Case Studies in Thermal Engineering 15 (2019) 100534

Contents lists available at ScienceDirect

Case Studies in Thermal Engineering

journal homepage: http://www.elsevier.com/locate/csite

Influence of U.V light on the thermal properties of HDPE/Carbon black composites

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ARTICLE INFO

Keywords:
Photo voltaic system HDPE material
Carbon black
Thermal properties

ABSTRACT

Solar Energy is one of the most abundant renewable sources of energy and free on planet earth. For water mounted solar photovoltaic systems, HDPE material is found to be best suited for the manufacturing of floating bed structure. The major limitation in this regard is the effect of UV radiations present in the natural environment that leads to the degradation of plastic materials. In the present study, the carbon black is used as a UV resistant additive which is mixed with the base HDPE material under different concentration starting from 1% to 3%. The thermal behavior of the HDPE/Carbon black composite floats so formed are observed before and after U.V exposure. FTIR and DSC curve confirms that carbon black is dispersed uniformly in the HDPE matrix and there is no degradation in the polymer after exposure to U.V light.

1. Introduction

Huge energy demand and continuous depletion of the fossil fuels focuses us on sustainable energy sources which are unlimited and are also eco-friendly for the environment [1,2]. Even though solar electricity has several advantages over other forms of energy generation, the major problem is the cost and requirement of vast land which is scarcely available in the world [3]. An innovative way of using solar power, i.e., floating solar power plants will address this issue. The floating solar plant can be installed in any water bodies which will not only escalate the amount of power generation because of the cooling effect of water but conjointly decrease the need for costly land.

The desirable characteristics of the floating structures are: 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 underwater without retrograde in their mechanical properties [4]. Main materials which can be used as structures are plastic float elements and stainless-steel elements. Since the metals are highly expensive, also they are less resistive various chemicals present in water bodies, which build interest for manufacturing of Plastics float because of their lightweight and good strength and resistive properties. Among the polymer family, HDPE material of Polyethylene group is the most commonly used material for the floating solar systems [5]. The density of HDPE material is 0.940–0.965 g/cm^3. Also, the mechanical properties of HDPE are found to be good and are not deteriorated with their use in natural weathering condition for a prolonged time make them ideal for making floating solar panel structure [6].

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https://doi.org/10.1016/j.csite.2019.100534
Received 15 June 2019; Received in revised form 9 September 2019; Accepted 14 September 2019
Available online 17 September 2019

One of the possibilities of polymer degradation could be exposed to ultraviolet (U.V) light. The morphology and the mechanical properties of the polymer changes when subjected to UV radiations from the sun, which cause the photodegradation of the polymer because of the chain scission or chemical cross-linking. Therefore it is important to find out a solution that can overcome this problem. Carbon black 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 acts as a light stabilizer in polyethylene which absorbs light from the entire range of the solar spectrum and protects the interior of the plastic from the penetration of high energy photons. A study of the interrelation between the polymeric material and the carbon black surface is important to study the stability over a period [9,10]. The resistance to degradation of plastic floats depends upon the particle size of carbon black used and its type. Furthermore, the scattering of the carbon black in the base matrix and its concentration also plays a vital role in resisting against the UV radiation [11]. Many 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].

Incorporation of the carbon black with the polymer lattice results in an increase in the different mechanical properties like tensile and flexural strength, however, the impact strength of the composite was observed to be decreased simultaneously [16,17]. This change may occur due to the density difference of the fillers, their morphology, geometrical parameters and the interfacial adhesion between the matrix and the filler [18].

Liu and Horrocks (2001) described the effect of carbon black masterbatch 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 masterbatch 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. (2001) 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 molding 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. (2009) 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 analyzed 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 up to when the concentration of carbon black reaches 5% [21].

Jassim et al. (2017) 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/cm^2) than that of virgin MDPE (137 kg/cm^2). 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/cm^2) [22].

After reviewing several kinds of literature 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 study the effect of the U.V rays on HDPE/Carbon black floating structure at different loadings (1%, 2%, and 3%).
- To study the thermal behavior of HDPE before and after U.V exposure using FTIR and DSC analysis.

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/m^3 and mesh number 800 is used as a filler and a High-Density PolyEthylene 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/m^3.

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.

