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Strain rate effect on the mechanical properties of thermoplastic polyolefin

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Abstract: Modern industries, including those in construction, increasingly uses various types of polymer materials, which should be characterized by good mechanical properties. In this work, the effect of strain rate (10, 20, and 50 mm/min) on the tensile and properties of three polymers (high-density polyethylene (HDPE), polypropylene (PP), and polyvinylchloride (PVC)) was studied. A twin-screw extruder was used for the preparation of samples. In order to study the influence of strain rate, tensile strength was used. Mechanical property results show that the tensile properties, tensile strength, and elastic modulus increased with the increase in the strain rate, while elongation at the break point decreased.

Keywords: polymeric materials, construction materials, mechanical properties, strain rate

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Introduction

Polymer materials are also often used in various economic sectors such as construction. In the construction sector they are used to produce thermal insulation, pipes, windows and doors, cladding, decorative and finishing elements. An important feature of these materials is their easy and cheap production, their malleability,

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high corrosion resistance, and uniform structure. In construction, polymeric materials can also be used as an addition to the production of materials, e.g. cement matrix composites, replacing part of the aggregate (Le et al., 2021; Rahman & Islam, 2012), or as dispersed reinforcement (Elgharbawy & Ali, 2022; Enfedaque et al., 2018; Qiu et al., 2023; Zych & Krasodomski, 2016) and to modify the properties of the aggregate (Spaeth & Tegguer, 2013). Another advantage of polymer materials is their ability to be recycled. Various types of polymer plastic waste are often used in construction, which is consistent with the idea of a closed-loop economy. These materials are used as additives to mortars and concretes (Balaha et al., 2007; Gesoglu et al., 2017; Helbrych, 2019; Jahidul Islam et al., 2016; Khaloo et al., 2008; Pietrzak, 2018; Pietrzak & Ulewicz, 2023).

The industry's interest in polymeric materials is systematically increasing because the physicochemical and mechanical properties of these materials can be easily shaped. Using various types of polymers, it is possible to obtain materials with desired features, such as lightness, ease of processing, and softness. Moreover, products made of polymeric materials are often cheaper compared to other materials. Additionally, the properties of polymers change under the influence of many elements when used in different applications (Deviprasad Varma et al., 2010). Unlike metals and ceramics, polymers show a more noticeable dependence on time and temperature. This is caused by the viscoelastic properties of polymers. Temperature and stress affect the mechanical response of polymers, which can cause the material to behave in ways such as linear elastic behavior, plastic deformation, plasticity, or cold drawing effects. At glass transition temperatures below the ambient temperature, some amorphous polymers may exhibit viscous flow or nonlinear but recoverable deformation (Salih, 2018; Sepe, 2016).

Mechanical properties are generally influenced by many parameters, including: temperature, polarity, pressure, cross-linking, crystallinity, copolymerization, plasticizers and molecular weight. Polymers are additionally sensitive to the loading rate. The ductility of the polymer frequently decreases as the strain rate increases. In contrast, as the loading rate increases, the modulus and yield or tensile strength rises. Polymers are extremely susceptible to the rate of deformation. In general, polymers exhibit a loss in ductility along with an increase in yield strength when the strain rate increases (Jacob et al., 2004; Jaques et al., 2018; Kantesh Balani et al., 2015; Yang et al., 2020). By lowering the temperature, a comparable reaction can be observed. The strain rate increases when the temperature decreases and vice versa. The overall material behavior displays a rigid and brittle reaction because the molecular mobility of the polymer chains is restricted at low temperatures or under high strain rates. Side groups, small molecular groups, or repeated polymer chains may rotate or move translationally as temperatures rise (Eqra & Moghim, 2016; Wellen et al., 2015).

The aim of this work is to study the effect of strain rate change on the tensile properties (tensile strength, elastic modulus, and elongation at break) of three polymers: high density polyethylene (HDPE), polypropylene (PP), and poly(vinyl chloride) (PVC).

1. Materials and methods

1.1. Materials

High-density polyethylene HDPE crystalline polymer, polypropylene PP semi-crystalline polymer, and polyvinylchloride PVC amorphous polymer were used in the preparation of polymeric samples. The physical properties of HDPE, PP, and PVC are shown in Table 1.

