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Mechanical Recycling of Waste Plastic (High Density Polyethylene) for Construction Purposes

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Abstract. Plastic waste leading to contamination and environmental hazard is a prioritized issue all over the world. Mechanical recycling is the easiest approach to convert waste plastic in to recycled plastic with least environmental effect. To the best of author's understanding, no research exists addressing the potential application of recycled plastic as an independent construction material instead of partial replacement in composites. This paper aims to investigate the compressive properties of mechanically recycled High Density Polyethylene (rHDPE). The compressive test has been performed as per ASTM D695-23 and stress-strain behavior has been obtained. In addition, gas emission analysis has been performed using smart sensor. The peak load reached up to 9.25 kN resulting in 18.25 MPa compressive strength. The compressive energy absorption was found to be 1.08 MJ/m^3. Gas emission analysis revealed that oxygen level of 20.6% is close to 21% which is typical concentration for safe breathing. Also, concentration of carbon monoxide was found to be 12 ppm well below the 50-ppm maximum allowable concentration. The concentration of hydrogen sulphide and explosive limits were negligible. The compressive properties of rHDPE can be utilized to manufacture building products like blocks. However, improvement in terms of toughness, durability and fire resistance is required for gross level implementation in construction.

Keywords: Plastic waste; Recycling; Compressive properties; Construction Material; Gas emissions.

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1. Introduction

Daily household use of plastic as an essential commodity eventually results in excessive generation of waste plastics. The driving factors in environmental hazards include waste plastic contamination as a major contributor. Reutilization practices exist but with a number of drawbacks like time consumption, expensiveness, etc. Mechanical recycling is one of the approaches that follows a simplified process with least impact to environment. The conventional process of collection, sorting, cleaning, and palletization makes it a sustainable approach to effectively utilize plastic wastes. On the other hand, the contribution of construction industry to carbon emissions and global warming is at an alarming stage. From cement manufacturing to diminishing natural stones for aggregate production, the construction industry has a leading role in environmental destruction. Waste plastic whether in recycled or non-recycled form, has been part of many studies but only limited to partial replacement in composites.

The plastic waste generation is expected to surpass 0.50 billion tons in 2050. This poses a great environmental challenge globally. In addition, the conventional material usage in construction industry needs to be diverted towards sustainable and economical use of waste material with desirable properties. To the best of author's understanding, no significant scientific data is available on complete use of recycled plastic for manufacturing building products as a sole construction material. The objective of this study is to mechanically recycle waste plastic particularly High-Density Polyethylene (rHDPE) and investigate its compressive properties for application in construction industry.

This research will outline the compressive characteristics of rHDPE plastic which can be utilized to manufacture building products like blocks. Conventional concrete blocks are brittle due to inherent properties of concrete. Recycled plastic blocks can have multiple advantages including cost effectiveness and ductility. Additionally, the waste plastic reutilization will also result in positive way towards environmental protection. Therefore, in this paper, a brief literature on waste plastic recycling, waste plastic utilization in construction is discussed followed by experimental work and results of compressive testing. The conclusions drawn from the study have been presented along with practical implications.

2. Literature Review

Plastics, due to attributes like weightless ness, cost effectiveness and flexibility, has become an essential part of our lives from industries like automotive, aerospace and electronics to building construction and medical applications (Sahoo et al., 2024). A significant portion of plastic waste is single-use plastic which is the main reason for high rate of pollution. Multilayered plastics constitute about 26% by weight of plastic packaging due to latest manufacturing technologies (Bassey et al., 2023; Laghezza et al., 2024). Globally, 8 million MT of plastic waste is disposed of in the ocean creating wildlife hazard (Tiwari et al., 2023). The gradual breakdown of plastics through physical and chemical mechanisms lead to generation of microplastics which can travel through air and water (Van Fan et al., 2022). Microplastics pose a significant risk as they can be absorbed by human cells and organs (Wu et al., 2022). Europe recovers 50% of its plastic waste through recycling to minimize the adverse effects and rest is sent to landfills (Wong et al., 2015). Asia is responsible for more than 50% global plastic production and yet some countries in Asia lack the basic recycling facilities (Liang et al., 2021).

Landfilling of plastics lead to accumulation and contamination of natural resources for tens to hundreds of years, whereas, incineration of plastics produces toxic gases (Li et al., 2024; Maitlo et al., 2022). Recycling methods for plastic wastes include mechanical recycling, pyrolysis, gasification, catalytic cracking, hydrocracking and incineration (Darko et al., 2023; Praveenkumar et al., 2024; Zhang et al., 2022). Mechanical recycling, also known as primary recycling involves cutting, shredding, washing, pelletizing and re-extrusion of waste plastic (Gopinath et al., 2020). Polyethylene terephthalate (PET) and HDPE have a high degree of recyclability followed by Low Density Polyethylene (LDPE) and polypropylene (PP) having moderate degree of recyclability and then non-recyclable plastics like polyvinyl chloride (PVC) and polystyrene (PS) (Khoaele et al., 2023). The carbon emission of plastics per ton of LDPE is the lowest; 3060 kg followed by HDPE; 3072 kg, PP; 3349 kg, mixed plastic; 3673 kg, PET; 4137 kg and PS; 4757 kg (Taghavi et al., 2021).

