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Physical and Mechanical Characterization of Injection Moulded Parts from Recycled Polyethylene Packaging Caps

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The common disadvantage of recycled plastics is the deterioration of physical properties. The study investigates the physical and mechanical properties of injection moulded parts fabricated from recycled polyethylene packaging caps. The properties of these recycled parts were systematically compared to those of parts made from virgin polyethylene. Initial characterization involved Fourier transform infrared spectroscopy to identify material composition. Subsequent assessments included measurements of weight, dimensional stability, tensile strength, and elongation at maximum force. Surface structure, colour, and gloss were also evaluated. The results indicated a significant reduction in elongation at maximum force for the recycled parts compared to their virgin counterparts, with only minor variations in tensile strength. Structural analysis revealed the presence of impurities and non-homogenized plastic streams within the recycled material. Additionally, noticeable differences in colour and gloss were observed across of different sample series. This study underscores the impact of recycling on the mechanical performance and aesthetic properties of injection moulded polyethylene parts.

topics: injection moulded, polyethylene, physical properties

1. Introduction

Nowadays, 40% of plastics produced are used as packaging. The packaging is a product with a very short shelf life of several months. The materials used in the packaging industry are most often polyolefins (22.1% is polyethylene and 15.4% polypropylene), as well as PET and PS (PET — polyethylene terephthalate, PS — polystyrene) [1]. According to the EU SUP directive, after July 1, 2024, all PET bottles must have caps attached. This increases the stream of polyolefins waste suitable for reprocessing [2]. The recycling process involves various steps such as collection, sorting, shredding, and regranulation to transform post-consumer bottle caps into new products [2, 3]. Work [4] has shown that the method of waste collection significantly affects the purity and properties of the recycled material. Additionally, the presence of cross-contamination by other plastics like polypropylene can affect the mechanical properties of the recycled material, showcasing the importance of material purity in the recycling process [5]. Furthermore, advancements in technology, such as the development of low-cost portable sorting machines based on colour codes, have facilitated the efficient sorting of bottle caps for recycling purposes [6–8]. These innovations contribute to the circular economy by enabling the reuse of plastic waste and reducing environmental pollution.

TABLE I

The main parameters of the injection moulding process

Parameter	Value
Injection temperature	210°C
Holding pressure	50 MPa
Mould temperature	2°C
Holding time	18 s
Injection speed	45 ccm/s
Injection time	0.72 s
Injection pressure	80 MPa
Cooling time	20 s

2. Material and methods

The aim of the work was to compare the moulded parts obtained from plastic caps of various types in relation to the primary material. Specimens, in the shape of tensile bars of 4 mm thickness (according to PN–EN ISO 527-1:2020 standard), were injected using a two-cavity mould mounted on a Krauss-Maffei KM65-160 C4 injection moulding machine. The injection moulding conditions are presented in Table I. The reference samples were made from virgin Hostalen GC 7260 LyondellBasell (HDPE). Other samples were made from plastic caps coming

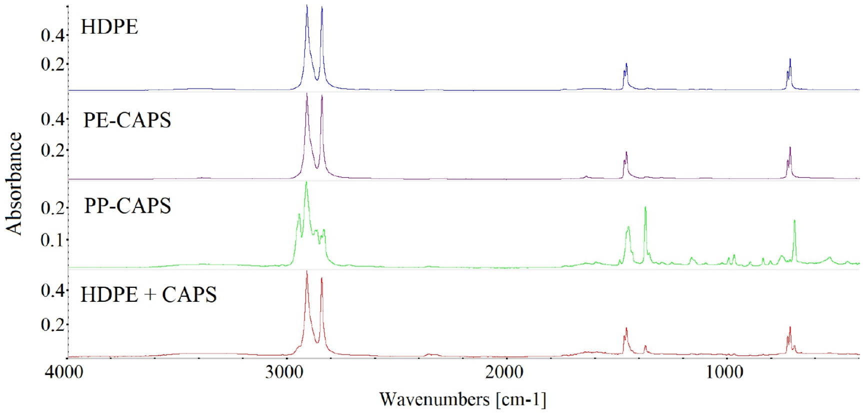

Fig. 1. FTIR diagrams of samples.

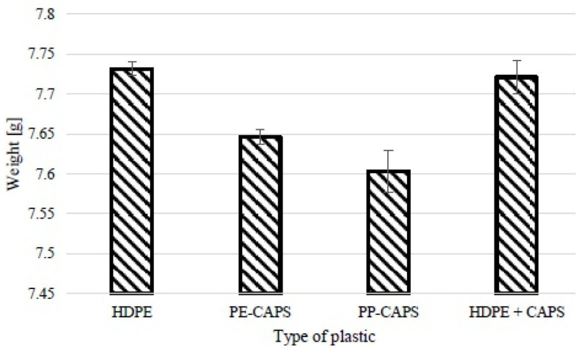

Fig. 2. Weight of samples.

