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Influence of injection moulding parameters on resistance for cracking on example of PP

D. Kwiatkowski*, J. Nabiałek, P. Postawa
Institute of Polymer Processing and Production Management, Czestochowa University of Technology, Al. Armii Krajowej 19c, 42-200 Czestochowa, Poland
* Corresponding author: E-mail address: kwiatkowski@kpts.pcz.czest.pl

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Materials

ABSTRACT

Purpose: Purpose of this paper is analysis of injection moulding conditions influence on fracture mechanics on example of PP.

Design/methodology/approach: For the cracking tests, polypropylene with the commercial name Reslen manufactured by Polimarky has been used. Samples for the tests have been made by injection method on injection machine Krauss-Maffei with symbol KM65 – 160. The machine was equipped with high class control system with symbol C4. Variability of the four following parameters of injection process was taken into consideration: injection temperature, temperature of mould, pressure of closing and injection speed. It also should be reminded about analysis of correlation multidimensional, analysis Pareto enabling evaluation of weight of following entrance values in model comparing (regression), what is the base of optimal actions. Crack resistance examination were carried out using a special device allowing measurements of basic parameters of crack mechanics, such as: coefficients of stress intensity, gap divergence and J integral.

Findings: On value of the integrity J being measure of crack resistance the biggest influence have the mould temperature and injection temperature.

Research limitations/implications: Analysis of influence the values of following injection parameters for changing the crack resistance during dynamic bending for PP has been done in the future.

Practical implications: The results of experiments will allow to determine the recommendations referring to the optimization of processing conditions, and as a result of this polymer will have high fracture resistance

Originality/value: The samples for the test have been prepared on base of elaborated schedule. It has been prepared with help of specialist modulus DoE Design of Experiment from packet STATISTICA 6.0 PL.

Keywords: Engineering polymers; Properties; Crack resistance; Statistic methods; Polypropylene

1. Introduction

Basic task of the mechanic of cracking is knowledge and characteristic of the process of cracking the testing material. For the purpose it is necessary to define of strange characteristic of the material, from which the construction is made of. That can be indicated by experience or defined on base of analyze of initial structure of tested material. The first of the way is typical empirical approach so and burden with errors related to conditions in which the experiment has been carried out. Nevertheless this is the most used method – first of all because of rather simple methods of definition strength characteristics, but measuring errors can be minimized by proper “treatment” of the statistic experimental results. The other way is unusual hard, because it takes into consideration whole complexity of matter construction. However it can give general look at the characteristics of the material being object of interest. Decreasing of strength of the tested material in relation to its theoretical strength is connected with presence of various defects, which can be divided into defects of I-st and II-nd kind. Defects of the I-st kind are the each types of concentrators of stress in form of sharp gaps or buildup with any optional shapes – therefore that are the defects with geometrical character, not joined with the structure and

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construction of the material. As the defects of II-nd kind it is understood the concentrators of stress in form of dislocation, voids located along the borders of adjoining grains, meddles of strange material causing the contact stresses and each other defects of internal construction of the material. As beginning of the analysis of bodies with macroscopic defects is considered in the Griffith's publication from the year 1920. Phenomenon of cracking, existing in polymers compounds conduct very often into repeatedly decreasing of its resistance and that are especially danger in fragile materials. Designer is able in some frames to change resistance for cracking the polymer compounds through proper choice of the treatment parameters [1,2,3,6,7].

During the injection process the plastic together with filler flowing in the plasticizing system in injection mould is subjected to deformation and activity of changing the temperature and pressure. Interaction of the filler and warp is caused by shrank in the time of production the composite and by different coefficient of heat expansion, exert significant influence for cracking process. In polymer composites strengthen with fillers appear problems with concentration of stress on the border filler – warp. The stresses have enormous influence for resistance on cracking.

Process of cracking in polymer composites is divided usually into three periods. The first period this is the initiation period, proceeding in microstructure of the warp of composite and conduct to coming into being some local defects. In the moment of arising of such defect, mostly in mould some micro gaps, up to obtaining its critical length, in polymer composites mostly caused by viscous and elastic properties of warp. In the moment the second period is rapidly finished, coming into third, that is to say the period of specific cracking, which proceeds with velocity similar to the sound velocity in material and can be the reason of macroscopic understood destroying [4,5,8].

In case, when in polymeric composite already exists some gap with dimensions significant exceeding size of the element of structure the composite can be applied solutions of anisotropic theory of elasticity to theoretical consideration. The theory provides three different types of cracking [1, 2, 3, 6, 7]:

- Through stretching of surface (I),
- Along cutting (II),
- Cross cutting (III).

Measures of resistance for cracking are:

- Coefficient of the stress intensity K_{α},
- Coefficient of releasing the energy G_{α} (α = I, II, III),
- Opening the gap δ_T
- Integral J.