Safe disposal strategies are essential to deal with ecological challenges caused by uncontrolled disposal of plastic (Sharma & Bansal, 2016). Plastic in virgin, waste and recycled form has been part of many past studies (Asif et al., 2024; Jawaid et al., 2023). Plastic fibers in concrete control the plastic shrinkage cracking during evaporation of water after placing (Guo et al., 2022; Huynh et al., 2023). Replacement of natural aggregates with plastic aggregates also alters the properties of concrete (Hamada et al., 2024; Haruna et al., 2024) especially for the pavement applications (Ma et al., 2022). In a state of Victoria, Australia, concrete footpaths were constructed using recycled plastic waste and recycled crushed glass (Wong et al., 2020). Also, recycled plastic fibers have been used to develop fiber reinforced concrete for pavement and footpath applications (Suksiripattanapong et al., 2022). Substitution of plastic waste with natural aggregates in concrete can decrease the density and dynamic elastic modulus leading to ductile behavior (Guo et al., 2023). Environmental challenge in terms of plastic waste contamination is being dealt with many strategies all over the world. Mechanical recycling is proven to be less resource consumable yet environmentally friendly approach. Utilization of recycled plastic in construction revolves around partial substitution in composites. Yet, complete usage of recycled plastic in any construction application is not witnessed.

3. Research Methodology

3.1. Mechanical Recycling of Waste Plastic

Waste plastic was collected and sorted to get HDPE bottles commonly used as milk and mobile oil bottles. After sorting, the HDPE waste was crushed using shredder. The shredded HDPE was then washed twice for thorough cleaning. The cleaned HDPE was then pelletized to small size grains. Afterwards, the rHDPE pellets were used in extrusion process for sample preparation. The extrusion setup consisted of a single screw extruder with electronic panel having temperature and speed controllers installed. Six heating coils were installed over extruder connected to two thermocouples. After introducing the material in screw case, it was kept at 120^{o}C to 140^{o}C for about 10-15 minutes to achieve adequate melting and flowability. Figure 1 shows the extrusion setup for recycled plastic sample preparation.

Fig. 01. Single screw extruder

3.2. Gas Monitoring

As the extrusion process uses melting of rHDPE at high temperature, the environmental effect of the process was taken into consideration. A smart sensor ST8900 was used to monitor and quantify the gas composition. The sensor was equipped with the capability to quantify the concentrations of oxygen, carbon monoxide, hydrogen sulphide and lower explosive limits of various compounds, i.e., methane, ethane, propane, butane, gasoline, kerosene, petroleum gas and turpentine.

During the extrusion process, the sensor was placed close to the outlet of extruder. The monitoring was performed at the time when extrudate was coming out of the outlet so that maximum emission could be under consideration. The results were compared with the ranges of gas emissions along with poisoning symptoms for human body described in the specification's manual of the smart sensor.

3.3. Sample Preparation

To prepare the cylindrical samples of 12.7 mm diameter as per ASTM D695-23, a sizing die having built-in water body was installed at the outlet of extruder that eliminates the rHDPE in the form of plain circular rods. While, the extrudate passes through the sizing die, it was being cooled down by circulating water in the die and after coming out of the die, again water was poured over hot circular rod for immediate cooling in order to sustain the circular shape.

After a span of 2-3 hours, the rods were cut in to samples having height of 25.4 mm. Figure 2a and 2b shows the sizer die used for sample manufacturing and manufactured sample for current study, respectively.

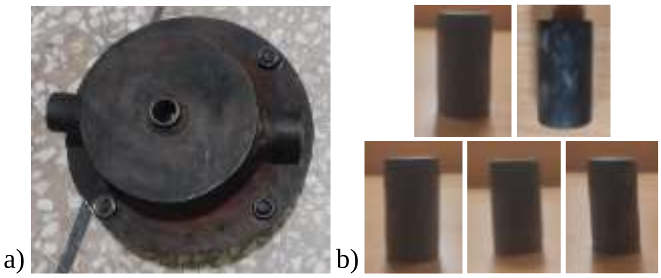

Fig. 02. Sample manufacturing; a) sizer die and b) manufactured samples

3.4. Test Setup

Compressive test was conducted as per ASTM D695-23. Loading rate was kept 1.6 mm/min. Peak load (P_{max}), maximum strength (σ_{max}), maximum strain (ε_{max}) and energy absorption (E) were determined from compressive test. Figure 3a and 3b shows the schematic illustration and actual test setup for compressive test.

