MORPHOLOGICAL, MECHANICAL, THERMAL AND TRIBOLOGICAL PROPERTIES OF ENVIRONMENTALLY FRIENDLY CONSTRUCTION MATERIALS: RECYCLED LDPE COMPOSITES FILLED BY BLAST FURNACE DUST

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ABSTRACT

This study focused on developing a sustainable composite material using metallic wastes of the iron-steel industry and plastic wastes of the plastic industry in order to reduce resultant waste from the production processes of various industrial products and to sustain waste management of these industries. In this study, different amounts of blast furnace dust (BFD), which is the major iron-steel industry waste and is used as filler for recycled low-density polyethylene (LDPE), was mixed with LDPE to produce the composite material. The morphology, mechanical, vicat softening temperature thermal conductivity, hardness and wear resistance properties of BFD filled LDPE composites were assessed. The increasing of BFD in recycled LDPE improved the heat resistance, increased thermal conductivity and wear resistance of composite materials. In addition, it was found that the composite materials had sufficient mechanical properties, when mechanical tests were evaluated. These results showed that the produced composite material could be used in buildings as a floor coating material and thereby saving raw materials and resources, as well as potentially reducing environmental problems.

KEYWORDS

Blast furnace dust, LDPE, plastic waste recycling, composites, mechanical properties, floor coating material

1. INTRODUCTION

In the iron steel industry, more than 400 kg of solid waste is produced for each ton of steel (Robinson, 2008). Most of this is in the form of slag used in the cement, construction and road industries (Robinson, 2005; Robinson and Ökvist, 2005; Difen et al, 2005; Shi and Qian, 2005; Robinson 2008). In addition to slag, iron steel wastes can be classified as dusts, sludge and mill scale (Robinson, 2005). These solids cannot be used in construction of the

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desired degree compared to slag. Although they can be recycled by converting back to the blast furnace (BF), traditionally they are very difficult to recycle without expensive pre-treatment because of the size of the particles and their contents of undesired impurities arising from K_2O, Na_2O, Zn components (Nyirenda, 1991; Fleischanderl, 1999; Robinson and Ökvist, 2005). In addition, a large amount of emergence and different size fractions complicates effective consumption and recycling ratios (Jalkanen et al., 2005). In this process, the most problematic solid wastes are blast furnace dust (BFD) and oxygen converter dust (OCD). In Turkey's iron steel industry, 375,000–425,000 kg ton of BFD products are generated annually (Dogantepe G, 2013). Therefore, these waste products require large landfill areas for storage, resulting in huge costs. Meanwhile, environmental pollution occurs because they contain high amounts of heavy metals (Van Hullebusch, 2015; Mikhailov, 2017; Wen-Tao Hu et al., 2018). Several papers have detailed the risks related to the release of toxic compounds from slag and the dust emitted by blast furnaces (Barna, 2004; De Andrade Lima, 2011a; De Andrade Lima, 2011b; Van Hullebusch, 2015). The recycling of these dusts in construction not only reduce costs but also prevents the transition of heavy metals to the human body through the soil, water and air.

Due to the significant advantage and convenience of plastics, such as being durable, strong and shaped easily (Hong, 2012), the production and usage of plastics have increased sharply in the world from 1.5 million tons (Mt) in 1950 to 312 Mt in 2014 (PLASFED, 2014). Furthermore, it has been estimated that plastic production might triple by 2050 (European Commission, 2013; Plastic Europe, Plastics—the Facts 2014/15, 2015). In Turkey, plastic usage is mostly shared between two industries, which are 36% percent of packing and 23% percent of construction (Pagev, 2015). The most produced types of plastics are low-density polyethylene tubular (LDPE-T) and low-density polyethylene (LDPE) (PETKIM, 2014). Thus, most plastic waste exports are LDPE in Turkey.

Plastics generate many environmental problems such as increasing greenhouse gas (GHG) emissions and waste management to its long waste life (Kaps, 2008; European Commission, 2011). Hence, the recycling of this plastic type and reuse in the construction industry provide an option to decrease waste plastics and therefore minimize environmental problems. There are many methods stated in the literature for the recycling of plastic wastes. Producing the composite material by using waste plastics is one of the most important recycling methods for wastes. In our previous report, a composite material that is produced by using BFD and LDPE had been presented, which could be used in the construction industry (Tuna Kayılı vd, 2016; 2018). Herein, the morphology, mechanical, thermal and vicat softening properties of the composite material were evaluated, and it was compared with five other BFD filler ratios. The results, in particular wear test showed that the composite material could be suitable for use in buildings as a floor coating material. In addition, this study provides evidence for reducing environmental pollution when sustainable construction materials are produced by using recycled materials.

2. EXPERIMENTAL METHOD

2.1 Materials and Preparation of LDPE Composites

In this study, BFD were obtained from an iron-steel factory (Kardemir A.Ş., Karabuk, Turkey). Granulometric analysis was made and the results showed that the particle size of the BFD was distributed between 125 and 500 μm. The results can be seen in Table 1. The chemical analysis was also conducted in a metallurgical quality laboratory (Kardemir A.Ş., Karabuk, Turkey). According to the analysis, BFD particles mainly consisted of iron oxide (52.97%) (Table 2).

TABLE 1. Granulometric analysis of BFD.

Size, μm	500	250	125	62	44	34	24	16	13	9	6.4	4.5
%	31.35	21.75	27.42	3.98	3.06	5.73	2.37	0.9	1.33	0.46	0.61	0.98

TABLE 2. Chemical content of BFD.

Content	Fe_2O_3	C	SiO_2	CaO	MgO	Al_2O_3	MnO	ZnO	K_2O	S	Na_2O
%	52.97	17.92	11.54	9.24	1.3	1.21	0.84	0.29	0.28	0.27	0.05

Waste LDPE pieces were obtained from a factory that produced plastic film (Kazan Industrial Area, Turkey). For coloring, white master batch was provided from the company Colorex, Inc.

