Original Article

Effect of UV exposure on bimodal HDPE floats for floating solar application

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Abstract

Keeping in view the conservation of natural resources, the power generation from the solar photovoltaic system is increasing day by day to meet the demand of energy worldwide. There are constraints of availability of space for ground mounted solar PV system for large installations. In some countries water bodies are being utilized to install solar PV system to reduce land use. Few floating systems using plastics have been developed to install a solar panel on it. After extensive literature studies on properties of polyolefins, High-density poly ethylene (HDPE) is found to be better material for this purpose.

In order to measure its sustainability, annotation of mechanical properties using bimodal poly ethylene under accelerated weathering condition has been carried out in different intervals till 1152 h, to perceive the lifespan of HDPE material. The change in its mechanical properties like tensile strength, elongation at break, maximum load bearing capacity, impact resistance and hardness were evaluated. It was observed that the tensile strength was reduced from 23.22 MPa to 14.64 MPa after accelerated UV exposure. It was observed that after 1000 h of exposure to accelerated weathering the material still has the tendency to hold a constant load of 637.81 N without rupture, compared to non-weathered sample (955.16 N). The elongation at break was reduced but elongation of 6.24% was maintained after 1152 h of accelerated exposure, which depicts the elasticity of the material, is still maintained. The impact resistance did not show a significant change during this period, the value varies in the range of 13.54–10.06 kJ/m\textsuperscript{2}. However, the hardness was increased from 61 to 66 (Shore D) due to deterioration of low molecular weight polymer present in bimodal PE. It is concluded that the mechanical properties of Biomodal HDPE material after accelerated UV exposure does not have much effect and is safe to bear the load of solar panels and other accessories mounted over it. Further studies can be done using UV stabilized bimodal HDPE.

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1. Introduction

The use of polyolefins, has increased significantly in recent decades and is very attractive materials due to their low cost, good mechanical properties, light weight, durability and versatility than other materials [1]. However, it is a fact that polyolefins are pollutants of the environment because of their non degradability [2] but conversely they are needed at some places for their durability and long life span. Many studies regarding the durability of polyolefins in the natural environmental condition have been reported in the literature. Among the polyolefins, high-density polyethylene (HDPE) has governed a dominating position because of the many excellent properties, cost and ease of fabrication and modifications to enhance the mechanical properties. Due to this it is being used in many applications such as automobiles, household goods, etc., and now particularly for the use of pontoons or floating blocks for the support structures of solar panel array.

Generally, for floating applications, the buoyant force will be stronger for less dense material. High-density (HDPE) material is slightly less dense than water. It’s resistant to most typical chemicals, so probably low-density type (LDPE) may also be suitable for water application. High-density polyethylene (HDPE), due to their lower density than water, has been widely used as a supporting platform for the arrangement of solar panels over the surface of water bodies [1,2]. Degradation of supporting blocks under water bodies is almost accompanied by the change in the chemical composition of a polymer with time due to the effects of heat, light or mechanical stress.

HDPE floats can undergo degradation in different ways depending on the environment. All polymers degrade in the outdoor environment due to the initiating effects of impurities introduced during the manufacturing operations. The rate at which they vary mainly depends on their chemical structure [3].

Polymer components normally fail either by bad engineering design or bad materials design or a combination of both [3]. Therefore, the composition of polymeric materials is important for determining its durability.

Mendes has studied Mechanical, thermal and microstructure evaluation of HDPE after weathering and concluded that non-stabilized HDPE material is mechanically dead after 2500 h of UV exposure [4].

The variations and changes in structure and mechanical properties of compression molded samples of commercial HDPE were reported by Carrasco et al. [5] when subjected to natural aging during a Canadian winter. They considered that there is a drastic decrease in impact energy of HDPE due to the loss of crystallinity and thermal fatigue. Gonzalez et al. [6] have reported the effect of mineral filler on photo-oxidation of HDPE in a UV-weathering chamber. They observed that the degradation follows a free radical chain mechanism and CaCO3 slows the carbonyl and hydroperoxide functional group formation acting as a protective barrier for UV light penetration.

1.1. Properties and structure of high-density polyethylene (HDPE)

Bimodal HDPE possesses highly regular arrangement of un-branched chains along with the copolymer of desired branched structure to maintain the impact strength along with the load bearing characteristic. Normally, these resins are produced using two polymerization reactors in series (LMW and HMW), each operated under separate process conditions. This process allows all of the comonomer to be incorporated into the high molecular weight fraction, where it is most needed to influence properties. The result of this technology is a substantial leap in physical properties at a given resin density.

