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Influence of the processing conditions on the dynamic mechanical properties of gas assisted injection moulded parts

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ABSTRACT

Purpose: The main purpose of this research was the estimation of the influence of processing conditions on dynamic mechanical properties moulidings made by Gas-Assisted Injection Moulding technology (GAIM). The research samples were cut from children cart holder – part made by gas-assisted injection moulding and tested using DMTA method.

Design/methodology/approach: One of the modern testing methods was used - Dynamic Mechanical Thermal Analysis which is used very often to determinate dynamic mechanical properties and transformations of the structure of polymers and composites as well as parts manufactured from these materials.

Findings: The impact of processing conditions used for manufacturing the parts made by gas-assisted injection moulding technology on mechanical properties of these parts were examined. The differences in storage modulus E' and loss factor tanδ were investigated. During the tests three of processing conditions were changed, on the base of the experimental plan generated in STATISTICA software, in Design of Experiment module.

Research limitations/implications: The differences in storage modulus - E' and mechanical loss factor tgδ were presented. The research carried out was limited to one material (Copolymer of polypropylene and polyethylene PP/PE included 10-14% of PE fraction) however during investigations some of processing conditions were changed.

Practical implications: Received and presented results are very useful from the point of view of industrial applications and they can contribute to the quality improvement of the parts obtained using gas-assisted injection moulding technology. Gas flow in melt polymer in GAIM technology is very unpredictable and it causes many defects in produced parts.

Originality/value: A new approach to the estimation of mechanical properties of moulded parts, produced using GAIM technology, gives information about the influence of the processing conditions on mechanical properties and quality of the parts.

Keywords: Polymeric materials; GAIM; Gas-assisted injection moulding; Thermal analysis; DMTA method

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PROPERTIES

1. Introduction

Gas assisted injection molding GAIM [1-18] has increasingly become an important process in industry, due to its flexibility in design and manufacturing of plastic parts. Although the gas assisted injection molding process has been developed for more than a decade [19-23], there are still some unsolved problems that confound the overall success of this technique. Gas-assist injection molding is a process that utilizes an inert gas (normally nitrogen) to create one or more hollow channels within an injection-molded plastic part. At the end of the polymer injection stage, the gas (N_2) is injected into the still liquid core of the molding (Fig. 1.). From there the gas follows the path of the least resistance and replaces the thick molten sections with gas-filled channels. Next, gas pressure packs the plastic against the mold cavity surface, compensating for volumetric shrinkage until the part solidifies. Finally, the gas is vented to atmosphere or recycled.

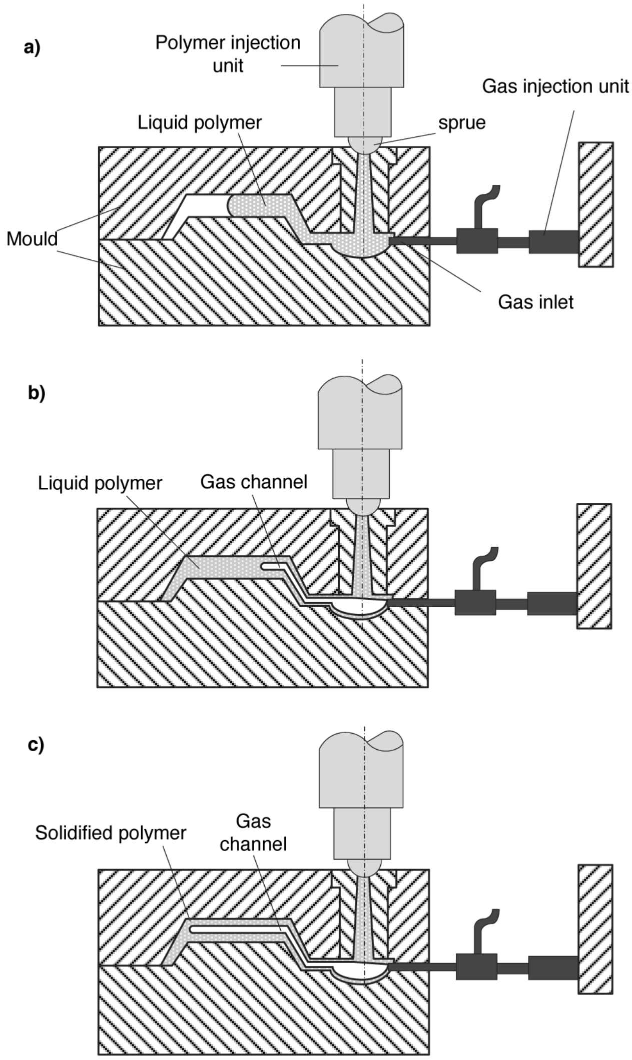

Fig. 1. Stages of gas assisted injection moulding GAIM

GAIM process include four (or sometimes more) phases:

- I - melt injection;
- II - gas injection;
- III - gas hold pressure and cooling;
- IV - gas remove.

