Experimental Determination and Comparison of Some Mechanical Properties of Commercial Polymers

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In the recent years the utilization of polymeric materials increased due to their good mechanical properties and easy manufacturing. Starting from automotive industry up to food industry polymeric materials are used for obtaining components by molding or by machining. Taking into account the wide range of applications, it is important to know the mechanical behaviour of these materials in different loading conditions. Accordingly, this paper presents an experimental study to determine mechanical properties on 11 commercial polymeric materials. Tensile and shear static tests and impact tests on notched and un-notched specimens were performed. The results are presented comparatively, and two new parameters were introduced for material selection purpose.

Keywords: mechanical testing, polymer materials, tensile strength, shear strength, impact strength

Generally the polymeric materials belonging to the categories of polyamides, polyoxymethylene, acetals, polyurethanes are characterized by high stiffens and wear resistance, high compression strength, good machining, resistance at wide range of solvents, very low absorption of humidity which assure a very good dimensional stability, [1]. These characteristics make polymeric materials compatibles for a wide range of applications in different industrial domains like: plain bearing, gearwheels (fig. 1), sliding ledges, plugs and connection blocks (fig. 2), insulators, rollers, housing parts, clock gearing, cams, seals, different fixtures, stamping tools and others.

Taking into account the great number of application for these materials it is necessary to know the mechanical characteristics for different type of loads (tensile, compression, shear, bending) and loading conditions (static, impact, fatigue). Unfortunately, the material data sheets edited by the manufacturers are lacking in providing reliable values for material properties, and the data differ from producer to producer. For example for some materials it could be found the impact strength for notched specimens, for other the impact strength for un-notched specimens, while for others these values are missing. On the other hand the polymeric materials have different chemical compositions and are produced in different conditions. So, in order to compare the mechanical characteristics of such materials it is necessary to determine the properties experimentally in the same testing conditions, [2, 3]. In some cases combined loads appear in many applications of polymer materials, and this could make difficult the material selection for a particular application, [4-6].

In recent years a series of studies were published regarding the mechanical behaviour of different type of polymeric materials in different loading conditions, like tensile tests of some polymers [7], assemblies of polymers [8], or tensile, compression and bending tests of polyurethane foams [9, 10].

Starting from these observations an experimental program was performed on mechanical properties of 11 different polymers. Tensile, shear and impact tests on notched and un-notched specimens were performed. The authors introduced two new parameters: the ratio between shear strength and tensile strength, and the ratio between impact strength for notched and un-notched specimens, useful for the material selection.

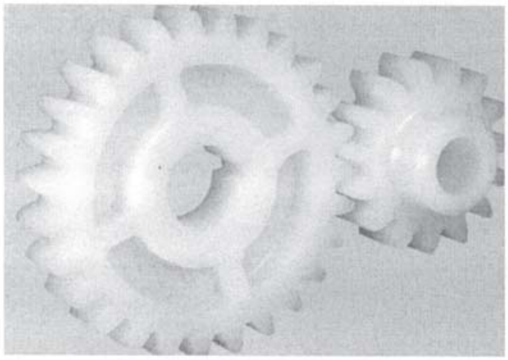

Fig. 1. Gear wheels (Material POM C)

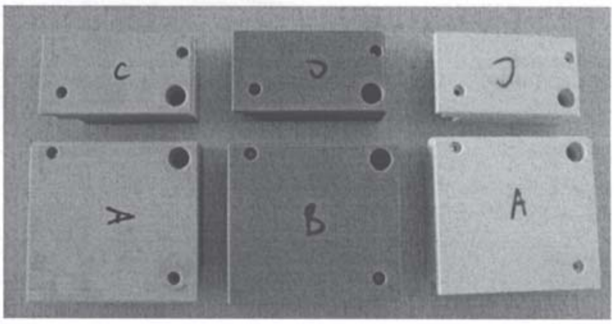

Fig. 2. Connector blocks (material RAKU TOOL 1404, SIKA M940 and RIM 624)

