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Experimental Methodology for Determination of Ductile Thermoplastics Mechanical Properties

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Abstract. Finite-element (FE) analysis is important instrument for prediction of plastic car bumper tests. Accuracy of FE analysis depends on accuracy of material input data. It has developed experimental methodology for identification of mechanical properties. The methodology leads to more accurate material input data for numerical simulations.

Introduction

Experimental mechanical tests are performed during the development of plastic car bumpers from the prototype phase to the final product phase. There are efforts to completely replace very expensive physical prototypes phase (and its experimental tests) with virtual simulations using Finite Element Method (FEM). It requires high degree of accuracy of numerical simulations results.

Result accuracy depends on the input material data quality. Current problem is the availability of these data. There are too many kinds of plastics and, moreover, mechanical properties are unique for different products of the same material. Therefore material data either are not commonly available or do not have sufficient accuracy. It is necessary to take into account the influence of manufacturing process on experimental identification of mechanical properties.

The material test must be performed on specimens cut out from a real product. It allows showing influence of production technology, material anisotropy, primer etc. Type, range and testing conditions of material tests must be chosen according to the desired purpose. They are numerical simulations of car bumper tests. These tests have a different character. Tests contain short-term static or impact load and long-term cyclic thermal load. Temperature range of the tests is from -40 °C to +80 °C, strain rate is in the range from 0 to 10^{+2} s^{-1} and duration of the load is up to hundreds of hours at long-term load.

Experimental methodics for identification of mechanical properties of ductile thermoplastics must reflect above-mentioned facts. It will allow more precise input material data for numerical simulations. Methodics must be effective enough and could be used in industrial practice.

Experimental Determination of Mechanical Properties

Input material data of FEM model in numerical simulations are represented tensile stress-strain curves. These curves are measured on universal test machine LabTest 5.050ST (for quasistatic load – strain rates: 10^{-2}, 10^{0} s^{-1}) and drop tester (for impact load – strain rate 10^{+2} s^{-1}). Drop tester was developed by company LENAM for purposes of plastic material testing. These test machines are equipped with a thermal chamber. Special clamps (for static and impact tests) have made for given type of specimen.

Drop tester, tensile deformation curve and illustration of impact tensile test recorded on hi-speed camera are shown in Fig. 1. It is used G'Sell equation [1] of viscoelastic material and law of conservation of volume for experimental curve fitting.

