic level or the cross-linking reaction that heads towards the hard and dense formation of the structure, as shown in figure 6. A comparison of the change in the mechanical properties of virgin HDPE floats, and floats made up of reinforced HDPE material with different % of carbon black is shown in table 1.

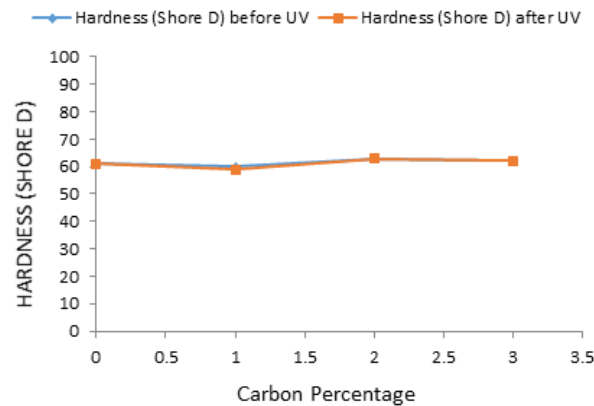


Figure 6. The variation of hardness w.r.t carbon % (before and after U.V).

Table 1. Comparison in change of properties after U.V exposure.

No	Properties	Test method	% change after addition of 1% carbon black	% change after addition of 2% carbon black	% change after addition of 3% carbon black
1	Tensile Strength	ASTM D638	(+)7.56	(+)15.36	(+)7.94
2	Elongation at Break	ASTM D638	(-)44.29	(-)37.86	(-)42.19
3	Flexural Strength	ASTM D 790	(+)6.23	(+)7.21	(+)0.07
4	Flexural Modulus	ASTM D790	(-)0.69	(+)6.85	(+)1.53
5	Izod Impact	ASTM D256	(-)23.18	(-)34.72	(-)40.45
6	Hardness	ASTM D2240	(-)3.28	(+)3.28	(+)1.64

4. Conclusion

In this study, the mechanical and thermal behavior of HDPE/Carbon black composites at different loadings (1%, 2%, and 3%) before and after UV exposure is assessed. The following are the major findings of the research work.

- The percentage change of mechanical properties is found to be best at a carbon black filler loading rate of 2% in the HDPE matrix. Also, properties are not affected when the samples are exposed to U.V environment.
- The value of tensile strength increases (15.36%) significantly upto 2% loading of carbon black which confirms uniform dispersion of carbon black and good interfacial adhesion with HDPE matrix thus the increase in tensile strength is observed because of the employed load is expeditiously transferred to the filler.
- Further increase of carbon black percentage (more than 3%) will reduce the mechanical properties due to the development of stress concentration and crack propagation.

Hence HDPE reinforced the material with carbon black is found suitable for manufacturing of solar photovoltaic floating structure used above the surface of water bodies.

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