TENSILE TESTING FOR DIFFERENT TYPES OF POLYMERS

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Jelena Milisavljevic-Syed
University of Liverpool

Emina Petrovic
University of Niš

Ivan Ćirić
University of Niš

Marko Mančić
University of Niš

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Jelena Milisavljević[1], Emina Petrović[1], Ivan Ćirić[1], Marko Mančić[1], Dušan Marković[1], Milan Đorđević[2]

[1]University of Niš, Faculty of Mechanical Engineering, A. Medvedeva 14, 18000 Niš, Serbia

[2]Univesity of Pristina, Faculty of Technical Sciences in Kosovska Mitrovica, Kneza Miloša 7, 38220 Kosovska Mitrovica

Corresponding author: jelena.milisavljevic@masfak.ni.ac.rs

1. Introduction

The applicability and service time of polymer details working in various media are limited by the degradation of their physical and mechanical properties. From the structural point of view the weakest places strongly affected by ageing are the surface and boundary regions of the crystallites.

If a material is subjected to high-strain deformation, it deforms permanently (plastic deformation) and ultimately fails. For sufficiently low stresses and strains, the polymeric material behaves as a linear elastic solid. The point where the behaviour starts to be non-linear is called the proportional limit. The local maximum in the stress-strain curve is called the yield point and indicates the permanent deformation. The corresponding stress and elongation are called yield strength and elongation at yield. Beyond the yield point the material stretches out considerably and this region is called the plastic region. Further elongation leads to strain hardening and the ultimate rupture of the material. At the rupture point the corresponding stress and strain are called the ultimate strength and the elongation at break. The stress-strain behaviour of a polymeric material depends on various parameters such as molecular characteristics, microstructure, strain-rate and temperature.

High-strain behaviour and failure for different kinds of polymers is described in this paper. Furthermore, the physical ageing of glassy polymers, due to the heat effect on the mechanical properties, is also described.

Composite materials, as polymers, are being tested due to its favourable characteristics which can be used in wind turbine blade technology to enable the development of longer blades that are lighter, more structurally and aerodynamically efficient, and impart reduced loads to the system, in the near future.

2. Tensile testing and the formation of the isochronous curves

Deviation from linearity begins at strains 0.001 to 0.01. However, at higher strains (0.01 to 0.1) the deviation becomes large that:

$$\frac{d\sigma}{d\varepsilon} = 0 \qquad (1)$$

Polystyrene has plastic fracture before yielding or polyethylene which fractures immediately after others and it can reach strains, as high as 25 mm/min, before final failure.

It is difficult to make a distinction between recoverable (elastic) and unrecoverable (plastic) strain, because the extent to which a polymer recovers its original dimensions depends upon temperature and upon time allowed for recovery (entropic).

Fig. 1 compares stress-strain characteristics for low density polyethylene (LDPE), high density polyethylene (HDPE), Polystyrene (PS), Nylon, Polycarbonate (PC), Polypropylene (PP), and Polymethyl-methacrylate (PMMA).

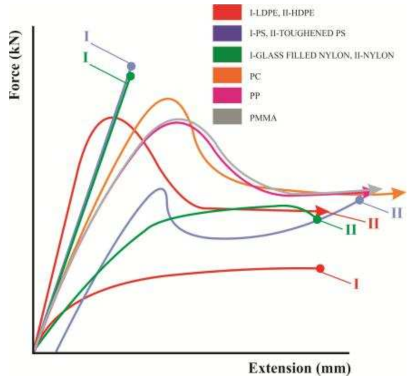

Fig. 1: Stress-strain curves for different kinds of polymers, to extension rate of 26 mm/min

	LDPE	HDPE	Toughened PS	PS
Limit of proportionality (MPa)	5	15	20	40
Maximum strength (MPa)	10	25	30	40
Elongation (%)	40	>100	10	0

Tab. 1: Comparison of characteristics for different types of polymers

	PA	Glass Filled PA	PC	PP	PMMA
Limit of proportionality (MPa)	60	125	35	20	70
Maximum strength (MPa)	70	125	65	30	70
Elongation (%)	20	0	>50	>100	0

Tab. 2: Comparison of characteristics for different types of polymers

3. Comparison to experimental results for different types of polymers

Long-term exposures of various industrial structural materials at sufficiently elevated temperatures cause substantial changes in materials structures and, consequently, substantial changes in their physical and materials properties, Fig. 2.