Materials and testing methodology

The experimental program consists on static tensile test and shear test on blocks, respectively impact tests on notched and un-notched specimens and was applied to 11 different types of commercial polymer materials: acetals (POM-C, POM-H), polyurethanes (LAB 920, LAB 1001, NECURON 1020, NECURON 1300, RAKU TOOL 1222, RAKU TOOL 1404, SIKA M940), urethanes (RIM 624) and polypropylene (PP-H). All tests were performed at room

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temperature, in the Strength of Materials Laboratory from Politehnica University of Timisoara.

Tensile tests

Tensile tests were carried out on a Zwick/Roell ProLine 5 kN testing machine, (fig. 3). A MFA25 extensometer was used for determining the Young's modulus. The tests were performed according to European Norms EN ISO 527-1 [11] and EN ISO 527-1 [12] on specimens with the shape and dimensions from figure 4. Loading speed was 2 mm/min for all tests. For each material a number of 8 specimens were tested.

During the tensile tests the load-displacement curves were obtained, figure 5 and based on the recorded data the mechanical characteristics: Young's modulus and tensile strength were determined. According with [11] the tensile strength or failure stress of the specimen was calculated:

$$\sigma_f = \frac{F_{\max}}{A_0}, \quad [MPa] \tag{1}$$

where

F_{max} is the maximum measured force in [N],

A_0 - the initial cross-sectional area of the specimen (product of width and thickness of specimen) in [mm^2].

Calculation of modulus of elasticity is based on two specified strain values ε_1 and ε_2:

$$E_t = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1}, \quad [MPa] \tag{2}$$

with σ_1 the stress in [MPa] measured at the strain value $\varepsilon_1 = 0.0005$, and σ_2 the stress in [MPa] measured at the strain value $\varepsilon_2 = 0.0025$.

Figure 5 presents the load – displacement curves from tensile tests for each of the 11 materials. Large differences between the investigated materials could be seen. We observed a brittle behaviour for polyurethane materials LAB 920, LAB 1001, NECURON 1020, NECURON 1300, and elasto-plastic behaviour of acetals POM-H and POM-C and a plastic behaviour for RAKU TOOL 1222, RAKU TOOL 1404 and polypropylene PP-H (for which the strains at fracture are higher than 100%). For PP-H material the tensile characteristic shows a linear part, a yielding part characterized by a maximum, which could be considered maximum yield stress, followed by a small softening part and a hardening region up to the breaking load.

Fig. 3. Zwick/Roell ProLine 5 kN testing machine

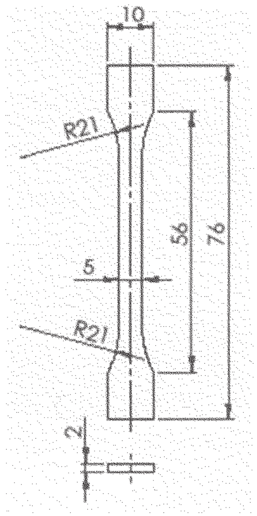

Fig. 4. Specimen for tensile tests

Shear tests

The shear tests were performed on a Walter+bai 100 kN hydraulic testing machine, using a special testing device designed for the plastic blocks, shown in figure 6. A 2 mm/min test speed was used for all experiments. According to ASTM D 732-02 [13] standard the shear strength:

$$\tau_f = \frac{F_{\max}}{A_f}, \quad [MPa] \tag{3}$$

where F_{max} [MPa] represents the maximum load required to shear the specimen and A_f [mm^2] is the area of the sheared edges, which is product of the specimen thickness by the shear contour. Four blocks were tested from each material.