Fig. 1 shows a comparison between the structures of LDPE (low-density polyethylene), bimodal HDPE (high-density polyethylene), and LLDPE (linear low-density polyethylene). Bimodal high-density polyethylene (HDPE) consist of LMW and HMW species in the polymeric chain, which results in improved performance equals longer service life and increased confidence that the blow molded container will maintain its integrity through even the most demanding of environments. This broad range of polymer chain sizes includes both smaller molecules, which affect processability (e.g., extrusion flow rates), and much larger molecules, which influence physical properties such as top load strength, environmental stress crack resistance (e.g., ESCR) and drop impact strength.

Density (or crystallinity) is a critical attribute for PE blow molding resins. For a given polyethylene material, reducing density improves many important physical properties related to ductility (or lack of brittleness), such as ESCR and impact strength. Density is controlled by the incorporation of comonomers into the polymer at relatively small levels during polymerization. Some of the important mechanical properties of a bimodal HDPE material are given in Table 1.

1.2. Objective of the study

Bimodal HDPE plastic material is considered for floating solar installations as these floats will be under the influence of ultra-violet radiations. Although many parameters are important, density strength, ductility, modulus and corrosion resistance are considered as primary factors for water applications. Keeping in mind the above constraints of the unstabilized HDPE material, bimodal HDPE is used in the present work.

![Fig. 1 – Structure of different types of polyethylene](image-url)
to study the properties for such applications. In this work, the effect of the accelerated UV radiations on bimodal HDPE floats was studied by evaluating the mechanical properties like tensile strength, elongation, and impact strength, hardness before and after accelerated UV exposure in the different time interval. Bimodal HDPE samples before and after accelerated UV weathering (conditioned in UV weatherometer at the intervals of 168, 360, 504, and 1152 h) were studied and properties were evaluated. Also, the load-bearing capacity of the material was observed to sustain in the given loading condition.

2. Experimental

2.1. Manufacturing process of HDPE floats by rotational molding

A bimodal, natural, HDPE 010DP45U [8] grade virgin material manufactured by Indian Oil Corporation Limited (IOCL) is chosen for manufacturing floats in the form of cubical blocks. The blocks were manufactured by roto molding process. Rotational molding is a four-step process: loading the mold with resin, rotating and heating the mold, rotating and cooling the mold, and finally, removal of the product. A predetermined weight of polyethylene powder is loaded into a cold mold, which is then closed. The mold is then transferred to an oven, where it is rotated and heated. A temperature in excess is not more than 250°C are commonly used [11]. Rotation typically takes place about two mutually perpendicular axes, which distributes the polymer powder over the interior surface. As the mold heats up, the resin begins to melt and adhere to its interior. Several minutes elapse before all the powder ceases to flow freely. Heating and rotation are continued until the molten resin flows under its own weight to form a void-free coating on the interior of the mold. Rotation is maintained while the mold is cooled with sprays of cold water or by fan-blown air. Once the polyethylene has solidified, the two halves of the mold are unbolted and the molding is removed. Cycle times are quite long, the time required for heating and cooling increasing with wall thickness. The minor residual stresses are found to arise from quenching effects. The outer skin layer is cooled more rapidly than the interior, resulting in a slight density gradient, with the density increasing toward the inner surface. This imparts a small degree of internal stress that can result in warpage if not controlled. The final HDPE Floats obtained from rotational molding process is shown in Fig. 2.

2.2. Sample preparation

The test specimens are made from the same material which is used to manufacture floats, i.e., HDPE 010DP45U [8] grade virgin material. The various mechanical properties of this grade of material are given in Table 2.

The test specimen (Fig. 3) was prepared by injection molding process for measuring different mechanical properties as per international standard (ASTM) shown in Table 3 [13].

2.3. Conditioning of samples by UV weathering

An accelerated UV test provides an alternative and generally much more rapid means of measuring the effects of UV radiation on polymers under consistent and reproducible conditions. The UV light is generally provided by xenon arc lamps and some modern UV exposure cabinet provides a very rapid assessment of polymeric materials and correlate well with

Table 1 – Different principle properties of bimodal HDPE material [8–10].

<table>
<thead>
<tr>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>0.941–0.965</td>
</tr>
<tr>
<td>Degree of crystallinity (%)</td>
<td>80–95</td>
</tr>
<tr>
<td>Flexural modulus (MPa @ 73°F)</td>
<td>31–1551</td>
</tr>
<tr>
<td>Tensile modulus (MPa)</td>
<td>413–1034</td>
</tr>
<tr>
<td>Tensile yield stress (MPa)</td>
<td>18–31</td>
</tr>
<tr>
<td>Tensile strength at break (MPa)</td>
<td>22–31</td>
</tr>
<tr>
<td>Tensile elongation at break (%)</td>
<td>20–130</td>
</tr>
<tr>
<td>Shore hardness type D</td>
<td>66–73</td>
</tr>
<tr>
<td>Izod impact strength (ft-lb/in. of notch)</td>
<td>0.8–14</td>
</tr>
</tbody>
</table>

Table 2 – Different mechanical properties of selected bimodal HDPE material [12].

