# MECHANICAL CHARACTERISTICS OF POLYMERS
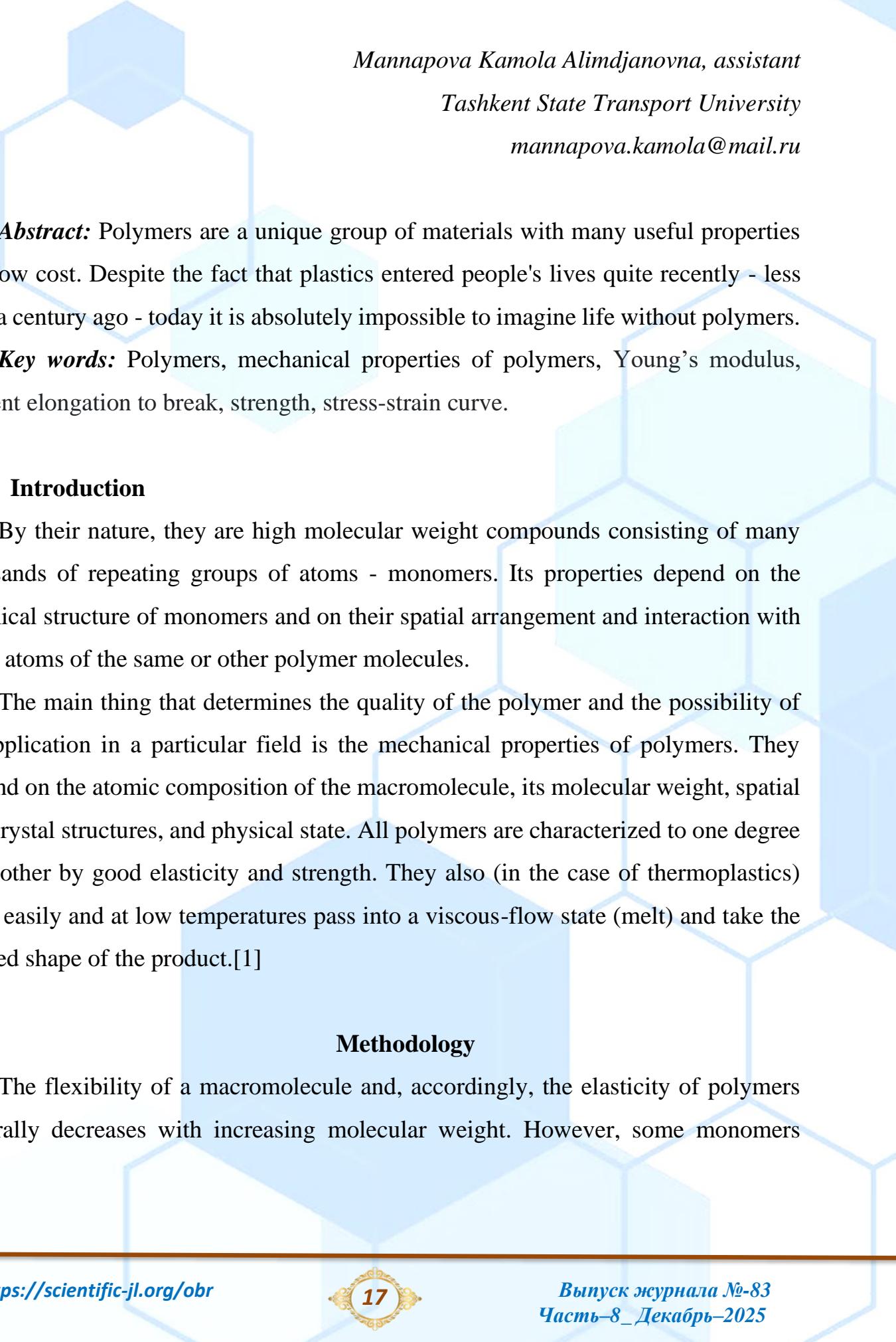
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***Abstract:*** Polymers are a unique group of materials with many useful properties at a low cost. Despite the fact that plastics entered people's lives quite recently - less than a century ago - today it is absolutely impossible to imagine life without polymers.

***Key words:*** Polymers, mechanical properties of polymers, Young's modulus, percent elongation to break, strength, stress-strain curve.

## Introduction

By their nature, they are high molecular weight compounds consisting of many thousands of repeating groups of atoms - monomers. Its properties depend on the chemical structure of monomers and on their spatial arrangement and interaction with other atoms of the same or other polymer molecules.

