ENVIRONMENTAL PROPERTIES OF ENVIRONMENTALLY FRIENDLY CONSTRUCTION MATERIALS: RECYCLED LDPE COMPOSITES FILLED BY BLAST FURNACE DUST

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ABSTRACT

This study focused on creating a sustainable composite material using blast furnace dust of the iron-steel industry and plastic wastes of the plastic industry in order to reduce the embodied energy of the material and generate more sustainable material. In this study, varying amounts of blast furnace dust (BFD), which is the primary iron-steel industry waste and which is used as filler for recycled low-density polyethylene (LDPE), was mixed to create the composite material. The embodied energy, emissions to water and air (volatile organic compounds) of BFD filled LDPE composites were determined. It was found that the composite materials had less embodied energy compared with polymer-based flooring materials such as epoxy, polyurethane (PU) and polyvinylchloride (PVC). In addition, it was determined that the composite material did not release emissions to water and have fewer total volatile organic compounds (TVOCs). These results showed that the produced composite material could be used in buildings as a sustainable floor coating material, thus saving raw materials and supporting indoor air quality and recycling.

KEYWORDS

LDPE composite, blast furnace dust, embodied energy, TVOCs, waste management

INTRODUCTION

Buildings and the building construction sector account for about 40% of overall direct and indirect CO_2 emissions and 36% of global final energy consumption. With growing access to energy in developing countries, greater ownership and usage of energy-consuming devices, and the rapid growth in the ground area of global buildings at about 3% per year, energy demand from buildings and building construction continues to rise (IEA, 2019). As a result, constructing buildings with the least amount of resources and environmental impact is a significant objective for the construction industry. The building sector, consequently, has the greatest potential for reducing emissions; therefore, green building policies tend to reduce the impact of a building on the environment.

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Aside from buildings, building materials account for half of all global materials derived from the earth (WGSC, 2004). The resources used in building material life cycles have an effect on the environment and human health. As a result, in the sense of sustainable architecture, choosing the right building material is important (Tuna, 2010).

Building materials that interact with the environment throughout their lives can cause great harm to the environment and can be a source of important environmental problems such as waste, toxicity, emissions and unnecessary energy expenditures (Tuna Kayili, 2016). The energy used in the production of construction products is called "embodied energy." This energy is very high for building materials such as steel, plastic, lead, and zinc (Hammond and Jones, 2006). More energy requirements during the production of building materials requires more resources to achieve the production of this energy. This situation causes the energy requirement needed in the building production process to be on an increasing and unsustainable trajectory.

The life cycle assessment method can be used to evaluate how materials communicate with the environment during their lives (LCA). LCA is a method for calculating a product's real effects (emissions, toxicity, and so on) from birth to disposal (Fava et al. 1990; Menge et al. 1996). LCA is especially useful for comparing a variety of options and determining the most effective choice (Haynes, 2010). The life cycle energy analysis approach can also be used to account for embodied energy (LCEA). This method calculates how much energy goes through raw material extraction, transportation, processing, assembly, disassembly, deconstruction, and/or decomposition, as well as human and secondary resources. Since energy consumption releases CO2, which contributes to greenhouse gas emissions, embodied energy is used to measure the overall environmental effect of building materials and systems. Embodied energy considers the effect of construction materials on the front end. It is depicted as a product stage in the Building Assessment Modules for Life Cycle Assessment according to EN 15804:2012 in Figure 1 (in a blue rectangle). Figure 2 is a flowchart that summarizes the elements needed to estimate embodied energy. The majority of embodied energy figures for specific materials are expressed as a "cradle to gate" distance (includes yellow boxes) (Haynes, 2010).

The embodied energy of building materials should be considered when using recycled materials, eliminating waste, how easily materials can be segregated, using locally sourced materials, the quality of building materials, determining uniform sizes of materials, and choosing materials that are manufactured using renewable energy sources when selecting building materials (Haynes, 2010). The embodied energy of a one-family house was reduced by about 45

FIGURE 1. Building Assessment Modules for Life Cycle Assessment according to EN 15804:2012 (Choi et al. 2016).

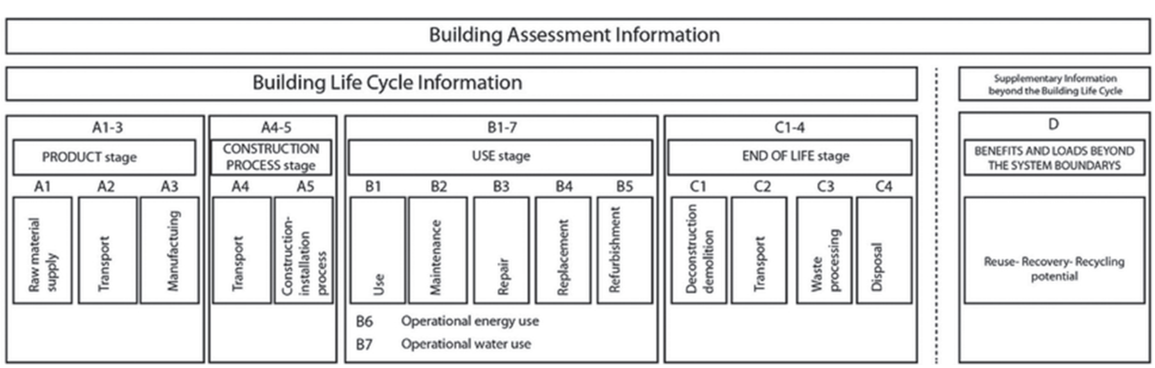
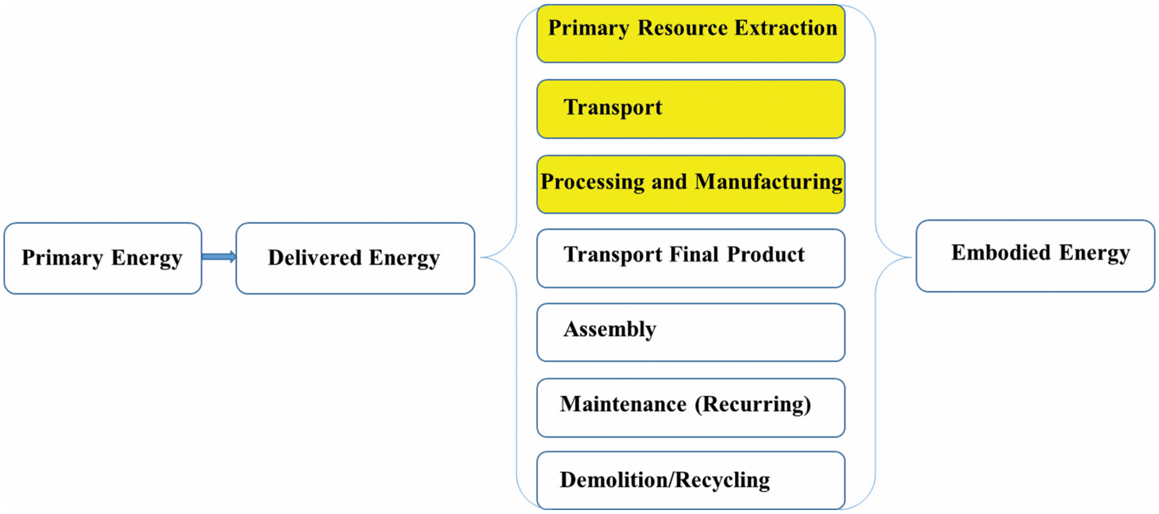


