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Physics Procedia 80 (2015) 148 – 150

Physics Procedia

26th International Conference on Nuclear Tracks in Solids, 26ICNTS

The influence of pores in track etched membranes and prepared on their base polymer/metal composites on their fracture strength

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Abstract

The strength of track etched membranes and prepared on their base polymer/metal composites is analysed in point of view of the pores form evolution during the extension and the interaction of elastic mechanical fields on closely positioned pores. The stress-strain curves for track membranes and composites PET/Cu are demonstrated for pore density $1.2\times10^7 cm^{-2}$ and diameters from 0.06 μm to 2.9 μm

Peer-review under responsibility of the Scientific Committee of 26ICNTS

Keywords: track etched membranes, composites, pores, strength.

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1. Introduction

The mechanical properties remain one of the main material performance characteristics independently of material application. The pores are the integral part of track membrane (TM) structure in Flerov G.N. et al. (1989) and they influence on the fracture owing to three effects. Firstly, it is the trivial decrease of the effective area. Secondly, it is an existence of mechanical stress concentration near the pores that should be take into account by means of the stress concentration coefficient β. Considering TM as a limit case of a composite with zero value of adhesion between the filling and matrix, we offered in Razumovskaya I.V. et al. (2009) a formula (1), which is similar to the formula for the composite material regular model, derived in Nielsen L.E. et al. (1974) and modified by Nicholas et al. (1976).

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Peer-review under responsibility of the Scientific Committee of 26ICNTS
doi:10.1016/j.phpro.2015.11.092

$$\sigma = \frac{\sigma_m}{\beta}(1-\sqrt{P}) = \frac{\sigma_m}{\beta}(1-\sqrt{V_f}) \qquad (1)$$

Here σ and σ_m – the strength of a composite and matrix accordingly; V_f – the volume fraction of the filling particles, which coincide in our case with the value of porosity P; the degree of the values P and V_f corresponds to our two-dimesional problem for through pores with constant cross section; the stress concentration coefficient on pore β is introduced.

2. Experiment

The stress-strain curves for track membranes and composites were obtained in the regime of uniaxial extension on the universal testing machine Autograph AGS – 5 kN by "Shimadzu" with speed of extension 2 mm/min. The samples were represented as strips with gauge light and widths 30×5 mm and were cut by manual cutting press machine REY RAN (Great Britain). Each point on the graph correspond at least 15 samples.

3. Result and discussion

For TM with pore density $n = 1.2\times10^7$ cm^{-2} and pore diameters 0.06 – 2.9 μm we showed that the stress concentration coefficient β changes from 1.2 to 1.6 (for other series TM value β reached 2.4), whereas the theory Landau L.D. et al. (2001) gives β = 3. We explained this fact by the pores form evolution during the process of extension. Let in assume that cross-section of the extended pore is an ellipse, we can write

$$\beta = 1 + 2\sqrt{\frac{b^2}{a^2}} = 1 + 2\frac{b}{a} < 3 \qquad (2)$$

where "a" and "b" – the major and minor semiaxises of the ellipse.

Thus, the deformation of TM leads to decrease of the pore-crack length and increase of the effective curvature radius, as a result β decreases.

The third factor, which should be considered for TM strength, is the interaction of elastic mechanical fields on closely positioned pores. As known in Landau L.D. et al. (2001), this interaction is generated when the distance between pores is less than five pore diameters.

The interaction of pores was modeled by interaction of artificially round holes with 0.3 mm diameter on the polyimide film. Mechanical stress fields were observed with digital camera Levenhuk C310 by microscope. Shear was detected, disposed under 45° to the direction of tension.

The interaction was observed for different holes disposition relatively to each other and for different stress in Razumovskaya I.V. et al. (2009). At the same distance between the pores (15 mm) the interaction of fields for holes, disposed under 45° to the extension direction lead to lower strength value.

If the distribution pores on TM surface would be regular (square lattice), the distance between they would be equal to $\langle r \rangle = 1/\sqrt{n}$. However, the real distribution is practically random, the pores interaction is determined by mean lowest distance, which is $\langle r_{min} \rangle = 1/(2\sqrt{n})$.

This conclusion was approved while comparison of TM strength and strength of polymer/metal composites based on TM. The composites were obtained by matrix synthesis method with electrolysis filling in pores in Bedin S.A. et al. (2010). Composites inherit from TM metal particles distribution. For their fracture the above-described effects remain essential, namely: stress concentration near the filling pores, evolution of pores form and interaction of elastic fields around the particles in pores.

The picture (Fig.1) shows an example of strength dependence on pore diameter for TM and corresponding composite PET/Cu; pore density equal to $1.2*10^7 cm^{-2}$. The effective area decrease because of pores (metal particles) is already taken into account. To the right from the dotted line the average distance between pores (metal particles) is lower than five diameters. To the right from the dash-and-dot line the average lowest distance between two neighboring pores is lower than five diameters. The decrease of TM and composite strength with the increase of diameter to the right of these lines may be interpreted as an influence of mechanical fields' interaction.

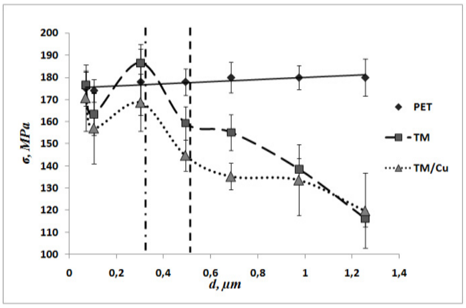

Fig. 1. Dependence of the strength on the pore diameter at a density of pores $1.2 \cdot 10^7$ cm^{-2}.

The composite strength provided to be lower than the same for TM, although the data of the electronic microscopy confirmed a good adhesion between metal and polymer. This can be explained by the different form of evolution for a cylindrical pore with cylindrical particle of filler inside: metal "cylinder" in pore fixes its width while deformation and doesn't let it to turn into safe "slit". When the pore diameters are larger the composites strength starts to increase. Perhaps it is connected with the noticeable growth of metal contribution in strength. For little diameters of pores TM strength within the limits of experiment error coincides with the strength of PET-film: not radiated, but similarly treated by chemical etching. Evidently, such little pores are dangerous for a fracture in the such degree as defects of polymer structure. It concerns the composite too, taking into account that for little pores the contribution of a metal filler in strength is not significant.

4. Conclusion

The strength of TM and composites on its base is essentially depends on pore form evolution during tension and interaction of elastic mechanical fields near closely positioned pores.

Acknowledgements

Work performed in the framework of the Russian Ministry of Education and Science. The authors thank P.Ju.Apel (Joint Institute for Nuclear Research, Dubna) for work results discussion and provided samples of TM.

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