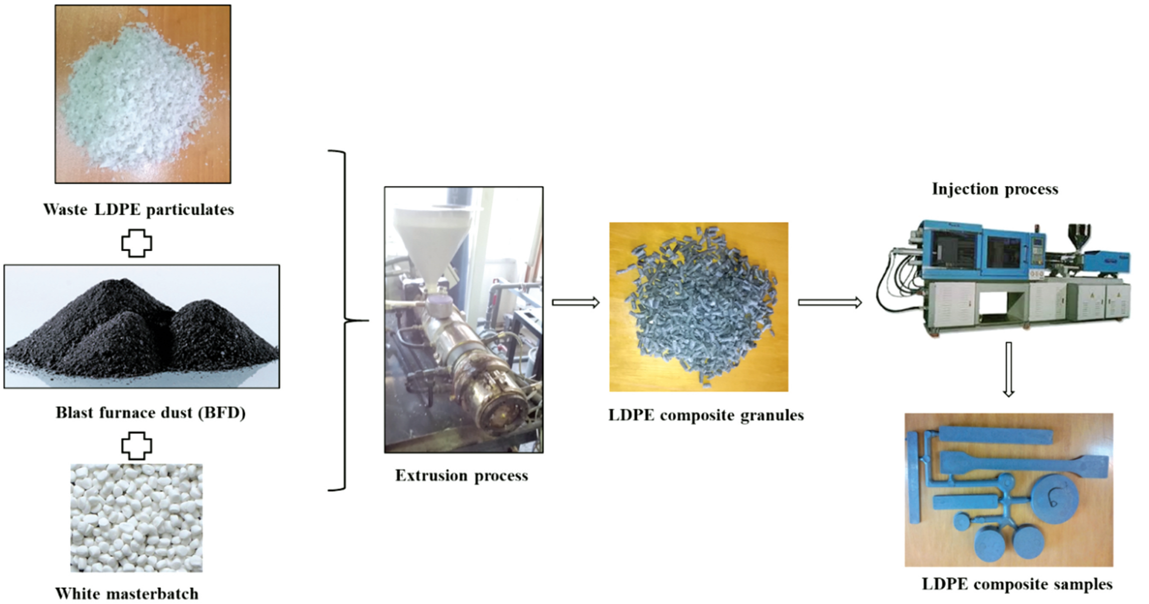
As shown schematically in Figure 1, BFD as a filler and the white master batch were mixed with waste LDPE (ρ:0.92 g/m^3, *Tm:* 120°C) according to the specific ratios for 3 minutes. The mixtures were extruded into thread with a twin-screw extruder in a dust metallurgy laboratory at Gazi University and composite granules were obtained. The temperature of the extrusion process was between 140 and 200°C and the screw was maintained at a speed of 50 rpm. The test specimens were shaped and prepared by an injection-moulding machine (Klasmak brand) at Mucit Plastic Co. Ltd., Konya, Turkey.

Before deciding the LDPE/BFD ratios of the composite material, the content of BFD 50% composite granules was first produced, and the MFI value of granules were investigated. In the rheological trial, the experiments were carried out by the load of 3.8 kg, the pressure of 524 kPa and the temperature of 240°C. MFI value of composite granules was detected to be 2.549 g/10 min in the experiments, which indicated that fluidity of the material was too low. This result showed that higher temperatures were required to produce higher than 50% content of BFD composite granules. In order to decrease energy requirements and costs of the material for the manufacturing processes, it was decided to keep the maximum BFD ratio at 50%. Afterwards, BFD ratios were increased from 0 to 50 by 1.5 times in order to ensure proper distribution of the test data, as shown in Table 3.

TABLE 3. BFD filler and waste LDPE ratios for composites.

Type	Waste LDPE (%)	BFD (%)	Masterbatch (%) (% depending on LDPE)
0	100	0	0
1	90	10	0.1
2	85	15	0.1
3	77.5	22.5	0.1
4	66.25	33.75	0.1
5	49.375	50.625	0.1

FIGURE 1. The production process of LDPE samples.



2.2 Morphological Observation

A SEM (scanning electron microscope) (Jeol JSM-6060LV) was used for the morphological analysis of the fine FRP and the brittle fracture face of the injection-moulded samples. Prior to the SEM experiments, the surfaces of the samples were coated with gold to prevent charging during the test.

2.3 Density of the Composites

Density was evaluated using the ASTM D792 standard. Five specimens of each sample were dried in a vacuum oven (Memmert, Germany) at 50°C for about 24 hours, and then they remained in a desiccator until it reached room temperature (nearly 23°C). The dimensions of the disk specimens were 4.5 cm in diameter and 6 mm thick. The specimens were measured in air, then submerged in water and weighed in water again. Periodically, the density of each specimen was calculated by Eq. 1;

$$\rho = gr\ 23/23°C = a/(a - b) \quad (1)$$

where ρ is gravity of the material, a is the apparent mass of the specimen in air, b is the apparent mass of the specimen completely immersed and of the wire partially immersed in water

2.4 Mechanical Tests

Tensile and flexural tests of LDPE composites were carried out by using a universal testing machine (Instron) according to TS EN ISO 527-2 and DIN EN ISO 527-5 Type 1-b (for tensile test) and ASTM D7264 (for flexure test) standards at room temperature (23°C). The dimensions of the flexural test specimens were 128×13×4 mm. Crosshead speed for tensile and the flexure test were set at 5 mm/min respectively. Seven specimens were measured for each test. The Izod notched impact tests were performed by an impact test machine (branded Alarge) according to ASTM-D256, at room temperature. The samples were previously notched with a 'V' shape. The dimensions of the izod notched specimens were 12.7×63×3 mm.

2.5 Vicat Softening Temperature Test

Vicat softening tests of LDPE composites were carried out by using a vicat softening testing machine (Devotrans HV-2000-M3W) according to the ASTM D1525 standard. The dimensions of the specimens were 10×10×3 mm. In this test, a flat-ended needle was loaded with 10 N and the specimen and then the needle was heated at a rate of 120°C.

2.6 Thermal Conductivity Test

Thermal conductivity tests of LDPE composites were carried out by using a thermal conductivity testing machine (laser comb) according to the TS EN 12667 standard. The dimensions of the disk specimens were 4.5 cm in diameter and 6 mm thick.