The main thing that determines the quality of the polymer and the possibility of its application in a particular field is the mechanical properties of polymers. They depend on the atomic composition of the macromolecule, its molecular weight, spatial and crystal structures, and physical state. All polymers are characterized to one degree or another by good elasticity and strength. They also (in the case of thermoplastics) quite easily and at low temperatures pass into a viscous-flow state (melt) and take the desired shape of the product.[1]

## Methodology

The flexibility of a macromolecule and, accordingly, the elasticity of polymers generally decreases with increasing molecular weight. However, some monomers

increase the elasticity, such as, for example, diene hydrocarbons. In the case of their introduction into the polymer matrix of any polymer, the elasticity, as a rule, increases.

Polymers have a special state of matter - highly elastic. In the case of thermosetting plastics, their molecules are able to form crosslinked structures at the elementary level, which are not capable of re-melting and processing.[2]

The strength properties of polymers increase with an increase in molecular weight, and, moreover, during crosslinking - first obtaining branched macromolecules, and then three-dimensional structures. Crystalline polymers are more durable than amorphous ones, even if they are chemically identical. Thus, the tensile strength at break of crystalline polyethylene is one and a half to two orders of magnitude higher than the strength of amorphous polyethylene.

The strength calculated on the basis of the area of high-molecular-weight compounds of high crystallinity is not very different from that of steel, and when calculated per unit mass, it is higher. Stereoregular polymers have better strength characteristics than disordered ones.

In general, the mechanical properties of polymers can be characterized in very much the same way as in the case of metals or other standard crystalline materials, in particular through the moduli of elasticity and various other classes of strength measurements, such as the yield and tensile strengths. We provide below a general summary of the most important mechanical and elastic properties of polymeric materials:[3]

1. **Strength**: represents the stress force necessary to fracture the material sample under consideration, whenever the applied force is stronger than a simple linear elastic deformation. Some of the most relevant types of strength quantities involved in typical materials characterization measurements comprise the tensile strength (stretching of the polymer), compressional strength (compressing the polymer), flexural strength (bending of the polymer), torsional strength (twisting of the polymer), and impact strength (e.g. under the effects of direct hammering).

2. **Percent Elongation to Break** (Ultimate Elongation): this quantity indicates the maximum strain that the polymer sample can attain before it ultimately fractures (at the above-mentioned strength point), as measured in terms of percentage change in the length of the material.

3. **Young's Modulus:** the ratio of stress to the strain in the linearly elastic response region of the material, thus effectively providing a measure of its overall stiffness.

## Results

Some physical factors which affect the strength and overall mechanical properties of semicrystalline polymers include the following considerations:

• The tensile strength of the polymer rises with increase in **molecular weight**. This correlation can be understood through the following reasoning: at low values of the molecular weight, the polymer chains are loosely tied together by weak intermolecular van der Waals interactions (thus resulting in low strength), whereas for the case of polymers with large molecular weights, the chains become bulky and consequently entangled together, producing high strength values for the polymer.

• The presence of a **cross-linked morphology** within the polymer structure inhibits the relative motion of the chains, and this results in a strengthening of the polymer.

• The strength of the polymer also increases with its **degree of crystallinity**, since crystalline phases are typically characterized by stronger intermolecular interactions.[5]

The overall mechanical characteristics of most polymer materials are embodied in the standard **stress-strain curve,** the simplest way to visualize the response of a general material under the effects of stress-induced mechanical deformation and loading. Such mechanical response properties are in general sensitive towards numerous external factors, such as the rate of deformation (the so-called **strain-rate**),

the temperature of the sample, and even on the presence of additional chemical products affecting the environment, such as water or organic solvents.