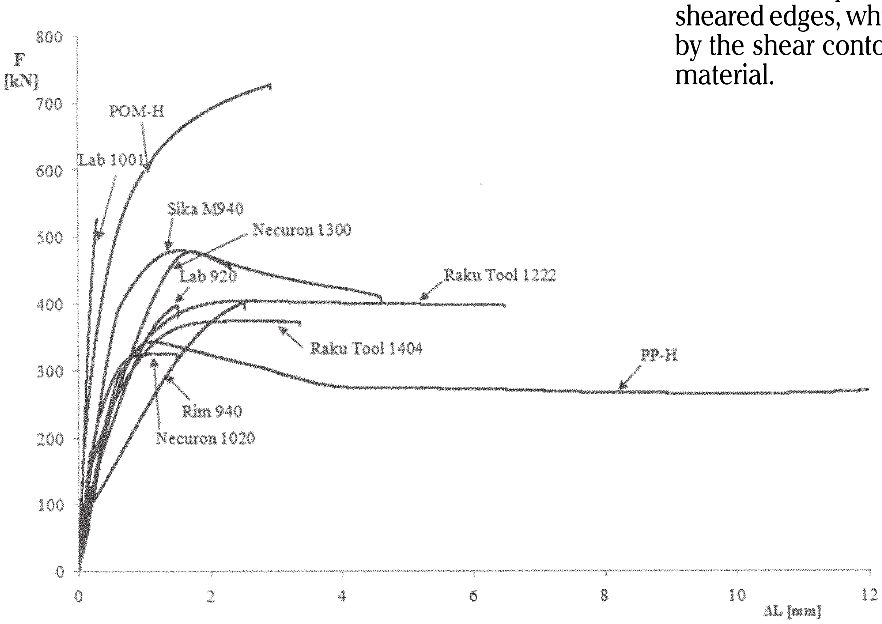

Fig. 5. Characteristic Load – Displacement diagrams recorded during tensile tests

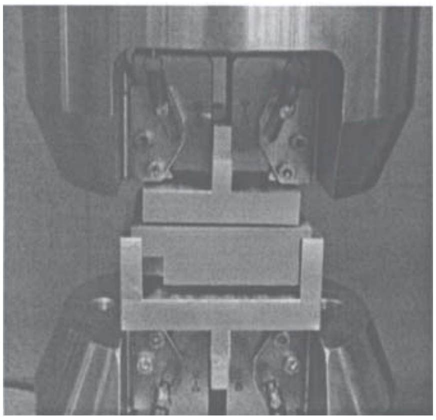

Fig. 6. Shear test fixtures and specimen

Imact tests

Impact tests were performed on notched specimens, fig. 8 and on un-notched specimens using a Charpy hammer, model Leipzig 5 kgf m with the following characteristics: mass m = 6.784 kg, length l=0.38 m. According to standard EN ISO 197-1, [14] the energy absorbed by breaking the test specimen was determined measuring the initial b and final a angles of the hammer:

$$W = W_1 - W_2 = G(h_1 - h_2) = mgl(\cos\beta - \cos\alpha), [J] \tag{4}$$

where W_1 represents the initial potential energy of the hammer in [J], W_2 is the final potential energy in [J], and g the gravitational acceleration [m/s^2].

Based on energy value the impact strength of notched specimens was calculated:

$$a_{cN} = \frac{W}{h \cdot b_N} 1000, \left[kJ/m^2\right] \tag{5}$$

h *is* the thickness of the specimen [mm] and b_N the remaining width of the specimen in the notched section [mm].

For the un-notched specimen the impact strength was:

$$a_{cU} = \frac{W}{h \cdot b} 1000, \left[kJ/m^2\right] \tag{6}$$

where h is the thickness of the specimen [mm] and b the width of the specimen [mm].

For each material a number of 10 specimens were tested.

