TAILORING MECHANICAL PROPERTIES OF POLYAMIDE BY AFFECTING ITS INHERENT STRUCTURE

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1. Introduction

It is known that the macroscopic properties of polymeric materials strongly depend on their inherent structure which may be in general influenced by the initial kinetics (topology of the individual building blocks) and the conditions that material is exposed to during processing and solidification [1]. Therefore, by accordingly adjusting material inherent structure one may tailor desired macroscopic mechanical properties what is of great interest when we want to achieve a particular functionality of products made from this material. Very illustrative examples of this are the polymeric bone implants where it is important that the artificial elements replacing missing part mimic functionality of the gradient bone structures. Besides biocompatibility, it is requested for the material used for the bone implant to possess comparable properties to the natural bone to avoid a phenomena of osteoporosis [2]. From this point of view, one of the most promising polymeric materials to be used for biomedical implant is polyamide (nylon) [3].

The fact above has motivated us to investigate the possibilities of tailoring time-dependent mechanical properties of polyamide 6 (PA6) by affecting its inherent structure via extreme processing conditions.

2. Materials and methods

Polyamide PA6, provided by BASF, with the bimodal mass distribution (distribution has two peaks) as a representative of the new generation of intelligent polyamides was used for this research. Bimodal PA6 has great potential to form different structures under different boundary conditions during processing and solidification due to its complex inherent molecular kinetics, and therefore offer more possibilities to tailor macroscopic properties by modifying the material inherent structure [1].

In order to check the effect of different boundary conditions on the macroscopic time-dependent mechanical properties cylindrical samples were prepared in two ways. Firstly, by the gravimetric casting according to the procedure described in [4]. This was to exclude the effect of processing parameters and consider the effect of inherent kinetics only, since the gravimetric casting is proved to have negligible effect on the formation of structure orientation. Secondly, cylindrical samples were prepared by injection moulding at the extreme pressure of 1600 bar and the temperature 220 °C. Direction of moulding was parallel to the length of cylindrical specimens, and it was expected that the extreme boundary conditions would affect structure orientation (achieving gradient structure).

Macroscopic mechanical properties were examined by measuring the shear creep compliance, $J(t)$, with the apparatus for torsional creep measurements that has been designed and manufactured at the Faculty of mechanical engineering, University of Ljubljana, Slovenia. Torsional creep measurements were performed in segmental form at 8 different temperatures in the temperature range from 30 to 100 °C, under the constant loading torque, which was within the material linear viscoelastic limit. Following the time-temperature superposition principle, the shear creep segments were shifted along the logarithmic time-scale in respect to the segment measured at the reference temperature, $T_{ref} = 40\ ^\circ\mathrm{C}$, to form the shear creep compliance master curve. For more details on the measuring and the shifting procedure see [4].

Based on the measured shear creep data of the bimodal PA6 the frequency-dependent storage, $J'(\omega)$, and loss, $J''(\omega)$, compliances were calculated by using the interconversion approximation proposed by Schwarzl [5]. As the last step, loss factor was calculated as $\tan\delta(\omega) = J''(\omega)/J'(\omega)$.

3. Results and discussion

In Fig. 1 the shear creep compliance master curves of the gravimetrically casted and injection moulded samples are presented, while Fig. 2 and Fig. 3 show their frequency-dependent behaviour.

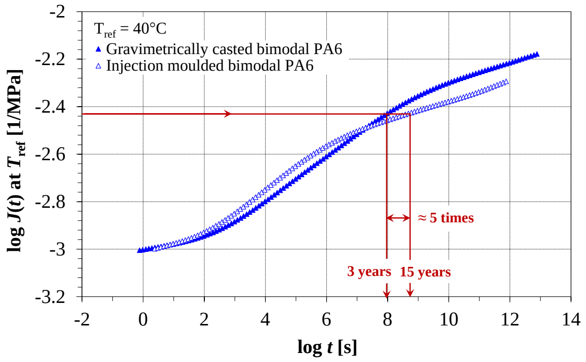

Fig. 1. Time-dependent shear creep compliance vs. time.

It is evident from Fig. 1 that the extreme processing conditions may affect the inherent structure of bimodal PA6 in a way of severely improving its creep time stability (for about 5 times) in the time range relevant for the implant applications.

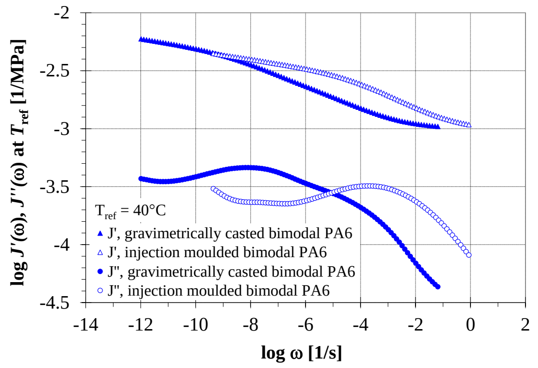

Fig. 2. Frequency-dependent storage and loss compliances vs. angular frequency.

Fig. 2 and Fig. 3 reveal that the extreme processing conditions also affected the frequency-dependent creep properties by finally resulting in the higher magnitude of loss factor (related to the damping capability of a material) and in the shift of its peak closer to the loading frequencies typical for different body functions (e.g., walking, chewing).

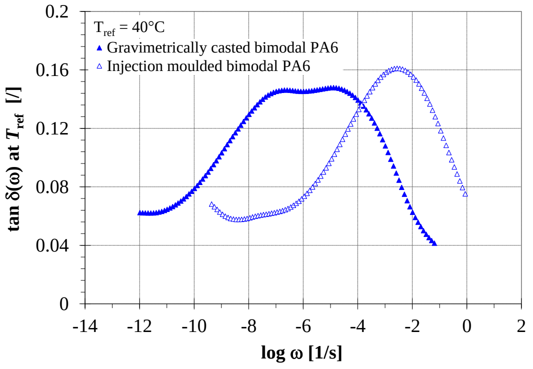

Fig. 3. Loss tangent vs. angular frequency.

4. Conclusions

This research indicates that the ability of different structure formation under particular processing conditions with a consequence of improving macroscopic mechanical properties makes bimodal PA6 to be a perspective implant material. Besides, it exhibits that mechanical testing may be used as a suitable tool to distinguish structural differences via macroscopically detected mechanical responses.

References

[1] Emri, I., von Bernstorff, B. S. The effect of molecular mass distribution on time-dependent behavior of polyamides. *J Appl Mech*, 2006, 73(5), 752–757.

[2] Nagels, J., Stokdijk, M., Rozing, P. M. Stress shielding and bone resorption in shoulder arthroplasty. *J Shoulder Elb Surg*, 2003, 12(1), 35–39.

[3] Rahim, T. N. A. T., Abdullah, A. M., Akil, H. M., Mohamad, D. Comparison of mechanical properties for polyamide 12 composite-based biomaterials fabricated by fused filament fabrication and injection molding. In *AIP Conference Proceedings*, 1791, 2016.

[4] Kubyshkina, G., Zupančič B., Štukelj, M., Grošelj, D., Marion, L., Emri, I. The Influence of Different Sterilization Techniques on the Time-Dependent Behavior of Polyamides. *J Biomater Nanobiotechnol*, 2011, 2, 361–368.

[5] Schwarzl, F. R. The numerical calculation of storage and loss compliance from creep data for linear viscoelastic materials. *Rheol acta*,1969, 8, 6–17.