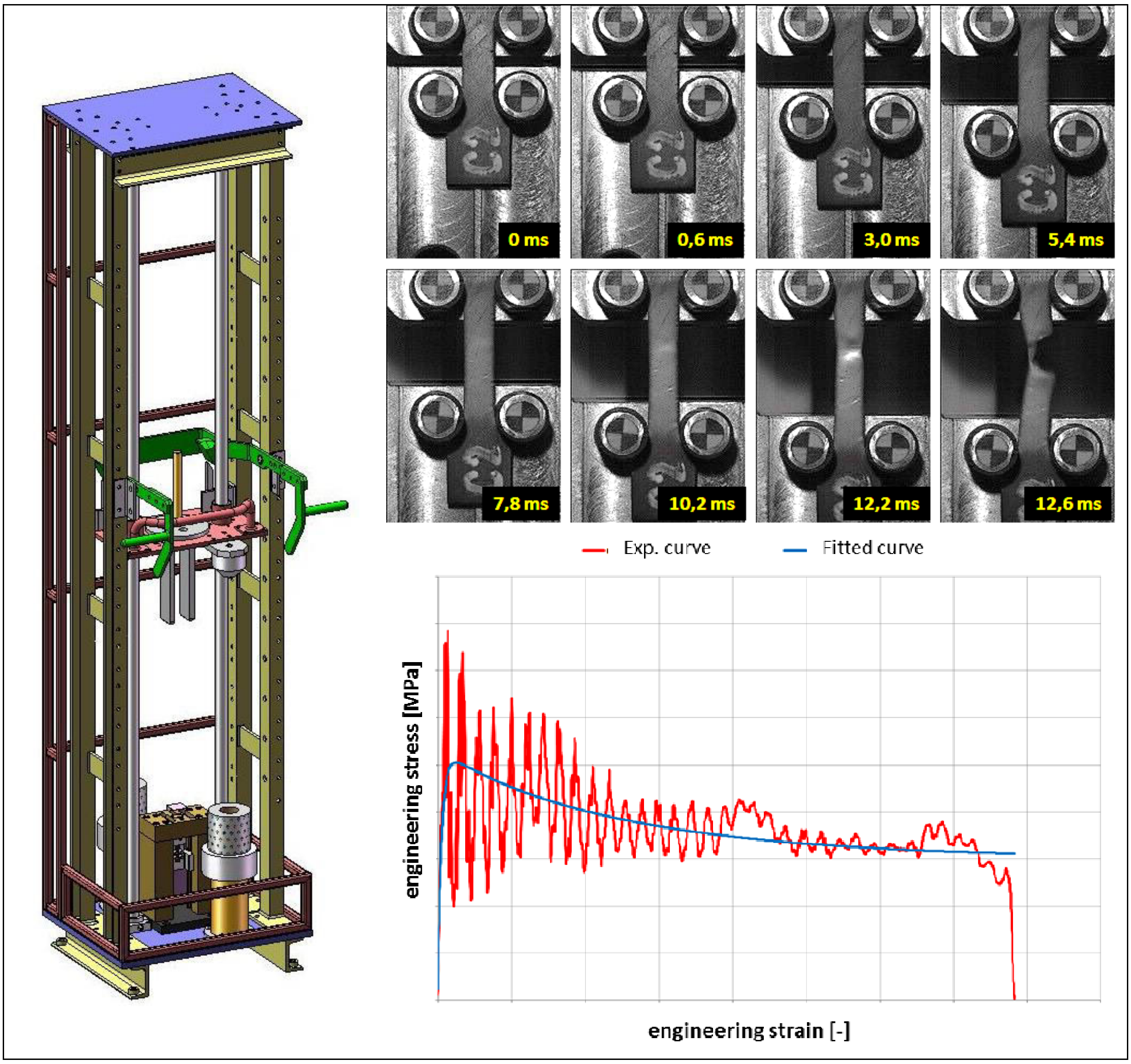

Fig. 1. Drop tester, images from impact tensile test captured on high-speed camera and impact tensile deformation curve.

Young's modulus is determined by three-point bending test on LabTest 5.050ST (for quasistatic load – strain rate: 10^{-2} s^{-1}).

Dynamic modulus is measured via dynamic mechanical analysis (DMA) on DMA Q800 tester, where tested specimen is cyclically loaded. DMA gives complex dynamic modulus dependent on load frequency. Complex dynamic modulus has a real and imaginary component. Real component is called storage modulus (describes deformation response) and imaginary component is called loss modulus (describes material damping given by energy disipation). Dependence of storage modulus on frequency is measured in three-point bending and tension test. Absolute values of modulus from DMA do not have to correspond to real values (espacially in tension). Therefore, only trend of measured curves is used. It means that these curves are shifted to quasistatic flexural modulus value. Frequency is converted on strain rate and so we get dependence of storage modulus on strain rate. Storage modulus dependence on log strain rate gives linear course in observed range (see Fig. 2).

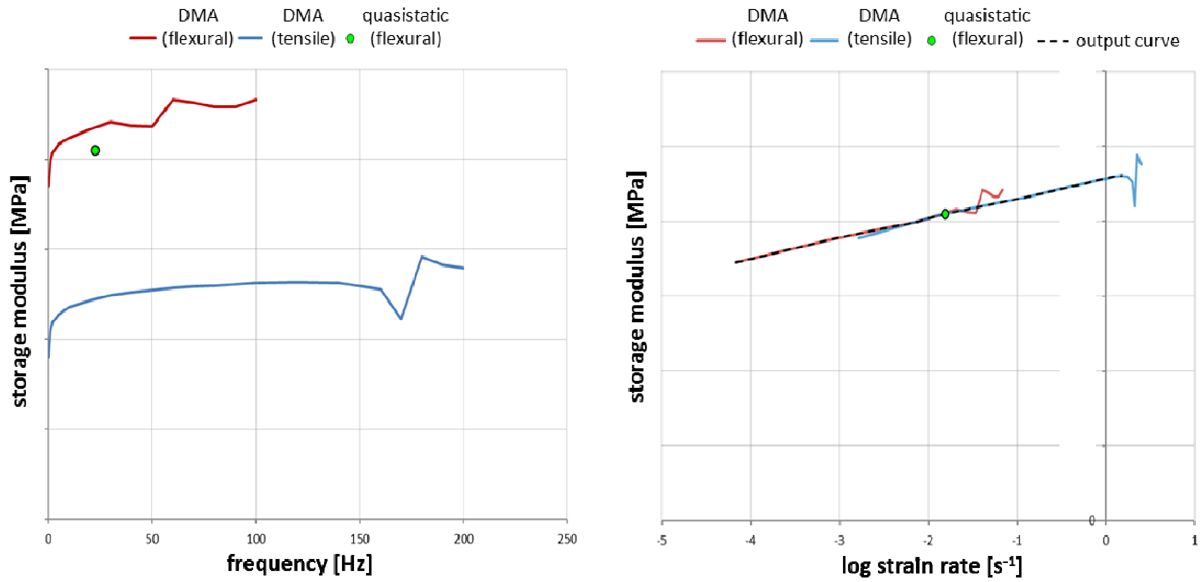

Fig. 2. Storage modulus dependence on frequency and strain rate.