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Properties</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tensile strength</td>
<td>MPa</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>Elongation at break</td>
<td>%</td>
<td>&gt;600</td>
</tr>
<tr>
<td>3</td>
<td>Flexural modulus</td>
<td>MPa</td>
<td>850</td>
</tr>
<tr>
<td>4</td>
<td>Notched Izod impact strength</td>
<td>J/m</td>
<td>300</td>
</tr>
<tr>
<td>5</td>
<td>Hardness</td>
<td>Shore D</td>
<td>60</td>
</tr>
</tbody>
</table>

Fig. 2 – HDPE floats made by rotational molding process.
environmental exposure. Any elements of the environment can be incorporated into a ‘weatherometer’. For example, condensation and relative humidity may be varied and an alternating water spray can be incorporated to simulate rain. Sufficient numbers of molded HDPE samples were conditioned in UV Weathering Chamber (Q Lab, USA make, model no. QUV/SE/240) (Fig. 4).

The materials were exposed to the action of weathering (Accelerated UV exposure Fig. 8) in agreement with ASTM G 154 [14]. This instrument has eight UVA-340 lamps of 40 W each, providing 8 h cycle for the irradiance of 0.73 W/m² at 340 nm wavelength with an incident radiation beam at an angle of 24° and the black panel temperature of 60 (±3) °C. After irradiance cycle 4 h condensation cycle at 50 (±3) °C is maintained.

2.4. Evaluation of mechanical properties

2.4.1. Tensile strength, maximum load and elongation at break

The tensile strength and elongation at break (%) of weathered HDPE samples were determined using Universal Testing Machine (Instron, USA make, Model: 3382K6825, 100 kN capacity). The test was conducted according to ASTM D 638 [15] at a speed of 100 mm/min, a gauge length of 115 mm at a temperature of 23 ± 2 °C and relative humidity of 50 ± 5%. The values of 5 specimens were taken and average values were reported.

2.4.2. Impact strength

The Izod impact test (notched) was conducted in an Impact testing machine (Tinius Olsen, USA make, Model: IT 504). The test was conducted according to ASTM D 256 [16] using hammer energy of 24.838 J at a temperature of 23 ± 2 °C and relative humidity of 50 ± 5%. The values of 5 specimens were taken and average values were reported.

<table>
<thead>
<tr>
<th>Test properties</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength</td>
<td>ASTM D 638</td>
</tr>
<tr>
<td>Elongation at break</td>
<td>ASTM D 638</td>
</tr>
<tr>
<td>Notched Izod impact strength</td>
<td>ASTM D 256</td>
</tr>
<tr>
<td>Hardness</td>
<td>ASTM D 2240</td>
</tr>
</tbody>
</table>

2.4.2.1. Hardness. The hardness of samples before and after aging was tested in a Shore D-Durometer (MICROTEST make, Model: 1993). The test was conducted according to ASTM D 2240 [17] at a temperature of 23 ± 2 °C and relative humidity of 50 ± 5%. The values of 5 specimens were taken and average values were reported.

3. Results and discussion

3.1. Analysis of mechanical properties

When plastics are degraded with UV radiations (exposure), its physical properties are affected. The original properties, i.e., properties before UV exposure and properties after UV exposures in different intervals were measured and compared.

3.1.1. Tensile strength analysis

Tensile strength is an important property for analysis of product in terms of its mechanical strength. Uniaxial tensile tests were conducted to investigate the effect of UV on the stress–strain behavior of bimodal HDPE. Figs. 5 and 6 presents the stress–strain curves of the HDPE samples before and after UV exposure. Before the weathering conditions and after accelerated weathering (UV radiation) in different intervals of
time of HDPE samples, the variation in tensile strength have been reported and shown in Fig. 7. The stress–strain behavior depends strongly on strain rate and strain. The average modulus of elasticity before and after UV exposure is around 685 MPa and 607 MPa respectively. A little decrease in the tensile strength values was observed during weathering condition in the early stages and then the deterioration is more & finally the value of 14.64 MPa is recorded after 1152 h of accelerated UV condition.

3.1.2. Maximum load bearing capacity
The maximum load bearing capacity of the samples are also reported and the variation is shown in Fig. 8. This is one of the most important properties to be analyzed as the HDPE material used in cubical blocks are being used for supporting structure of the different shape and size solar panels in water bodies. From the above figure it was observed that the maximum load bearing capacity before UV radiation is nearly constant and decreases gradually in case of weathering as the exposure time increases. It was observed that after 1000 h of exposure to accelerated weathering the material still has the tendency to hold a constant load of 637.81 N without rupture, compared to non-weathered sample (955.16 N). The material may fragile but do not break in this region.