Table 1. The physical properties of HDPE, PP PVC (*own research*)

Property	Material		
	HDPE	PP	PVC
Tensile strength [MPa]	27	35-37	20
Elastic modulus [GPa]	0.5-1.2	0.12-0.13	0.1-0.3
Density [kg/m^3]	0.94	0.89-0.90	1.10-1.35
MFR [g/10 min]	0.45	9	12

1.2. Sample preparation

Samples were prepared using 100 g of PP, PVC and HDPE granules. Before the extrusion process, the polymeric pellets were dried in an oven with a vacuum at a temperature of 50-60°C to remove any moisture from the material. The samples were then extruded using twin-screw extruders. At the end of the extrusion, the melt passes through a die in the form of a sheet. The extruder operational conditions were 25 rpm in the beginning, then increased to 50 rpm. The preparation temperatures for PP samples, PVC samples, and HDPE samples for zones 1 and 2 were 165-175°C, 170-180°C, and 200-210°C, respectively. Once the material was melted out of the extruder, it was forced through two co-rotating rollers to give it a high molecular orientation and remove any voids. The samples were cut according to the required shapes by using a laser CNC machine on a Chinese device. Cutting was done according to international standard specifications (ASTM).

1.3. Characterization – tensile test

The tensile test on the specimens (HDPE, PP, and PVC) was carried out using a universal testing machine (WDW-5E machine) according to ASTM D 638 at a strain rate of 10, 20, and 50 mm/min for all the samples at room temperature. For each sample, three samples were tested, and the mean values were considered.

2. Results and discussion

2.1. Tensile properties

Figure 1 shows the effect of different strain rates on the tensile strength of HDPE, PP, and PVC. It was found that the tensile strength increases as the strain rate increases. For HDPE, it was found that the tensile strength is 16 MPa, and it increases with the increase in speed from 10 to 50 mm/min. The tensile strength increases by 11 and 6 MPa with the increase in strain rate from 10 to 50 mm/min. For PP, it was found that it has a 16 MPa tensile strength, and it increases by 9 and 7 MPa with the increase in strain rate from 10 to 50 mm/min. While for PVC it was found it has 12.4 MPa tensile strength and it increases by 3.9 and 1.6 MPa with the increase in strain rate from 10 to 50 mm/min. These behaviors occur because, as the strain rate increases, the chains in polymers do not have enough time to align themselves in the force direction, so the material breaks. These results are in agreement with (Plöckl, 2019; Richeton et al., 2006) because these authors showed that the behavior of material changes with the strain rate change, and the rate of change is affected by the polymeric material type, whether it is amorphous, semi-crystalline, or crystalline. They showed that PMMA, PC, and PS are much more highly affected by the change in strain rate than PA6.

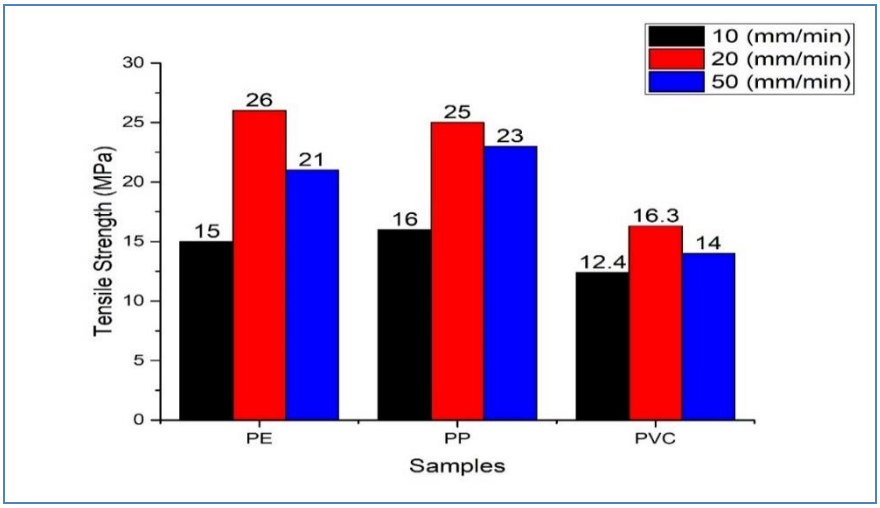

Fig. 1. Tensile strength of HDPE, PP, and PVC at different strain rate (*own research*)

Figure 2 shows the effect of different strain rates on the elastic modulus of HDPE, PP, and PVC. It was found that the elastic modulus increases as the strain rate increases. For HDPE, it was found that the elastic modulus is 0.5 GPa, and it increases with the increase in speed from 10 to 50 mm/min. The elastic modulus increases by 0.19 and 0.11 GPa with the increase in strain rate from 10 to 50.

For PP, it was found that it has a 0.36 GPa elastic modulus, and it increases by 0.49 and 0.1 GPa with the increase in strain rate from 10 to 50 mm/min. While for PVC, it was found that it has a 0.128 GPa elastic modulus and increases by 0.182 and 0.192 GPa with the increase in strain rate from 10 to 50 mm/min. These behaviors occur because, as the strain rate increases, the material behavior changes from ductile to brittle, causing an increase in the elastic modulus. These results are in agreement with (Lamri, 2020). Lamri (2020) who showed that the elastic modulus of HDPE is strongly affected by the strain rate, and as mentioned earlier in the above results of tensile behavior, the material behavior changes from ductile to brittle.