FIGURE 2. Breakdown of embodied energy calculations (Haynes, 2010).



percent when reused materials were used (Thormark, 1999). In a study of recycling nationally generated building waste, it was discovered that recycling could save around half of the embodied energy (Thormark, 2001).

The building materials can cause significant environmental effects as emitters of greenhouse gas emissions, acidification and depletion of biotic and abiotic resouces (Chou and Yeh, 2015). Buildings account for approximately 38.5 percent of all CO_2 emissions in the United States (Zhang, 2015), and CO_2 emissions from buildings around the world are predicted to rise dramatically (USEIA, 2016). As a result, CO_2 emissions generated during the manufacturing of building materials cannot be overlooked (Choi et al. 2016).

The iron and steel industry is one of the building industries with a high embodied energy. For iron and steel processing, the industry uses high-temperature furnaces, which has become the industry's second-largest energy user (Department of Energy, 2008). In addition, carbon dioxide (CO_2) emissions from iron and steel plants constitute the highest rate in the manufacturing sector with approximately 27% (IEA, 2007). This industry on average, for every ton of steel pro-duced, 2–4 tons of wastes are generated (including solid, liquid, and gas) (Pajgade and Thakur, 2013). The amount of the annual flue dust as waste is given as 375000–425000 tons in Turkey (Doğantepe, 2014). These wastes include blast furnace slag, dust and mill scales. Dust-sized flue dust wastes, which are generated in various steps of steel production, contain iron as well as heavy metals such as carbon and zinc, lead and heavy hydrocarbons. For this reason, it is very difficult to recycle these dusts in the iron-steel production process and to dispose of them from waste areas without special treatment (Kardemir Iron and Steel Factory, 2013; Nayak, 2008; Fleischanderl, 1999; Doğantepe, 2014). In addition, these wastes are dangerous for the environment and human health (Erünsal, 2005; Önkibar, 2006; Cansaran-Duman et al., 2011; Tuna Kayili, 2016).

Another of the high embodied energy industries of the construction sector is the plastics industry. It is estimated that more than 300 million tons of plastic waste was produced in 2015. Approximately 79% of waste is dumped in landfills, garbage or the environment, while 12% and 9% are sent to incineration and recycling, respectively (Geyer et al., 2017). This industry grows due to its durable, insulating, lightweight, forming ability. The growth of the industry also brings about an increase in plastic waste. External plastic waste exports, as well as plastic waste problems in Turkey is a great deal more. Turkey, processed a volume of approximately 11.4 million tons in 2019, which is the point of being the biggest waste imported from the EU.

According to 2004 figures, this figure has almost tripled in 15 years (Eurostat, 2020). Polyethylene has a maximum utilization ratio in Turkey and thus has a high waste ratio (PETKIM, 2014).

In addition to the environmental impact of construction materials with their embodied energy, their impact on the indoor air quality should not be ignored. It is stated that 60% of the total volatile organic compounds affecting indoor air quality originate from building products (Sundell, 2004). These building products are wooden furniture, carpets/carpet coverings, adhesives, paints, cleaning agents, household plants and bathroom materials (Wolkoff et al. 2000; Nazaroff and Weschler, 2004). In addition, polymeric building materials such as vinyl coating, plastic-based wall covering material, nylon carpet, heat insulation material, paint, varnish and membrane cause VOCs that may significantly affect indoor air quality (WHO, 1989; Gustafsson, 1992; Schmidt-Etkins, 1994; Maroni et al., 1995; Yu and Crump, 1998; EPA, 2014). If building materials are used outdoors, it is inevitable that they will come into contact with water caused by external factors. In case of prolonged contact of the material with water, it is likely that it will be capable of releasing contaminants into the biotic or abiotic environment. In this case, it is important to determine the emissions to air and water of the composite materials produced for environmental health.