2.7 Wear and Hardness Tests

Prior to starting the investigation of the tribological properties of LDPE composite disk samples, in order to remove the surface roughness of the abrasive material, sanding/polishing should be carried out. For this reason, the abrasive surface of the disk samples was wet sanded against 0, 100, 240, 400, 600, 1000, 1200 SiC abrasive paper (Struers brand) sanding/polishing device in the powder metallurgy laboratory of Gazi University. The dimensions of the disk specimens were 3 cm in diameter and 10 mm thick.

Tribological properties of the LDPE composites were examined using a pin-on-disk test device. In the present study, the bottom movable flat surface was treated steel and the upper fixed surface was an Al_2O_3 ball with a 8 mm diameter. The ball was fixed and the disk sample was rotated at a speed of 300 rpm (0.3 m/s). The applied load on the fixed ball was 5 N and the wearing roads were 450 and 900m for each test. Wear tests were carried out in the unlubricated condition at room temperature. The friction coefficient was continuously recorded during the tests. Surface profiles of the wear tracks on the disks were measured by a surface profilometer. Wear volume of the disk specimen was determined from the cross-sectional area of the wear track obtained perpendicularly to the sliding direction. Two wear experiments were conducted for each sample and three measurements were performed using the surface profilometer on each wear track and the mean value is reported.

The hardness of the LDPE composites was measured on the disks by using a shoremeter according to ASTM D 2240. For each type of composite in thickness 3 mm, hardness measurements were made on seven test samples and the measurements were repeated seven times for each sample. Hardness values were determined by the arithmetic mean method for each type of composite material.

3. FINDINGS

3.1 Morphological Observations

Figure 2 shows the SEM image of LDPE composites including BFD powder and its energy spectrum analysis. Microscopic observation reveals that the LDPE composite contains fibre-particulate bundles and blast furnace dust powders as shown in Figure 2(a). The energy spectrum analysis showed the chemical compositions of BFD. As seen in Figure 2(b), the existence of the elements iron, silicon and calcium indicate the substance of Fe_2O_3, SiO_2, and CaO in

BFD. The elements of carbon determined in EDX analysis is probably derived from ethylene in LDPE composites, as shown in Figure 2(c).

Figure 3 shows the SEM of the fracture surface of LDPE composites filled with a ratio of 10, 15, 22.5, 33.75 and 50.62 wt% of BFD, respectively. As expected, by the analysis of the materials containing different amounts of the BFD particulates, SEM images clearly show that the amount of BFD particulates on the surface of LPDE composites are increased. In Figure 3(b) the LDPE composites containing BFD particulates indicate that when compared with unfilled recycled LDPE (pristine LDPE), the addition of BFD into the medium provides formation of more porous material. Also, the surface of the LDPE composite gains an amorphous structure

FIGURE 2. Scanning electron micrograph of BFD (a) and its energy spectrum analysis (b), energy spectrum analysis of BFD composite (generally) (c).

