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Determination of crack resistance on the basis of the J integral for talc filled PP and PA composites

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Abstract: The results of investigations of the influence of a talc content in PP and PA composites on the J integral value have been presented. PP and PA composites with 25% talc content were prepared in an industrial production line in Polimarky company from Rzeszów. Test specimens from PP and PA composites with 5, 10, 15, 20 and 25% talc content were moulded using Krauss-Maffei KM65 – 160 C1 injection molulding machine. 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. The influence of talc powder content on the J integral value for PP and PA composites has been graphically presented. Some comparisons and conclusions have been presented.

Keywords: PA, PP composites, Crack resistance, Integral J

1. INTRODUCTION

Cracking phenomena which occur in polymer composites, often lead to a few-times decrease in its strength and are peculiarly dangerous in brittle materials. The designer is able, within certain limits, to change crack resistance of polymeric composites through proper choice of their ingredients.

During the injection process the plastic and filler, flowing inside the plasticizing system and inside injection mould, undergoes the deformation and is influenced by changing temperature and pressure. Mutual interactions of filler and base material caused by the shrinkage during manufacturing the composite and different coefficient of thermal expansion significantly influence the cracking processes. In polymeric composites reinforced by the fillers, the problems with stresses concentration at the interface – filler – base material arise. These stresses exert significant influence on the crack resistance. Particular emphasis will be put on filler preparation since as it is know from the scientific research, the most material failures appear at the interface filler - base material [4,5].

The process of cracking in polymeric composites is usually divided into three stages. First stage is an initiation period which happens in microstructure of composite base material and leads to appearance of a local damage. At the moment of the appearance of such a damage, mostly in form of microcrack, next period starts, of a slow crack development until reaching

its critical length, in polymeric composites usually triggered off by the viscoelastic properties of the base material [4,5]. In this moment the second period suddenly ends, replaced by another one, third i.e. the period of the cracking itself, which happens at the speed similar to the speed of sound in material and may be the reason of the damage understood in a macroscopic way. In polymeric composites, in case of a crack with the dimensions much higher than the size of the composite structure element, the solutions of anisotropy elasticity theory can be applied to theoretical considerations. This theory assumes three different types of cracking [1,2,3]:

- through the surface elongation (I),
- through the longitudinal shear (II),
- cross-sectional shear (III)

The stresses and dislocations will be calculated independently for each type of the load, and next the superposition of solutions will be done.
The measure of the crack resistance may be [1,2,3]:

- stress intensity coefficient K_α,
- energy release coefficient G_α (α = I, II, III),
- crack spacing δ_T
- integral J.

The measures, which values are defined for the moment of initiation of the crack development, assume critical values and are found as material constants.

2. MATERIAL, APPARATUSES AND INVESTIGATION METHODOLOGY

For the crack resistance investigations the polyamide 6 with commercial name Tarnamid T -27 by Zakłady Azotowe S.A. in Tarnów, Poland and polypropylene with commercial name Malen P J – 400 by PKN Orlen S.A. have been used. For reinforcing the both plastics, powder filler in form of talc have been used. PP and PA composites with 25% of talc concentration have been produced at the industrial manufacturing line in Polimarky company in Rzeszów, Poland. The samples for the investigations made of PA and PP composites with concentration of 5%, 10%, 15 %, 20% and 25 % of talc have been prepared by means of injection method with the Krauss-Maffei KM65 – 160 injection moulding machine.
In non-linear materials the stresses distribution at the start of a crack peak depends on the integral J which is presented as a relation [1,2,3]:

$$J = -\left(\frac{\partial U}{\partial a}\right)_{u_t=const} = -\int_0^{u_t}\left(\frac{\partial P}{\partial a}\right)dU = \int_0^{P_t}\left(\frac{\partial U}{\partial a}\right)_{P_t=const} dP$$

where: ut – dislocation of a traverse of testing machine;
P – registered force

In case of linear materials an unambiguous dependency appears between stresses intensity coefficient K_α and energy release coefficient G_α

$$G_\alpha = \frac{K_\alpha^2}{E}.$$

Energy release coefficient G_α defines the change of potential energy of a sample made of polymeric composite along with infinitesimal increment of a crack length:

$$G_\alpha = -\frac{\partial U}{\partial a}$$

where: U – potential energy
a – crack length

For linear material J=G. In a given work the material constant J called also Reice's integral will be empirically determined in case of quasi-static loads. The integral measurement is realized by the three-point bending of the samples with the notch. The integral J will be determined by means of method of change in flexibility of the sampled made of polymeric composite. The change in flexibility of a sample is determined by the test of three-point bending together with partly unloading up to 10% of the applied force. On the basis of the change in flexibility, next increments of crack will be calculated out of the dependency[1]:

$$\Delta a_i = \frac{b \cdot (C_i - C_0)}{C_0}$$

where: b – the length of the cracked part at the starting point of the crack peak,
C_i, C_0 – present and initial flexibility of a sample