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 centered in the ultraviolet wavelengths. A cycle of 192 h is chosen for conditioning the samples at 23± 2 °C and relative humidity of 50 ± 5% for further test.

2.4. Evaluation of thermal properties

2.4.1. Fourier transform infrared spectroscopy (FTIR) studies of HDPE/carbon black composites

IR Prestige-21, Shimadzu, Japan equipped with attenuated total reflectance (ATR) accessory is used for FTIR studies of all the samples. All samples are analyzed in a range of 4000–400 cm^{-1} wavenumber with a resolution of 4 cm^{-1} in transmission mode. An air background is taken to run at 200 scans for every sample before each test of the specimen.

2.4.2. Differential scanning calorimetric (DSC) studies of HDPE/carbon black composites

DSC studies of all the samples were done by DSC-3 Mettler Toledo, Switzerland between 25 °C and 200 °C range of temperature in a controlled nitrogen atmosphere. The rate of heating and cooling is selected as 20 °C/minute according to ASTM D3418-15 (2015) [29].

3. Results and discussion

3.1. Analysis of thermal properties

3.1.1. FTIR analysis

FTIR analysis of virgin HDPE & loading with different percentage of carbon black is as shown in Fig. 1 (a to d). The HDPE spectrum demonstrated typical bands of C–H group at 2912 cm^{-1} and 2847 cm^{-1} that were attributed to asymmetric and symmetric stretching vibrations, respectively. The presence of CH_2 bending arises a spectral band at 1470 cm^{-1} [33]. Moreover, the presence of a typical band at 717.5 cm^{-1} represents CH_2 rocking [34]. After the loading of HDPE with different wt% of carbon black (1%, 2%, and 3%)