Measures, which values are defined for a moment of initiation advancement of the gap, taking critical values and are considered as constant material. Mechanic of braking deliver so additional tool for designer to be able to count properly resistance of construction with defects.

2. Materials, apparatus and methods of tests

For the cracking tests, polypropylene with the commercial name Reslen manufactured by Polimarky has been used. Samples for the tests have been made by injection method on injection machine Krauss-Maffei with symbol KM65 – 160. The machine was equipped with high class control system with symbol C4.

The samples for the test have been prepared on base of elaborated schedule. It has been prepared with help of specialist modulus DoE Design of Experiment from packet STATISTICA 6.0 PL.

Variability of the four following parameters of injection process was taken into consideration: injection temperature, temperature of mould, pressure of closing and injection speed. The applied schedule is the central composition schedule with coefficient alpha of rotation equal 2. It consist of 18 different systems in accordance with which the samples for tests were made. The systems varying between them, with accepted conditions of treatment, in addition every incoming value existing on five levels. It gives wide possibilities for tests of forming tested values in function of accepted conditions of treatment. It also should be reminded about analysis of correlation multidimensional, analysis Pareto enabling evaluation of weight of following entrance values in model comparing (regression), what is the base of optimal actions.

As bounds of resistance for cracking accepted integral J. the method on base of indication the energy released during cracking with method of multi samples, is quite complicated. Looking for easier solution the scientist Rice developed the easier method for indication the integral J during cracking, which is cold the method of one sample. It bases on establishment of full plasticizing of the area laying on extension the plane of the gap, so it establish existing of the plastic articulation. Finally, the question of definition the integral J, has been solved by Rice and Ernst and Paris. The point of way out for definition the integral J for beam bended in three points is the formula [1,2,3,6,7]:

$$J = -\int_0^u \left(\frac{\partial F}{\partial l}\right)_u du$$

$$M = M_{pl}\, h\left(\theta_{pl}, \frac{\sigma_{ys}}{E}, n\right)$$

Obtained torque varying linear and is proportional to maximal. This condition enabling to write it as M = cPL. The angle of revolution θ is almost equal $\theta = 4u/L$, in addition *u* means bending the beam In cross section of the gap. Converting the formula (2) we will obtain [7]:

$$F = \frac{B b^2 \sigma_{ys}}{4 c L} h\left(\frac{4u}{L}, \frac{\sigma_{ys}}{E}, n\right)$$

Using the relation (4) obtained the sub-integral function of the integral (1), which is [7]:

$$\left(\frac{\partial F}{\partial l}\right)_u = -\frac{2 B b \sigma_{ys}}{4 c L} h\left(\frac{4u}{L}, \frac{\sigma_{ys}}{E}, n\right)$$

Next after using the formula (3) we obtain [7]:

$$\left(\frac{\partial F}{\partial l}\right)_u = -\frac{2}{b}F$$

Placing the relation (6) to (1) obtained final formula of the integral J [7]:

$$J = \frac{2}{B\,b}\int_0^u F\,du$$

or

$$J = \frac{2A}{B(W-1)}$$

In which:

A – Area under the curve of force – relocation obtained in experimental trial.

B – Wide of the sample

W – High of the sample

I – length of notch

The sample with rectangular notch is fixed with dimension 80x10x4 mm on two supports in clamping of measuring tool for testing resistance for cracking. In half of distance, between supports, on placed sample effects force. Distance between supports is 40 mm. During bending the three points measuring apparatus sending analog signal through AC card to computer, where the signal is changed into digital signal (fig. 1). Obtained measuring points being relation the force from relocation were subjected to treatment in software package STATISTICA 6.0 PL to count the area under the curve force – relocation. The area is the energy released during cracking the sample. On the base of energy of releasing for tested polymer composite the integral was calculated being measure of resistance for cracking for static load.

