Experimentální Analýza Napětí 2011
Experimental Stress Analysis

Identification of Impact Resistance of Plastics for the Purposes of FE Computations

Petr Horník[1]

Abstract: Due to increasing demands on the knowledge of polymer materials behaviour for the purposes of improvement of FE computations, a special experimental device (a drop tester) has been designed, serving to identification of impact resistance of plastic materials. The device enables uniaxial tensile loading of plastic specimens at higher strain rates. Part of the experiment is an acquisition of visual record by means of a hi-speed camera.

Keywords: High speed testing, Strain rate, Material model

1. Introduction

For the purposes of FE computations, description of material behaviour at real loading is essential. Material is most frequently described via tensile test. Input parameters for FEM computations are determined from the tensile test diagram. The results from static tensile tests, which are commonly available, are often insufficient. For instance, due to applications of polymer materials in automotive industry, car crashes are often simulated. The crash situations take place at loading velocities in the order of units to tens of m/**s**. Since plastics are velocity dependent materials, strain rate is an important parameter under the loading conditions. Another factor influencing material behaviour, which is not commonly considered, is production technology. On real plastic mouldings e.g. influence of material anisotropy, cold links, varnishing etc. can be visible.

2. Material model

To describe uniaxial tensile state of stress, G'Sell-Jonas relation [1] is applicable. The material parameters, which are introduced into this mathematical model, are determinable via tensile test curves. This material model is suitable for thermoplastic materials as it includes variation of Young's modulus of elasticity in dependence on loading conditions.

$$\sigma = K \cdot e^{\left(\frac{\beta}{T}\right)} \cdot \left(1 - e^{-(w \cdot \varepsilon)}\right) \cdot e^{h \cdot \varepsilon^2} \cdot \left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)^m \tag{1}$$

K – material consistency

w – viscoelastic coefficient

h – strain hardening coefficient

m – coefficient of strain rate influence

β – coefficient of temperature influence

[1] *Ing. Petr Horník; Technical University of Liberec; Studentská 2, 46117 Liberec, Czech republic; petr.hornik@tul.cz*

The mathematical model can be divided into several parts. The first part reflects temperature influence. The second part describes material behaviour up to the yield point. The third part considers the strain hardening in the area beyond the yield point. The fourth part describes strain rate influence. The model is not dependent on determination of the yield point. The initial value of modulus of elasticity equals to the product

$$E = K \cdot w \tag{2}$$

Only three parameters are sufficient for the description of the curve.

$$\sigma = K \cdot \left(1 - e^{-(w \cdot \varepsilon)}\right) \cdot e^{h \cdot \varepsilon^2} \tag{3}$$

3. Experimental arrangement

In order to observe influences of production technology, e.g. material anisotropy caused by a different orientation of macromolecular polymeric chains during injection moulding, the tested specimens were cut out from the real products. The tested specimens were cut out in two directions –a longitudinal one and the one perpendicular to the direction of the melt flow. It is obvious from the Fig. 1, where the white rectangles represent specimen locations. In that case it was a car mud-guard made of PP material. The tested specimen model can be seen in the right side of the Fig. 1.

Fig. 1. Lay-out of specimens cut out from a plastic car bumper

For determination of mechanical properties of plastics during dynamic processes, a special measuring device – a drop tester has been designed and assembled, which enables specimen loading by uniaxial tension. The drop tester principle consists in a free-fall of a drop hammer as a source of loading. The drop hammer falls vertically down conducted by guide columns. The specimen is fixed in jaws. The upper one is fixed, the bottom jaw is sliding (non-stationary). The specimen is loaded by the impact of the drop hammer on the bottom jaw. The downward movement of the bottom jaw stretches the specimen until rupture (see Fig. 2). Kinetic energy of the drop hammer is equalled to potential energy before its release. Potential energy value is given by the pre-set drop height and the drop hammer weight. Impact loading velocity is given by the drop height. Considering the specimen length and knowing the loading velocity, the strain rate can be determined. During the test, the force is recorded. The force is measured via a capacity dynamometer. The dynamometer is placed in the clamp jig which holds the specimen. Also, visual record is acquired by a hi-speed camera, from which the real loading speed, elongation and the instant of specimen rupture can be determined. The device allows to measure mechanical properties of plastics at various loading velocities in the range of 1.2 to 5.3 m/s.