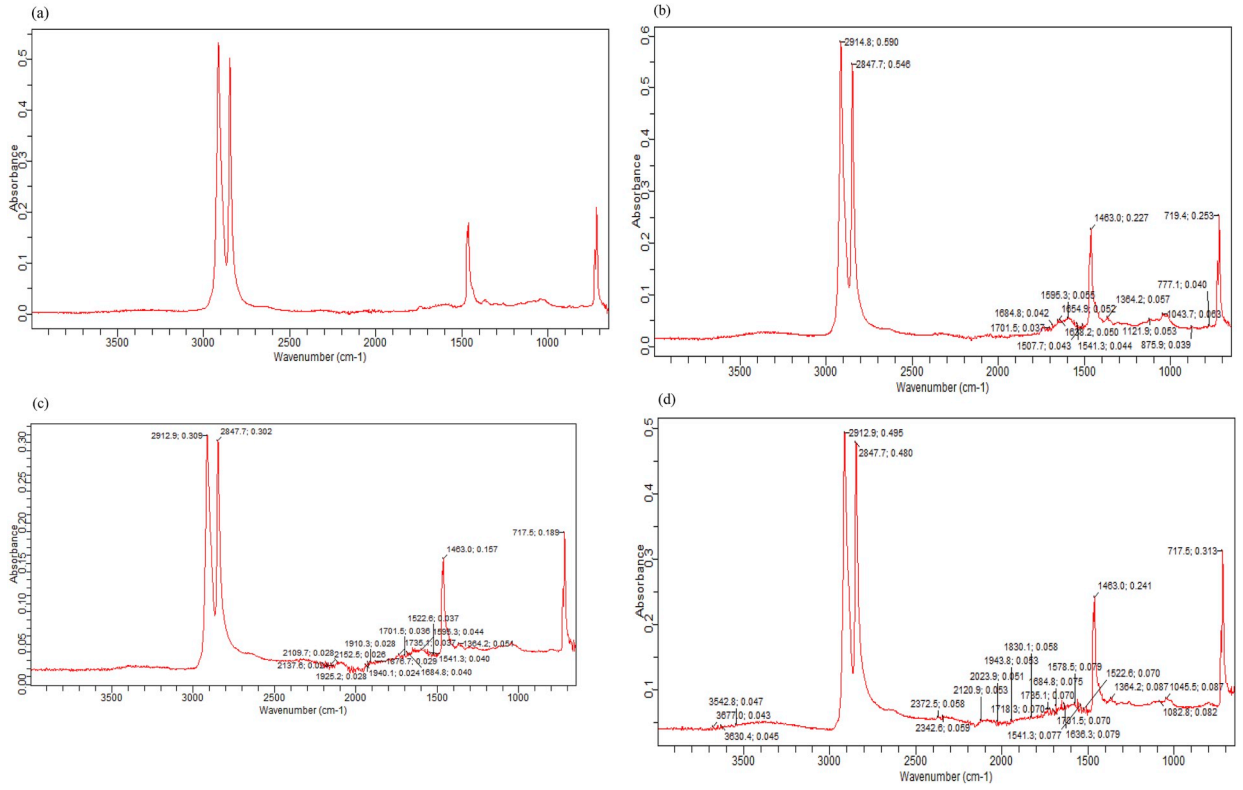


Fig. 1. FTIR spectrum of HDPE/carbon black composites (before U.V). (a): HDPE VIRGIN. (b): HDPE With 1% Carbon black. (c): HDPE With 2% Carbon Black. (d): HDPE With 3% Carbon Black.

spectra show some short peaks dispersed in between the frequency range of 1000–2000 cm^{-1}. This is due to the presence of various groups from the carbon black molecular structure. After exposure to U.V light, the FTIR spectra remains almost the same with all peaks at their position as shown in Fig. 2 (a to d). This result confirms that after exposure to U.V light there has been no degradation in the material as a result of which no bond break takes place, and no new bond formation occurred at the molecular level. This suggests for long-term use of HDPE with carbon black as light stabilizing filler.

3.2. DSC analysis

The DSC analysis was used to examine the effect of carbon black on the crystallinity and melting point of the polymer before and after U.V. Fig. 3 (a) and (b) shows the comparison of crystalline temperature of HDPE reinforced with (1%, 2%, and 3%) carbon black before and after U.V. It can be observed from the figure that the effect of UV does not remarkably change the material structure. All samples exhibited nearly same crystalline temperature ~ 116 °C suggesting that addition of filler does not give rise to the formation of new small particles (nuclei) as a result of which no change in the size of spherulite takes place [35]. Also, Fig. 3 (c), and (d) shows the comparison of melting temperature of HDPE and carbon black composite at different loadings (1%, 2%, and 3%) before and after U.V. It is again observed that UV exposure does not appreciably change the melting point of the polymer. All samples exhibited, irrespective the aging and the carbon black amount, the melting point at ~130 °C suggesting that addition of carbon-black work as a light stabilizer and U.V shielding by protecting the polymer from getting degrade [36].

4. Conclusion

In this study, the 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.

- After the loading of HDPE with different wt% of carbon black (1%, 2%, and 3%) FTIR spectra show some short peaks dispersed in between the frequency range of 1000–2000 cm^{-1}. This is due to the presence of various groups from the carbon black molecular structure. The FTIR spectra remain almost same with all peaks at their position.
- DSC curve also confirm that carbon black is dispersed uniformly in the HDPE matrix and there is no degradation in the polymer after exposure to U.V light. All samples exhibited, nearly the same crystalline temperature of 116 °C and same melting point of 130 °C irrespective the aging and the carbon black amount.
- As a result of which no bond break takes place, and no new bond formation occurred at the molecular level. The thermal properties are not affected when the samples are exposed to U.V environment.
- This suggests for long-term use of HDPE with carbon black as light stabilizing filler. 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.

