Phenomenological modeling of the ductile fracture of polycarbonate

M.M. Kasaei (INEGI, Portugal), E.A.S. Marques, R.J.C. Carbas, L.F.M. da Silva

Advanced Joining Processes Unit

Introduction

Polycarbonate (PC) is a thermoplastic polymer with an amorphous structure that possess several advantages such as lightweight, transparency, corrosion resistance, ductility and superior impact resistance. Cold forming of polymers has recently received much attention due to short time cycles, less energy, better mechanical properties and simpler and less expensive tooling [1]. Since the plastic deformation of PC sheets is limited by ductile fracture in cold forming processes, the accurate prediction of fracture initiation is vital to design an appropriate process. In the current research work, the ductile fracture of polycarbonate sheets is investigated under the distinctly different deformation paths.

Experiments

This study was conducted on PC with 2mm thickness. The mechanical properties of PC were obtained from uniaxial tensile test according to BS 2782 standard. To investigate the ductile fracture under mode I, different specimens were tested with quasi static condition (Figure 1). A digital image correlation system was employed to measure surface displacement and strain over the gauge region (Figure 2).

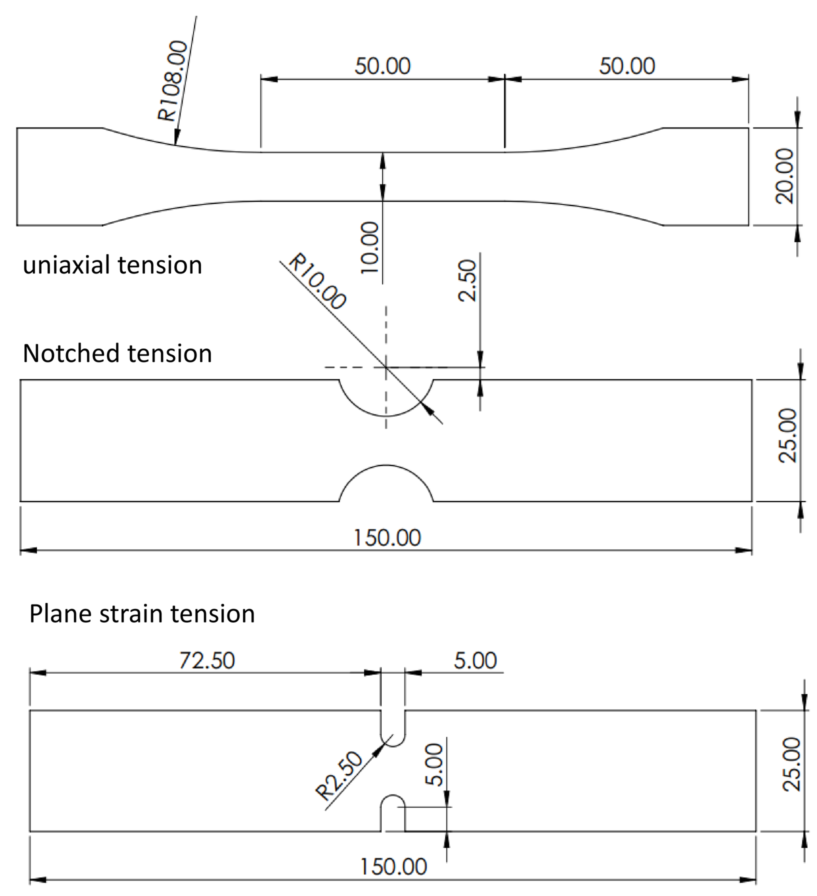

Figure 1 – Specimens used in this study

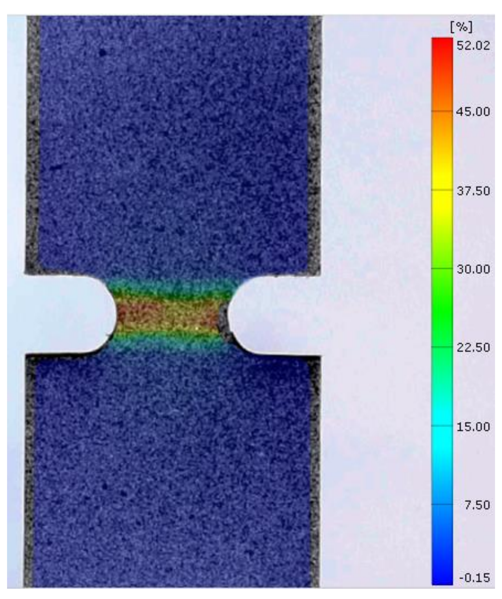

Figure 2 – Experimental distribution of major strain at the onset of fracture obtained from DIC

Finite element modeling

The finite element simulations of the formability tests were performed with the commercial software ABAQUS (Figure 3). A dynamic explicit solver with a time scaling technique was used. The elastic and plastic behaviours of the material were modelled based on the results of the tensile test. To predict the ductile fracture, a non-coupled void growth damage-based criterion proposed for tensile fracture [2], equation (1), was defined in the finite element models by a user subroutine VUSDFLD. The validity of the finite element model was examined through a comparison with experimental data (Figure 4).

$$D = \int_0^{\bar{\varepsilon}_p} \left(\frac{\sigma_m}{\bar{\sigma}}\right) d\bar{\varepsilon}_p \qquad (1)$$

