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Anisotropy of physical properties injection moulded parts and its analysis

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Materials

ABSTRACT

Purpose: Anisotropy of physical properties in injection mouldings is a phenomenon commonly performing and very difficult to avoid. However in some cases for its size occurring of diversity of the property the using of such a element is becoming impossible. Chosen effects of examinations of anisotropy of properties depending on of the place and the method of the sampling research were presented in the article.
Design/methodology/approach: A Dynamic Mechanical Thermal Analysis method giving possibility in the very precise solution was take advantage in examinations of differences between samples taken from each places injection moulding part. Research samples were cut from the flat plate and then were taken advantage to research. The method of the sampling was presented in the figure.
Findings: How were presented in the discussion of effects of research in polymer materials processing particularly thermoplastics polymers, anisotropy of physical properties with indispensable phenomenon. Occurring anisotropy is involving diversity of durability of each areas of injection moulding part and different behaviour oneself during using. Samples taken from the beginning of the flow way were marked by better mechanical properties but poor suppressing properties. However samples taken parallel to the direction of the polymer flow in the mould were marked (in temperatures over 40 deg) with better suppressing properties.
Practical implications: Analysis of examinations of anisotropy of mechanical and using properties in injection molded parts (presented in the article) could find practical application in polymer processing industry, both small and large enterprises. There are many problems with very complicated mouldings and the know-how presented in this article could be very useful industry application.
Originality/value: New approach to precocious estimation anisotropy of physical properties were present in the paper.
Keywords: Engineering polymers; Mechanical properties; Injection moulding; DMTA method

1. Introduction

Continuous improvement in injection moulding technologies and appearance of new kinds and methods of manufacturing using these technologies offers huge opportunities of both fast and cheap production. However, the expansion of top technologies into new industries, especially the automotive, precision and electronics industries dictates very high quality standards connected with dimensional and shape precision and with repeatability and stability of the process.

One of the imperfections of polymer processing is a heterogeneity of plastic mould properties [1, 2, 3]. This concerns especially the moulded pieces with larger dimensions, however, it happens more or less for any injection product. There are many reasons for its existence; the differences in plastic flow during filling phase, irregularity of the thickness of individual areas of the moulded piece and consequently different times of cooling of these areas. As a result of differentiation of individual areas of the mould the differences in value of crystallinity degree occur; they are accompanied with the phenomena of stress relaxation and the orientation of macromolecules during flow [4, 5].

2. Description of work methodology, materials for research, experiments

2.1. Methodology

Dynamic tests of mechanical properties by means of DMTA (Dynamic Mechanical Thermal Analysis) are one of the methods of assessment of transitions which occur in polymeric plastics within wide range of temperature and frequency of load changes (load time) [6-8, 9, 10, 11]. As a result of such an analysis, the profiles for changes in dynamic modulus and the angle of mechanical loss tangent (mechanical loss coefficient) are obtained. Knowledge about these changes enables to determine the relation between molecular structure and the mechanical properties of polymeric plastic; comparing the two profiles a difference with each other can be observed [12-18].

2.2. Specimen preparation conditions

A plastic moulded piece for determination of moulding shrinkage (according to ISO 294-3:1996(E) standard [2]) has been used for the investigations. The moulded piece with the runner have been presented in the Fig. 1. The tested material was a polyoxymethylene POM by Rhodia, which belongs to the group of partly crystalline plastics.

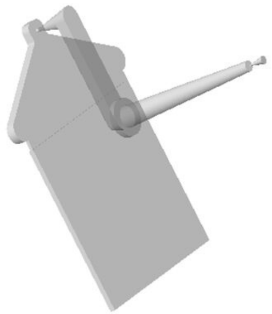

Fig. 1. Tested moulded piece

The specimens were prepared using the injection moulding machine with following conditions:

- mould temperature - 50°C,
- injection temperature - 205°C,
- cooling time - 8 s,
- injection rate - 70 mm/s,
- clamping pressure - 45 MPa.

2.3. Equipment, preparation of specimens and conditions of measurements

The tests were performed by means of *DMA 242* device by NETZSCH® (Fig. 2a) with the holder for three-point free bending in the form of a bean. The measured part with a sample has been presented in Fig. 2b.