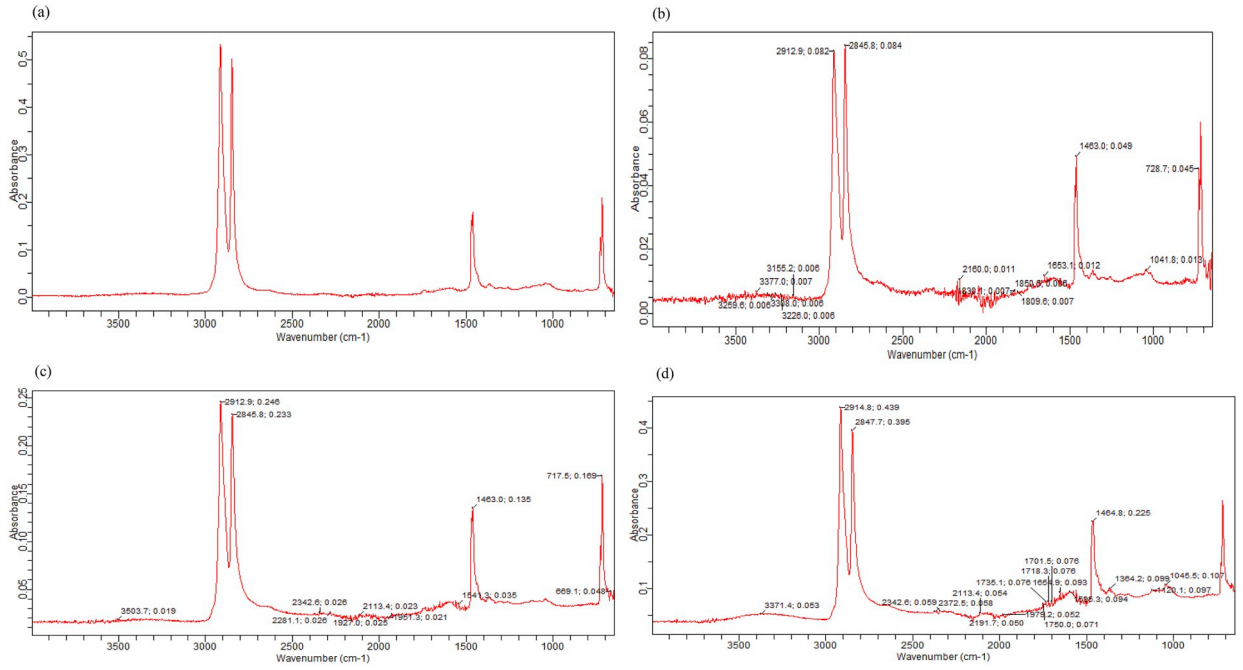
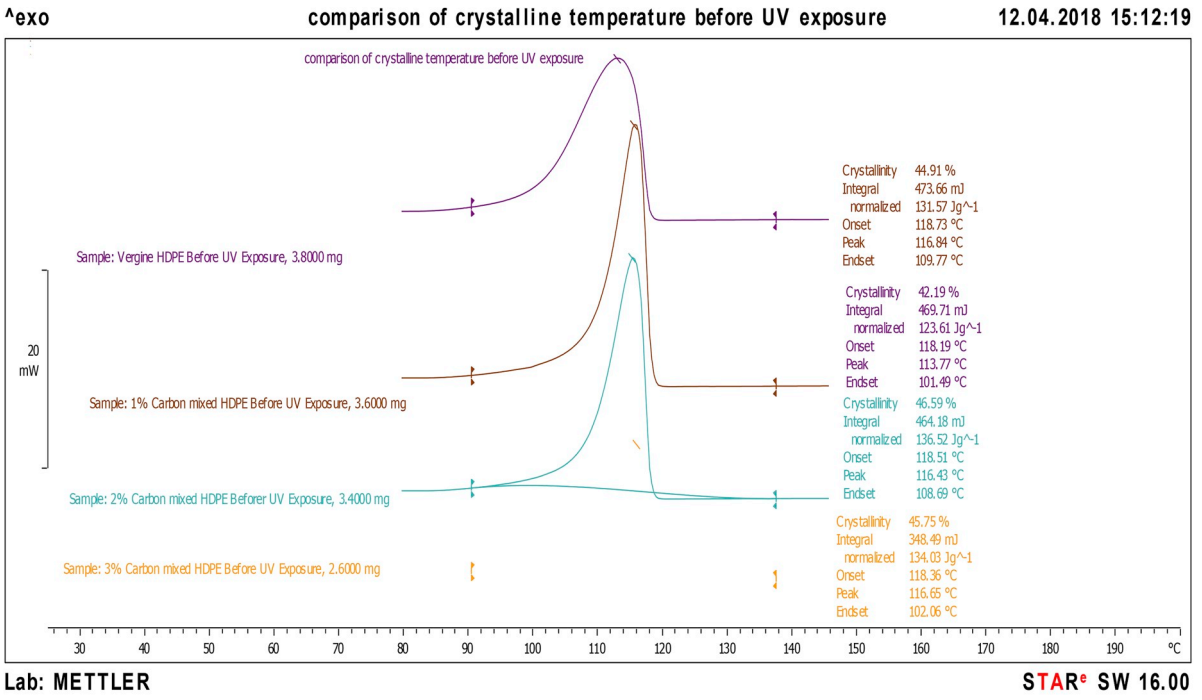


Fig. 2. FTIR spectrum of HDPE/carbon black composites (after U.V). (a): HDPE Virgin. (b): HDPE With 1% Carbon black. (c): HDPE With 2% Carbon Black. (d): HDPE With 3% Carbon Black.