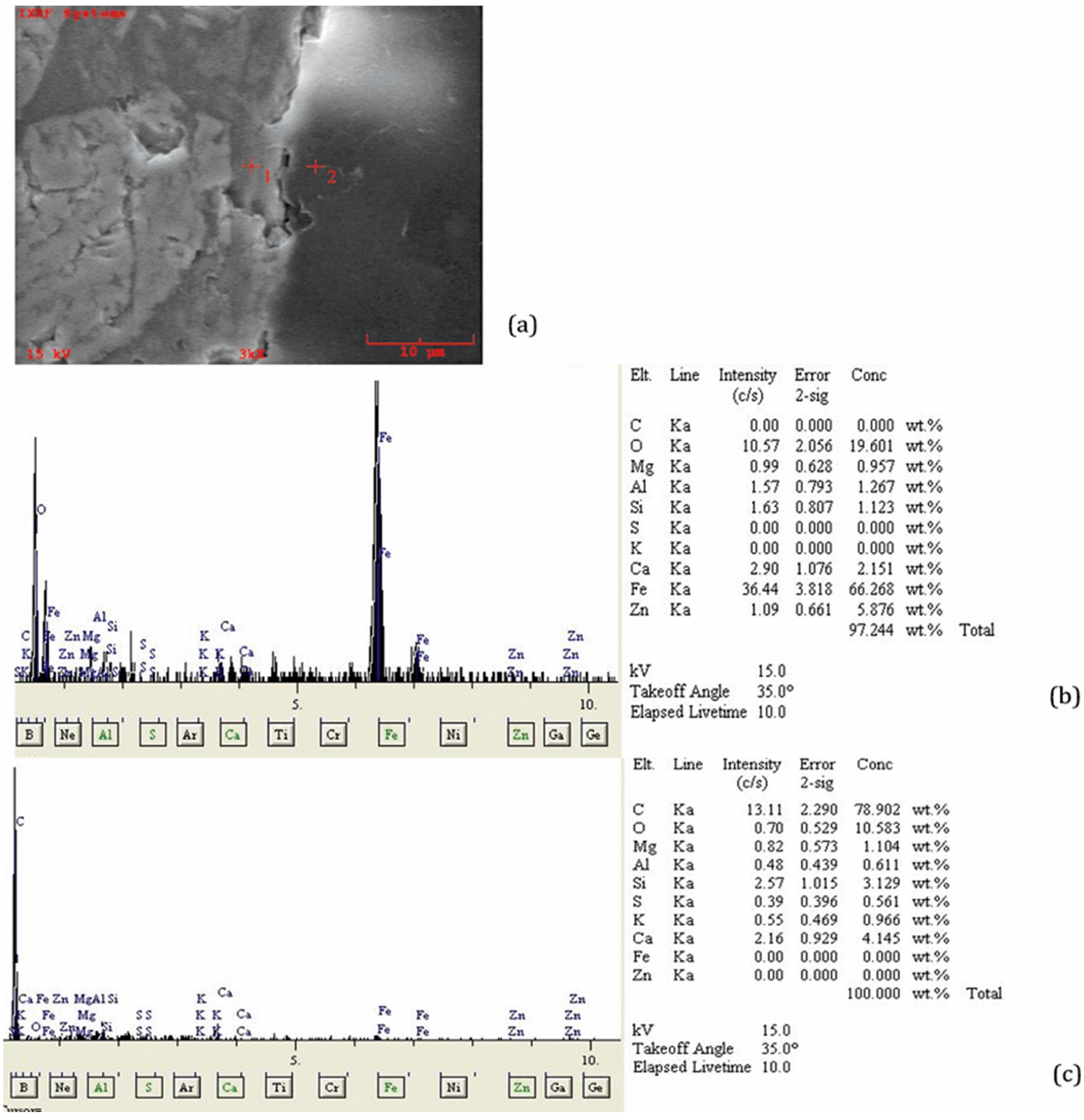
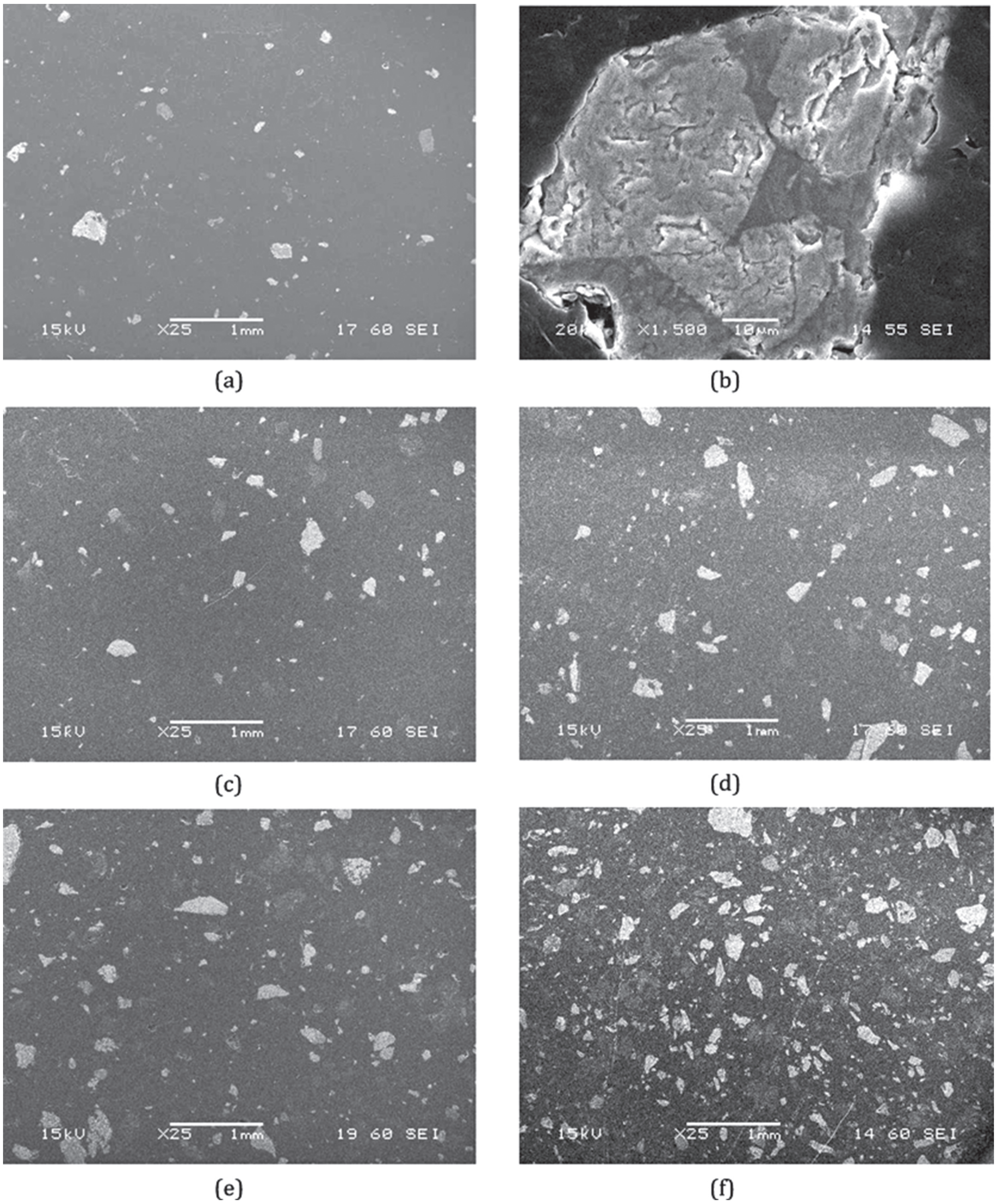


FIGURE 3. SEM images of LDPE composites: (a) filled with a ratio of 10, (b) surface morphology of BFD, (c) 15, (d) 22.5, (e) 33.75, (f) 50.625 wt% BFD.



by the addition of BFD particulates. The BFD particulate on the surface of LDPE composites is distributed irregularly as shown in Figure 3 (a, b, c, d, e and f).

3.2 The Density of LDPE Composites

Construction materials are expected to have proper features of the materials such as, low density for effective thermal insulation, lightness, time and labor savings, ease of transport and assembly operations. Therefore, locating the density of the LDPE composites is important. Examination showed that the density analysis of recycled LDPE composites filled with BFD varied from 0 to 50.62% by weight. Besides this analysis, the density of BFD and pristine LDPE was determined and found to be 1.998 g/ml and 0.92 g/ml, respectively. The density of composite materials increased directly with increasing BFD filler as expected (Figure 4). At the contents of 10%, 15%, 22.5%, 33.75% and 50.62% BFD, the increment of density of the composites were 2%, 4.5%, 11.6%, 29% and 57% respectively when compared to unfilled recycled LDPE.

3.3 The Mechanical Properties of LDPE Composites

3.3.1 Tensile Properties

The mechanical properties of recycled LDPE composites filled with BFD were evaluated for usability in buildings as a construction material. The mechanical properties of recycled LDPE composites filled with BFD are given in Table 4.