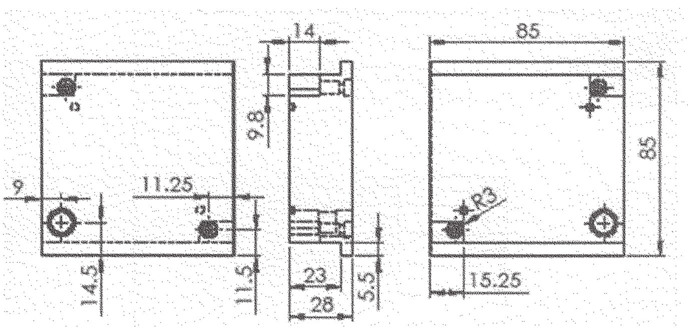

Fig. 7. Connecting block specimen used for shear tests

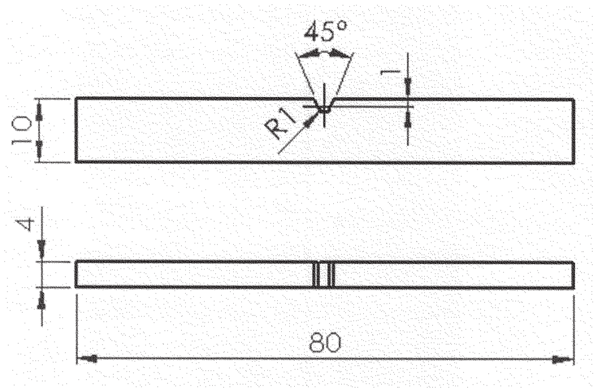

Fig. 8. Notched impact specimen

Experimental results

Figures 9 to 13 present comparatively the obtained mechanical characteristics for the 11 commercial polymer materials.

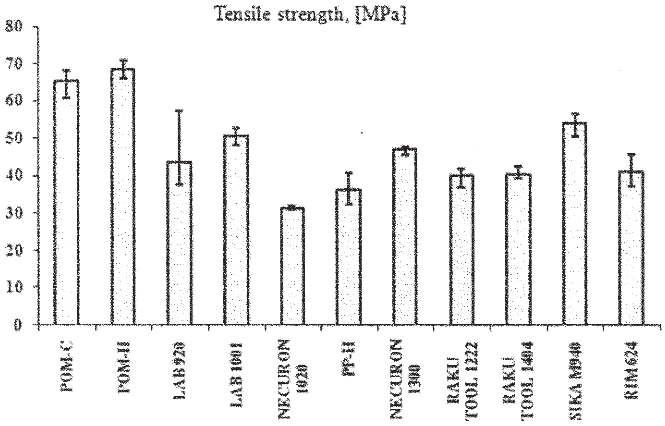

Fig. 9 .Tensile strength, σ_r in [MPa]

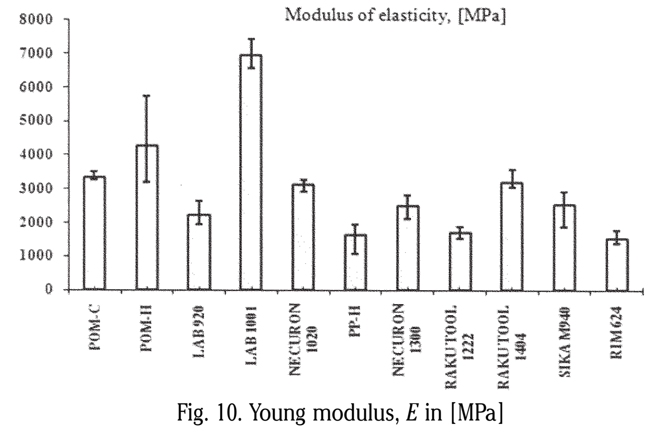

Fig. 10. Young modulus, E in [MPa]

