FRACTURE MECHANISMS AT GEOMETRY CHANGES

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Tensile tests and three point bending tests have been carried out on PMMA specimens containing moulded-in or machined geometry changes. Furthermore, the fracture surfaces have been examined. It was found that in all cases the moulded geometry changes showed a higher load carrying capacity than those which were machined. The morphology of the fracture surfaces revealed that two types of crack initiation occurred for machined geometry changes. For the moulded geometry changes similar initiation types were found although the initiation point was shifted to another location.

INTRODUCTION

Stress concentrations due to geometry changes are often the cause of failure in plastic products. In many situations a product will be moulded with geometry changes included. This will cause an additional effect, which can either increase or decrease the load carrying capacity. Most research in this field is concerned with disadvantage effects as e.g. due to weld lines. However, an increase in loadability due to injection moulding geometry changes has been reported earlier by Crawford et al (1) for fatigue tests.

Subject of the work reported here is to determine the influence of injection moulding geometry change on the mechanical properties at different conditions and furthermore to make a connection between the experimental results and the fracture surface morphology. The fracture surfaces have been examined for a wider range of test conditions in tensile tests than referred to in the experiments described below by means of a better reference.

EXPERIMENTAL

The tensile tests were made on injection moulded PMMA (Röhm) specimens corresponding to ISO/R 527 type 1, having a cross section of 4*10 mm^2 and an effective length of 100 mm. Cylindrical holes with diameter 2 and 3 mm were

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moulded or drilled in the center of part of the specimens. Specimens were tested as moulded or after annealing at 90°C for 16 hours followed by cooling down at 10°C/h. The tensile tests were carried out at 29°C at a crosshead speed of 5 mm/min, using five tests for each datapoint.

The specimens for the three point bending tests were made of PMMA (ICI, Diakon CMG 302) from the same shape as was used for the tensile tests, containing a 2 mm moulded or drilled hole. After machining the sides a saw cut was made on one side of the specimens. All specimens were annealed. The tests were carried out at bending rates of 0.08, 0.8, 8 and 80 mm/s at 23°C, using five tests for each datapoint.

The fracture surfaces were examined by use of an optical stereo microscope.

RESULTS

Fracture surface morphology

From the fracture surface morphology of the PMMA specimens with drilled holes it was found that two different types of failure mechanisms occurred. i.e. fracture initiated either at the hole surface or inside the material near the hole surface.

The first type (figure 1a), hereafter referred to as type 1, shows a semi-circular mirror zone. The morphology corresponds to the circular mirror zone found on the fracture surface of specimens without a geometry change, grown from a visible flaw inside the material. It is obvious that this failure mechanism is favored by irregularities at the hole surface.

The second type (figure 1b), hereafter referred to as type 2, shows an elliptical mirror zone, around the fracture origin, inside the material. The structure of this mirror zone is different from the first type and does not show a visible flaw at the fracture origin. These fracture surfaces are similar to the ones described by Narisawa et al (2), where the craze initiates at the tip of a plastic zone which coincides with the maximum of the hydrostatic stress. Concerning this type of failure, craze breakdown seems to determine the strength. It might be expected that failure type 1 is determined by crack growth (3). Indeed, a considerable reduction of the strength has been found for some specimens, however, mostly it is restricted to a few percent.

Regarding failure type 2 it should be noticed that the distance of the fracture origin to the hole surface depends on the material behaviour, or in agreement with (2) on the extension of the plastic zone. It was found (4) that at higher strain rates the fracture origin shifts towards the hole surface (figure 1c). The same holds for lowering the temperature of annealing the specimens. At a cross head speed of 500 mm/min at 23°C for annealed specimens the initiation point lies at the hole surface (figure 1d). Although this is the same as for type 1, a distinction can be made by the morphology and the total shape of the mirror zone.