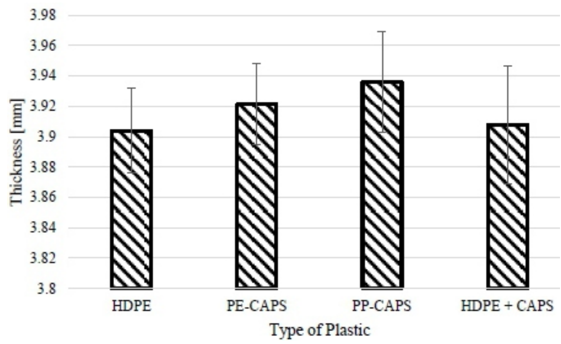

Fig. 3. Thickness of samples.

from PET bottles (PE-CAPS), and further other samples were made from caps coming from not-PET bottles (PP-CAPS), as well as from virgin HDPE mixed in a 50/50% wt ratio with milled plastic from all caps (25% wt PE-CAPS and 25% wt PP-CAPS); these samples were marked as (HDPE+CAPS).

2.1. FTIR investigations

Fourier-transform infrared spectroscopy (FTIR) was performed using the Thermo Scientific Nicolet iS5 device. The results of FTIR of samples are presented in Fig. 1.

According to software analysis comparing the measurement results with the plastics database, the PE-CAPS samples show 96.51% match with the HDPE samples, the PP-CAPS samples show 92.74% match with the PP samples, and the HDPE+CAPS samples show 96.67% match with the HDPE samples.

2.2. Moulded parts weight

The results of the weight of the moulded parts are presented in Fig. 2. The standard deviations of all measurements are given in of figures. The Sartorius CP225 balance with a close measurement space was used and the weight of the parts was determined with a ±0.1 mg accuracy.

The weight analysis of the moulded parts showed minor variations between the samples. The PE-CAPS and PP-CAPS samples had slightly lower weights than the HDPE samples, likely due to impurities and non-homogeneous distribution. The HDPE+CAPS samples closely matched the weight of pure HDPE, indicating that the addition of recycled material did not significantly affect the mass.

2.3. Dimesional stability

The dimesional stability (thickness) of the sample was measured in the middle of the moulded parts using a digital micrometer with an accuracy of ±0.01 mm. The height of the mould cavity was 4.1 mm. The results of the thickness measurements of the moulded parts are shown in Fig. 3. The dimensional stability measurements indicated that the HDPE samples exhibited the largest deviation from the mould cavity height of 4.1 mm.

The PE-CAPS and PP-CAPS samples showed slightly better stability with smaller deviations.

TABLE II

The gloss measurement results.

	HDPE	PE-CAPS	PP-CAPS	HDPE+CAPS
Gloss units [GU]	18.06	27.7	18.6	20.98

TABLE III

Colour measurement results.

	HDPE	PE-CAPS	PP-CAPS	HDPE+CAPS
L [$\frac{\text{cd}}{\text{m}^2}$]	71.3	40.02	60.6	43.3
a [-]	0.54	-5.49	-4.08	-10.77
b [-]	5.71	7.90	8.05	5.47

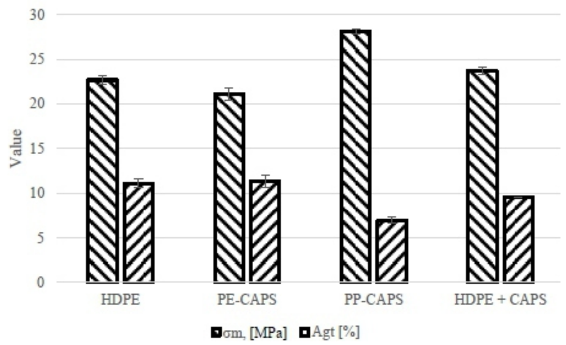

Fig. 4. Thickness of samples.

The HDPE+CAPS samples maintained a thickness close to that of pure HDPE, indicating that the addition of recycled material did not significantly affect the dimensional stability. The PE-CAPS and PP-CAPS samples exhibited slightly higher thickness, possibly due to the presence of impurities and uneven plastic flow.

2.4. Mechanical properties

In tensile tests, the tensile strength (σ_m) and the elongation at maximum force (A_{gt}) were examined. The tests were carried out using Hegewald & Peschke Frame Desk 20 machine. The tension speed was 50 mm/min. The measurement results are presented in Fig. 4.

The tensile strength tests revealed notable differences among the samples. The HDPE samples demonstrated the highest tensile strength. The PE-CAPS samples exhibited slightly lower tensile strength, likely due to the presence of impurities and recycled content. The PP-CAPS samples showed the highest tensile strength among the recycled materials, surpassing both PE-CAPS and HDPE+CAPS. However, the elongation at maximum force was significantly reduced for the recycled samples compared to virgin HDPE, highlighting the impact of recycling on the material flexibility. Overall, while the recycled materials can achieve comparable tensile strength, their elongation properties are compromised.

