Tensile and Flexural Properties of Recycled HDPE for Application in Building Products

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Abstract. Plastic waste generation is a major environmental threat with far-reaching consequences that needs to be dealt with. High density polyethylene (HDPE) is a common plastic waste coming out of daily household products. Recycling of HDPE plastic waste has been a viable alternate to disposal. To the best of author's knowledge, no work has been reported on the material properties of recycled HDPE in perspective of building products. This study investigates the tensile and flexural properties of mechanically recycled HDPE for potential application in building products. The specimen's behaviour under loading has also been reported. Based on the findings, 2.5% elongation at fracture was observed having 14.25 MPa strength against tension. Whereas, 32.6 MPa modulus of rupture was obtained with toughness index of 1.45 against flexure. In addition, potential application of recycled HDPE for manufacturing building products has been discussed keeping in line the material properties of recycled plastic. The adoption of recycled waste material instead of conventional materials can significantly influence the construction industry positively.

1 Introduction

Plastic is widely used across various sectors such as households, healthcare, industry, agriculture, and textiles [1]. Most of the plastic is single-use and a considerable portion ends up being disposed of [2]. Recycling of plastic waste through numerous techniques has been in practice globally. Companies like Green Earth Recycling in Pakistan are producing various items such as benches, chairs, tables, and more by recycling plastic wastes [3]. These recycled products offer advantages like low maintenance, eco-friendliness, resistance to slips and splinters, durability, and a lifespan of approximately 25 years. Out of mechanical, chemical, thermal and biological recycling techniques, preference is given to mechanical recycling for plastics that are clean, well-separated, and exhibit similar properties [4]. Thus, the simplified technique of mechanical recycling makes it the most convenient procedure to be adopted.

Virgin plastics are widely used in the manufacturing industry for multiple purposes ranging from packing material to auto parts and insulation materials. 3D printing of plastics has gained vast attention during the past years with focus on mechanical properties [5, 6].

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The yield strength of recycled polypropylene is reported to be 16 MPa [7]. Also, with the current trends of blending plastic with other materials like wood and fibers, researchers have focused extensively on the application of existing standards for testing of complex materials [8, 9]. HDPE being a recyclable material has been a part of studies for additive manufacturing and fabrication [10].

Traditional construction remains vulnerable to damages during its service life [11]. The frequency of casualties in case of failure is more due to the excessive weight of the structure [12]. The inherent flexibility of plastic allows it to alter its shape when heated. This flexibility enhances its tensile strength [13]. To date, the majority of studies on utilizing plastic in construction materials have focused on incorporating or substituting plastic in cement-based composites, either as aggregates or shredded fibers [14]. This includes replaced thermoset plastic by 5% fine aggregates [15], using combination of HDPE and sand for the application in floor tiles [16], addition of processed plastic in wearing course bitumen [17] and in modified bitumen [18]. However, plastic as an absolute alternative to any construction material has not been part of any study. The durability of plastic makes it a suitable material for construction purposes.

To the best of author's knowledge not work has been done to evaluate the mechanical properties of recycled HDPE material for application of manufacturing building products. Thus, the purpose of current study is to investigate the tensile and flexural properties of recycled HDPE with prime focus on exploring the potential of manufacturing building products using recycled plastics. The significance of this work is the adoption of recycled waste material as a potential alternative to conventional materials.

2 Experimental Program

2.1 Plastic Waste Recycling

Single screw extrusion machine was used for current study. The extrusion machine comprised of a hopper at the inlet, connected to a barrel having enclosed screw. A total of six heaters connected to two thermocouples were employed over barrel for heating. Temperature and speed controllers were also part of the setup. Locally available shredded recycled HDPE plastic was used. The extrusion machine was heated at a temperature ranging from 120ºC to 140ºC through coils connected to thermocouples. The material was introduced through the inlet in the extrusion machine and was kept in it for 10 to 15 minutes for adequate melting. Once the melted material coming out of outlet was checked for acceptable flowability, the mould was attached to the outlet for filling.