Design engineers and processors alike are discovering that this technology is an attractive option for certain applications and offers many benefits:

- substantial cost reductions resulting from:
- reduction in molded plastic weights, and therefore cost of material;
- reduction in molding time cycles, and therefore cost of production;
- reduced in-mold pressures, and therefore less wear on molds;
- the use of the gas as a means of transmitting pressure uniformly throughout the molding;
- elimination of sink marks;
- avoidance of plastic packing from the molding machine;
- reduced in-mold pressures by up to 70%, and therefore reduced press lock forces enabling larger moldings on smaller machines;
- reduced power consumption;
- reduced molded in stress, and therefore improved dimensional stability with no distortion.

The processing conditions are very important in any technological processes and has main impact on properties of moulded parts [39].

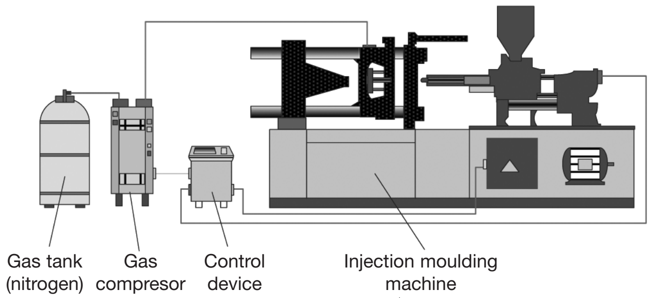

Fig. 2. Scheme of connections between injection moulding machine and equipment for GAIM process (located in ANITEX Comp)

GAIM is much more complex process than traditional injection moulding because gas (nitrogen) flow inside melted core of moulding is unpredictable and depends on many conditions related with:

- properties of processing materials and its rheological properties;
- correctness of mould construction;
- processing conditions.

This article was to study influence of processing conditions on the dynamical mechanical properties mouldings made by gas assisted injection moulding technology (GAIM) made with different processing conditions. To the best knowledge of the authors, no research paper [24-32] has ever studied the above-mentioned problem regarding with influencing of GAIM processing condition on dynamic mechanical properties moulded parts.

2. Materials and sample preparing

Copolymer of polypropylene and polyethylene PP/PE included 10-14% of PE fraction produced by Slovnaft has been used for investigations. Experiments were carried out on an 300-ton injection-molding machine HAITIAN HTF300X equipped with a high-pressure nitrogen-gas injection unit produced by CINPRES company (SP3000). Scheme of connections between injection moulding machine and equipment for GAIM process is present in Fig. 2. Two-cavity mould with a gas channel across the center was used. Various processing conditions were studied in terms of their influence on the dynamic mechanical properties of molded parts during preliminary tests:

- melt temperature;
- mould temperature;
- melt filling speed;
- gas pressure;
- gas injection delay time.

For the final experiment only 3 parameters which has the biggest influence were chosen, its were presented in Table 1. The mould used in investigations is present in Fig. 3.

The view and cross-section of injection moulded part used for investigation was presented in Fig. 4.