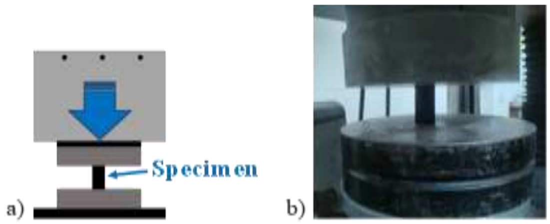

Fig. 03. Compressive test setup; a) schematic illustration and b) actual test setup

4. Results and Discussions

4.1. Gas Composition Analysis

The oxygen level recorded near the outlet of extruder came out to be 20.6% which is close to the typical 21% concentration of oxygen (O_2) in air. The hydrogen sulphide (H_2S) concentration was 0 parts per million (ppm) which is less than the safe limit of 0.025 ppm. Thus, it came out to be nonhazardous to human body. The lower explosive limits (LELs) came out to be 0% which categorizes this process as non-explosive. The carbon monoxide (CO) concentration came out to be 12 ppm which less than the maximum allowable limit of 50 ppm for safe breathing. Figure 4 shows the recorded gas composition through smart sensor.

Fig. 04. Gas composition analysis

4.2. Compressive Strength Results

Samples were subjected to compressive load and stress-strain behavior was obtained. Figure 5a shows the stress-strain behavior of recycled HDPE plastic sample under compressive load. Compressive load was applied till the strain reached up to 10% of the total height of sample. Beyond 0.04 strain, the sample started to bulge out. At 0.10 strain, the compressive strength came out to be 17.59 MPa. Figure 5b shows the post-test compressive sample having visible outward bulging of 125% of the diameter.

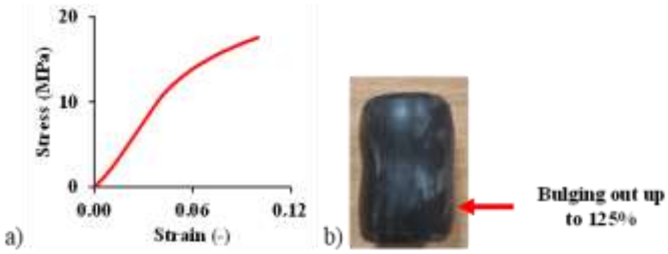

Fig. 05. Sample's compressive behavior; a) stress-strain curve and b) tested sample

The results of compressive tests are shown in Table 1. The peak load in compression test came out to be 9.2 kN with a standard deviation of 0.90 kN. Consequently, the maximum strength came out to be 18.3 MPa with a standard deviation of 1.7 MPa. Similarly, the maximum strain came out to be 0.1 with a standard deviation of 0.0001. The corresponding energy absorption was obtained to be 1.08 MJ/m^3 with a standard deviation of 0.1 MJ/m^3.

Table 1. Compressive strength results

Loading	P_{max}	σ_{max}	ε_{max}	E
	(kN)	(MPa)	(-)	(MJ/m^3)
Compression	9.2 ± 0.9	18.3 ± 1.7	0.1 ± 0.0001	1.08 ± 0.1

4.3. Internal Fractured Surfaces of Tested Specimens

The specimens used for compressive test were cut longitudinally and transversely to see the internal fractured surfaces. It was revealed that minor cavities were present probably due to formation of small bubbles during the extrusion process. Also, fractured region due to straining was identified in one of the specimens as shown in figure 6.

Fig. 06. Internal fractured surfaces of specimens.

5. Practical Implementation

Use of mechanical recycling to convert waste plastic into recycled plastic can have multiple benefits including effective waste management, sustainable reutilization of waste, lease effect to ecological environment, etc. Recycled plastic can be used to manufactured building products like blocks, rebars, corrugated tiles, pavers.

Due to the durability and ductile characteristics of plastic, practical implementation of recycled plastic in construction industry can address the issues of brittle nature of concrete, time consuming construction processes, expensiveness of materials, etc.

6. Conclusions

Use of recycled plastic as partial constituent in many construction applications has been witnessed. However, recycled plastic as a sole alternative to any construction material for manufacturing building products has not been explored yet.

In current study, compressive characteristics of rHDPE have been investigated for potential application in construction. Extrusion process was adopted for sample manufacturing and ASTM standard was followed for compressive testing. Following conclusions have been drawn from this study:

- The gas emission of carbon monoxide and oxygen concentration in nearby working environment during extrusion are within acceptable range for safe working environment. Conversely, the presence of LELs and H_2S was negligible.
- The peak compressive load of rHDPE at 10% strain was found to be 9.2 kN resulting in a compressive strength of 18.3 MPa having energy absorption of 1.08 MJ/m^3.
- Due to straining, fracturing of surface was observed in transverse along with presence of minor cavities.
- The favorable compressive strength results of recycled plastic material, in comparison to conventional material strengths, can be utilized to manufacture building products intended to sustain compressive loads.

The material attributes of recycled plastic in terms of environmental susceptibility, and long-term durability needs in-depth investigation to make it industrially viable in manufacturing of building products.

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