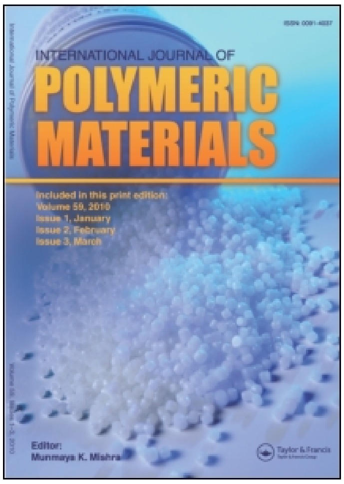

International Journal of Polymeric Materials
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713647664

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To cite this Article Kozlov, G. V. , Zaikov, G. E. and Mikitaev, A. K.(1999) 'Physical Sense of Fractality of Polyethylene Fracture Surface', International Journal of Polymeric Materials, 43: 1, 13 — 18

To link to this Article: DOI: 10.1080/00914039908012122

URL: http://dx.doi.org/10.1080/00914039908012122

Intern. J. Polymeric Mater., 1999, Vol. 43, pp. 13–18
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Printed in Malaysia.

Physical Sense of Fractality of Polyethylene Fracture Surface

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(Received 8 September 1997; In final form 10 December 1997)

On an example of fracture of samples of polyethylene in impact tests is shown that the properties at fracture are formed prior to the beginning propagation of a main crack. It assumes, that the characteristics of a surface of fracture and property of polymers can be connected only indirectly. The basic role belongs dissipations of led energy by mechanisms of local deformations. Simple model for determination fractal dimension of a surface of fracture is offered, proceeding from zones local shear on a surface of fracture of samples polyethylene.

Keywords: Fracture surface; fractal dimension; polyethylene; impact tests; Koch constructions

INTRODUCTION

Several studies have been recently published in which the fractal dimension of surface fracture is unequivocally connected with the ultimate characteristics of materials, mainly with the critical stress intensity stress intensity factor [1–4]. These studies were experimental [1, 2] as well as theoretical [3, 4]. However, there exists another point of view which is now gaining support [5–8] namely that these correlations lack general validity. Ivanova and Vstovsky [9] had pointed out that with the surface of fracture cannot be explicitly described with the help of only one fractal dimension. In this connection

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they suggest to apply a multyfractal concept to the modeling of fracture processes.

RESULTS AND DISCUSSION

The multifractal concept assumes that multifractal geometry can be described with the help of an infinite number of fractal dimensions, provided the parameters are properly set. This idea was explored by Vstovsky *et al.* [10]. The aim of this communication is to examine this idea on the fracture process of high density polyethylene (HDPE) samples with a sharp notch.

Thd data of the impact tests of industrially produced samples of HDPE (mark 273) with a sharp notch made according to Sharpy technique on an instrumented machine at the temperature of 293 K [11] were used.

The insert in Figure 1 shows a typical diagram for "loading-time" ($P-t$) is for a HDPE sample with a sharp notch to illustrate the process of quasi-brittle fracture. Such a $P-t$ diagram allows us to formulate the following interpretation of the processes of deformation and fracture of the samples studied [12]. When a sample is bent, the accumulation of elastic energy occurs and at the tip of the notch (stationary crack) a zone of local deformation is formed which prevents the propagation of the main crack. When the maximum loading $P_{\max}$ is achieved the level of the accumulated elastic energy becomes sufficient for the fracture of sample. The fracture process is realized as a very fast propagation of the unstable crack indicated by the vertical line of loading dropping below $P_{\max}$. Thus, all the mechanical properties of a sample are determined at the stage of its deformation and not at the stage of fracture. So, a notched impact strength A_p is a linear function of the size of zones of local plastic deformation r_p ("lips of shear"), visually observable on the surface of the fracture [11]. The same could also be said about other parameters of the fracture process. The energy of fracture is determined by the area under diagram $P-t$ and vertical decay of a loading below $P_{\max}$ signifies a practical lack of any energy expense spent at the fracture process itself, if the latter is understood as a new surface formation. Thus, any direct relations between the characteristics (fractal ones included) of the fracture surfaces and the parameters of the fracture process cannot exist. However, an indirect the relationship of this kind can be observed in fracturing samples similar to polyethylene if it is assumed that the major contribution to the fractality (or, crudely speaking roughness) of the fracture surfaces are those "lips of shear", which, define the macroscopic ultimate properties of the samples. In such an interpretation of fractality the fracture surfaces of HDPE samples acquire a rather definite sense for material science. If we assume that "the lips of shear" can be schematically as shown the bottom insert of Figure 1 we will find it convenient to model them by means of elements of Koch's figure shown in the top insert of Figure 1. In this case the fractal dimension of Koch's figure is determined as $\ln 4/\ln 3 = 1,263$ *i.e.*, as the ratio of natural logarithms of the number of elements after and before the transformation. From the schematic section of a surface of fracture it can be seen that since the size of "lips of shear" r_p can be arbitrary, the numbers of elements will consequently be fractal. Then the fractal dimension of a surface