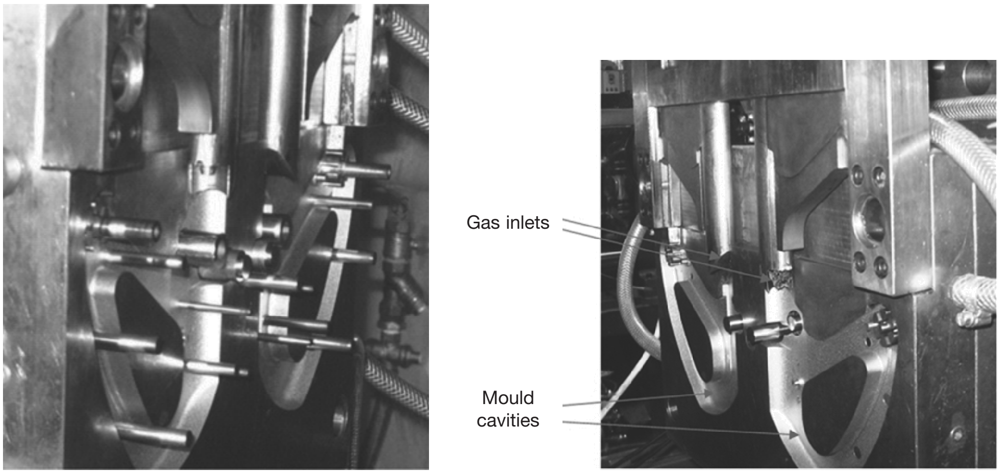

Fig. 3. Experimental two cavities mould (left and right side)

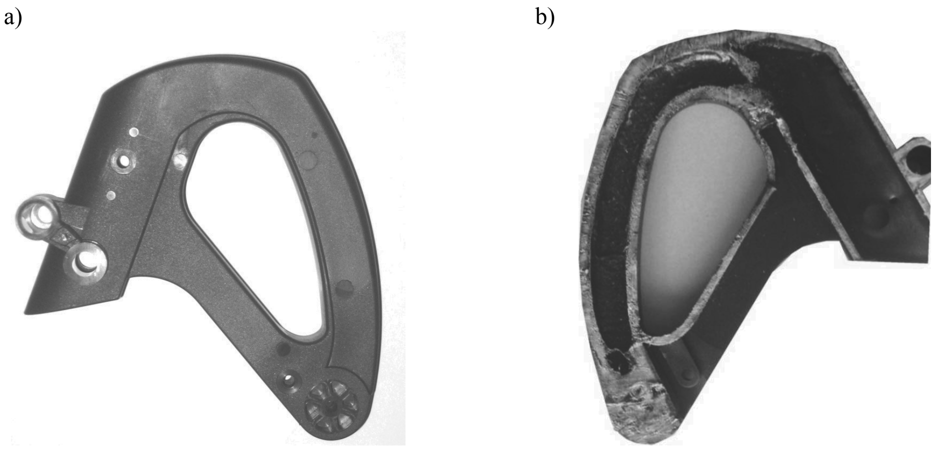

Fig. 4. View of moulded part (a), and its cross section (b)

2.1. Plan of experiment DoE

The preparation of research samples were carried out under the conditions set up in Design of Experiment module of STATISTICA software. As mentioned three main process conditions were selected during preliminary research, and then matrix of experiment was prepared. Plan of experiment is present in Table 1. For DMA research only samples no 9, 10, 11, 12, 13, 14 were choose, rest samples will be used for future investigations of mechanical properties as: stiffness, hardness of surface and other.

Samples for research were cut off from injected parts as a cuboids beam with dimensions of 3x8x16 mm, and then tested in order to determine the dynamic mechanical properties by means of DMTA method, thus to determine the storage modulus E' and the mechanical loss factor tgδ, responsible for dispersion of mechanical energy.

Table 1.
Matrix of investigation plan

Sampling plan No.	Melt Temperature T_w, °C	Gas injection delay time , t_{pg}, s	Gas injection time t_d, s
1	185	1	35
2	185	1	47
3	215	1	35
4	215	1	47
5	185	3	35
6	185	3	47
7	215	3	35
8	215	3	47
9	200	0	41
10	200	4	41
11	175	2	41
12	225	2	41
13	200	2	31
14	200	2	52
15(C)	200	2	41
16(C)	200	2	41

A wide range of temperatures was assumed for investigations from -60°C to 150°C. This will enable to assess the changes in dynamic mechanical properties of investigated materials not only in useable temperature, narrow range of temperatures (-5 to 35°C), but it will enable to track the differences in morphological structure, which could be revealed only outside the range of usable temperatures.