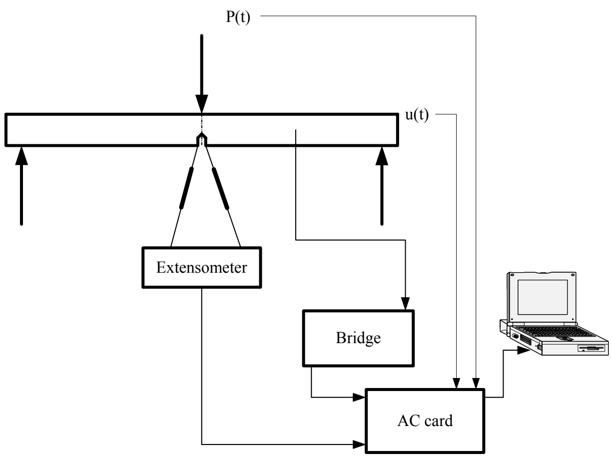

Fig. 1. Scheme of device for testing resistance for cracking

3. Investigation results and discussion

Results of analysis Pareto concerning influence conditions of injection for value of the integral J for PP on fig. 2. The figure shows, that temperature of mould and temperature of injection are the principal determining factor about resistance for cracking. In significant less degree remaining parameters of the injection process, i.e. pressure of clamping and injection speed. Sign near absolute value of evaluate the effect explain the way of relation. If next to value exist the sign „-”,it means, that increasing the value of the variable causing decreasing the analysis variable. And such for PP the sign „+” next to T_w indicates , that increasing of value the injection temperature causing also increasing the integral J being measure of resistance for cracking. With higher injection temperature plastic has lower viscosity and therefore during phase of pressing following better packing of macromolecules (bigger density), in a row lower viscosity causing lower resistance related to flowing the plastic through running channels, narrow and forming cavity.

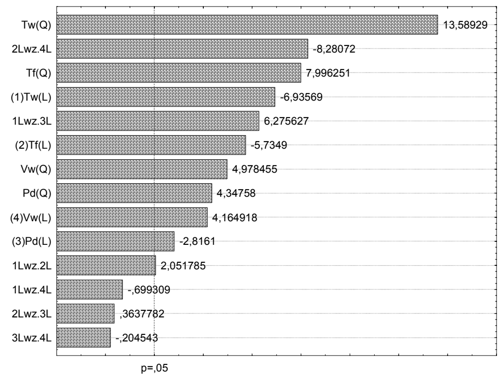

Fig. 2. Chart Pareto for PP

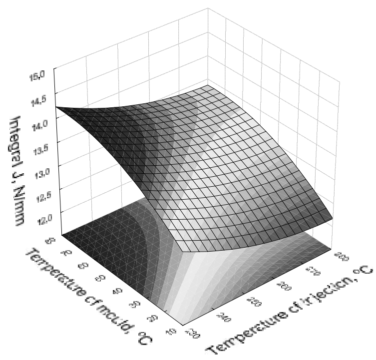

Fig. 3. Relation of integral J from temperature of mould and temperature of injection for PP

On fig. 3 is presented relation changing of value the integral J in function of the mould temperature and injection temperature for PP. maximal values of the integral J obtained with maximal injection temperature and minimal mould temperature.

On fig. 4 is presented relation of changing value the integral J in function of mould temperature and injection speed for PP. Maximal values of integral J obtained with maximal mould temperature and minimal injection speed and with maximal injection speed and minimal mould temperature. Parts obtained with higher mould temperature, characterizing bigger value of degree of crystallization. This is connected with thermodynamic state of the plastic in cooling phase. With higher mould temperature, cooling time for parts, is subjected to increasing for every thanks of increased activity is facilitated conforming the physical structure of polymer.

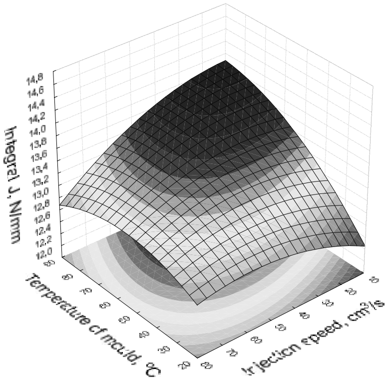

Fig. 4. Relation of integral J from injection speed and temperature of mould for PP

4. Conclusions

On the base of analysis Pareto influence of values the following injection parameters for changing of resistance for cracking the injected parts has been estimated. As the most important measure of resistance for cracking the injected parts is acknowledged the integrity J. Analysis of influence the values of following injection parameters for changing the resistance for cracking for PP has been done. Determined parameters of model equations describing varying the integrity J being measure of resistance for cracking in function of selected injection conditions. High values of coefficients of fitting R^2 of the equations (more than 95%) to experimental results, testify, that obtained on the way of static analysis the model equations accurate reflect the results of experimental tests. On value of the integrity J being measure of crack resistance the biggest influence have the mould temperature and injection temperature. All remaining injection parameters have influence, but lesser. For PP the mould temperature and injection temperature are positive correlated with resistance for cracking i.e. together with increasing the mould temperature or injection temperature the resistance for cracking increase. With higher injection temperature, viscosity of plastic is lesser and because of that during pressing phase it is coming better packing of macromolecules of plastic, we obtain higher density. With higher mould temperature, cooling time for injected part is subjected to increasing, and because of that we obtain improving of putting in order the physical structure of polymer. Obtained injected parts with higher mould temperature are characterizing with bigger value of degree of crystallization.

Acknowledgements

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