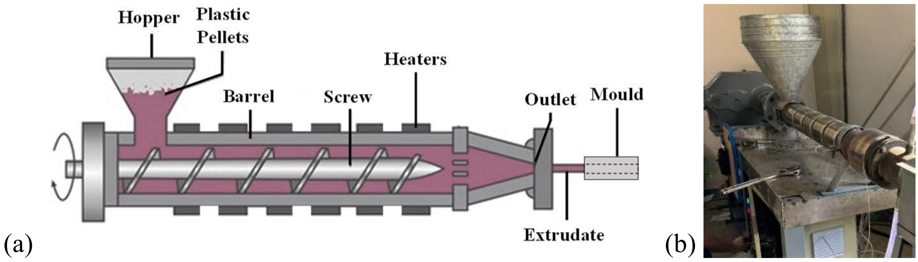

Fig. 1. Plastic waste recycling setup: (a) schematic illustration of components of extrusion machine [19] and (b) extrusion machine used for current study.

2.2 Test Specimens

Pressurized filling was used to fill the moulds at a controlled speed. Three-layer moulds were used for manufacturing test specimens. After fixing the mould with the outlet of extrusion machine, the mould was tightened with a confining frame to avoid any displacement/bending of mould plates due to pressurized extrudate. After filling of the mould, the nozzle of the extrusion was locked for further filling. Demoulding was delayed for about 8 to 10 minutes so that the specimen gains a significant hardness. Similarly, all specimens were fabricated following the procedure. The weights of the specimen for tensile and flexural strength tests were 0.17 lbs and 0.08 lbs, respectively. Figure 2a shows the test specimen manufactured for tensile test and figure 2b shows the test specimen manufactured for flexural test.

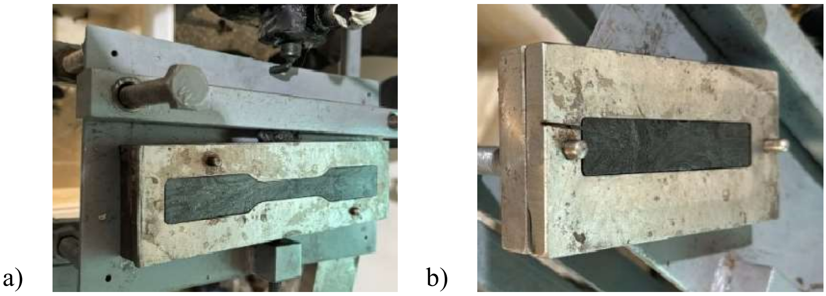

Fig. 2. Manufactured specimens: (a) for tensile test and (b) for flexural test.

2.3 Test Setups

Tensile and three-point flexural tests were conducted as per ASTM D638-22 [20] and ASTM D790-17 [21], respectively. The tensile and flexural loading rates were kept 45 mm/min and 1.3 mm/min, respectively. Peak load (P_{max}), strength (σ_T) and percentage elongation at fracture ($\varepsilon_{\Delta L}$) were determined from tensile test. Peak load, modulus of rupture (MoR), deflection at peak load (Δ), pre-crack energy absorption (E_α), post-crack energy absorption (E_β), cumulative energy absorption (E_T) and toughness index (T.I) were determined from flexural test. The setups for tensile and flexural tests are shown in Figure 3. A specialized assembly was used for the tensile test due to the limitations of servo-hydraulic testing machine. An average of three readings has been taken to represent a particular output parameter.

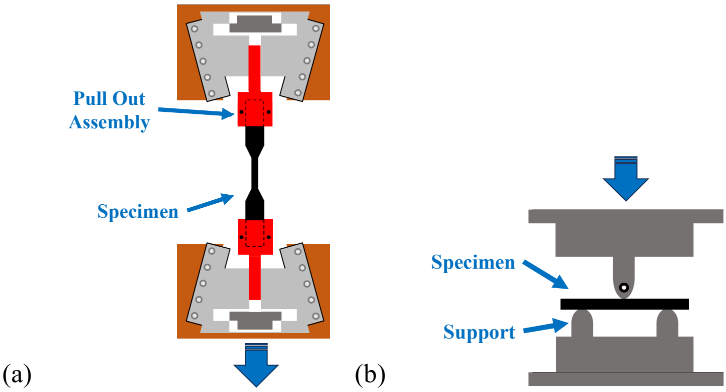

Fig. 3. Manufactured specimens: (a) for tensile test and (b) for flexural test.

3 Results and Analysis

3.1 Tensile Strength

Specimens were subjected to tensile load and load-elongation behaviour was obtained. Figure 4a shows the load-elongation behaviour of recycled HDPE plastic specimen under tensile load. The specimens showed elastic behaviour up to 2.75 mm elongation and split at 2.9 kN. The percentage elongation at fracture was 2.5%. Figure 4b shows the post-test split specimen having breakage from the gauge length.