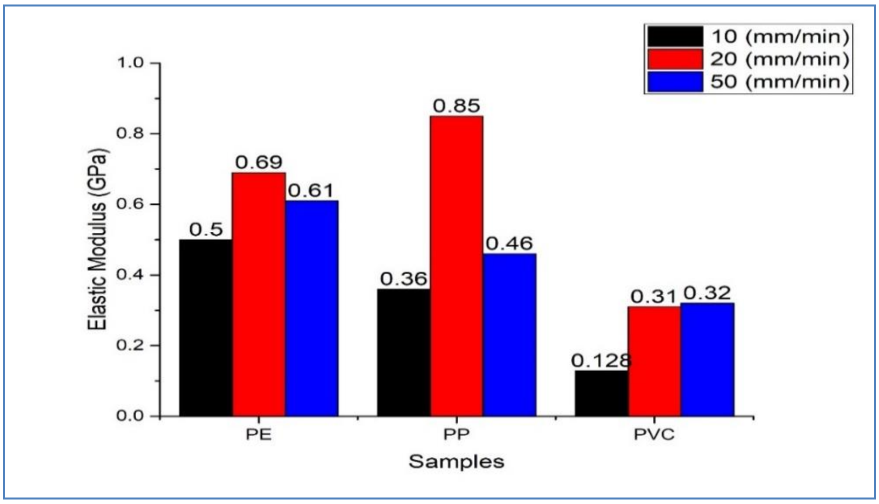

Fig. 2. Elastic modulus of HDPE, PP, and PVC at different strain rates (*own research*)

Figure 3 shows the effect of different strain rates on the elongation at the break point of HDPE, PP, and PVC. It was found that the elongation at the break decreases as the strain rate increases. For HDPE, it was found that elongation at the break point was 37.5% and decreases with the increase in speed from 10 to 50; the elongation at the break decreases by 5%; and the strain rate increases from 10 to 50. For PP, it was found that it has a 16.5% elongation at the break point, and it decreases by 0.5 and 7% with the increase in strain rate from 10 to 50. While for PVC, it was found it has a 362% elongation at the break pont and it decreases by 78.5 and 168% with the increase in strain rate from 10 to 50 mm/min. These behaviors occur because, as the strain rate increases, the material behaves as a rigid material, resulting in lower elongation than a flexible material. These results are in agreement with (Jacob et al., 2004). These authors showed that the strain rate changes affect the mechanical properties of polymeric composites, and they found that the elongation at the break point for the composites was lower than that for pure polymers, and decreased further as the strain rate increased, which was attributed to the restriction of chain movement as the fillers were added to the polymeric material.

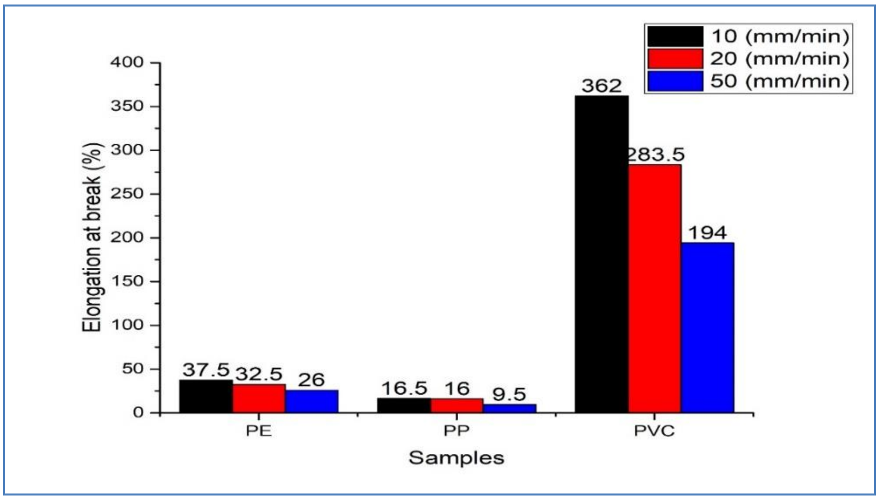

Fig. 3. The elongation at the break point of HDPE, PP, and PVC at different strain rates (*own research*)

Conclusions

Polymer materials are an alternative to natural materials such as wood, stone, glass or metal. Currently, these materials are one of the most frequently used construction materials in almost every industry, including construction. From the obtained results, the following conclusions can be summarized:

1. Both tensile strength and the elastic modulus of tested polymers (HDPE, PP and PVC) increased as the strain rate increased, and it was found that the best value was achieved at a strain rate of 20 mm/min for all samples.
2. The elongation at the break point decreased as the strain rate increased from 10 to 50 mm/min. This is due to the change in material behaviour as the strain rate increased.

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