(a)



(b)

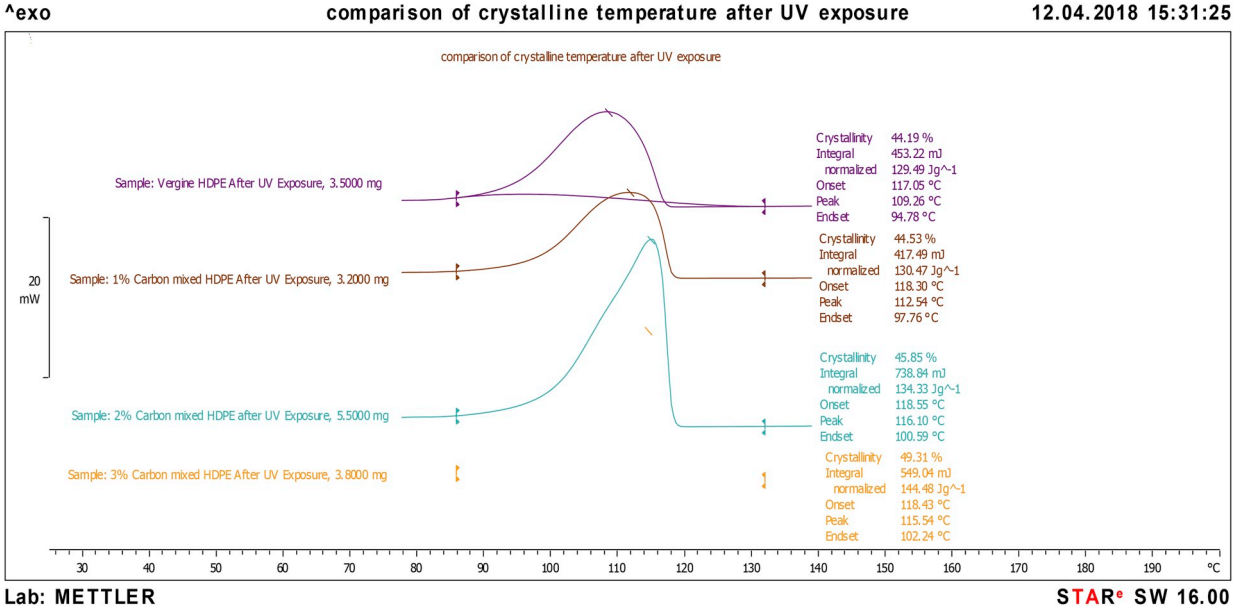
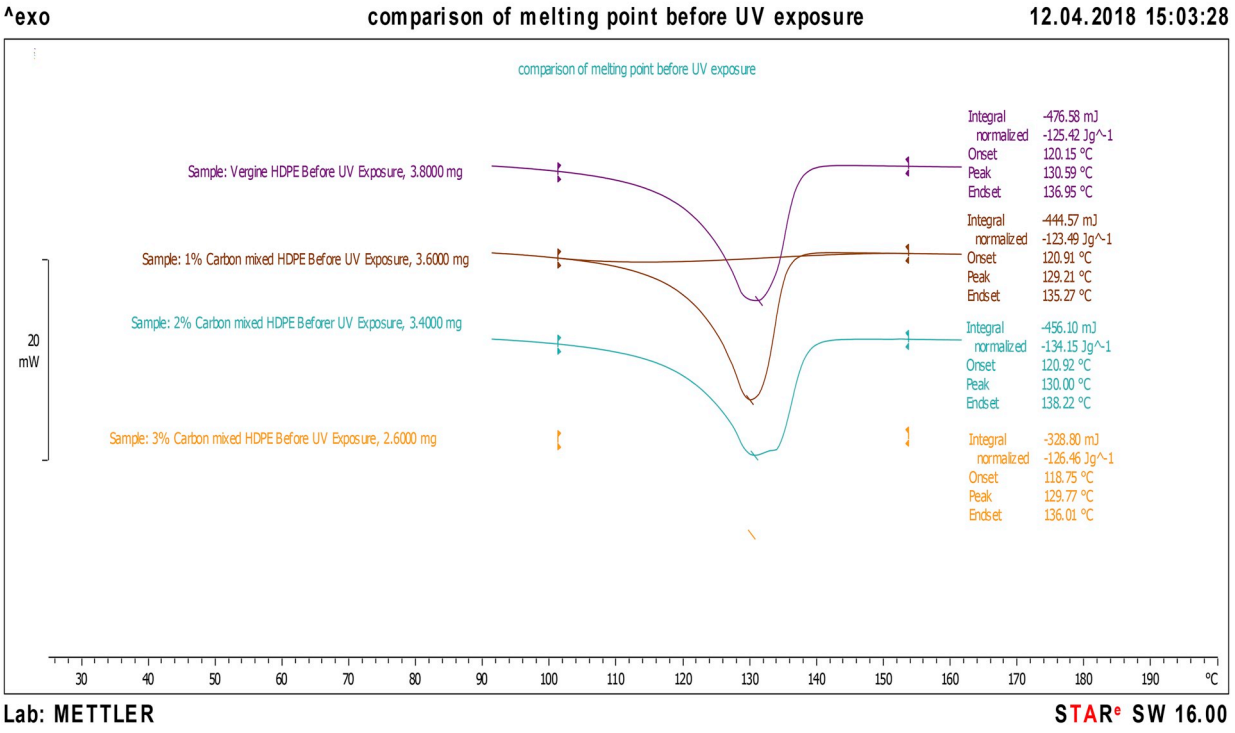