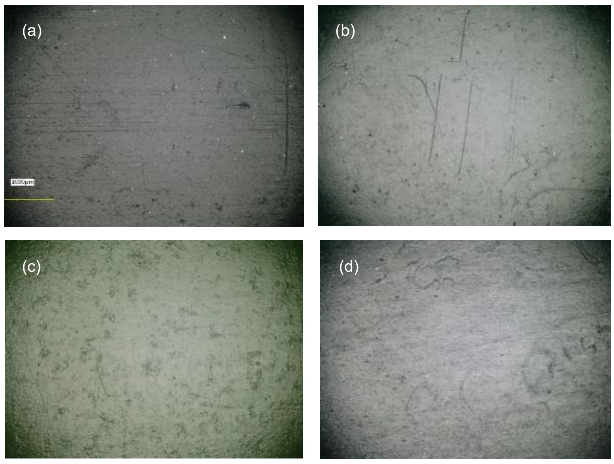

Fig. 5. Structure of surface (with magnification of 100x) of (a) HDPE, (b) PE-CAPS, (c) PP-CAPS, (d) HDPE+CAPS.

2.5. Gloss and colour

The gloss examinations were carried out using the Elcometer 406L glossmeter, at 60° of lihgt incidence. For the colour analysis, an X-Rite spectrophotometer was used. Colour analysis was performed using the CIELab method. The gloss measurement results are presented in Table II, and the colour measurement results in Table III. The results are presented in the form of coordinates a, b, and L. The dimensionless value a determines the colour change from green (negative value) to red (positive value) and dimensionless value b from blue (negative value) to yellow (positive value), while L is the luminance expressed in cd/m^2. For zero values of a and b, L determines the colour change from black ($L = 0$) to white ($L = 100$).

The gloss measurements showed significant differences. Virgin HDPE had the highest gloss, while PE-CAPS and PP-CAPS had much lower values due to impurities. The HDPE+CAPS samples had gloss values close to those of virgin HDPE, indicating better surface quality. Colour analysis showed noticeable differences. The HDPE samples had neutral colour profiles. PE-CAPS and PP-CAPS had significant deviations in lightness and colour shifts towards green and yellow. The HDPE+CAPS samples had intermediate colour values, reflecting the influence of recycled content.

2.6. Structure

The structure of the samples was examined in reflected light using a VHX-900F Keyence microscope. From the microscopic images, it can be seen that in the case of moulded parts made from recycled plastic, small inclusions can be found in the material structure (Fig. 5).

3. Conclusions

This study evaluated the physical and mechanical properties of injection moulded parts made from recycled polyethylene packaging caps compared to virgin polyethylene. The results indicate that although recycled materials can be used effectively, there are notable differences in their properties. The recycled PE-CAPS and PP-CAPS samples showed minor variations in weight and thickness, with HDPE+CAPS samples closely matching virgin HDPE, indicating that the addition of recycled material does not significantly affect dimensional stability. The tensile strength of of recycled samples, especially PP-CAPS, was comparable to or higher than virgin HDPE, but their elongation at maximum force was significantly reduced, highlighting reduced flexibility due to impurities. Gloss measurements revealed lower values for recycled samples, though HDPE+CAPS maintained better surface quality. Significant colour deviations were observed in the recycled samples, with shifts towards green and yellow hues. Overall, while recycled polyethylene is feasible for moulding, properties like elongation and surface aesthetics may be compromised. Advances in recycling technology are essential to enhance the quality and performance of recycled plastics, promoting sustainability and offering economic benefits.

References

[1] Plastics Europe, *The Circular Economy for Plastics — A European Analysis*, (2024).

[2] M.H. Akhras, P.J. Freudenthaler, K. Straka, J. Fischer, *Polymers (Basel)* **12**, 2685 (2023).

[3] M.Z. Chaari, M. Abdelfatah, S. Al-Sulaiti, F. Daroge, R. Al-Rahimi, G. Pereira, *SN Applied Sciences* **128**, 128 (2023).

[4] U. Salahuddin, J. Sun, Ch. Zhu, M. Wu, B. Zhao, P.X. Gao, *Advanced Sustainable Systems* **7**, 2200471 (2023).

[5] R.F. Suleiman, A.S. Zulkarnain, M.M. Bahurdin, *Advances in Technology Transfer Through IoT and IT Solutions*, pp. 19–29 (2023).

[6] J.A. Oyewalwe, K.T. Lagouge, Tartibu, I.P. Okokpujie, *Journal of Design & Nature and Ecodynamics* **1**, 63 (2023).

[7] M. Gall, A. Schweighuber, W. Buchberger, W.R. Lang, *Sustainability* **24**, 10378 (2020).

[8] M.H. Akhras, P.J. Freudenthaler, K. Straka, J. Fischer, *Polymers* **15**, 2685 (2023).