The tensile strength of composites increased at the first stage with the increase of BFD particulates up until 15% of the BFD containing LDPE composites and were followed by irregular variations. The results show that the tensile strength of LDPE composites is variable by the addition of BFD fillers in all contents as can be seen in Figure 5a. This behavior was also observed in previous studies where studies showed that tensile strength was variable with the addition of metal fillers (Luyt et al, 2006). Obviously, the tensile strength of 15 wt% BFD filled composite is the obtained maximum value and with this composite the tensile strength increases 5.87% when compared to unfilled recycled LDPE. After the filling of 15 wt% BFD, 22.5 wt%, 33.75 wt% and 50.62 wt% BFD filled composites, the tensile strength decreases slowly. A similar observation was also reported in particulate filled composites where tensile strength decreased by the addition of the particulate filler (Gungor, 2006). This is happens

FIGURE 4. Density property of recycled LDPE composites with BFD filler.

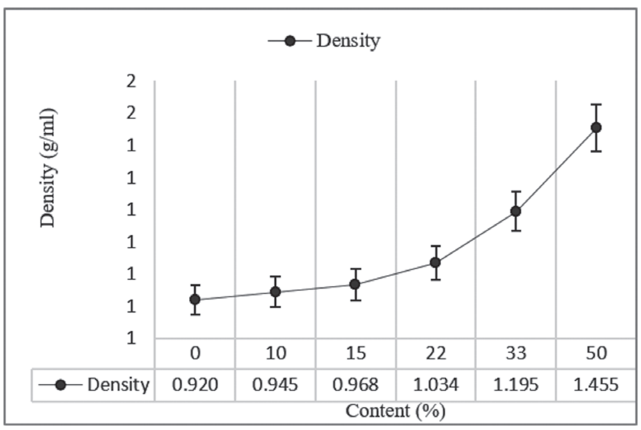


TABLE 4. Mechanical Properties of LDPE Composites Filled with BFD.

Content of BFD (%)	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)	Flexural strength (MPa)	Flexure Elongation (mm)	Impact strength (KJ/m^2)
0	12.26	168.32	209.39	9.901	13.73	52.47
10	12.57	232.96	138.554	10.451	13.26	51.84
15	12.98	243	112.56	11.090	13.57	51.70
22.5	12.59	279.16	96.612	12.280	13.05	50.83
33.75	11.83	362.38	75.29	12.968	12.95	39.31
50.625	11.72	626.29	29.95	16.502	12.25	23.68

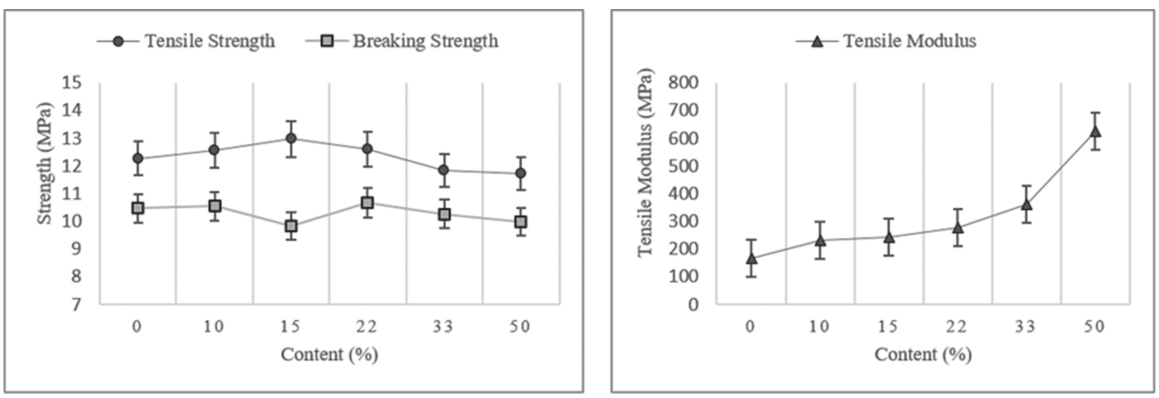
because the particulate form of fillers cannot provide the strength increase. In addition, there is a reduced ratio of the matrix in the unit section that results in falling stress values.

The tensile modulus of LDPE composites is increased by the addition of BFD fillers in all content ratios, when compared to unfilled recycled LDPE as can be seen in Figure 5b. In this study, it is clearly seen that the BFD fillers decrease the elasticity of recycled LDPE because of it consisting of Fe in particulate form and decreasing matrix ratio, which shows the elasticity in the unit section of the composite. Beside the form of BFD, the size and distribution of filler particles also play an important role in the stiffness. The BFD is much stiffer than LDPE matrixes with increasing BFD filler content. A similar observation was also reported that in particulate filled composites, the tensile modulus increases by the addition of the particulate filler (Bigg, 1987; Rusu et al 2001; Gungor, 2006; Kaps, 2008).

3.3.2 Flexural Properties of LDPE Composites

In this work, recycled LDPE composites filled with BFD varied from 0 to 50.62% by weight were designed to be used in buildings as a construction material. The presence of the flexural strength is important to determine the deformations while loading on the material.

FIGURE 5. Tensile property of recycled LDPE composites with BFD filler: (a) tensile and breaking strength and (b) tensile modulus.



(a) (b)