The wastes originating from life cycle stages of building products cause water and soil pollution and, in general, habitat pollution. In addition, leaving industrial and residential wastes to the environment without treatment, storage of construction and demolition wastes in areas open to transportation and living spaces, effects of fossil fuels used in production damage the abiotic and biotic environment (Mackenzie, 1991). The heavy metals in industrial and residential wastes have a toxic effect in direct proportion to its concentration to aquatic life. Especially heavy metals such as mercury, lead and chromium cause physiological accumulation as they cannot be removed from living organisms. During the landfill of the building products wastes, toxic substances that can damage the abiotic and biotic environment (Cansaran-Duman et al., 2011) due to the release as dusts during storage, or heavy metals entering the soil and groundwater (Sarja, 2002). In addition, while recycling of products, energy is required during waste collection and recycling rate decrease in collection type in which source separation method is not used (Apotheker, 1990; Edwards and Schelling, 1999). The planning of waste management at the design stage of material is very important in sustainable material design. The first and foremost rule proposed in the waste management hierarchy is to reduce waste extraction as much as possible. Subsequently, waste materials should be reused without the use of any chemical application if the mechanical features or function does not have a loss of performance. Where reuse is not possible, waste material should be recycled by producing for the same material function. Wastes with loss of performance should be recycled by applying a physical/chemical process in the functions that are suitable for low performance. Energy must be recovered by incineration of non-recyclable wastes or these wastes must be stored in an area with dust and noise control (Stein, 1993; Edwards and Schelling, 1999; European Commission, 2008; Vefago and Demirbaş, 2011; Avellaneda, 2013; Wu et al., 2014).

There are many studies of composite materials based with waste. The waste materials used in composite material studies can be counted as PET, PP and HDPE waste, paddy husk, waste bamboo fibers, waste rice stalks, waste wheat and corn stalks, polyolefins, paper plastic laminates, waste wood products. However, a composite material study produced with bfd and pe was not encountered in the literature, except for the previous work (Tuna Kayili et al. 2020) of the authors.

There are past studies involving adding waste bamboo fibers to polypropylene matrix material (Chen et al., 1997), adding waste rice stems to HDPE (Panthapulakkal et al., 2005), and adding waste wheat and corn stalks to polypropylene (Panthapulakkal and Sain, 2006). In 2007, it was stated that PET bottles were used in the production of polymer mortar and this mortar could be used in the construction of paving stones and sewer pipes (Fareed et al., 2007). Waste paper with limited recycling possibilities is transformed into composite granules by using Paper Plastic Laminates-PPL and the PP extrusion method. Afterwards, composite materials with high mechanical properties can be achieved by shaping with the injection method (Mitchell et al., 2014). In addition, many composite material studies are produced by combining waste natural fibers with waste plastics (Al-Oqla and Sapuan, 2014; de la Orden et al., 2007; Faruk et al., 2012; Kazemi, 2013; Koronis et al., 2013; La Mantia and Morreale, 2006) and this contributes to the acceleration of the recycling of agricultural and plastic waste.

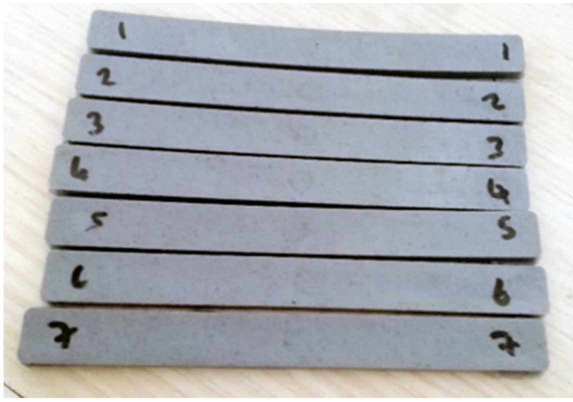
There are 355 bridges in various parts of the world, where composite materials were used as structural elements, all of elements such as cables, decks and beams were built using fiber polymer composite materials (Potyrala, 2011). There are many examples in which composite materials can be used as building materials, building elements, as well as the structure itself. In 1982, the 20.70m long and 9.90m wide Miyun Bridge is the first bridge completed in China, built entirely of glass wool reinforced polymer composite material (Günaydın et al., 2015). It is clear that composite materials made based on waste make a great contribution to waste management. However, determining the environmental impacts of the composite material produced during the production and usage stage is equally important. This study examines the embodied energy, the emissions to air (TVOCs) and water, the waste management of LDPE composite material filled by blast furnace flue dust. The production stage, physical, mechanical, chemical and thermal properties of the LDPE composite material were given in detail in the previous study (Tuna Kayili et al., 2020). In the previous study, LDPE composite material was suggested as a floor coating material in buildings. Therefore, the environmental effects of LDPE composites were compared to the other polymer-based flooring material (PVC, epoxy, and polyurethane), and as a result, the comparison results were shown, in other words, construction materials are produced by using recycled materials with less environmental effect and that emit fewer emissions than construction materials that are produced by using raw materials. In addition, this study is the first study to determine the environmental performance, which is the second step of the first composite material study produced with LDPE and BFD wastes.

2. EXPERIMENTAL METHOD

2.1 Preparation of LDPE Composites filled by BFD

In this study, BFD was obtained from an iron-steel factory (Kardemir A.Ş., Karabuk, Turkey). Waste LDPE parts were obtained from a factory that produced the plastic film (Kazan Industrial Area, Turkey). For coloring, the white master-batch was provided from the company Colorex, Inc. BFD as a filler and white master-batch were mixed with waste LDPE (ρ: 0.92 g/m^3, Tm: 120 °C) for 3 minutes according to certain ratios (0, 10, 15, 22.5, 33.75 and 50.62% BFD) at the Laboratory of Dust Metallurgy and composite granules were obtained. The temperature of the extrusion process was between 140°C and 200°C and the screw was maintained at a speed

FIGURE 3. Samples of recycled LDPE composites filled by BFD (50.6% BFD).



of 50 rpm. The composite granules were shaped by an injection-moulding machine (Klasmak brand) at Mucit Plastic Co. Ltd., Konya, Turkey. After the performance tests and experiments, it was decided that the product can be used as a flooring material (for the detail; Tuna Kayili et al., 2020).

2.2 Embodied energy of the LDPE composite filled by BFD

The life cycle energy analysis method (LCEA) was used to account for the embodied energy of this composite material. One kg of composite product was selected as the functional unit. In the study, embodied energy was calculated for LDPE composites filled by the content of 50.6% BFD. The inferred data for injection and extrusion energy for composite materials (for polyethylene) was taken from the Granta CES EduPack 2015 database, and the assumed data is given in Table 1. Embodied energy values of the other polymer-based flooring materials were provided from Granta CES EduPack 2015 database to compare with the values of LDPE composite material filled by BFD.