Fig. 3. (a): DSC curve (crystalline temperature) of HDPE/Carbon black composites (Before U.V). (b): DSC curve (crystalline temperature) of HDPE/Carbon black composites (After U.V). (c): DSC curve (melting temperature) of HDPE/Carbon black composites (Before U.V). (d) DSC curve (melting temperature) of HDPE/Carbon black composites (After U.V).

(c)



(d)

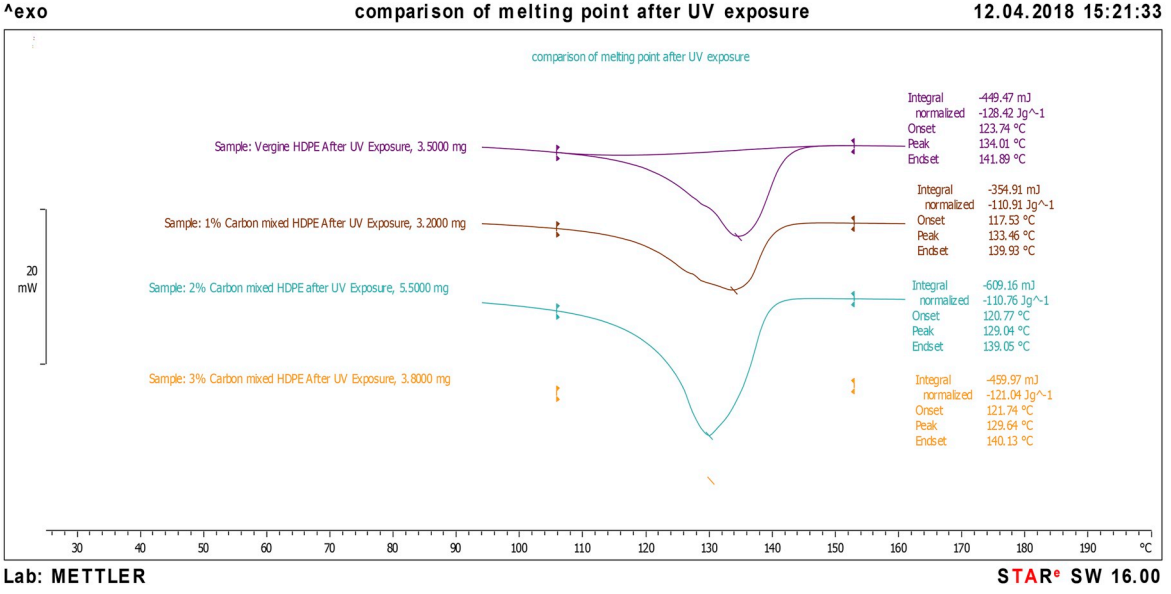


Fig. 3. (*continued*).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.csite.2019.100534.

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