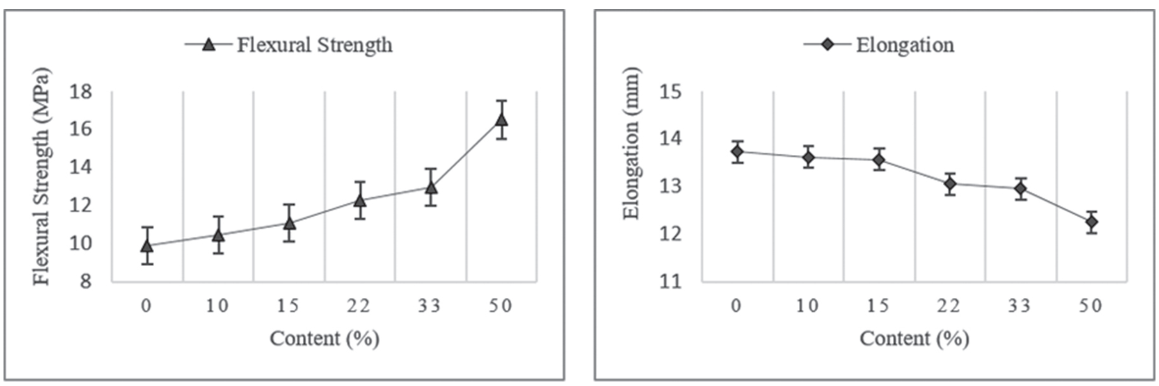
Figure 6a and Table 4 show that the flexure strength of recycled LDPE composites filled with BFD varied from 0 to 50.62% by weight, respectively. The flexural strength of recycled LDPE composites increased with the addition of dust filler contents. The flexural strength of recycled LDPE was determined as 9.90 MPa, and the flexural strength of the LDPE composite was increased to 10.45 MPa by filling 10 wt% BFD. The flexural strength of the LDPE composite increased together with the rise of BFD, and it was 11.09 MPa with addition of 15 wt% BFD. As the BFD contents increased to 22.5 wt%, the flexural strength reached 12.28 MPa in the experiment. The flexural strength of LDPE composite rose as the BFD filler increased and it was 12.96 MPa with the addition of 33.75 wt% BFD. As the BFD contents increased to 50.62 wt%, the flexural strength was further improved and reached 16.50 MPa. At the contents of 22.5%, 33.75% and 50.62% BFD, the increments of flexural strength of composites are detected in 24%, 30.9% and 66%, respectively, compared with unfilled recycled LDPE. In addition, breakings are not observed in any of the recycled LDPE composites. A similar effect on flexural strength in plastic composites was reported by other researchers (Zheng et al, 2009; Yang et al, 2015).

As expected, the elongation at maximum flexure strength of all recycled LDPE composites is continuously decreased with the increase of BFD filler content, indicating that the failure mode of LDPE from ductile behavior to brittle behavior as shown in Figure 6b. A similar observation was also reported that in particulate filled composites, the tensile modulus increased while the elongation at maximum flexure strength with increasing particulate filler loading (Tavman,1996; Tavman, 1997; Gungor, 2006; Yang et al, 2015).

3.3.3 Impact Strength of LDPE Composites

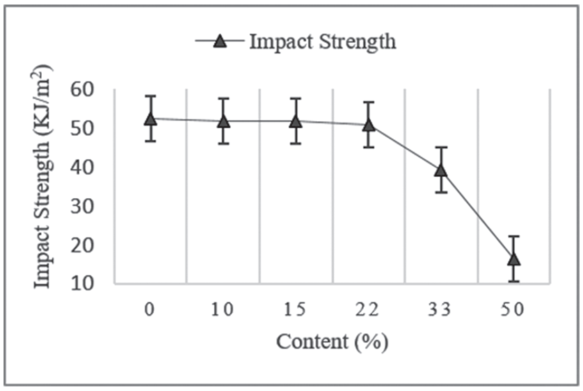
Figure 7 and Table 4 show the Izod impact strength of recycled LDPE composites filled by BFD. The addition of rigidity BFD fillers to recycled LDPE caused a sharp drop in the impact strength with an increase in filler. This issue can be especially observed after 22.5%wt of BFD addition to LDPE. When the impact strength is 52.47 kJ/m^2 for recycled LDPE, the impact strengths are 39.31 kJ/m^2 and 23.68 kJ/m^2 for 33.75 wt% BFD and 50.62 wt% BFD filled LDPE composites, respectively.

FIGURE 6. Flexural property of recycled LDPE composites with BFD filler: (a) flexural strength and (b) flexure elongation.



(a) (b)

FIGURE 7. Impact strength of recycled LDPE composites with BFD filler.



Reduction of Izod impact strength of the LDPE composites are mainly due to the presence of Fe particles. This may increase stress concentration and radiate with less energy compared with unfilled recycled LDPE due to weak interfacial adhesion between the fillers and the LDPE matrix.

Therefore, together with the BFD content increase, poorer interfacial regions led impact strength to reduce gradually. A similar effect on impact strength in metallic or non-metallic plastic composites was reported by other researchers (Rusu et al., 2001; Gungor, 2006; Toro et al., 2007; Yang et al., 2015).

3.4 Vicat Softening Temperature of LDPE Composites

The vicat softening temperature is defined as the temperature at which a material deflects by 1 mm under the application of a load (10 or 50N). This value is particularly important in the transformation of the composite into the product for their potential practical application and in the determination of terms for the use of the composite in construction. As seen in Figure 8 and Table 5, the addition of BFD to recycled LDPE caused the vicat softening temperature increase to be stable. Clearly, in 50.62 wt% of BFD filled composites, the vicat softening temperature increases to 6.6°C when compared to unfilled recycled LDPE. This is mainly derived from the significant improvement in vicat softening temperatures of LDPE composites by adding BFD.

FIGURE 8. Vicat softening properties of recycled LDPE composites with BFD filler.

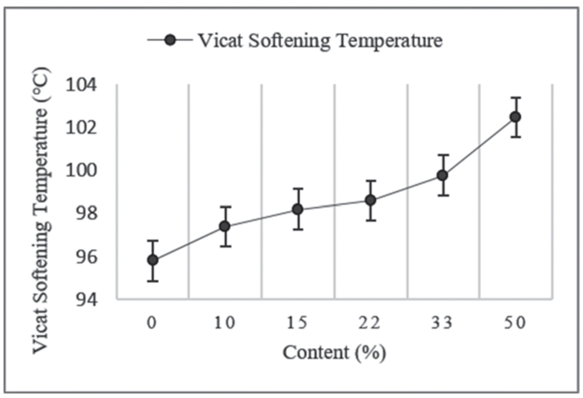


TABLE 5. Vicat softening temperature of LDPE composites filled with BFD filler.