As shown in Figure 4, according to EN 15804, the system boundaries for the embodied energy calculations of composite material included production processes (A2) (extrusion and

FIGURE 4. System boundaries for embodied energy.

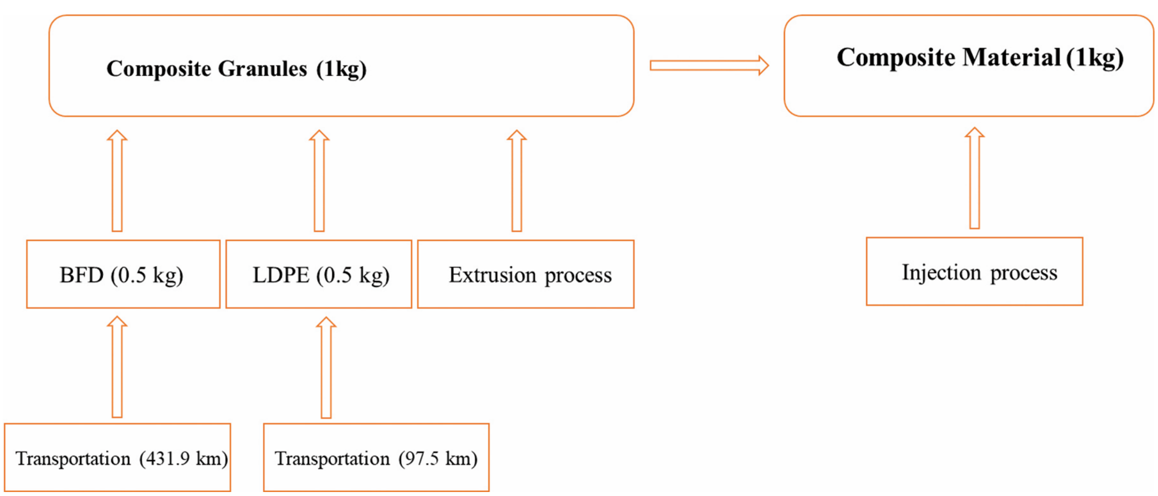


TABLE 1 Energy and emission values for extrusion and injection molding of polyethylene (Granta CES).

	Energy (MJ/kg)		CO_2 Emission (kg CO_2 eq/kg)	
Product	Extrusion	Injection	Extrusion	Injection
Polyethylene (1 kg)	6.2	22	0.46	1.60

TABLE 2. Transportation data.

Interval	Device	Distance (km)	Tour	Total Distance (km)
GULDM-KISF	3.5–7-ton truck	215.99	2	431.98
GULDM-IAK	3.5–7-ton truck	48.77	2	97.54

injection), and transportation (A3) due to the use of waste material instead of raw material. Eco Transit World Tool (Ecological Transport Information Tool for Worldwide Transports) was used to calculate the energy requirement and CO_2 emissions for transportation according to EN 16258. The manufacturing area was assumed as Gazi University, the Laboratory of Dust Metallurgy (GULDM), Ankara, Turkey. Blast furnace dust wastes were provided with Kardemir Iron-Steel Factory (KISF) in Karabük, Turkey and wastes of LDPE were provided with Industry Area of Kazan (IAK) in Kazan, Turkey. Transportation distances were determined by using the Google Map Tool and are given in Table 2.

2.3 Emissions to water

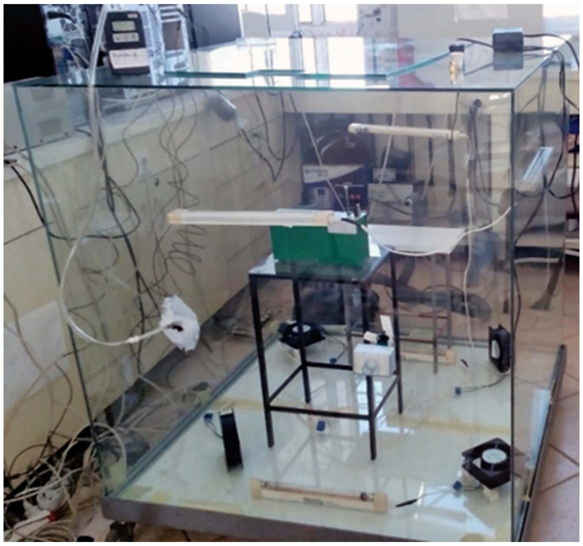
The emissions of the composite material to water were analyzed based on a liquid-liquid extraction method by using a gas chromatography-mass spectroscopy (GC-MS) instrument with modifications (Polyakova et al. 2016; Thacker et al., 2015). Before starting the analysis, different flue powder additive composite samples were incubated in pure water for 24 hours. The water samples were then mixed with 1 ml of dichloromethane and allowed to stand for 30 minutes. The organic phase was then removed from water + dichloromethane solution and was analyzed by Agilent 6890N model gas chromatography-mass spectroscopy (GC-MS).

2.4 Emissions to air (VOCs)

For the VOCs analysis of composite materials, a 1 kg sample was heated at 25°C and 70°C and was allowed to stand at the sampling station for 12 hours, as shown in Figure 5. In this process, indoor air samples were collected at an average of 3–4 hours in stainless steel tubes filled with Chromosorb 106 sorbent at 20–30 mL/min flow through pump according to ISO 16017 and ASTM D5116-10 (Mentese ve Akca 2020). Samples collected from a 1m^3 sampling station were analyzed by using the TD-GC/ FID system at Hacettepe University Environmental Engineering Laboratory. The percentage variation of TVOCs occurring at 20 degrees and 70 degrees was determined using Eq 1.

$$\% \text{ difference} = \frac{\text{TVOCs } 70°\text{C} \times 100}{\text{TVOCs } 20°\text{C}} \quad \text{(Eq 1)}$$

FIGURE 5. Sampling station.