2.2. Equipment and conditions of measurements

The tests were performed by means of DMA 242 device by NETZSCH® (Fig. 5a) with the holder for three-point free bending in the form of a beam. Fig. 5b presents a measurement device with a specimen, mounted and loaded. For the specimen the vibrations with different frequency and fixed amplitude were applied while it heating. On the basis of the value of force and deformation (read by means of extensometer sensors in-build in the device), with consideration of the specimen dimensions, the value of the storage modulus E' and loss modulus E" as well as tgδ are calculated. Next, the obtained results are presented in the form of chart of changes in the above-mentioned values as a temperature function [33-37].

a) b)

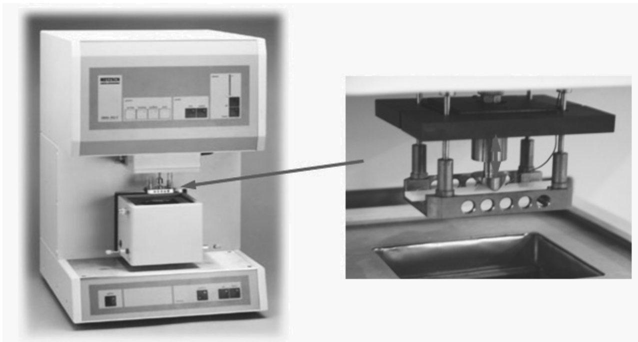

Fig. 5. DMA 242 device by NETZSCH, a) general overview; b) specimen holder overview

3. Description of achieved results of dynamic mechanical research

The follow Figs. 6-8 present results of DMTA investigations and all of them presents changes in storage modulus (E'), mechanical loss factor(tgδ) as a function of temperature.

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

- range of the elastic strain up to -20°C;
- range of the glass transition from -20°C to +20°C;
- range of the highly elastic strain from +20°C to +100°C;
- range of plastic transition, above 100°C.

All samples were made in different conditions, and during research two of samples are compare in each DMTA investigations. All research was performed in the same temperature range for between -55°C and 150°C.

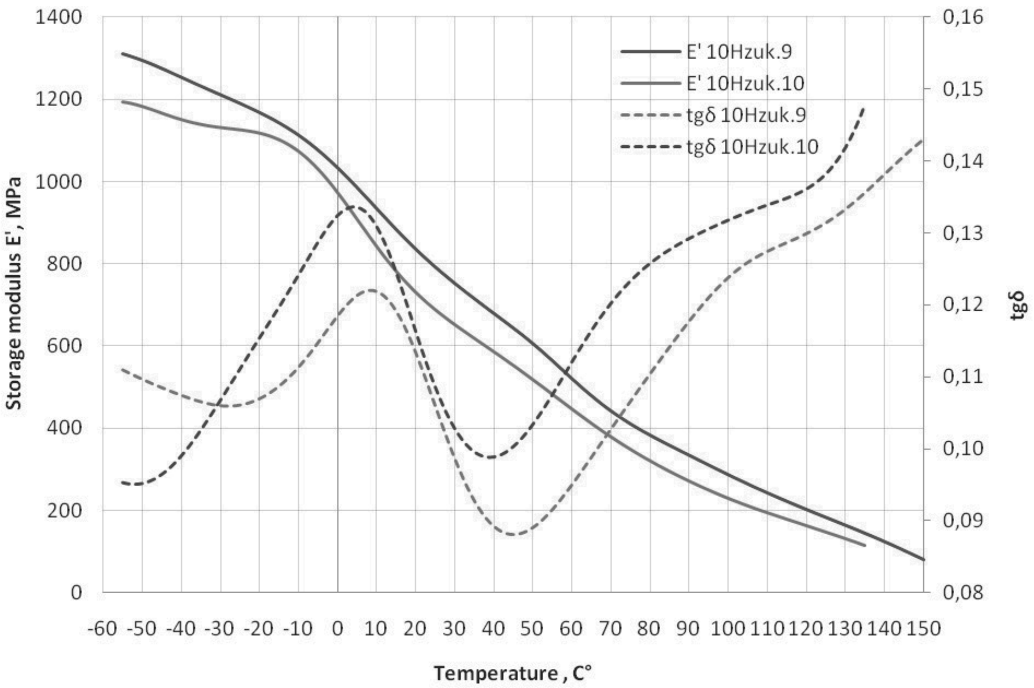

Fig. 6. Dependent of storage modulus E' and the value of loss tangent tgδ as a function of changes gas injection delay time: red line - 4 s, blue line 8 s. Vibration frequency 10 Hz