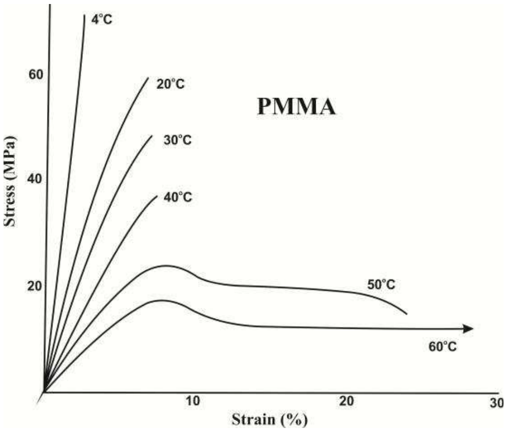

Fig. 2: The effect of heat on the mechanical properties of glassy polymers (T. S. Carswell and H. K. Nason, Symposium on Plastics, American Society for Testing Materials, Philadelphia, 1944)

Two types of polymers are used while conducting the experiment. Polystyrene is a glassy, brittle polymer with low toughness and a softening temperature of only 100°C. The brittle characteristics of polystyrene can be relieved by the incorporation of around 5% butadiene rubber into the microstructure. The rubber exists as second-phase particles of approximately 1 mm diameter and this increase the toughness of polystyrene by an order of magnitude. This type of polymer is used because its advantage over other polymers, or the ease with which it can be processed by extrusion, injection and vacuum forming. The second and perhaps the simplest polymer used is Polyethylene, with composed chains of repeating –CH2– units. Catalyzed by organometallic compounds at moderate pressure (15 to 30 atm), the product of high density polyethylene, HDPE is used. Under these conditions, the polymer chains grow to very great length, and molar masses average many hundred thousand. HDPE is hard, tough, and resilient. Most HDPE is used in the manufacture of containers, such as milk bottles and laundry detergent jugs.

Various types of deviations from ideal behavior are observed, once strains (1% - 2%) are reached. The strain

$$\varepsilon = \frac{L - L_i}{L_i} = \lambda - 1 \tag{2}$$

where L_i is the initial length, L is the length at which point the force is F and λ is the extension ratio.

The nominal stress

$$\sigma = \frac{F}{A_i} \tag{3}$$

where A_i is the initial area of the cross-section.

It can be seen at Fig. 3, from 0 to point A, the PE behaves as a linear elastic solid. At this region the Young`s module $E = \sigma / \varepsilon$. Point B is called the yield point and indicates the onset of plastic deformation. From B to C it is the plastic region. Beyond B the material stretches out considerably and a “neck” is formed.

The neck stabilizes and begins to extend by drawing fresh materials from the tapering regions on either side until the whole of the parallel section of the specimen has yield. Then during the alignment and orientation of the polymer chains, which is called strain hardening, the neck will continue to thin down until it breaks. The point C is the break point, at which point the corresponding stress and strain are called the ultimate strength and the elongation at break.

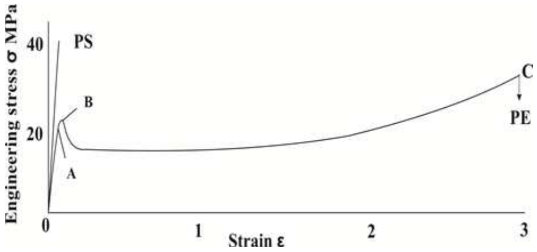

Fig. 3: Stress-strain curves for polystyrene (PS) and polyethylene (PE)

The necking of polymers is affected by two opposing factors: dissipation of mechanical energy as heat can raise the temperature in the neck, causing significant softening; the deformation resistance of the neck, which has a higher strain rate than the surrounding polymer, can rise as a result of the strain-rate dependence of the yield stress. Slip occurs in the crystalline lamellae and the individual lamellae.