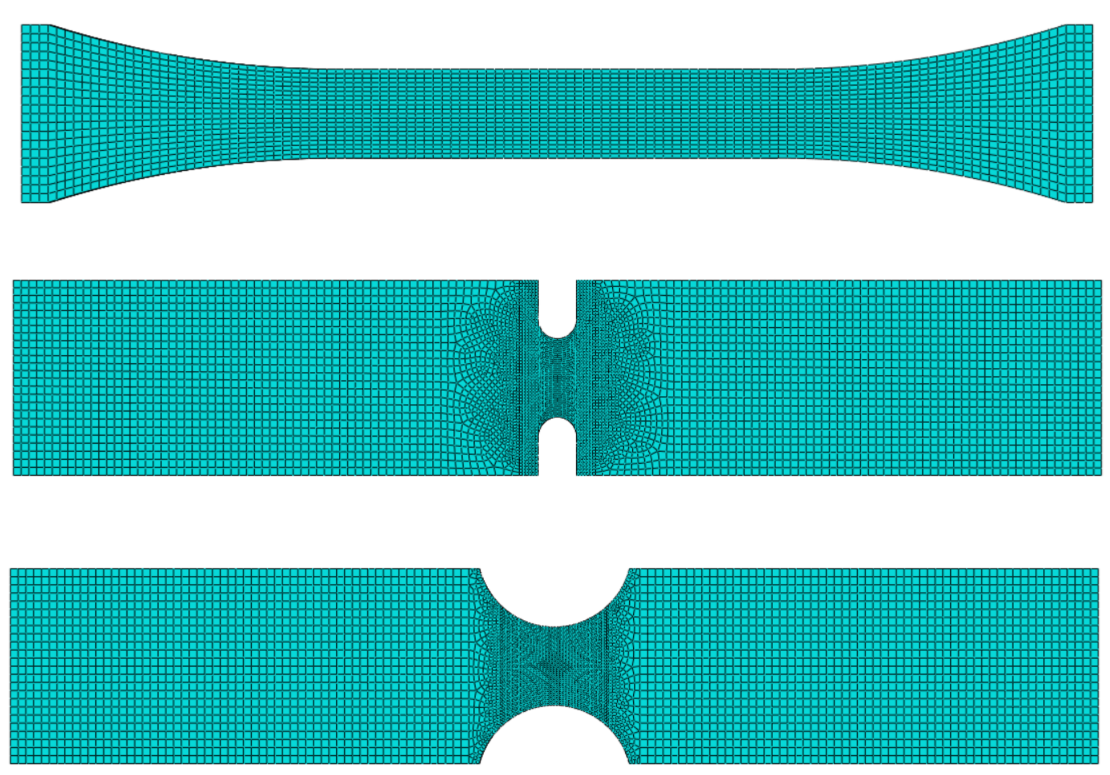

Figure 3 – Finite element models with details of the meshes

Experimental and numerical results

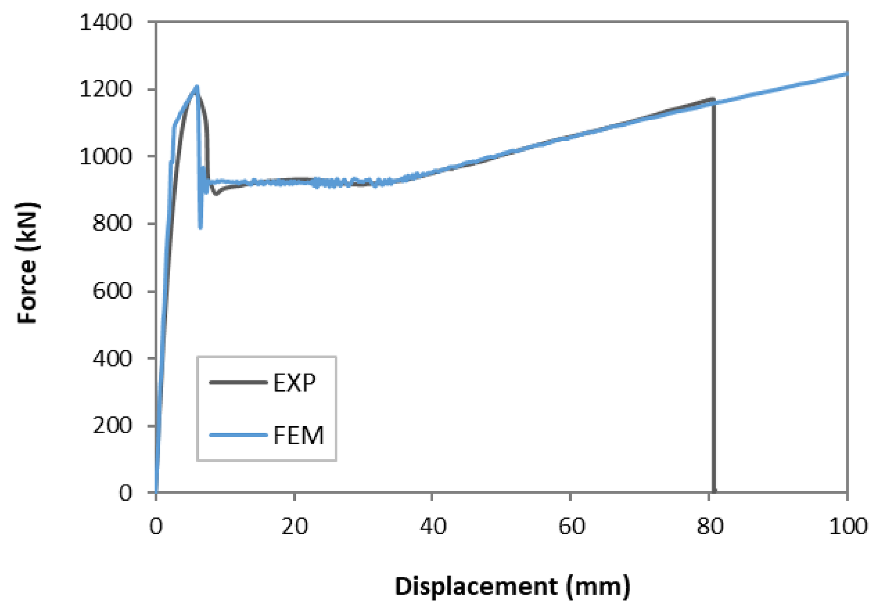

Figure 4 – Comparison of the numerical and experimental force-displacement curves in the uniaxial tensile test