The mechanical behaviour of different classes of polymers is demonstrated in the below image, in the form of distinct stress-strain curves. It can be seen that there are essentially three different such classes of stress-strain behaviour within the world of polymers.
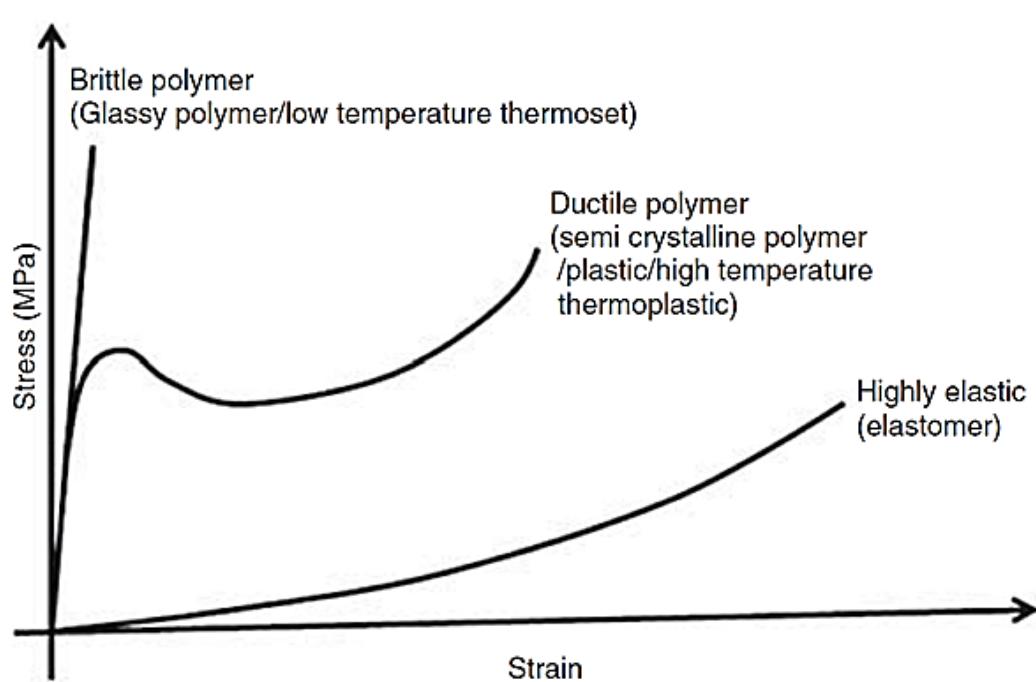


Fig 1. Stress–strain behavior of different types of materials. [1]

From the above image, we deduce that rigid materials such as **brittle polymers** have high Young's modulus, but at the same time will undergo fracture when subject to stress and associated elastic compression much earlier (in terms of total elongation strain) than the other classes of polymer materials, as denoted by the end of their corresponding stress-strain curves. At the other extreme, we find the mechanical behaviour of a highly elastic and rubbery class of polymers known as **elastomers**, that have both low values of the Young's modulus and are capable of enduring large amounts of recoverable stretching, before ultimately breaking.[6]

**Discussion**

For the intermediate case of **ductile (plastic) polymers** shown above, the distinction between elastic deformation (the initial linear part of the curve) and plastic flow (everything that follows) mechanical behaviours of the material is particularly striking. The stress point separating these two behavioural regimes is known as the **yield strength** or **elastic limit $\sigma_y$** of the material. As mentioned previously, as the external stress load and associated sample strain are progressively increased even further, any material will ultimately reach also its **tensile strength (TS)**, at which point the total fracturing and breaking of the material occurs, and thus it no longer makes sense to continue plotting its stress-strain curve. The position of these two limiting behaviours are depicted in the image below.
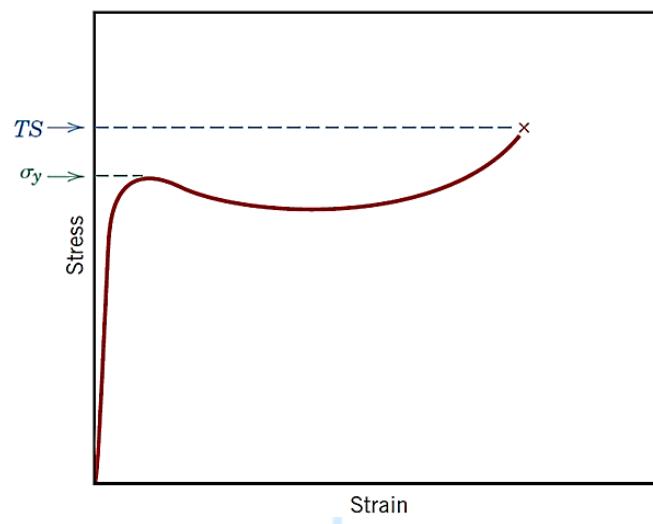


Fig 2. Schematic stress–strain curve for a plastic polymer showing how yield and tensile strengths are determined. [1]