3. RESULTS AND DISCUSSION

3.1 Embodied energy of the LDPE composite filled by BFD.

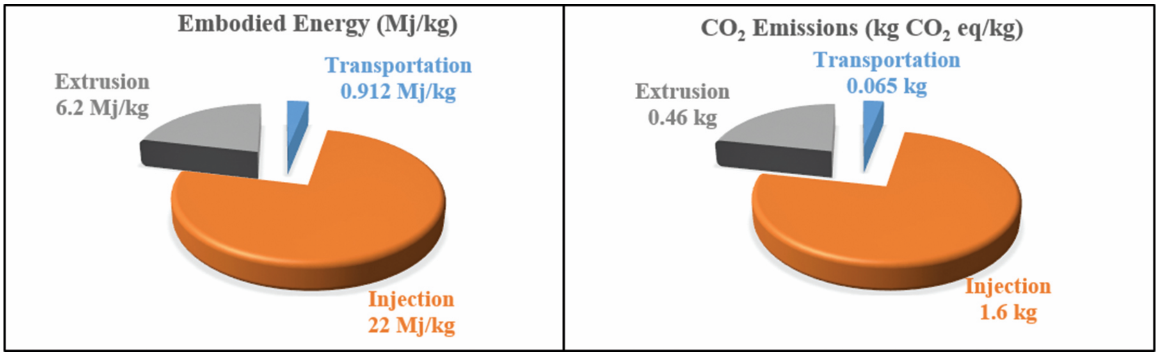
The embodied energy was determined for LDPE composite material (50.6% filled by BFD) by using the data in Table 1 and Table 2. As can be seen in Table 3, the total energy spent on extrusion, injection (A2) and transport (A3) constitute the embodied energy of 1 kg of LDPE composite product. The highest energy consumption (20.8 MJ/kg) was determined in the injection process as it contained both heating and cooling energy. The energy required for the extrusion process, which is also based on heating, is 5.9 MJ/kg. The energy required for transporting the wastes (LDPE and BFD) to the production site is 0.912 MJ/kg according to the online calculation tool (Eco Transit World Tool).

In addition, as can be seen in Table 3, the highest CO_2 emission was observed in the injection process (1.56 kg CO_2 eq/kg) due to high energy consumption. For extrusion process and transport, the values are 0.442 kg CO_2 eq/kg and 0.065 kg CO_2 eq/kg, respectively. According to these data, the embodied energy and embodied carbon of 1 kg LDPE composite material

TABLE 3. Embodied energy and embodied CO_2 values of the LDPE composite filled by BFD (Granta CES).

LDPE Composite material (1 kg)	Embodied Energy (MJ/kg)	CO_2 Emission (kg CO_2 eq/kg)
Extrusion value	6.2	0.46
Injection value	22	1.60
Transportation	0.912	0.065
Total	**29.112**	**2.125**

FIGURE 7. Embodied energy and embodied CO_2 of the LDPE composite filled by BFD.



produced using 50% blast furnace dust and 50% waste LDPE was calculated as 29.112 MJ and as 2.125 kg CO_2 eq. Since composite material was produced from wastes, eliminating the need for primary raw materials, the embodied energy and embodied carbon was less than other polymer-based flooring materials as epoxy, polyurethane (PU) and PVC, as can be seen in Table 4. In addition, while there was no water consumption in the LDPE composite production, there was water consumption up to 200 liters in other polymer-based flooring materials (Table 4).

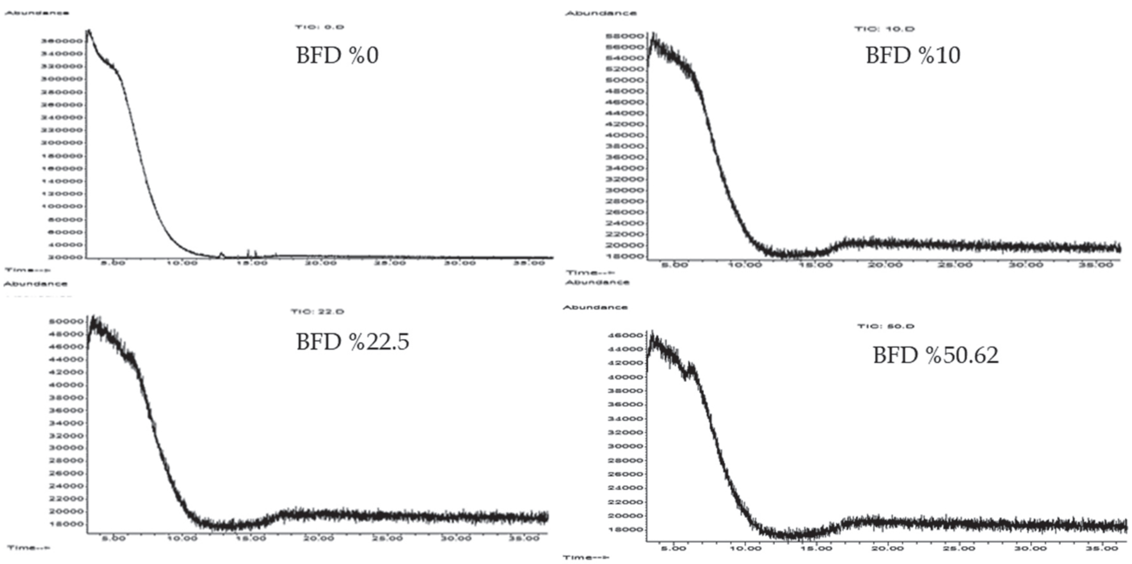
3.2 Emissions to water

The emissions of the composite materials to water were determined by gas chromatography-mass spectroscopy (GC-MS). When the obtained chromatograms were examined (data not shown), compounds such as benzene, methylene chloride, perchloroethylene, xylene, ethylene glycol, toluene, 1,3-butadiene which could pass from the samples to the aqueous solution were not found (Figure 8). This can be interpreted that the composite material produced is stable and does not release into the solution phase; its content is composed entirely of nature-tested

TABLE 4. Comparison of environmental impacts of LDPE composite filled by BFD with other plastic based flooring materials (Epoxy, PU and PVC data were taken from Granta CES).

