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RELAXATION OF MATERIALS OBTAINED USING POLYJET TECHNOLOGY

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Abstract: *The paper presents the results of stress-relaxation test on materials which has been produced using PolyJet printing technology. The test has been described and a rheological model has been fit to the relaxation curve determined in the experiment. Values of the parameters of the rheological model has been estimated.*

Keywords: Additive technologies, Material relaxation, Rheological model.

1. Introduction

Development of printing technologies also impacts on development of materials used in these types of technologies. On the market, there are more and more new materials with various physical and mechanical characteristics that are objects of research. These materials include photocured resins used in PolyJet printing technology (Paz et al., 2016). Building models by using PolyJet printing technology consists of spraying layers of resin with a special head and every new layer accurately reflects a model section in the given working plane. This way of building models and at the same time creating material that models are made of, causes the anisotropy of mechanical characteristics. That problem was presented by many studies (Bass et al., 2016)(Beyer and Figueroa, 2016). This is, for sure, a disadvantage of the technology in comparison to e.g. injection moulding or mechanical operations (Nowakowski and Wijas, 2016) where the anisotropy does not exist or is slightly less.

Printed materials are characterised by, like most of polymers, stress relaxation which causes the need of research on the subject. Stress relaxation in polymer materials was described in many studies, e.g. (Blanco et al., 2014)(Chivers et al., 2014) but there are not many research results concerning stress-relaxation for printed materials (Adamczak and Bochnia, 2016). Worth mentioning are the studies on stress-relaxation of rheological models which are also known as models of ideal bodies (Hernandez-Jimenez et al., 2002)(Del Nobile et al., 2007). The relations of the stress changes in the function of time $\sigma = f(t)$ are particularly interesting. This paper presents the results of a stress relaxation test performed for a material created using PolyJet technology and Connex 350 printer. Created specimens and the relaxation test with adapting selected rheological model to a relaxation curve determined by experimentation were described. The rheological model parameters were also estimated. The test results can be needful in various modelling projects for engineering calculations (Bochnia, 2012), construction works (Takosoglu et al., 2016) or research (Blasiak and Zahorulko, 2016).

2. Methods

The specimens were made of photocured resin, Vero White, by means of an Connex 350 3D printer based on PolyJet technology. The solid model of the test pieces was generated in a 3D CAD program and saved as an *.stl* file. The settings determining the model accuracy selected in the STL Mesh Export Options dialogue box were as follows: resolution – adjusted, deviation – 0.015 mm tolerance, angle – 5^0 tolerance. Then, the Objet Studio program was used to arrange the models horizontally on the build tray of the Connex350 printer. The specimens were printed in the Glossy mode to achieve smooth surfaces. Printed specimens on a build tray of the printer are presented in Fig. 1.

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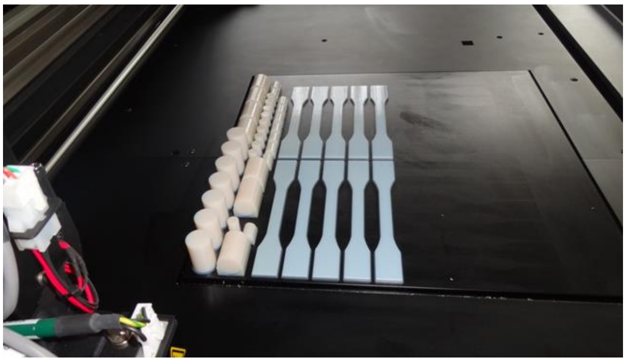

Fig. 1: Printed specimens on a build tray of Connex 350 printer.

A flat specimen of dimensions complied with ASTM D638 standard was chosen for the relaxation test: width of the narrow section, 13 ± 0.02 mm; length of the narrow section, 57 ± 0.02 mm; overall width, 19 ± 0.025 mm; overall length, 165 ± no max; gauge length, 50 ± 0.01 mm; distance between the grips, 115 ± 0,02 mm; fillet radius, 76 ± 0.04 mm; and thickness, 4 ± 0.4 mm. The test of relaxation was made using the Ispect mini (Hegewald & Peschke MPT GmbH) testing machine with range of 3 kN. Measurement, data acquisition and setting the parameters of the test was performed in the LABMASTER program (Version 2.5.3.21), which is supplied with the Inspect mini machine.

It is very difficult to describe the relaxation process mathematically using a solid model as the description needs to have some physical significance. The Maxwell-Wiechert model for the second order was used for a description. The generalized Maxwell model, also known as the Maxwell-Wiechert model, is shown in Fig. 2.

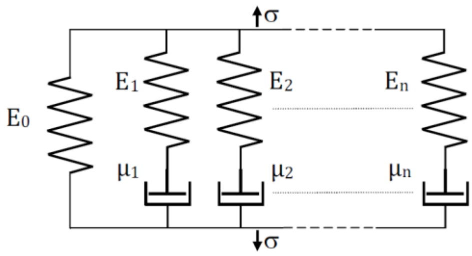

Fig. 2: Generalized Maxwell model (Maxwell-Wiechert model).