In order to get a reasonable conviction we used X-ray fluorescence analysis (XRF analysis) for a more detailed analysis of the structure of soot (Fig. 3). As seen in fig. 5, such elements as Kr, Nb, Ru, In and In, Cs and Cs are distinguished; moreover, in quantitative terms, all these elements taken together do not exceed 0.1% of the total carbon black composition and are apparently consistent with the factory data of the filler. Secondly, we used integrated research (IR) spectroscopy ("Specord 75 IR") to determine elements such as Fe, Ni, Co, Mn, Mg in the studied objects [3]. We were not

able to obtain good IR spectra for pure soot, which is apparently due to the strong absorption of infrared rays by soot particles. However, in the IR spectra of the PS+soot (0.01), as shown by the results of studies in the wavelength range from 400 cm-1 to 4000 cm-1 , there are no characteristic absorption bands of Fe, Ni, Co, Mn, Mg or compounds on their basis. The facts established by IR and X-ray fluorescence analysis stubbornly deny the possibility of the origin of such a wide electron paramagnetic resonance (EPR) signal from elements of Fe, Ni, Co, Mn, Mg.[7]

## Conclusion
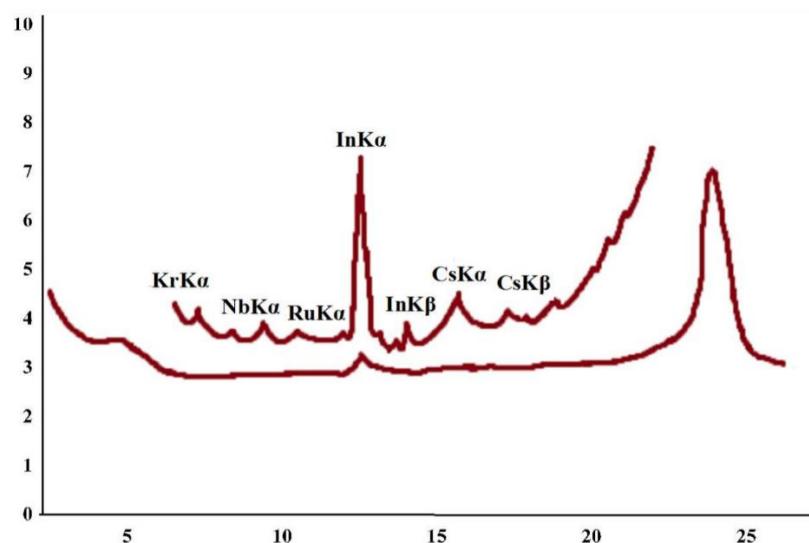


Fig.3. X-ray fluorescence analysis of the structure of soot

An overview of the mechanical properties of a selection of important polymer materials is offered in the table below:

| Material | Specific Gravity | Tensile Modulus [GPa (ksi)] | Tensile Strength [MPa (ksi)] | Yield Strength [MPa (ksi)] | Elongation at Break (%) |
|---|---|---|---|---|---|
| Polyethylene (low density) | 0.917–0.932 | 0.17–0.28 (25–41) | 8.3–31.4 (1.2–4.55) | 9.0–14.5 (1.3–2.1) | 100–650 |
| Polyethylene (high density) | 0.952–0.965 | 1.06–1.09 (155–158) | 22.1–31.0 (3.2–4.5) | 26.2–33.1 (3.8–4.8) | 10–1200 |
| Poly(vinyl chloride) | 1.30–1.58 | 2.4–4.1 (350–600) | 40.7–51.7 (5.9–7.5) | 40.7–44.8 (5.9–6.5) | 40–80 |
| Polytetrafluoroethylene | 2.14–2.20 | 0.40–0.55 (58–80) | 20.7–34.5 (3.0–5.0) | — | 200–400 |
| Polypropylene | 0.90–0.91 | 1.14–1.55 (165–225) | 31–41.4 (4.5–6.0) | 31.0–37.2 (4.5–5.4) | 100–600 |
| Polystyrene | 1.04–1.05 | 2.28–3.28 (330–475) | 35.9–51.7 (5.2–7.5) | — | 1.2–2.5 |
| Poly(methyl methacrylate) | 1.17–1.20 | 2.24–3.24 (325–470) | 48.3–72.4 (7.0–10.5) | 53.8–73.1 (7.8–10.6) | 2.0–5.5 |
| Phenol-formaldehyde | 1.24–1.32 | 2.76–4.83 (400–700) | 34.5–62.1 (5.0–9.0) | — | 1.5–2.0 |
| Nylon 6,6 | 1.13–1.15 | 1.58–3.80 (230–550) | 75.9–94.5 (11.0–13.7) | 44.8–82.8 (6.5–12) | 15–300 |
| Polyester (PET) | 1.29–1.40 | 2.8–4.1 (400–600) | 48.3–72.4 (7.0–10.5) | 59.3 (8.6) | 30–300 |
| Polycarbonate | 1.20 | 2.38 (345) | 62.8–72.4 (9.1–10.5) | 62.1 (9.0) | 110–150 |

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