Materials	Raw material supply (RMS)			Manufacturing			
	Energy for RMS prod. (MJ/kg)	CO_2 emissions for RMS (kg/kg)	Water consumption for RMS (L/kg)	Energy for extrusion (MJ/kg)	Energy for injection / polymer melting (MJ/kg)	CO_2 emissions for extrusion (kg/kg)	CO_2 emissions for injection/ polymer melting (kg/kg)
BFD 50%	—	—	—	**6.2**	**22**	**0.46**	**1.60**
Epoxy	127–140	6.83–7.55	26.6–29.4	—	21–23.1	—	1.68–1.85
PU	82.7–91.5	3.52–3.89	93.5–103	—	22–24.2	—	1.76–1.94
PVC	55.4–61.2	2.37–2.62	197–218	14–15.4	5.65–6.25	0.424–0.469	1.05–1.16

FIGURE 8. GC-MS chromatograms of the solutions extracted from waters which were incubated with composite materials.



materials, and no benzene, toluene or formaldehyde doped material is added during production. In this case, if the material is used outdoors, it can be said that it does not cause harmful emissions to the biotic and abiotic environment in contact with water.

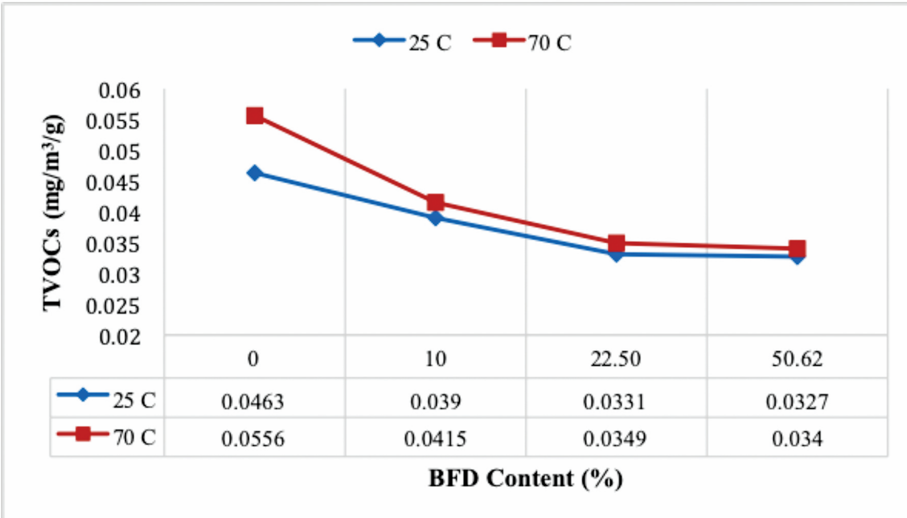
3.3 Emissions to air (VOCs)

Table 5 and Figure 9 show the quantity of VOCs of LDPE composites filled with a ratio of 0, 10, 22.5 and 50.62 wt.% of BFD, respectively at 25°C (RT) and 70°C. As expected, TVOCs amount of composite materials decreased directly with the increasing of BFD filler. The results show that the TVOCs released from LDPE generally. In addition, TVOCs of composite materials increased directly with the increasing of temperature. A similar observation was also reported that in building materials: the TVOCs amount increases by temperature (Bremer et al., 1993; Yang, 1999; Cox et al., 2005; Lee and Kim, 2012). Environmental variables such as temperature, air velocity, and humidity have an effect on VOC emissions from materials (Wolkoff, 1998). The temperature increase does not have a significant effect on emissions of low boiling

TABLE 5. TVOCs emission rate from the LDPE composite materials filled by BFD.

Content of BFD (%)	TVOCs at 25°C ($mg/m^3/g$)	TVOCs at 70°C ($mg/m^3/g$)	Rate of increase (%)
0	0.0463	0.0556	20.08
10	0.0390	0.0415	6.41
22.5	0.0331	0.0349	5.43
50.625	0.0327	0.0340	3.97

FIGURE 9. TVOCs value of the composite materials.



volatile compounds but have a stronger effect on high boiling volatile compounds (Sollinger et al., 1993; Lee and Kim, 2012). For further information, TVOCs at 25°C (RT) and 70°C are given in Appendix 1.

4. CONCLUSION

This study showed that the materials produced by using waste have less embodied energy and are more sustainable. According to these data, the embodied energy and embodied carbon of 1 kg LDPE composite material produced using 50% blast furnace dust and 50% waste LDPE was calculated as 29.112 MJ and as 2.125 kg CO_2 eq. When the chromatograms were examined, it was determined that the compounds could not pass from the samples to the aqueous solution. In addition, TVOCs amount of composite materials decreased directly with the increasing of BFD filler and increased with the increasing temperature. Furthermore, it was also determined that LDPE composite materials can be reused, recycled with the re-heat and down-cycled at the end of the life LDPE composites.

As a result of the experimental studies, it has been determined that the composite material which has recycled material content, recyclable material, and low embodied energy is suitable for use in buildings. Nowadays, epoxy-based flooring materials are used in many areas. Epoxy-based flooring materials are not possible to reuse and recycle as they are not thermoformed due to being thermoset material. Many epoxy products also contain organic solvents, fillers, and pigments. The composite material produced can be recommended as an alternative to plastic-based flooring materials in industrial buildings due to its aesthetic appearance, high abrasion resistance, release, and sufficient strength values, low VOCs release, heat recyclability or reuse.