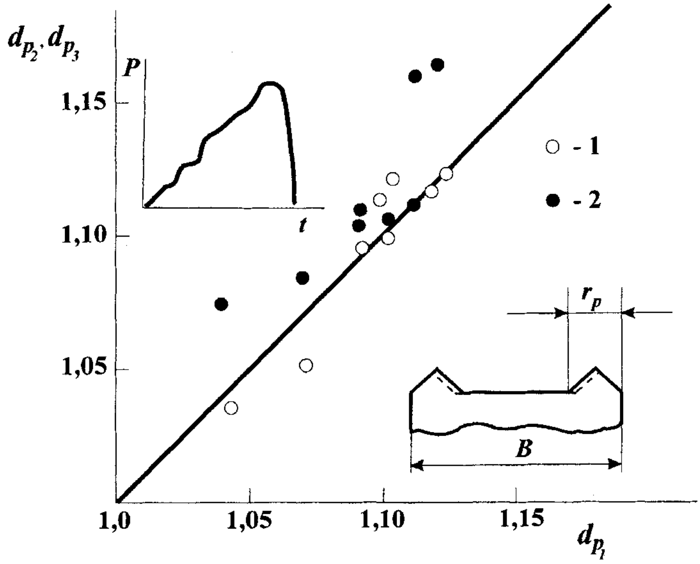

FIGURE 1 Correlation between fractal dimensions surfaces of fracture d_{p_1}, d_{p_2} (1) and d_p (2), calculated according to the Eqs. (1)–(3), accordingly for HDPE. On the insertion above – diagram P–t for a sample HDPE with sharp notch. On the insertion below – schematic cross section sample with "lips of shear".

fracture d_{p_1} can, by analogy to the Koch's figures, be presented as follows:

$$d_{p_1} = \ln(B + 2r_p)/\ln B, \tag{1}$$

where factor 2 of the size r_p shows the presence of two "lips of shear" on a surface of fracture.

The correctness of the estimation of dimension d_{p_1} is possible in two ways based on the estimation of the fractality of surface fracture using the known values of Poisson ratio μ. The first of one uses the equation [14]:

$$d_{p_2} = 10(1 + \mu)/(7 - 5\mu) \tag{2}$$

and second one the formula [15]:

$$d_{p_3} = 1 + \mu^m, \tag{3}$$

where m is the parameter, describing the mechanism of fracture of solids.

In further calculations the value $m = 2$ is used (Griffit's fractal crack, quasi-brittle fracture) [15], taking into consideration the presented P–t diagram. Since the Eq. (2) gives values d_{p_2} for three-dimensional space and we are considering fractality for two-dimensional euklidean spaces, the value $d_{p_2}/2$ [15] was used for comparison.

The μ value was determined by the results of mechanical tests [11] in accordance with the following relationship [16]:

$$\sigma_T/E = (1 - 2\mu)/6(1 + \mu), \tag{4}$$

where σ_T – yield stress, E – modulus of elasticity.

Figure 1 present the comparison of parameters d_{p_1}, d_{p_2} and d_{p_3} calculated in the two of the above given ways. It can be seen from the data a good correspondence is observed between them, which confirms the correctness of the method.

It is obvious that the physical sense given to the fractality of the surface fracture presupposes the correlation of d_p and A_p; the increase in d_p causing the growth of A_p. In fact, the dependence shown in Figure 2 $A_p(d_{p_1})$ confirms this conclusion. We will notice, however, that the empirical correlations similar to the one, given in Figure 2 are

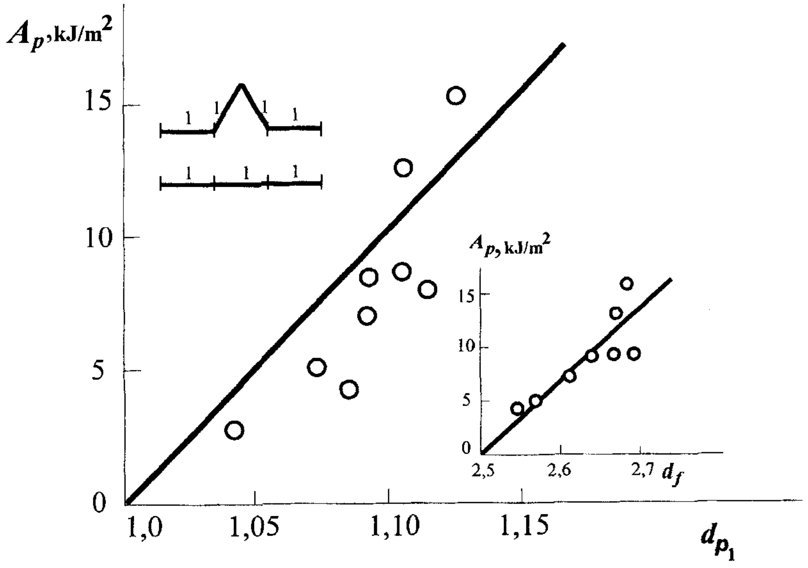

FIGURE 2 The dependence of notched impact toughness A_p from fractal dimensions of a surface of fracture d_{p_1} for samples HDPE with sharp notch. On the insertion above – elements of Koch's figures, illustrating the definition of fractal dimension for "lips of shear" (Fig. 1, the bottom insertion). On the insertion below – the dependence of notched impact strength A_p from the fractal dimension of structure d_f for samples HDPE with a sharp notch.

not common since the density of energy dissipated on the "lips of shear" varies from polymer to polymer.

Considering that the fractal dimension d_f of the polymer structure is also determined by the value of Poisson ratio [14]:

$$d_f = (d - 1)(1 + \mu) \tag{5}$$

where d – the dimension is euklidean space in which the fractal is embedded (in this case $d = 3$), then the correlation $A_p(d_f)$ is expected according to the given results and it is presented in the bottom insert of Figure 2. Though the correlations $A_p(d_p)$ and $A_p(d_f)$ have analogous character the latter carries a considerably greater physical sense, since it is clear that the level of local plasticity of a polymer under fixed loading conditions is determined by its structure.

Thus, the direct use fractal dimensions of the surfaces fracture, formed by an unstable crack for characterizing the ultimate properties of polymers is groundless. Application of the multifractal interpretation [10] in the given case does not change the situation. Nevertheless, if fractal dimension reflects the degree of local plastic deformation then such correlations might, a least be of some practical importance.

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