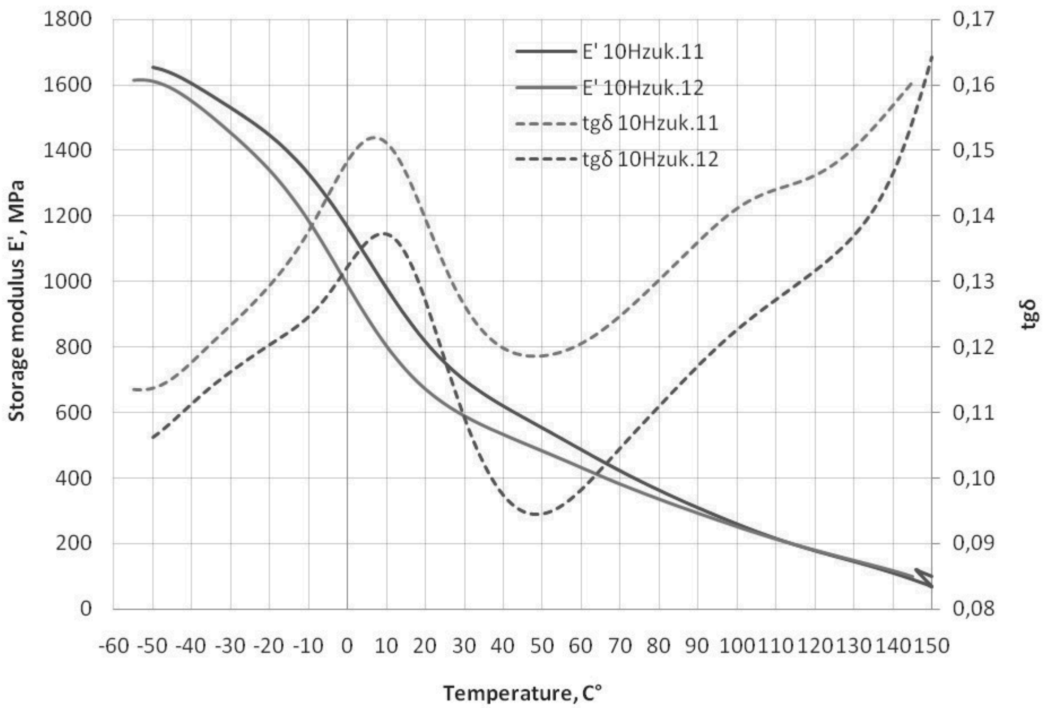

Fig. 7. Dependent of storage modulus E' and the value of loss tangent tgδ as a function of changes of melt temperature: red line - 175ºC, blue line 225ºC. Vibration frequency 10 Hz