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APPENDIX 1. VOCs OF LDPE COMPOSITE MATERIAL AT 25 °C AND 70 °C

TABLE 1. VOCs of LDPE material at 25 °C and 70 °C

VOCs	mg/m³/gr 25 °C	mg/m³/gr 70 °C
BUTANAL, 2-METHYL- 2-METHYLBUTANAL	0,006489	0,00715
BENZENE	0,001108	0,009856
ETHENE, TRICHLORO- 1,1,2-TRICHLOROETH	0,00043	0,000136
1-Propene, 1,3-dichloro-, (Z)- cis-1,	7,27E-06	6,47E-05
Toluene	0,001776	0,001524
BENZENE, ETHYL- ETHYLBENZENE .ALPH	0,001099	5,85E-05
o-Xylene	0,006861	0,002824
Styrene	3,65E-05	0,002232
Ethane, 1,1,2,2-tetrachloro- S-Tetrac	1,29E-05	4,12E-05
PROPANE, 1,2,3-TRICHLORO- 1,2,3-TRICH	7,48E-05	2,22E-05
BENZENE, (1-METHYLETHYL)- CUMENE	9,25E-05	0,013301
Benzene, bromo- Bromobenzene $$ Monob	0,007017	0,012192
Benzene, 1-chloro-2-methyl- $$ Toluene,	5,97E-06	2,98E-06
BENZENE, (CHLOROMETHYL)- CHLOROMETHYL	7,89E-05	1,86E-06
BENZENE, 1,3,5-TRIMETHYL- 1,3,5-TRIME	2,52E-05	1,55E-05
2-BROMO-1,2-DICHLOROPROPANE PROPANE,	5,78E-06	3,67E-05
Benzene, 1,2,4-trimethyl-.psi.-Cumen	7,46E-07	2,29E-05
Benzene, 1,4-dichloro- Benzene, p-dic	0,000924	0,000265
BENZENE, (1-METHYLPROPYL)- SEC-BUTYLB	0,000555	8,02E-06
Benzene, 1-methyl-4-(1-methylethyl)-	2,07E-05	3,3E-05
BENZENE, BUTYL- BUTYLBENZENE 1-BUT	0,001106	4,66E-06
NAPHTHALENE ALBOCARBON CAMPHOR TAR	0,00019	4,06E-05
Dodecane n-Dodecane Adakane 12	0,011772	0,000127
1,1'-BIPHENYL PHENYLBENZENE 1, 1'-	0,003309	3,02E-05
1,1'-BIPHENYL, 2,2'-DIMETHYL- 1, 1'-B	1,01E-05	1,88E-05
ETB	0,001099	0,002824
m-p-Ksilen	0,002284	0,002843
TOTAL (TVOCs)	0,0463	0,0556

TABLE 2. VOCs of LDPE composite material filled by 10% at 25 °C and 70 °C

VOCs	mg/m^3/gr 25 °C	mg/m^3/gr 70 °C
BUTANAL, 2-METHYL- 2-METHYLBUTANAL	0,00195	0,001583
BENZENE	0,003308	0,006767
ETHENE, TRICHLORO- 1,1,2-TRICHLOROETH	0,001116	0,000947
1-Propene, 1,3-dichloro-, (Z)- cis-1,	0	1,5E-05
Toluene	0,002292	0,002808
BENZENE, CHLORO- CHLOROBENZENE ABL	0	0,000173
o-Xylene	0,000568	0,001175
Styrene	0,000647	0,000801
Ethane, 1,1,2,2-tetrachloro- S-Tetrac	0,001125	0,001229
PROPANE, 1,2,3-TRICHLORO- 1,2,3-TRICH	1,62E-05	3,9E-05
BENZENE, (1-METHYLETHYL)- CUMENE $$ (	0,003286	0,002976
Benzene, bromo- Bromobenzene Monob	0,003224	0,003205
Benzene, 1-chloro-2-methyl- Toluene,	8,19E-05	7,57E-05
BENZENE, (CHLOROMETHYL)- CHLOROMETHYL	2,47E-05	4,27E-05
BENZENE, 1,3,5-TRIMETHYL- 1,3,5-TRIME	4,14E-05	1,46E-05
2-BROMO-1,2-DICHLOROPROPANE PROPANE,	6,33E-05	6,83E-05
Benzene, 1,2,4-trimethyl- .psi.-Cumen	0,000195	0,000163
Benzene, 1,4-dichloro- Benzene, p-dic	0,000273	0,000332
Benzene, 1-methyl-4-(1-methylethyl)-	3,01E-05	3,95E-05
BENZENE, BUTYL- BUTYLBENZENE 1-BUT	1,81E-05	4,17E-05
Benzene, 1,3,5-trichloro- s-Trichloro	0	0
NAPHTHALENE ALBOCARBON CAMPHOR TAR	0,006995	0,006574
Dodecane n-Dodecane Adakane 12 $$	0,010239	0,008706
1,1'-BIPHENYL PHENYLBENZENE 1, 1'-	0,001843	0,00166
1,1'-BIPHENYL, 2,2'-DIMETHYL- 1, 1'-B	2,66E-05	3,38E-05
ETB	0,001527	0,001916
m-p-Ksilen	0,000174	0,000175
TOTAL (TVOCs)	0,039	0,0415