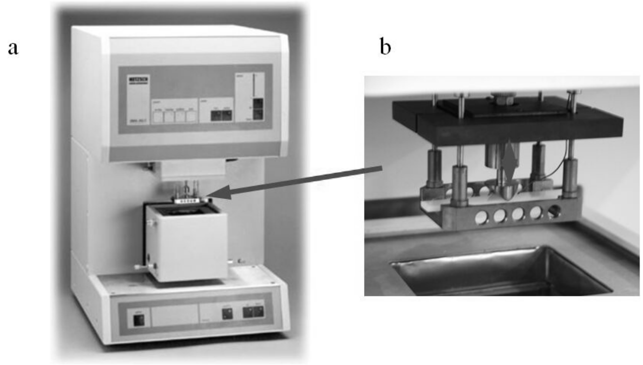

Fig. 2. DMA 242 device by NETZSCH, a) general overview; b) specimen overview

Fig. 2b presents a measurement device with a specimen, mounted and loaded. For the specimen in the sample the vibrations with different frequency and fixed amplitude were applied while heating the specimen. On the basis of the value of force and deformation (read by means of extensometric sensors in-build in the device), with consideration of the specimen dimensions, the value of the preservation modulus *E'* and loss modulus *E"* as well as $tg\delta$ are calculated. Next, the obtained results are presented in the form of chart of changes in the abovementioned values as a temperature function.

From the measurement part of each moulded piece the specimens in form of a beam with the dimension of: width 6 - 7 mm, length 55mm, thickness 2,1mm (moulded piece thickness) were cut and prepared (from the areas presented in Fig. 3). First tests concerned analysis of differences resulting from orientation, thus the specimens were taken in a perpendicular (crosswise) and lengthwise directions in relation to the plastic flow (Fig. 3a). Next tests concerned determination of anisotropy of mechanical properties for the samples taken at the beginning and the end of the flow (Fig. 3b). The measurements of the specimens were performed with the precision of 0.01mm by means of the micrometer by Mitutoyo. The specimens after preparation were placed in the three-point bending holder.

A result of the investigations is obtaining the chart of changes in preservation modulus *E'*, loss modulus *E"* and $tg\delta$ in relation to temperature and the assumed vibration frequencies.

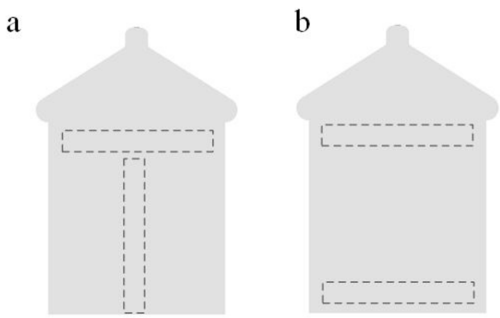

Fig. 3. Location of the specimens taken from the moulded piece: a) in the direction perpendicular and parallel to the flow, b) at the beginning and the end of the flow

3. Description of achieved results of own researches

Fig. 4 presents the chart of changes in preservation modulus *(E')*, mechanical loss coefficient *(tgδ)* as a function of temperature presented in the Fig. 3a. The chart presents the profiles obtained for both specimens.

While analysing the curves of *E'* and *tgδ* as a function of temperature of the specimens taken from the moulded piece according to the scheme (Fig. 3a) the highest impact of temperature increase can be observed for the specimen cut lengthwise, for which higher values of *E'*, comparing to the crosswise specimen can be observed; however, this advantage exists only for the range of low temperature values.

On all the charts, on the temperature axis the ranges for phase transitions which occur for the tested plastic have been marked; they include:

- A – range of the plastic strain up to ca. -100°C,
- B – range of the glass transition from -100°C to ca. -40 °C
- C – range of the highly elastic strain from ca. -40°C to ca. 80°C,
- D – range of plastic transition, above 80°C.

In the range of A and further up to temperature T_g = -70°C the difference between *(E')* values of the specimens decreases to 0, and in the range of positive temperatures it reaches slightly higher value. The mechanical loss coefficient *tgδ* for the specimen taken lengthwise is higher than for the crosswise specimen in the glass transition zone and the part of the highly elastic strain range. For the temperatures above 30°C, however, the opposite situation takes place and at the temperature of 100°C *tgδ* for the crosswise specimen it reaches comparatively high value of 0.16, which proves very good damping properties (dissipation of energy).