Time dependence of relaxation modulus is determined by relaxation tests for purpose of long-term load of a car bumper test. Relaxation tests are performed at temperatures 23, 40, 60 and 80 °C and they last 1 hour at each temperature. Relaxation modulus dependence is extended with values from static test at temperature 0, -20, -40 °C. Relaxation modulus is evaluated according to time-temperature superposition principle and WLF equation [2]. Temperature and time dependence of modulus is seen in Fig. 3.

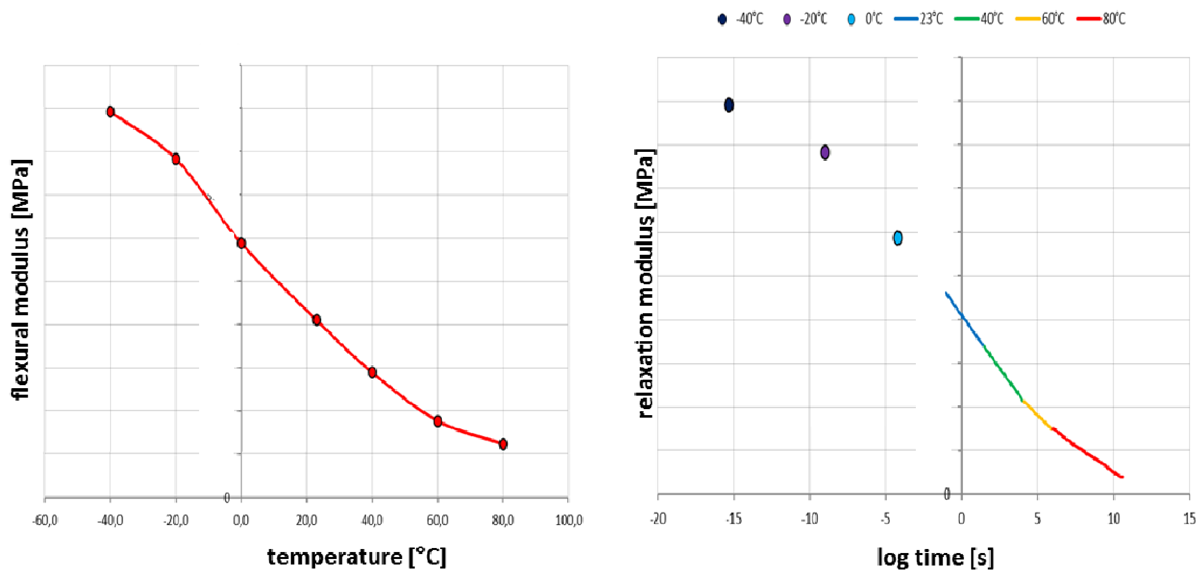

Fig. 3. Temperature and time dependence of modulus.

Further evaluation of the measured data is based on theoretical and practical knowledge and is adapted for finite-element material model. Measured data are elaborated or corrected and FE material model is created with combination of various test outputs. For example, stress-strain curves are corrected according to flexural modulus because tensile tests run without extensometer.

Strain recovery, material anisotropy and primer effect is also examined.

Comparison of Numerical Simulation with Experiment

Two finite-element material models were compared with results of experimental test (front car bumper crash test). The first of them is (standard) model used in industrial practice and the second (new) model is created according mentioned experimental methodology.

The standard model differs from the new model in following parameters. It does not include hardening of elastic modulus. Hardening of plastic deformation area is described via analytic model. It works only with one value of strain at break for all strain rates and temperatures.

The new model includes hardening of elastic modulus with strain rate and temperature influence. Hardening of plastic deformation area is created according to experimental data. Strain at break is a function of strain rate and temperature.

Difference between results (of penetration to car bumper) of numerical simulation and experiment is 3.5 % (in case of standard FE material model) and 0.7 % (in case of new FE material model). It is important the new material model can more reliably predict failure of a car bumper parts in comparison with standard material model.

Conclusions

It is possible to determine stress-strain curves and modulus values dependent on temperature, strain rate and time in required ranges. It allows more accurate input material data for numerical simulations. It also shortens the duration of experimental work.

Acknowledgments

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