Content of BFD (%)	0	10	15	22.5	33.75	50.625
Vicat softening temperature (°C)	95.8	97.4	98.2	98.6	99.77	102.47

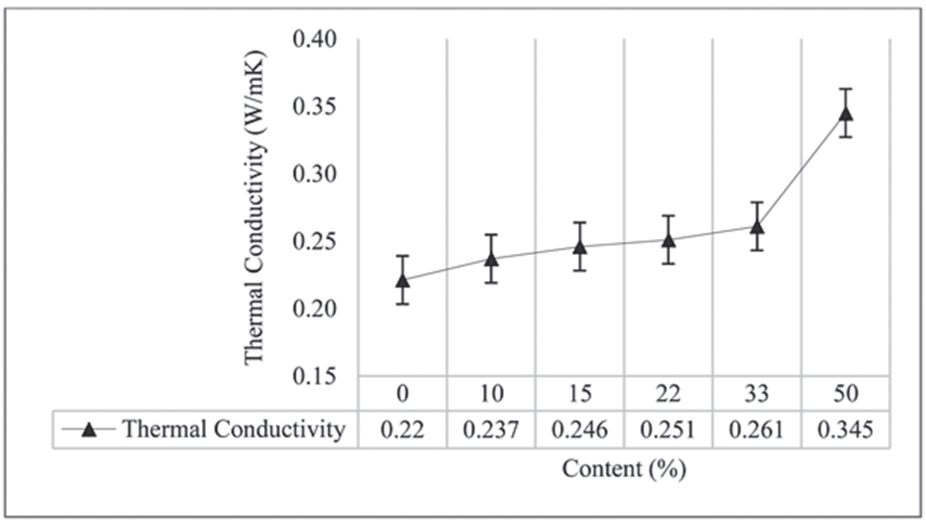
Higher heat resistance might be due to the Fe which consists in the BFD. Fe which consists in BFD mainly prevents the deformation of the composite effectively. A similar result was reported in the study of previous metallic plastic composites (Rusu et al., 2001; Gungor, 2006).

3.5 Thermal Conductivity of LDPE Composites

The thermal conductivity coefficient of the building materials is expected to be low due to providing thermal comfort, reduction of heat loss, prevention of humidity, mould and condensation, and energy efficiency. In the context of sustainable architecture, the use of heat insulation and insulation materials with a low thermal conductivity coefficient is an important parameter in the creation of energy efficient buildings.

Figure 9 shows the thermal conductivity of recycled LDPE composites filled with BFD varied from 0 to 50.62% by weight, respectively. The thermal conductivity of recycled LDPE composites increased with the addition of BFD fillers. The thermal conductivity of recycled LDPE was determined as 0.221 W/mK, and the thermal conductivity of LDPE composites increased to 0.237 W/mK by filling 10 wt% BFD. The thermal conductivity of LDPE composites increased together with the rise of BFD, and it was 0.243 W/mK with an addition of 15 wt% BFD. As the BFD contents increased to 22.5 wt%, the thermal conductivity reached 0.251 W/mK. The thermal conductivity of LDPE composites rose as the BFD filler increased, and it was 0.266 W/mK with the addition of 33.75 wt% BFD. As the BFD contents increased to 50.62 wt%, the thermal conductivity was further improved and reached 0.345 W/mK in

FIGURE 9. Thermal conductivity of recycled LDPE composites with BFD filler.



the experiment. It may be said that this is caused by the hematite (Fe_2O_3) in the contents of the blast furnace dust. In similar studies, it is observed that the electrical and thermal conductivity in polymer composites increases significantly depending on the ratio of reinforcing materials such as graphite (Wang and Qiu, 2010; Azeem et al., 2012) and many metal powders such as silver (Rybak et al., 2010), aluminum (Carson, 2011), nickel (Lebedev et al., 2010) which are incorporated into the polymer.

3.6 Hardness and Wear Values of LDPE Composites

The determination of the wear behavior of the building materials will help to estimate the magnitude of deformations that may arise from the conditions of use in the structure. Results of the hardness and wear tests, wear track loss of LDPE composites with BFD filler were given in Table 6. With the increase in filler of BFD, an increase in the hardness and a decrease in the wear loss were observed.

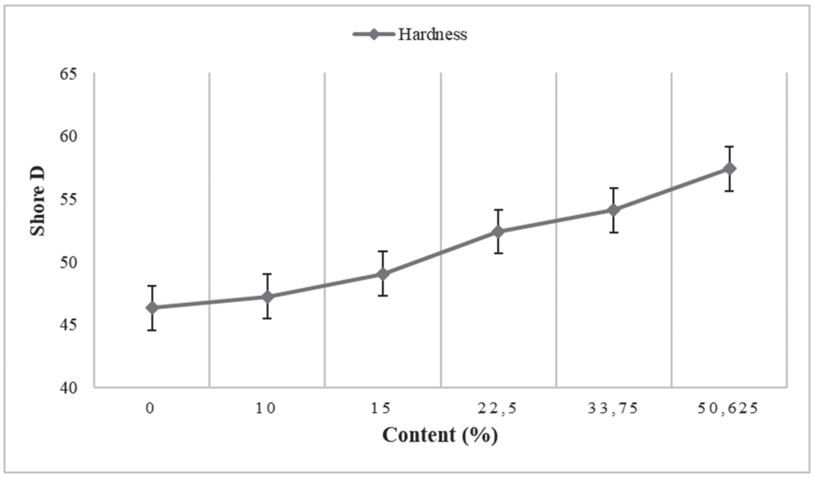
The hardness of recycled LDPE was determined as 46.33 SHORE D, and the hardness of LDPE composite was increased to 47.24 SHORE D by filling 10 wt% BFD, as can be seen in Table 6 and Figure 10. The hardness of LDPE composite increased together with the rise of BFD; it was 49.05 SHORE D with addition of 15 wt% BFD. As the BFD contents increased to 22.5 wt%, the hardness reached 52.39 SHORE D. The hardness of LDPE composite rose as the BFD filler increased; it was 54.1 SHORE D with the addition of 33.75 wt% BFD. As the BFD contents increased to 50.62 wt%, the hardness was further improved and reached 57.41 SHORE D in the experiment. It may be said that this is caused by the hematite (Fe_2O_3) in the contents of the blast furnace dust. In similar studies, it is observed that the hardness in polymer composites increases significantly depending on the ratio of reinforcing materials such as zink powder (Rusu et al, 2004) and graphite (Elfaham et al, 2018) and many powders such as nanoclay (Kastan et al, 2015) and basalt (Akinci et al, 2009), which are incorporated into the polymer.

Figure 11 and Table 6 show the wear loss of recycled LDPE composites filled with BFD varied from 0 to 50.62% by weight, respectively. The wear loss of recycled LDPE composites

TABLE 6. Results of the wear and hardness test of LDPE composites filled with BFD filler.