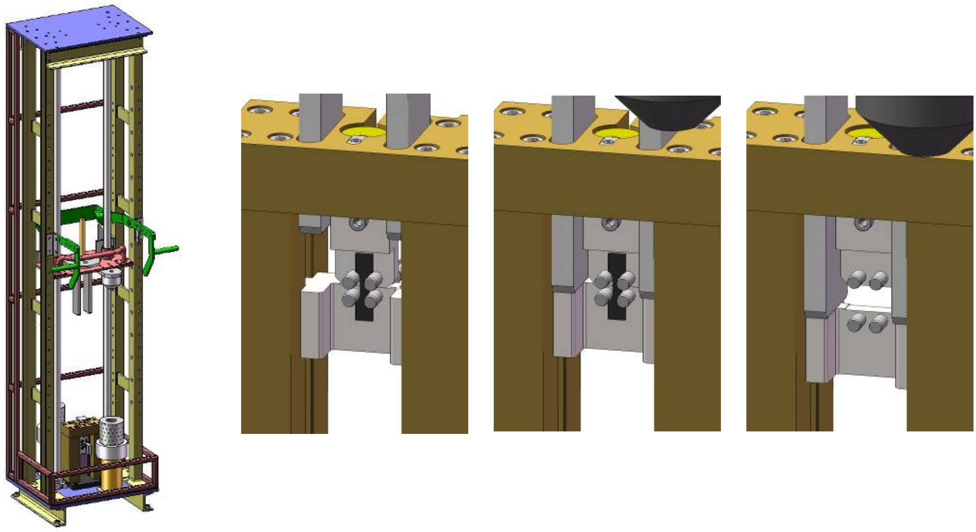
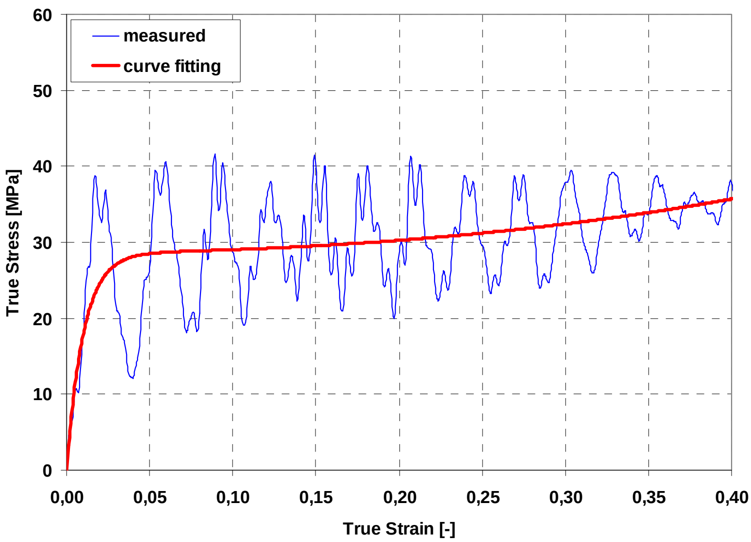


Fig. 2. Full view of the drop tester CAD model and details of the jaws

4. Results

Force-elongation dependence has been drawn up from the measured data, and finally engineering stress-engineering strain dependence was made up. The values of engineering stress and engineering strain have been converted to the values of true stress and true strain. This behaviour was approximated by the G'Sell-Jonas´s equation by the least squares method (see Fig. 3). The measurement was carried out at the loading velocity of 1.2 m/s. This corresponds to the strain rate of 10^2 s^{-1}.