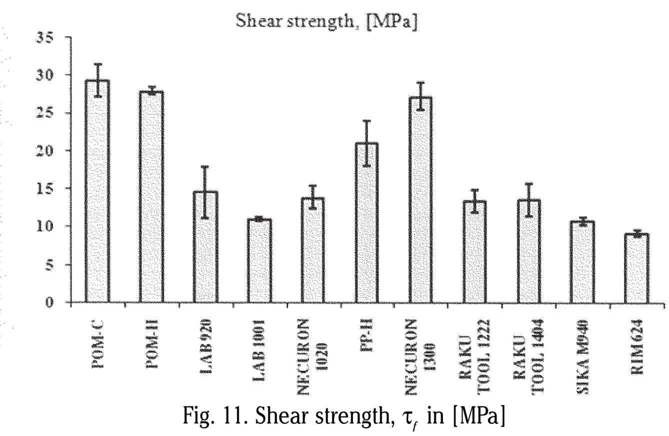

Fig. 11. Shear strength, τ_r in [MPa]

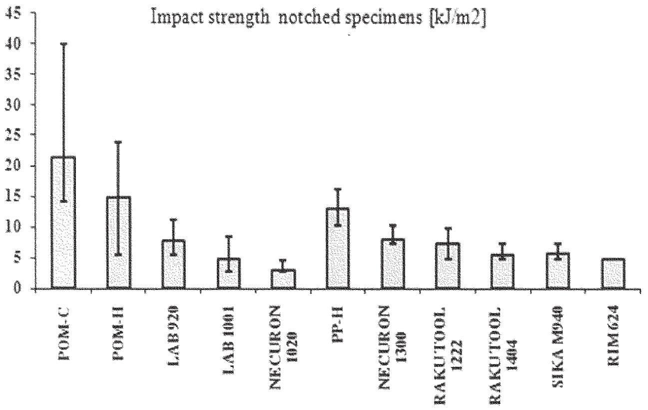

Fig. 12. Impact strength on notched specimens, a_{cN}

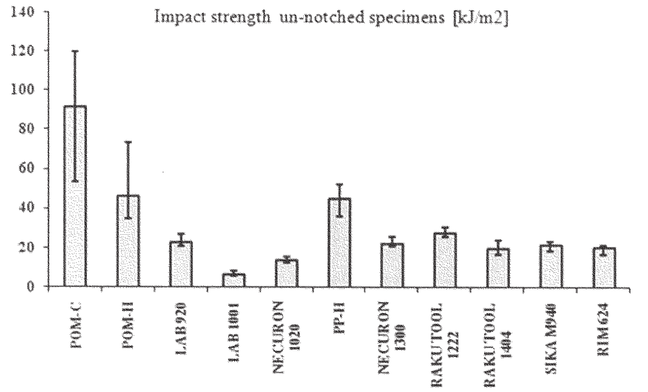

Fig. 13. Impact strength on un-notched specimens, a_{cU}

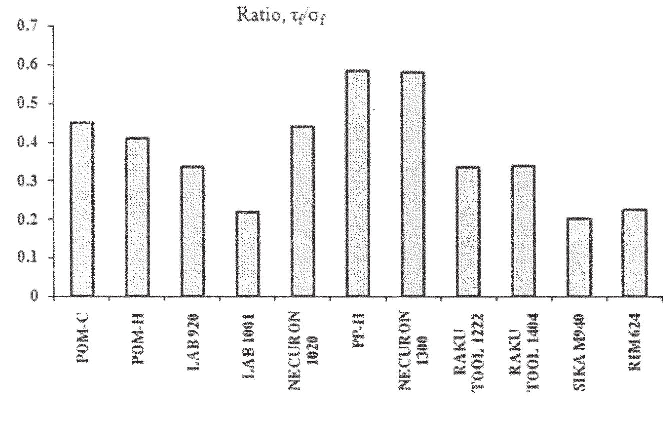

Fig. 14. Comparison of the strength ratio τ_f/σ_t

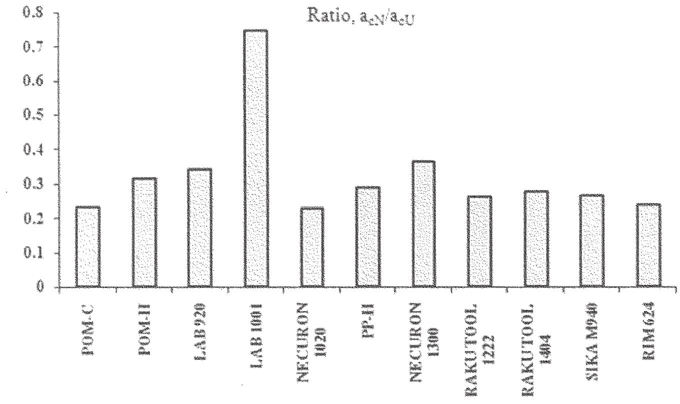

Fig. 15. Comparison of the impact strength ratio a_{cN}/a_{cU}

Form figure 9 it can be observed that the higher tensile strength was obtained for materials POM-H (68.5 MPa) and POM-C (65.2 MPa) the lower value of NECURON 1020 (31.5 MPa). The Young's modulus values are in the range 1600 MPa for RIM 624 to 6940 MPa for LAB 1001, (fig. 10). For the shear test maximum values of shear strength were obtained for POM-C (29.4 MPa), POM-H (28 MPa), but also for NECURON 1300 (27.3 MPa) and the minimum values for SIKA M940 (11 MPa), respectively RIM 624 (9.2 MPa), (fig.) 11. The maximum impact strength was obtained for POM-C for both types of specimens notched (21.3 kJ/m^2) and un-notched (92 kJ/m^2), (fig.12). The minimum values of the impact strength using un-notched specimens was obtained for LAB1001 material (6.4 kJ/m^2), respectively for NECURON 1020 material (3.1 kJ/m^2) with notched specimens, figures13 and 14 presents comparatively the ratio between shear strength and tensile strength (τ_f/σ_f), which could be used as a design parameter for combined stresses. The effect of notch on impact tests was also highlighted using the ratio between impact strength for notched specimens and impact strength for un-notched specimens (a_{cN}/a_{cU}), (fig. 15). A unity value for the ratio a_{cN}/a_{cU} indicates that the presence of notch has no effect on the impact strength. Decreasing the ratio a_{cN}/a_{cU} from unity indicates the increasing influence of the notch on impact strength.

Conclusions