Polystyrene behaves very differently, forming crazes at very low strain and fracturing without showing any significant deviation from a linear stress-strain curve. The graph shows the intricate network of fibrils connecting the two bulk surfaces of the polymer. The fibrils are drawn out of the solid polymer to an extent that is controlled by the concentration of molecular entanglements. There are interesting parallels between macroscopic drawing in PE and the microscopic internal drawing of craze fibrils in PS, Fig. 4.

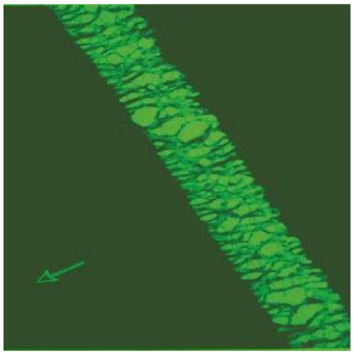

Fig. 4: A craze in polystyrene

Although, at the macroscopic level the break point can be only seen in PE there are also certain crazes in PS. Cracks are formed in the direction of tensile stress, Fig. 4.

The mechanical properties are summarized in Table 3. It reports the secant modulus determined, the engineering yield stress, the engineering failure stress, the engineering yield strain, engineering failure strain, and the actual strain rates calculated between 0.1 to 0.4 strain. The scatters in the secant modulus values are relatively high.

Material	Secant Modulus (MPa)	Yield stress	Yield Strain	Failure Strain	Strain Rate
PE	1811.2 ±251.4	70.2 ±0.4	0.052 ±0.008	0.869 ±0.061	72
PS	7770.1 ±931.2	215.2 ±1.3	0.032 ±0.004	0.032 ±0.004	

Tab. 3: Tensile Properties of Polymers, nominal strain rate is 40/s

Nevertheless, it indicates a trend of increase in modulus with strain rate. Table 4 provides the ratios for the above engineering properties between the two strain rates. However, that trend is not so exhibited in PS and PE.

Material	Secant Modulus	Yield Stress	Yield Strain	Failure Strain
PE	1.032	1.095	1.082	0.976
PS	1.130	1.060	1.0	1.0

Tab. 4: Ratio of Mechanical Properties Measured at 40/s

4. Conclusion

Tensile tests at intermediate and high strain rates, though complicated, are achievable. Due to the lower modulus, the elastic waves are much slower and hence the wave propagation effects become significant at lower rates in plastics than in metals. A high strain rate tensile test of plastic materials was carried out. Two materials, PE and PS, were tested at nominal strain rates of 40/s. The results show that the actual strain rate experienced by the specimen depends on the material. The strain rate increases during initial loading phase and becomes constant at strain >10%. The current strain measurement set up is not accurate enough at small strains and yet the range is less than the failure strain of many plastics.

5. Acknowledgements

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6. References

[1] James N Hay, The physical ageing of amorphous and crystalline polymers, Pure&Appl. Chern., Vol. 67, No. 11, pp. 1855-1858, 1995.

[2] J. Kohout, Modelling of changes in physical and mechanical properties of structural materials during long-term exposures at elevated temperatures, J. Phys. IV France, Vol. 120 (2004), pp. 191-199.

[3] Xinran Xiao, Dynamic tensile testing of plastic materials, Polymer Testing, Vol. 27, pp.164–178, 2008.

[4] Instrumented Impact Testing of Plastics and Composite Materials, ASTM STP 936, S.L. Kessler, G.C. Adams, S.B. Driscoll and D.R. Ireland, Eds., American Society for Testing and Materials, Philadelphia, 1987.

[5] Dean, G., B. Read, Modeling the Behavior of Plastics for Design Under Impact, Polymer Testing, 20, 677-683, 2001.

[6] Xiao, X., Plastic material modeling for FMVSS201 simulation, SAE2002-01-0385.

[7] Cheresh, M.C., S. McMichael, Instrumented Impact Test Data Interpretation, in Instrumented Impact Testing of Plastics and Composite Materials, ASTM STP 936, S.L. Kessler, G.C. Adams, S.B. Driscoll and D.R. Ireland, Eds., American Society for Testing and Materials, Philadelphia, 1987, 9-23.

[8] Thomas D. Ashwill, Joshua A. Paquette, Composite materials for innovative wind turbine blades, Wind Energy Technology Department, Sandia National Laboratories, Albuquerque, NM 87185, 2008.