K = 28.6 MPa

w = 97.3

h = 1.38

Fig. 3. Comparison of measured and fitting curves with parameters of material model

An example of the measured force-elongation dependence and photographs recorded by a hi-speed camera can be seen in the Fig. 4.

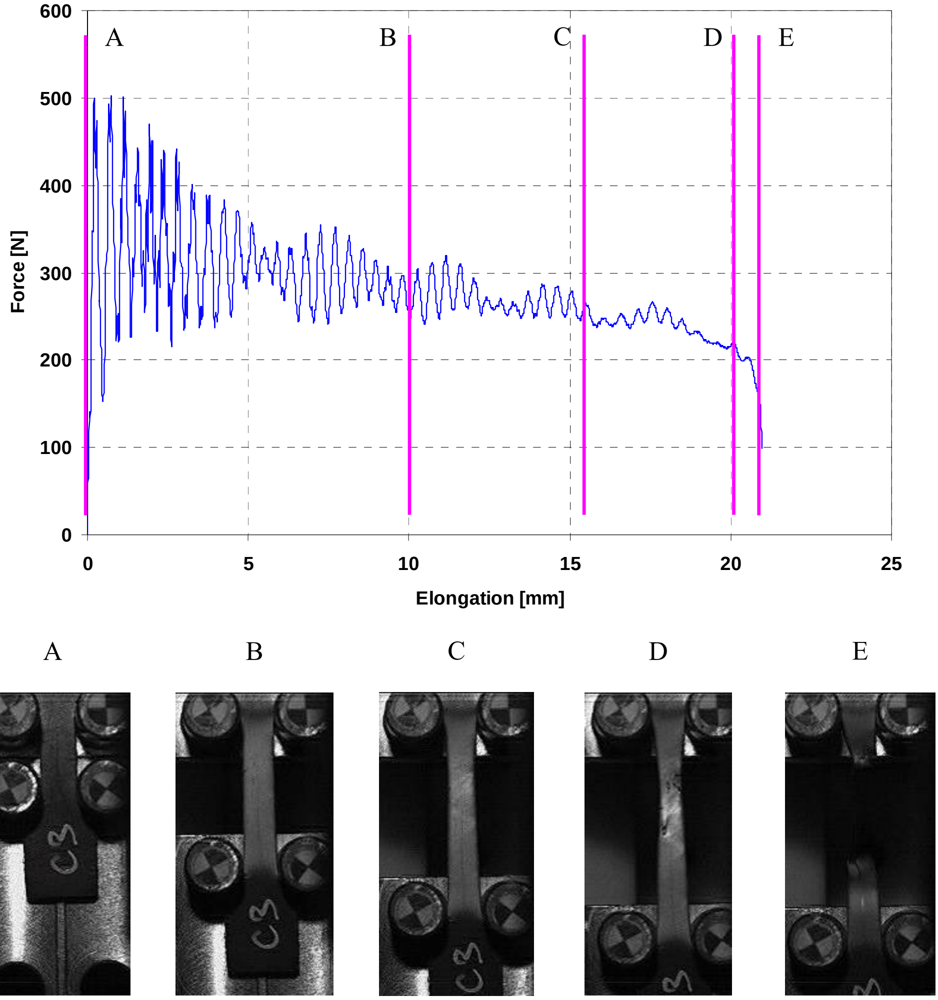


Fig. 4. The measured force-elongation dependence and the hi-speed camera shots

5. Conclusion

Having compared values of mechanical properties from the static test stated in material data sheets with the values measured in the drop-tester, velocity dependence of material can be observed. Higher strain rates resulted in higher values of the yield points and modulus of elasticity. In the future the measurement should be made in a wider range of strain rates and at higher or lower temperatures. Then it would be possible to determine two remaining parameters of the material model which describe influence of strain rates and temperatures.

References

[1] Becker F., Kraatz A. and Wieser J., "Determination of the Behaviour of Thermoplastics at High Strain-Rates Using the Invariant Theory," *Available from* http://www.dynamore.de/documents/papers/conference-08/D-III-02.pdf *Accessed:* 2011-04-09.