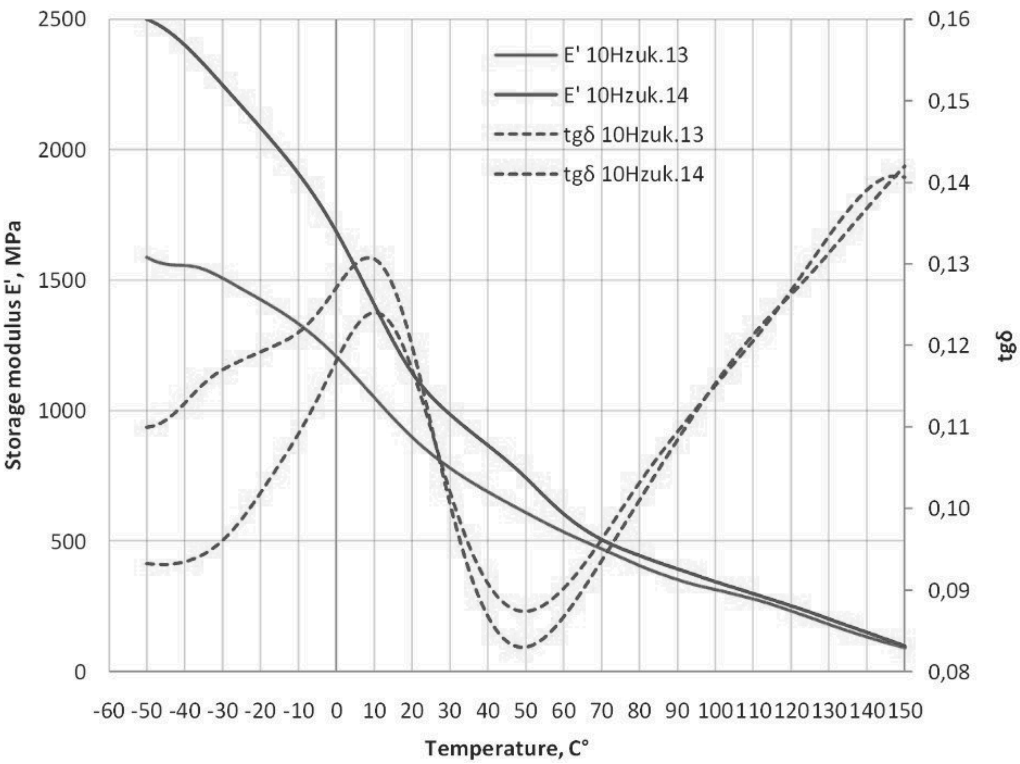

Fig. 8. Dependent of storage modulus E' and the value of loss tangent tgδ as a function of changes of gas injection time: red line - 52 s, blue line 31 s. Vibration frequency 10 Hz

3.1. Effect of gas injection delay time

In the Fig. 6 changes of storage modulus E' and mechanical loss factor tgδ vs. temperature and differences between sample 9 and 10 concern gas injection delay time were presented. For sample no. 9 gas injection delay time was 4 s, and for sample no. 10 was 8 s. In Fig. 6 we can observe that higher value of storage modulus was obtained using short time of gas injection delay, maximum value of E' was about 1300 MPa. We didn't see clearly point of inflection E' curve. For samples 9 and 10 the differences of E' are not big, but not the same in the whole temperature range. The biggest difference we can observe in the range of the elastic strain.

3.2. Effect of melt temperature

Next curve (Fig. 7) presented changes of storage modulus E' and mechanical loss factor tgδ vs. temperature and differences between sample 11 and 12 concern value of melt temperature. Sample no. 11 was made with melt temperature 175ºC and next (no. 12) with 225ºC. The higher value of storage modulus was obtained using low melt temperature, maximum value of E' was about 1700MP, and we can see that the biggest differences in value of E', are in range of the glass transition and the highly elastic strain from (-20°C to +60°C).

The curve of mechanical loss factor tgδ show peak around temperature of +5°C - it is a glass transition temperature and that value is constant for all investigated samples, because it is connected with chemical structure of raw material used for research.

We observe quite big differences in tgδ curves especially above 20°C. In temperature 50°C this difference between investigated samples was 0.25.

3.3. Effect of gas injection time

The last of curve, presented in Fig. 8, show changes of storage modulus E' and mechanical loss factor tgδ vs. temperature and differences between sample 13 and 14 concern gas injection time were presented. The biggest differences we can observe in that figure, that concerned especially E' curves of investigated samples. For sample no. 13 gas injection time was 31 s, and for sample no. 14 was 52 s. In temperature of -50°C value of E' (for sample made with 52 seconds gas injection time) was around 2500 MPa. It is about 1000 MPa more than sample made with 31 seconds gas injection time, and much higher than rest of samples investigated during whole researches. That difference between samples no 13 and 14 decreasing in range of temperature form -50°C to +70°C, and above 70°C storage modulus (E') (for investigated samples) maintain more or less the same value. For mechanical properties of injection moulded parts, especially stiffness and density the biggest influence has post filling stage. In GAIM technology gas injection time has that same importance like hold pressure in conventional injection moulding technology. Using long time of post filling stage we can obtain better mechanical properties (stiffness and density) but to high gas injection time and gas pressure could have negative influence for residual stresses of mouldings [39-42].

4. Conclusions

Presented in the article investigations of dynamic mechanical properties by means of DMTA method are useful for interpretation of many phenomena which occur during polymer processing. The fact of existence of influence of used processing conditions on dynamical mechanical properties analysing use DMTA were presented.

The most influence on dependence of the storage modulus E' and the mechanical loss factor tgδ has gas injection time, and for this processing parameter observed differences was biggest. In the rest investigation we can see some differences too but its importance were much more smaller.

The macromolecule packing density (dependent on gas injection time) influence on stiffness of moulded parts.

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.

That paper is only one of whole part of research regarding influence of processing condition on properties parts made using gas assisted injection moulding. Rest of results (mechanical properties: stiffness, hardness and other) will be compare with presented in present article.

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