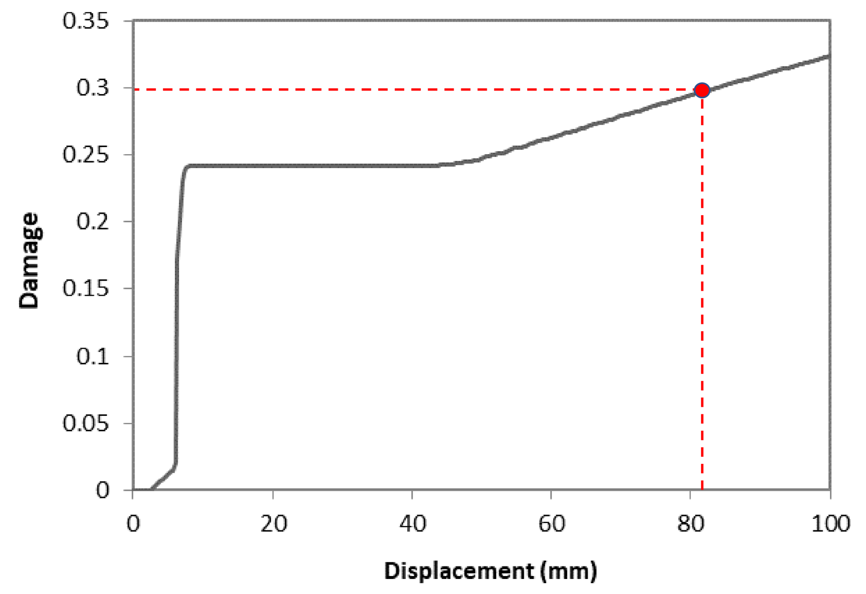

Figure 5 – Damage evaluation with displacement in the uniaxial tensile test

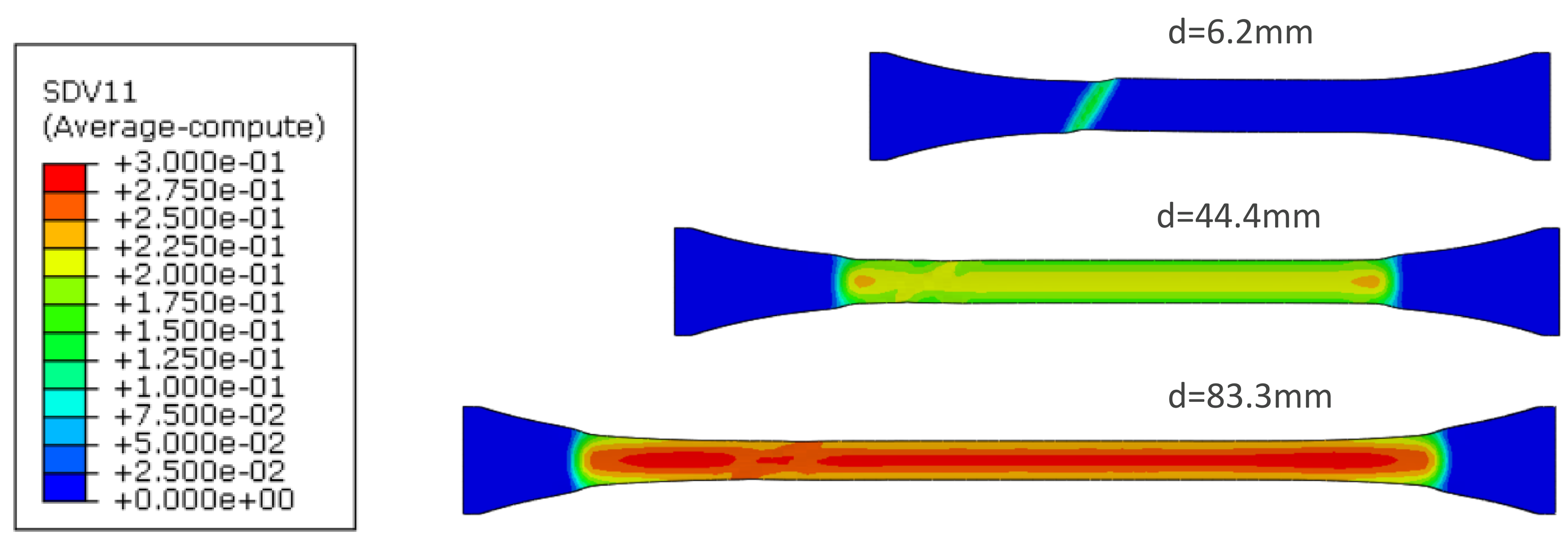

Figure 6 – Distribution of damage during the uniaxial tension test

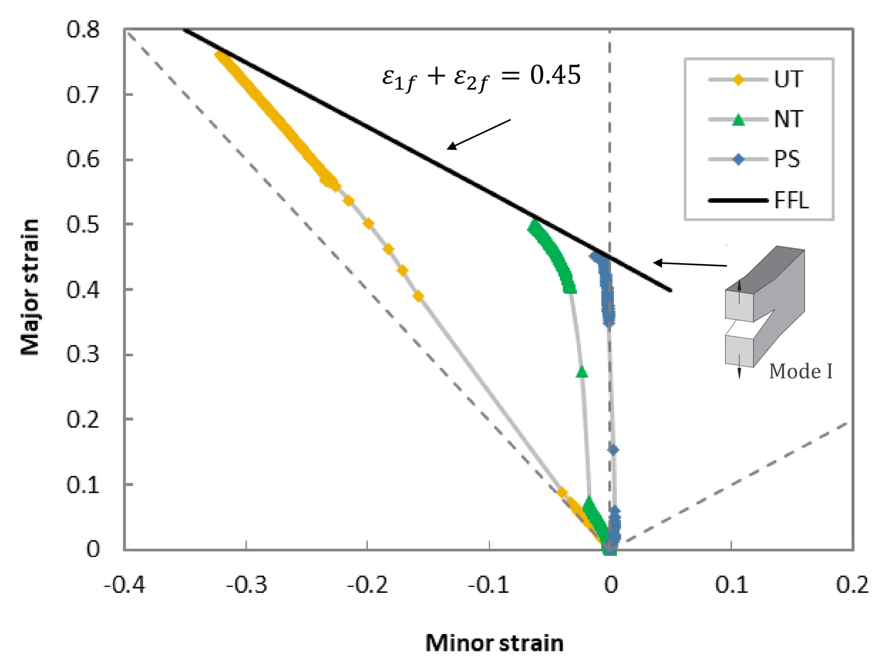

Figure 7 – the strain paths obtained from uniaxial tension, notched tension and plane strain tests that were utilized to determine the fracture forming line (FFL)

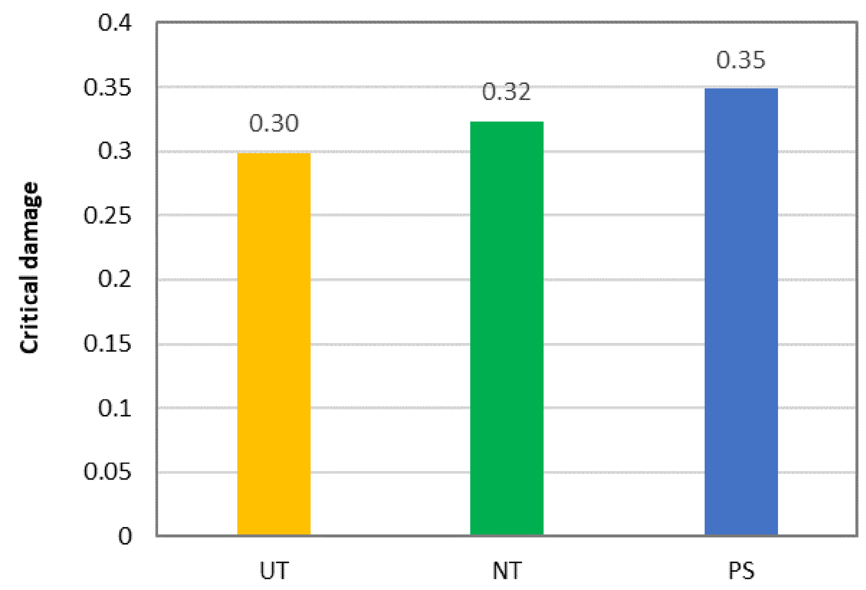

Figure 8 – Critical damage values in the different formability tests

Conclusions

The results showed that in the uniaxial tension test, the damage increases rapidly and significantly with the occurrence of necking, but it remains constant during the neck propagation. After the necking of the entire specimen, the damage increases until the fracture happens at a region that does not necessarily correspond to that region where the necking started (Figures 5 and 6). The same trends were seen in the other two tests, however, due to the fact that the cross-section of the deformation area is not constant, the propagation of the necking is more limited. The fracture limit line (FFL) was estimated with a line with a slope of '-1' (Figure 7), which is completely consistent with the proposed theoretical method for tensile fracture in metallic sheets [2]. According to the presented theory, this line represents the critical damage value of 0.3 for the McClintock criterion when loading paths are assumed to be linear. However, in the notched tension and plane strain tests, due to changes in the loading path, the critical damage was obtained 0.32 and 0.35, respectively (Figure 8).

References

[1] Rosa-Sainz, A., Centeno, G., Silva, M.B., López-Fernández, J.A., Martínez-Donaire, A.J. and Vallellano, C., Materials 13(2020), 928.

[2] Martins, P.A.F., Bay, N., Tekkaya, A.E. and Atkins, A.G., International journal of mechanical science, 83(2014), 112-123.