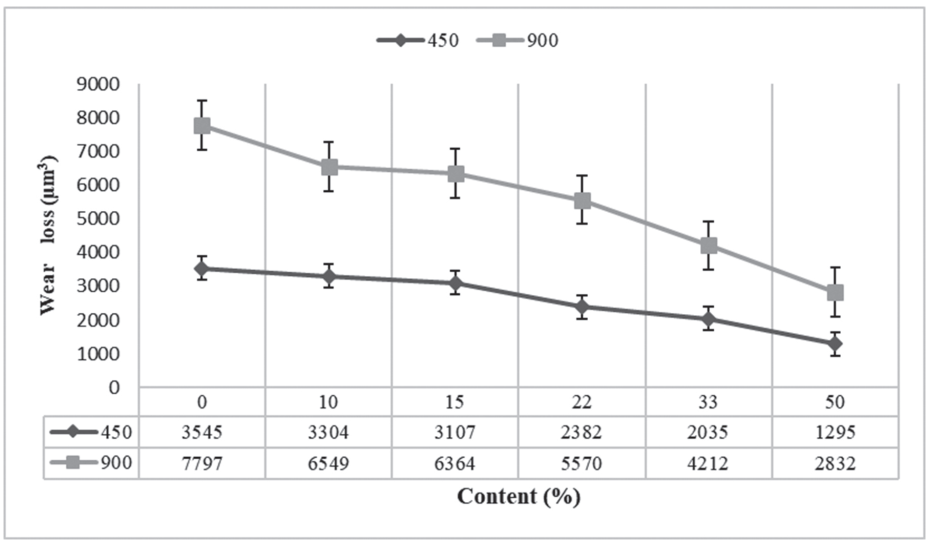
Content of BFD (%)	Friction coefficient (μ) for 450m	Friction coefficient (μ) for 900m	Roughness Ra(μm)	Wear loss (μm^2)		Wear loss (μm^3)		Hardness Shore D
				450m	900m	450m	900m	
0	0.052	0.049	0.185	3545	7797	1.357	2.962	46.33
10	0.055	0.059	0.212	3304	6549	1.255	2.488	47.24
15	0.049	0.046	0.222	3107	6364	1.180	2.418	49.05
22.5	0.047	0.042	0.229	2382	5570	0.905	2.116	52.39
33.75	0.037	0.032	0.297	2035	4212	0.773	1.600	54.1
50.625	0.043	0.027	0.314	1295	2832	0.492	1.076	57.41

FIGURE 10. Hardness of recycled LDPE composites with BFD filler.



decreased with the addition of BFD fillers contents. The wear loss of recycled LDPE was measured as 1357 μm^3 and 2962 μm^3 for 450 m and 900 m wear road respectively and the loss values of LDPE composite was decreased to 1.255 μm^3 and 2.488 μm^3 for 450 m and 900 m wear road respectively by filling 10 wt% BFD. As the BFD contents increased to 50.62 wt%, the wear loss was measured as 0.492 μm^3 and 1.076 μm^3 for 450 m and 900 m wear road respectively. The reason for this result is the increase in the amount of BFD that increased the amount of hard particles putting up resistance on the surface during wear and the decreased the amount of recycled LDPE. The increase in hardness with the increase in the BFD ratio also confirms this result. In similar studies, it is observed that the wear resistance in polymer composites increases significantly depending on the ratio of reinforcing materials such as Al_2O_3 (Solmaz et al., 2011) and graphite (Zang et al., 1997) and many metal powders (Yu et al, 1998) and inorganic fillers (Yu et al., 1998), which are incorporated into the polymer.

FIGURE 11. Wear loss of recycled LDPE composites with BFD filler.



3.7 Usage in Construction

Construction materials can be classified as load-bearing, protective and covering materials according to the place of use. Bearer materials require high mechanical properties due to their use in the constructional bearing system. When the physical and mechanical properties of the produced LDPE composite material are examined, it can be observed that it does not have mechanical properties of a load bearing material due to the use of recycled LDPE.

Protective materials are insulation products that protect from internal and external factors such as heat, sound and water. According to ISO and CEN standards, if the thermal conductivity of material is less than 0.065 W/mK, this material is defined as thermal insulation material, otherwise it is called building material. When the thermal conductivity of the produced LDPE composite material is examined, it can be observed that it cannot be thermal insulation material.

Coating materials are finishing products such as paints, wood, parquet and ceramics, which are used on the surfaces of building elements and perform different tasks in the direction of their functions. It is observed in wear tests that LDPE composites can be used as a finishing product for a floor coating material due to low wear values. In addition, LDPE composites can be painted and this feature can contribute to increasing the aesthetic quality of the space interior.

4. CONCLUSION

This study showed that BFD in the iron-steel industry could be used as reinforcing fillers in recycled LDPE composites. The addition of BFD provides formation of more porous material when compared with unfilled recycled LDPE. Also, the surface of the LDPE composite gains an amorphous structure by the addition of BFD particulates. As the content of BFD was increased to 50 wt%, the increment of tensile modulus and flexural strength of composites was 372% and 166%, respectively compared to unfilled LDPE. On the other hand, by increasing the BFD filler, the tensile strength of composites increased at the first stage and then decreased. Addition of BFD fillers to recycled LDPE caused the impact strength to drop sharply when the filler is increased, especially after 22 wt% BFD. Furthermore, the BFD improved the vicat softening temperature of the LDPE composites for their potential applications. However, the addition of BFD increases thermal conductivity in LDPE composite material. In order to reduce the heat conduction coefficient, the extrusion process can be initiated after the powder particles are coated with a liquid to reduce the thermal conductivity during the composite sample production. With the increase in filler of BFD, an increase in the hardness and a decrease in the wear loss were observed. It is noted that this is caused by the hematite (Fe_2O_3) in the contents of the blast furnace dust and the increase in the amount of hard particles putting up resistance on the surface during wear and the decrease in the amount of recycled LDPE.

To conclude, the reuse of BFD and recycling of LDPE in composites and the further applications of the material in the construction industry as a material may represent a promising way for producing sustainable coating material. This can also provide the advantage of saving resources and reducing waste.

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