STRESS CONCENTRATIONS IN PLASTIC PRODUCTS

A.J. Heidweiller*

The effect of geometry discontinuities in PMMA specimens has been studied. Therefore tensile tests and three point bending tests were made. Further, the morphology of the fracture surfaces have been studied. The test results have been analyzed, using FEM technique. The objective is to develop local fracture criteria, which are based on the actual non-linear material behavior. Next the model will be applied to predict the load carrying capacity of plastic products with various geometry discontinuities.

INTRODUCTION

Plastic products often fail due to stress concentrations near geometry discontinuities. However, in consequence of material non-linearity, the effect is often less worse, than the prediction based on linear-elastic theory. This has been studied experimentally for a lot of polymers, especially by Takano and Nielsen (1). The aim of the research project is to get a better understanding of the basic mechanism(s).

Tensile test experiments on injection moulded PMMA specimens were made at temperatures of 22, 30 and 40 °C and at elongation rates of 5, 50 and 200 mm/min. The stress raisers were drilled holes of resp. 0.5, 1.0 and 2.0 mm and double sided notches with tip radii of resp. 0.01, 0.03, 0.1, 0.3 and 1.0 mm.

In addition to the tensile tests also three point bending tests were made using four different cross-head rates. Both razor blade cracks and blunt notches with

* Faculty of Industrial Design Engineering,
Delft University of Technology.

the same radii as applied to the tensile specimens were used.

Next the fracture surfaces of the specimens were analyzed. Besides, stress and strain fields near geometry discontinuities have been calculated using the finite element method (FEM).

RESULTS

The nominal strength of the specimens was determined for all applied combinations of temperature and cross-head rate. The notch factor K_s was calculated with the formulae:

$$K_s = \sigma_Y / \sigma_{nom,u} \quad \text{.............................} (1)$$

Where σ_Y is tensile strength at yield and $\sigma_{nom,u}$ is nominal (ultimate) strength.

As was expected, the differences between K_t en K_s were rather high. E.g., with respect to the tensile tests, the nominal strength (mean net strength) of the specimens with a drilled hole appeared to be at least 76% higher than the nominal linear elastic strength, σ_Y / K_t. At the other hand for the same specimens $1.02 < K_s < 1.48$ was found, which means that the notch factor can not be neglected.

Other conclusions with respect to the tensile tests are:

- Increase of the cross-head rate results in increase of the notch factor. The same tendency holds when the temperature decreases, although then the effect is less pronounced.
- Linear elastic theory is not able to explain the test results. This is opposite to the conclusions of Fraser and Ward (2) for blunt notched PMMA specimens.

Figure 1 shows for three combinations of temperature and cross-head rate, the relationship between the stress concentration factor and the mean net strength of the double sided notched tensile specimens with a 3 mm notch depth ($K_t = 1$ is related to the tensile stress at yield). The figure shows a beneficial effect of blunting especially when high K_t-values are applied.

Figure 2 yields for three temperatures the relation between the nominal strength divided by the absolute temperature and the logarithm of the cross-head speed. The three upper plots represent the tensile strength at yield of the smooth specimen. The parallel position of the plots corresponds with the flow model of Eyring. The three lower plots represent the mean net strength of the double sided notched tensile specimens (notch depth 0.3 mm, tip radius 0.01 mm). Note the smaller time and temperature dependency in case of the notched specimens. This corresponds with the fact that the notch factor rises when the cross-head rate increases.

Fracture surface morphology

With respect to the specimens with a hole, two types of fracture surfaces have been observed. Similar to (2) it is assumed, that one type of fracture mechanism is determined by crack initiation while for the second type craze initiation is determining for the strength. Indeed it appears, that the strength of the first type is higher than the strength of the second type, however the difference was not more than a few percent.

Finite element method calculations

Stress and strain fields have been calculated applying brick elements. Piecewise linear work-hardening material behavior has been assumed. It is aimed to formulate strength criteria based on local stresses and strains. This approach is very similar to the approach of Ishikawa et al. (3), however, the application of the FEM technique makes it possible to include the non-linear (visco-elastic) material behavior more accurate. In future, special attention will be paid to the well known models for cleavage fracture (like the Weibull model) and for ductile fracture (like the Tracey and Rice model).