TABLE 3. VOCs of LDPE composite material filled by 22.5% at 25 °C and 70 °C

VOCs	$mg/m^3/gr$ 25 °C	$mg/m^3/gr$ 70 °C
BUTANAL, 2-METHYL- 2-METHYLBUTANAL	0,00042	0,000509
BENZENE	0,000397	0,001041
ETHENE, TRICHLORO- 1,1,2-TRICHLOROETH	0,000145	0
1-Propene, 1,3-dichloro-, (Z)- cis-1,	2,67E-05	3,68E-06
Ethane, 1,1,2-trichloro- .beta.-T	0	0
Toluene	0,006506	0,002731
Ethane, 1,2-dibromo- .alpha.,.beta.-D	0	0
ETHENE, TETRACHLORO- 1,1,2,2-TETRACHL	2,79E-05	0
BENZENE, CHLORO- CHLOROBENZENE ABL	0,000299	0,00139
o-Xylene	0,007981	0,003357
Methane, tribromo- Bromoform Methe	2,73E-05	7,86E-05
Styrene	1,96E-05	9,6E-05
Ethane, 1,1,2,2-tetrachloro- S-Tetrac	2,95E-05	1,84E-05
PROPANE, 1,2,3-TRICHLORO- 1,2,3-TRICH	0,000101	8,01E-05
BENZENE, (1-METHYLETHYL)- CUMENE	0,003988	0,004406
Benzene, bromo- Bromobenzene Monob	0,000432	0,000465
Benzene, 1-chloro-2-methyl- Toluene,	0,00028	6,54E-05
BENZENE, (CHLOROMETHYL)- CHLOROMETHYL	2,45E-05	3,13E-05
BENZENE, 1,3,5-TRIMETHYL- 1,3,5-TRIME	1,93E-05	4,3E-05
2-BROMO-1,2-DICHLOROPROPANE PROPANE,	4,94E-05	0,00015
Benzene, 1,2,4-trimethyl- .psi.-Cumen	0,000844	0,000848
Benzene, 1,4-dichloro- Benzene, p-dic	2,15E-05	1,84E-06
BENZENE, (1-METHYLPROPYL)- SEC-BUTYLB	0,00032	0,000338
Benzene, 1-methyl-4-(1-methylethyl)-	1,81E-05	0
Benzene, 1,2-dichloro- Benzene, o-dic	3,65E-05	2,09E-05
BENZENE, BUTYL- BUTYLBENZENE 1-BUT	6,08E-05	0
(R)-(-)-1,2-DIBROMO-3-CHLOROPROPANE	0,001703	0,013343
Benzene, 1,3,5-trichloro- s-Trichloro	0,011967	0,015056
NAPHTHALENE ALBOCARBON CAMPHOR TAR	8,13E-05	0
Dodecane n-Dodecane Adakane 12	0,000641	0,000246

TABLE 3. *(Cont.)*

VOCs	mg/m^3/gr 25 °C	mg/m^3/gr 70 °C
BENZENE, 1,2,3-TRICHLORO- 1,2,3-TRICH	2,95E-05	0,000103
1,3-Butadiene, 1,1,2,3,4,4-hexachloro-	0,003379	0,006188
1,1'-BIPHENYL PHENYLBENZENE 1, 1'-	0,001216	0,001036
1,1'-BIPHENYL, 2,2'-DIMETHYL- 1, 1'-B	1,17E-05	7,21E-05
ETB	0,008018	0,006188
m-p-Ksilen	0,001246	0,001343
TOTAL (TVOCs)	0,0331	0,0349

TABLE 4. VOCs of LDPE composite material filled by 50.6% at 25 °C and 70 °C

VOCs	mg/m^3/gr 25 °C	mg/m^3/gr 70 °C
BUTANAL, 2-METHYL- 2-METHYLBUTANAL	0,005574	8,82001E-05
BENZENE	0,001264	0,002500273
ETHENE, TRICHLORO- 1,1,2-TRICHLOROETH	0,001038	4,33741E-05
1-Propene, 1,3-dichloro-, (Z)- cis-1,	0,000201	5,08149E-06
Ethane, 1,1,2-trichloro-.beta.-T	5,64E-06	0
Toluene	1,55E-05	0,004530509
ETHENE, TETRACHLORO- 1,1,2,2-TETRACHL	8,86E-05	0
BENZENE, CHLORO- CHLOROBENZENE ABL	9,66E-06	1,03445E-05
BENZENE, ETHYL- ETHYLBENZENE .ALPH	0,001935	0,001619542
o-Xylene	4,39E-05	0,005452617
Styrene	0,001534	0,00060379
Ethane, 1,1,2,2-tetrachloro- S-Tetrac	7,27E-05	3,26667E-06
PROPANE, 1,2,3-TRICHLORO- 1,2,3-TRICH	2,01E-07	0
BENZENE, (1-METHYLETHYL)- CUMENE	0,007954	5,9526E-05
Benzene, bromo- Bromobenzene Monob	3,949492	0,010142648
Benzene, 1-chloro-2-methyl- Toluene,	3,62E-06	0,0002499
BENZENE,(CHLOROMETHYL)- CHLOROMETHYL	2,01E-05	4,17408E-05
BENZENE, 1,3,5-TRIMETHYL-1,3,5-TRIME	5,23E-06	1,45185E-06

TABLE 4. *(Cont.)*

VOCs	mg/m^3/gr 25 °C	mg/m^3/gr 70 °C
2-BROMO-1,2-DICHLOROPROPANE PROPANE,	6,24E-06	5,44445E-05
Benzene, 1,2,4-trimethyl- .psi.-Cumen	1,29E-05	1,41556E-05
Benzene, 1,4-dichloro- Benzene, p-dic	0,159961	0,000336649
BENZENE, (1-METHYLPROPYL)- SEC-BUTYLB	2,82E-06	1,81482E-07
Benzene, 1-methyl-4-(1-methylethyl)-	2,3E-05	0,000318137
Benzene, 1,2-dichloro- Benzene, o-dic	1,89E-05	0
BENZENE, BUTYL- BUTYLBENZENE 1-BUT	3,42E-06	2,15963E-05
Benzene, 1,3,5-trichloro- s-Trichloro	2,74E-05	0
NAPHTHALENE ALBOCARBON CAMPHOR TAR	0,003835	0,000695075
Dodecane n-Dodecane Adakane 12	9,52E-05	0,004385323
BENZENE, 1,2,3-TRICHLORO- 1,2,3-TRICH	1,15E-05	0
1,1'-BIPHENYL PHENYLBENZENE 1, 1'-	0,000672	0,000351349
1,1'-BIPHENYL, 2,2'-DIMETHYL- 1, 1'-B	9,46E-06	2,37741E-05
ETB	0,000375	0,002267251
m-p-Ksilen	0,000282	0,000250445
TOTAL (TVOCs)	0,0327	0,0340

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