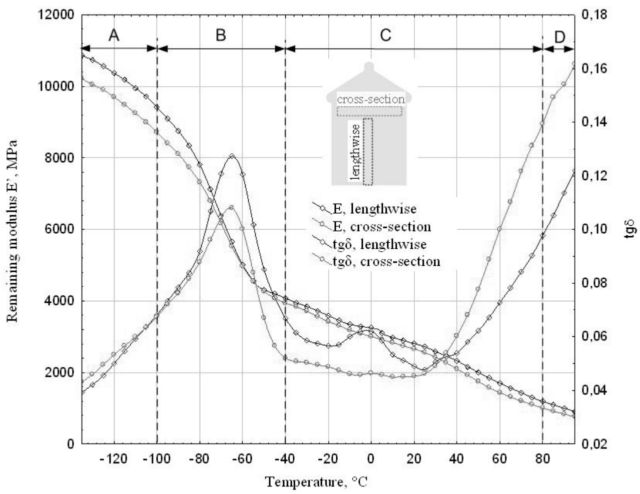

Fig. 4. Dependence of the preservation modulus E' and the mechanical loss coefficient tgδ on the temperature for POM cut from the moulded piece perpendicular (crosswise) and parallel to the flow direction, vibration frequency 5 Hz

During next test the specimens were taken at the beginning and the end of the flow for single moulded piece, according to Fig. 3b.

The results of DMTA tests have been presented in the Fig. 5. The specimens taken at the beginning and the end of the moulded piece differ from each other in terms of mechanical properties.

For very high temperature values in the range of elastic transitions the difference in *E'* value between the specimens reaches even 2000 MPa. Then the difference decreases within the range of the usage temperatures ((-50 to 70°C) and it is within the range of from 1100 to 500 MPa. Changes in the *(E')* value are connected with the change in density of the plastic which occurs during the increase of temperature. The drop in *E'* value within the range of glass transition amounts from 9000 to 4000 MPa, while for the usage range from 0°C to 60°C the value fluctuates within 3200 to 1600 MPa.

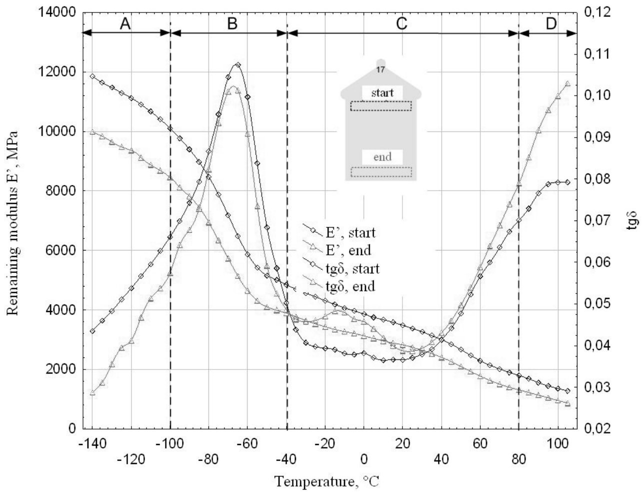

Fig. 5. Dependence of the preservation modulus E' and the mechanical loss modulus tgδ on the temperature of specimens taken at the beginning and the end of the moulded piece

4. Conclusions

The dynamic investigations of the mechanical properties by means of DMTA method are useful for interpretation of many phenomena which occur during phase transitions in polymers. The fact of existence of a diverse morphology in individual zones of moulded piece causes the diversification of the physical properties, thus it impacts further use of the moulded piece and possible defects and damage.

The reasons for existence of anisotropy of the mechanical properties are numerous. Except process conditions which significantly impact this phenomenon, one of the equally important reason is diversity of the temperature profile for the mould cavity and the flow-related phenomena (macromolecules orientation). The macromolecule packing density and consequently the density at the beginning and the end of flow of plastic is varied, which impacts the mechanical properties of the specimens taken from the two areas (Fig. 5). The results and the methodology of the investigations are an example of use of methods of thermal analysis for qualitative assessment of the injection technology, especially in relation to industrial moulded pieces which have to meet high quality standards.

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