SYMBOLS USED

K_s = notch factor
K_t = (theoretical) stress concentration factor
$\sigma_{nom,u}$ = nominal (ultimate) strength (MPa)

REFERENCES

(1) Takano, M., and Nielsen, L., J. of Appl. Pol. Sc., Vol. 20, 1967, pp. 2193-2207.

(2) Fraser, R., and Ward, I., J. Mat. Sc., Vol. 9, 1974,pp. 1624-30.

(3) Ishikawa, M., Ogawa, H., Narisawa, I., J. Macr. Sc.-Phys., B19(3), 1981, pp. 421-443.

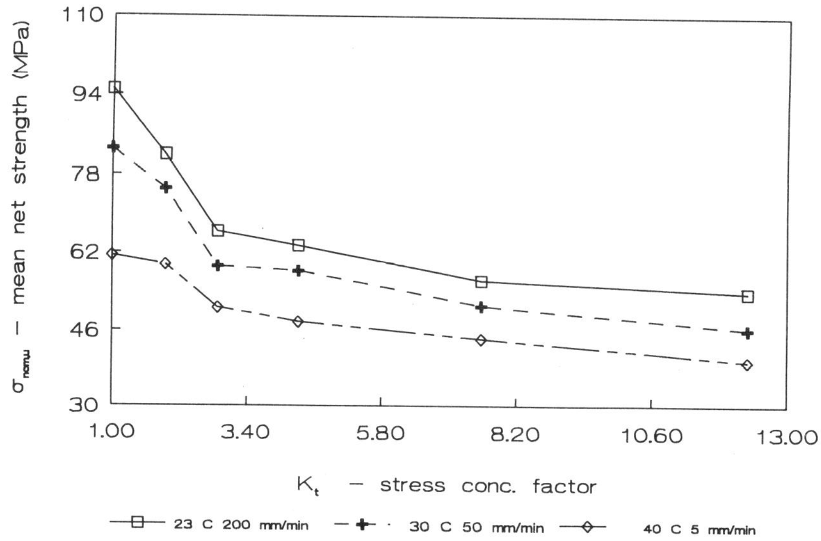

Figure 1 Mean net strength of double sided notched tensile specimens versus K_t. Notch depth is 0.3 mm.

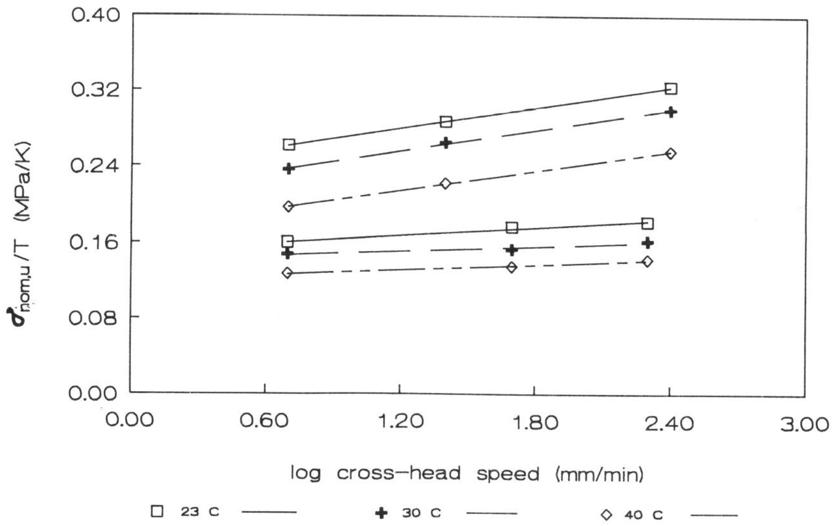

Figure 2 Nominal strength (tensile strength at yield resp. mean net strength) vs. log. cross-head rate.