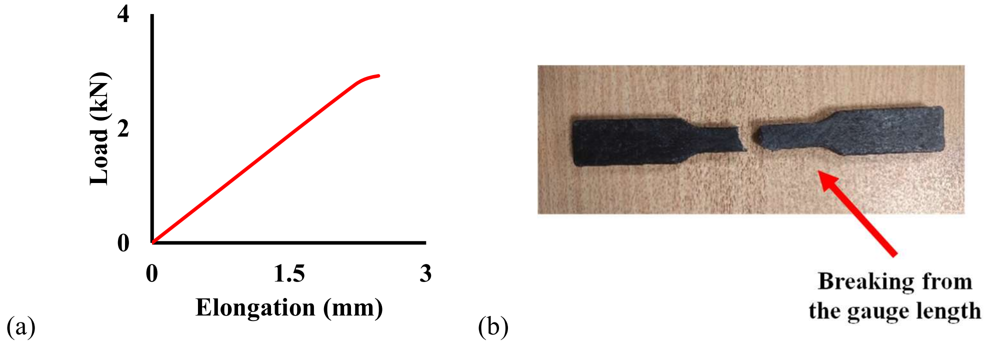

Fig. 4. Specimen's behaviour : (a) load-elongation curve and (b) tested specimen.

The results of tensile tests are shown in Table 1. The peak load in tensile test came out to be 2.90 kN with a standard deviation of 0.40 kN. Consequently, the maximum stress came out to be 14.25 MPa with a standard deviation of 0.22 MPa. Similarly, the corresponding percentage elongation at fracture was obtained to be 2.5% with a standard deviation of 0.36%.

Table 1. Tensile strength results.

Specimen	**P$_{max}$**	$\boldsymbol{\sigma_T}$	$\boldsymbol{\varepsilon_{\Delta L}}$
	(kN)	**(MPa)**	**(%)**
Tensile	2.90 ± 0.40	14.25 ± 0.22	2.51 ± 0.36

3.2 Flexural Strength

Specimens were subjected to flexural load and load-deflection behaviour was obtained. Figure 5a shows the load-deflection behaviour of recycled HDPE plastic specimen under flexural load. The specimens showed elastic behaviour up to 2 mm deflection and fractured. The test was terminated at a deflection of 3 mm. The peak load achieved during the test was 0.91 kN. Figure 5b shows the post-test fractured specimen. The crack in specimen was observed up to 75% depth, the remaining 25% depth was still bonded showing the strong withholding effect in bottom layer of the specimen.

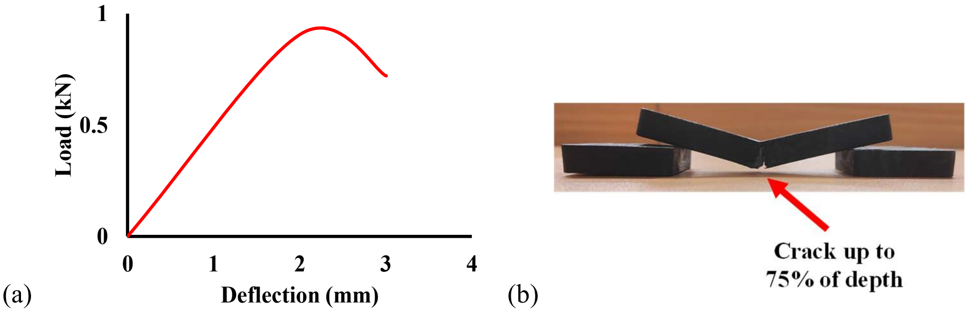

Fig. 5. Specimen's behaviour : (a) load-deflection curve and (b) tested specimen.

The results of flexural tests are shown in Table 2. The peak load in flexural test came out to be 0.88 kN with a standard deviation of 0.03 kN. Consequently, the corresponding modulus of rupture came out to be 32.63 MPa with a standard deviation of 1.15 MPa. The corresponding deflection at the peak load was 5.67 mm with a standard deviation of 0.66 mm. The pre-crack energy absorption before peak load was obtained to be 1.94 joules with a standard deviation of 0.22 joules. The post-crack energy absorption beyond peak load came out to be 0.88 joules with a standard deviation 0.07 joules. The cumulative energy absorption was computed to be 2.82 joules with a standard deviation of 0.29 joules. Thus, the obtained toughness index of the specimen was found to be 1.45 with a standard deviation of 0.02.