The model consists of n simple Maxwell models assembled in parallel and Hooke's law, where E_0, E_1, E_2 …E_n are the elastic moduli and μ_1, μ_2, …μ_n are the coefficients of viscosity of the simple models. The equation describing this model is written as:

$$\sigma(t) = \varepsilon_0 \left(\sum_{i=1}^{n} E_i e^{\frac{-t}{t_i}} + E_0 \right) \tag{1}$$

where: ε_0 – predetermined displacement,
n – number of simple Maxwell models,
i – number of the subsequent model.

For n = 2, i.e. for two simple Maxwell models and Hooke's law assembled in parallel, Equation (1) can be written as:

$$\sigma(t) = \sigma_0 + \sigma_1 e^{\frac{-t}{t_1}} + \sigma_2 e^{\frac{-t}{t_2}} \tag{2}$$

where: σ_0 – initial stress at $t = 0$,
t_1 – relaxation time.

The relaxation time, defined as the ratio of the properties of a Newtonian fluid and a Hookean solid, can be written as:

$$t_1 = \frac{\mu_1}{E_1}, \qquad t_2 = \frac{\mu_2}{E_2} \tag{3}$$

where: μ_1, μ_2 – coefficients of viscosity,
E_1, E_2 – elastic modulus.

3. Results

The relaxation test was conducted using block programming. The given displacement value was 0.1 mm. In this stage the displacement value of an arm of a tensile testing machine was 0.1 mm causing specimen stress. Next, the displacement value of 0.1 mm was kept for 300 s and during that time the stress decreased what means that the stress relaxation occurred. The last stage was specimen offloading. The chart of loading and relaxation is presented in Fig. 3.

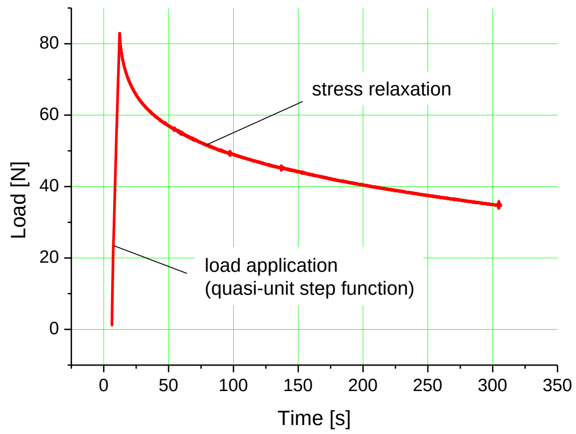

Fig. 3: A stress relaxation plot for Vero White.

Next, only a part of the chart with stress relaxation was analysed. The curve obtained experimentally for the equation (2) was fitted with the approximation method. Origin computer programme was used for approximation performing. The results of curve fitting are presented in Fig. 4.

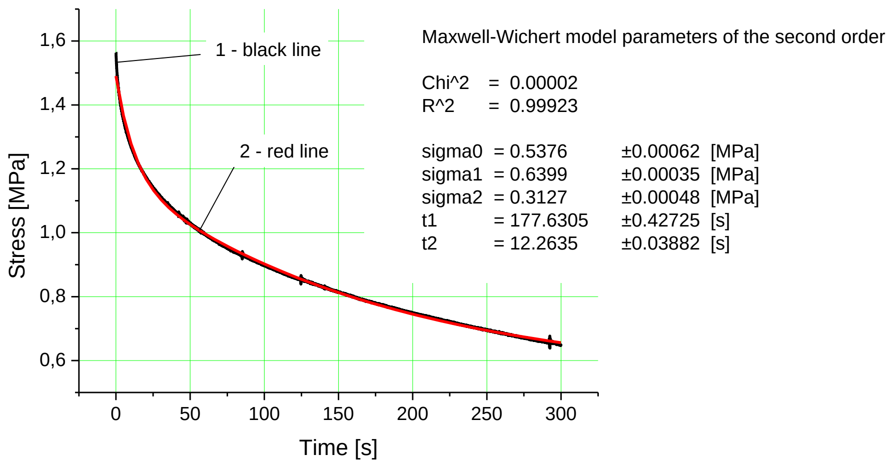

Fig. 4: Experimental curve compared with the approximation curve. 1 – experimental curve for specimen made of Vero White, 2 – approximation curve obtained using Equation (2) for two Maxwell models and Hooke's law connected in parallel, Chi^2 - a chi-squared test, also written as χ^2 test, is any statistical hypothesis test wherein the sampling distribution of the test statistic is a chi-squared distribution, R^2 (R squared) - the coefficient of determination, is a number that indicates the proportion of the variance in the dependent variable that is predictable from the independent variable.

For the experimental relaxation curve, the approximation was conducted using equation (2) to determine σ_0, σ_1, σ_2, t_1, t_2 parameters and values for Chi2 test and R2 coefficient. The parameters values are presented in Fig. 4. The conclusion of Fig. 4 quality assessment is: a high fitting level of the approximation curve to the real curve (experimental) using the equation (2) was obtained.

This paper presents only one experiment but procedures for further research are also determined, so the research will be continued and described in a more voluminous publication.

4. Conclusions

Estimating parameters of the relaxation function using approximation (2) shows full overview of curves fitting and confirms suitability of the adapted model of an ideal body for describing real materials. The description of the experimental relaxation curve with determined approximation accuracy is very important because of physical characteristics of the obtained parameters.

The conducted experiment widens knowledge on new materials characteristics made using printing technologies- in this case using PolyJet technology.

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