The flexibility will be calculated out of the dependence $C_i = \left(\frac{\Delta u}{\Delta P}\right)_i$

u - dislocation of a point where the force is applied

The integral J is calculated on the basis of a Srawleya equation

$$J = \frac{\eta \cdot A}{w \cdot b}$$

where: A – surface area under the P(u) dependence curve
$\eta = 2$ – for the three-point bending

3. INVESTIGATION RESULTS AND DISCUSSION

According to the theory of the composite design, receiving the proper, planned final effect requires not only appropriate matching the composite components but also optimising the size, quantity and the shape of the reinforcing filler introduced to the base material. In the Fig. 1 the influence of the filler (in form of talc) concentrations on the value of integral J for different thermoplastics have been presented.

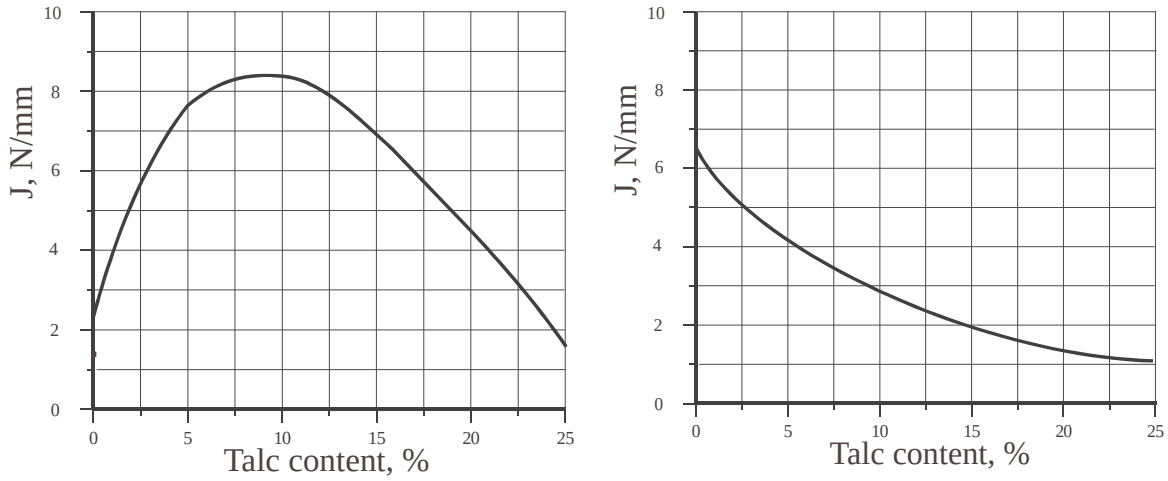

Figure 1. Influence of the filler (in form of talc) concentration on the value of integral J for different polymers a - PP; b – PA.

The investigations of the crack resistance on the basis of integral J prove that the crack resistance depends not only on the talc concentration but also on the type of a polymer base material. In case of polyamide 6, increase in powder filler (in form of talc) concentration causes determined continuous decrease in the integral value, while in case of polypropylene it increases the value of the J integral up to certain values and only then it starts to decrease

4. FINAL CONCLUSIONS

Cracking mechanics issues in polymeric composites are still up-to-date and very important from the usability point of view. The description of initiation and crack development processes in polymeric composites still causes a lot of trouble, very often showing literature ambiguities and also disputable results of conducted analyses. The results of investigations received within the confines of the given research project will enable to determine the factors which influence crack resistance. Some crack resistance investigations results quoted above prove the fact that exchanging the thermoplastic polymers by their composites poses opportunities to increase the brittle cracking resistance in a number of constructional polymeric plastics, however, proper designing of such a composite requires detailed analysis of the phenomena (on a micro scale) which occur in the processes of damaging the material and also the experimental verification of the established dependencies. The phenomena of cracking that occur in polymeric composites lead very often to a few-times decrease in its strength and are especially dangerous in brittle materials. The designer can change, within some limits, the crack resistance of polymeric composites through proper selection of:

- concentration, shape and filler type
- processing conditions

The latter of the mentioned factors will be the issue of further investigations on that matter.

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