This paper presents an experimental study on the mechanical characteristics of 11 commercial polymer materials. The results of the tensile, shear and impact strength of the materials allows comparing the polymeric materials. Acetals (POM-C, POM-H) have the higher values for all mechanical properties. Materials from polyurethane class (LAB 920, LAB 1001, NECURON 1020, NECURON 1300, RAKU TOOL 1222, RAKU TOOL 1404, SIKA M940) have medium to low values for shear strength and impact strength. Urethane (RIM 624) has low values for shear strength and impact strength, while polypropylene (PP-H) has medium value for tensile and shear strength and good impact strength.

The two ratios defined between static and impact properties allow drawing some important conclusions for materials selection. For example material LAB 1001 has a brittle behaviour: high tensile strength, high moduli of elasticity, but small shear strength, consequently ratio (τ_f/σ_f)= 0.219 is relatively small recommending this material for applications where predominantly is the tensile load. In the same time the impact strength ratio a_{cN}/a_{cU} = 0.74 indicating that the presence of notches at impact loading has a small effect. From figure 14 it can be observed that materials PP-H and NECURON 1300 have a high shear strength comparing with their tensile strength being suitable for applications with predominantly shear loads. For POM-C, NECURON 1020 and RIM 624 materials the presence of notch decreases considerably, with approximately 80%, the impact strength. So it should be avoided using parts or components with notches made by these materials and the loads are applied by impact. The investigations need to be extended in order to appreciate the effect of loading speed and, temperature on mechanical properties of polymers.

The subject was also studied by other different researchers [15-17].

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