Table 2. Flexural strength results.

Specimen	**P_{max}**	**MoR**	**Δ**	**E_α**	**E_β**	**E_T**	**T. I**
	(kN)	**(MPa)**	**(mm)**	**(J)**	**(J)**	**(J)**	**(-)**
Flexure	0.88 ± 0.03	32.63 ± 1.15	5.67 ± 0.66	1.94 ± 0.22	0.88 ± 0.07	2.82 ± 0.29	1.45 ± 0.02

3.3 Damaged Surfaces of Specimens

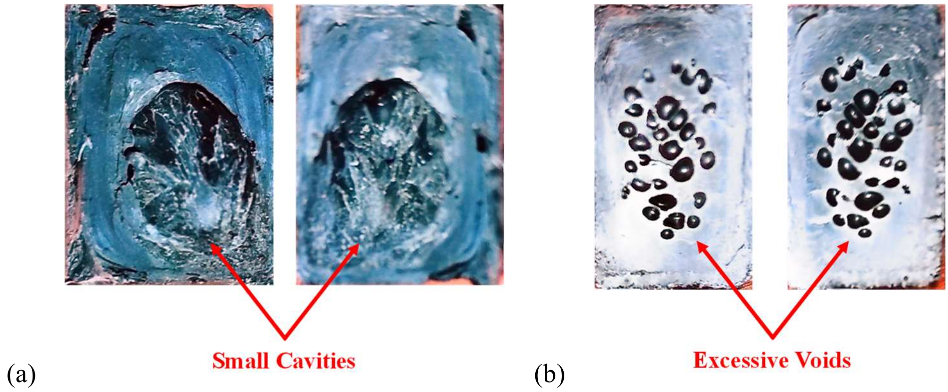

Fig. 6. Fracture surfaces at splitting interfaces : (a) specimen tested under tension and (b) specimen tested under flexure.

The specimen used for tensile test revealed solid internal filling with minimal cavities as shown in Figure 6a. However, the specimen used for flexural test revealed entrapped voids evident from naked eye, due to bubble formation during the extrusion process as shown in Figure 6b. The reason seems to be the transition time taken during the demoulding of prepared specimen followed by fixing the mould again for filling. During this period, the high temperature results in formation of gas bubbles with in the static melted plastic that further transforms in to voids upon cooling. This phenomenon leads to reduction in the strength.

4 Exploring Potential of Recycled Plastic for Building Products

Conventional buildings products are mainly comprised of various elements like beams, columns, slabs etc., constructed using concrete and steel reinforcements. The flexural and tensile stresses govern when larger spans exist. Concrete and steel are proven to be best suited for construction due to inherent properties to withstand these stresses. However, the economic and environmental factor in terms of material cost and carbon emissions during cement manufacturing process leads to globally challenging concerns. Also, the post-fracture performance of concrete might turn out to be less than plastic due to carbon chain structure of plastic. A similar display of bridging effect after fracture can be visualized in Figure 5b.

Plastic waste after recycling and enhanced strength characteristics can serve as an acceptable alternative to such challenges. Use of recycled plastic to manufacture building blocks has been part of various housing projects under social initiatives in developing countries. But, extensive scientific data regarding the material characteristics for manufacturing of building products is not available to develop design guidelines. Thus, recycled plastic as a material after enhanced properties can lead to manufacturing of buildings products with desired characteristics for development of alternative novel houses.

5 Conclusions

Recycled plastic waste has been utilized for multiple industrial applications. Till now, no study reported its use for manufacturing building products. In current study, tensile and flexural properties of recycled HDPE plastic have been investigated. The work can highlight the significance of recycled plastic as an alternative material for manufacturing building products. The specimens were prepared using extrusion machine through injection moulding. Following are the conclusions drawn from this study:

- Tensile strength of the material was found to be 14.25 MPa with 2.5% elongation at the fracture.
- Flexural strength of the material came out to be 32 MPa with the toughness index of 1.45, indicating 45% more energy absorption beyond initial failure.
- Transition time for demoulding creates gas bubbles which remain entrapped in the material beyond cooling, resulting in loss of strength.

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