3.1.3. Elastic modulus analysis
The variation in elastic modulus is shown in Fig. 9 for UV stabilized grade of HDPE that is nearly unchangeable. The value varies in the range of 500–750 MPa showed a good sign of elasticity. The reduction in Young’s modulus was attributed to changes in molecular mobility of the sample. For stabilized HDPE, the values of tensile stress and modulus of elasticity are practically constant.

3.1.4. Elongation at break analysis
Several authors have shown elongation at break value can be a good measure to monitor the aging of polymers [8,18,19]. During the initial stage of exposure, the value of elongation at break drops up to 60% of the initial value and then a continuous drop in this value is noted until it reaches value to a minimum or constant. This type of behavior can be explained because of the obvious reason that the parental chain of HDPE separates or there is a division in the main chain that causes a decrease in the molecular weight of the material. Due to long exposure brittleness occurs and the sample loses this property. The variations of the elongation at break percentage values for the HDPE specimen before & after weathering are presented in Fig. 10.

Primarily, the chain was long and the molecules were entangled with weak Vander Waal forces to each other and the movement of entire molecules is associated with the viscous flow. This is obviously depending upon the number of entanglements but at the time of steep drop in elongation at break, these entanglements of the molecules get reduced or breakdown occurs because of the chemical changes like the formation of carbonyl groups that reduces the entanglements [2].

3.2. Impact resistance analysis
The impact resistance of the samples before and after UV exposure at different intervals is shown in Fig. 11. For both the conditions before and after weathering, the Izod impact resis-
tance is reduced till 500 h and after that it starts increasing slightly in case of the sample after UV exposure. The decrease of impact resistance in starting of HDPE samples is mainly due to deterioration of low molecular weight polymer present in bimodal PE.

3.3. **Hardness analysis**

The results of hardness analysis are shown in Fig. 12. The aged samples had higher values of hardness than found for the untreated sample. The hardness of HDPE is more than another polyolefin [20,21]. The material gets harder because of the aging process and the change occurs due to the closer packing of the material in a macroscopic level that leads to the dense and hard formation of the sample. Later on, it was investigated here that after 1200 h of aging the hardness remains constant. The intermolecular packing of material can be attributed to modifications in the amorphous regions. Also, the cross-linking reactions lead to increases in hardness [21].

Bimodal HDPE is relatively hard and resistant to impact and can be subjected to temperatures of up to 120 °C without being affected. It has many properties that make it important in the manufacturing of different products opaque or translucent appearance. Also, HDPE does not absorb liquid readily; making it good barrier material for liquid containers. Recyling of HDPE is also possible making it ideal for floating solar application.

4. **Conclusion**

In the present work, bimodal HDPE material was subjected to various weather parameters such as humidity, rain, visible light and UV radiations and the degradation of HDPE material was observed. The following conclusions were drawn from the study.

1. The tensile strength was reduced from 23.22 MPa to 14.64 MPa after accelerated UV exposure. It was observed
that after 1000 h of exposure to accelerated weathering the material still had the tendency to hold a constant load of 637.81 N without rupture, compared to non-weathered sample (955.16 N). The loss in tensile strength of weathered samples is very less and not affected much by the accelerated UV weathering condition.

2. The elongation at break was reduced maintaining elongation of 6.24% due to the presence of low molecular weight in bimodal HDPE after 1152 h of accelerated exposure, which depicts the elasticity of the material, was still maintained. The gradual and progressive deterioration of the elongation at break could be mainly due to the presence of low molecular weight species in bimodal HDPE and to some extent by the increase of crystallinity due to the effect of UV radiation.

3. The impact resistance did not show a significant change during this period, the value varies in the range of 13.54–10.06 kJ/m². However, the hardness is increased from 61 to 66 (Shore D) due to increase in crystallinity. The increase in hardness after weathering of samples indicates an increase in crystallinity of the material as well as cross-linking of the polymer.

4. Bimodal HDPE technology delivers a substantial improvement in mechanical properties, which include increased
environmental stress crack resistance (ESCR), increased top load resistance for higher stacking requirements and ability to lightweight containers while maintaining drop impact resistance.

5. It is concluded after experiments that the mechanical properties of biomodal HDPE material after accelerated UV exposure was not much affected and it is safe to bear the load of solar panels and other accessories mounted on it.

**Conflicts of interest**

The authors declare no conflicts of interest.
**Fig. 11** – Variation of impact strength before and after exposure of various intervals.

**Fig. 12** – Hardness before and after various intervals of time.

### REFERENCES