Tensile tests

Experimental results. Starting from the annealed specimens (figure 2a) the experimentally determined strength of the specimens with a 2 mm drilled hole is considerably higher (2 times) than the strength based on linear elastic calculations. While the latter predicts a stress concentration factor of 2.5, a notch factor of only 1.27 was found. The nominal strength of the specimens containing a moulded hole is 20% higher due to orientation around the hole. This results in a notch factor of only 1, meaning that there is no reduction of the nominal (net section) strength.

The not annealed specimens (figure 2b) exhibit more ductile behaviour and a lower strength due to a lower yield point. The specimens with geometry changes, however, show a higher strength. This effect can be explained by the larger amount of non linear deformation around the hole (2,4). Here we find a notch factor of 1 for drilled holes. The specimens with moulded holes again reach a higher strength (17%) resulting in a notch factor of 0.85. This means that the reduction of the cross section to 80% is nearly compensated by the notch strengthening effect. For some of these specimens fracture occurs outside the net cross section.

The specimens with 3 mm holes show similar results. Now, the reduction of the cross section is 70% and no fracture outside the net cross section occurs.

Fracture surfaces. The annealed specimens with a drilled hole show fracture type 1 and 2, the latter having a fracture origin close to the hole surface. The not annealed specimens all showed a mirror zone according to type 2, with the fracture origin at a greater distance from the hole surface.

The annealed specimens with a moulded hole have a mirror zone with the structure of type 2, but at another location on the fracture surface (figure 1e). Another feature of the fracture surfaces is a crater-like circle. The not annealed specimens show a mirror zone in the middle of this circle (figure 1f). This "jump" can be explained either by a loss of orientation or by a less ductile behaviour, both due to annealing.

Three point bending tests

Experimental results. Like in the tensile tests the specimens with moulded holes appear to have a higher load carrying capacity than those with drilled holes (figure 3). The difference is rather high (30%), when low bending rates (0.08 and 0.8 mm/s) are applied. At higher bending rates (8 and 80 mm/s) the difference tends to decrease, but still is 18%.

The results for the drilled holes show that the maximum load increases linearly with the logarithm of the deflection rate. However, for the moulded holes there is no such a linear relationship.

Fracture surfaces. The specimens with drilled holes all show a fracture surface according to type 2 (figure 1d), however, with a mirror zone consisting of more than one craze lying against the hole surface. Specimens loaded at higher bending rates show more crazes on and underneath the fracture surface. It is pointed out that these fracture surfaces correspond to those for tensile tests for the same material at strain rates of the same order of magnitude. At lower tensile rates (cross head speed: 0.5 mm/min) using not annealed specimens, a mirror zone is found like the one that is represented in figure 1b.

The injection moulded holes again result in another shape of the mirror zone. At the lowest bending rate (0.08 mm/s) the shape of the mirror zone (figure 1g) is similar to the one found in the tensile tests on the annealed specimens. At the higher bending rates another morphology appears. The fracture initiates at the hole surface (figure 1h) in the oriented surface layer with a different structure from the 2 types mentioned above. This transition corresponds with the transition observed in the experimental data.

CONCLUSIONS

In the tensile tests as well as in the three point bending tests it has been found that the moulded geometry changes can resist a higher loading than the machined ones. Values varying from 17 to 30% have been found. Examination of the fracture surfaces revealed that these differences correspond with different shapes and sites of the mirror zone. This effect is caused by orientation around the geometry change.

The fracture surfaces of the specimens with a machined geometry change exhibit gradual changes with respect to site of the fracture origin due to different test conditions that can be related to trends in the strength of the specimens.

Unlike the former, the fracture surfaces of specimens with moulded geometry changes showed that under different conditions sudden transitions can occur with respect to the site of fracture initiation.

The specimens with machined as well as with moulded geometry changes show in some cases different failure mechanisms under the same conditions. This is sometimes, but not always, related to a significant difference in strength.

ACKNOWLEDGEMENT

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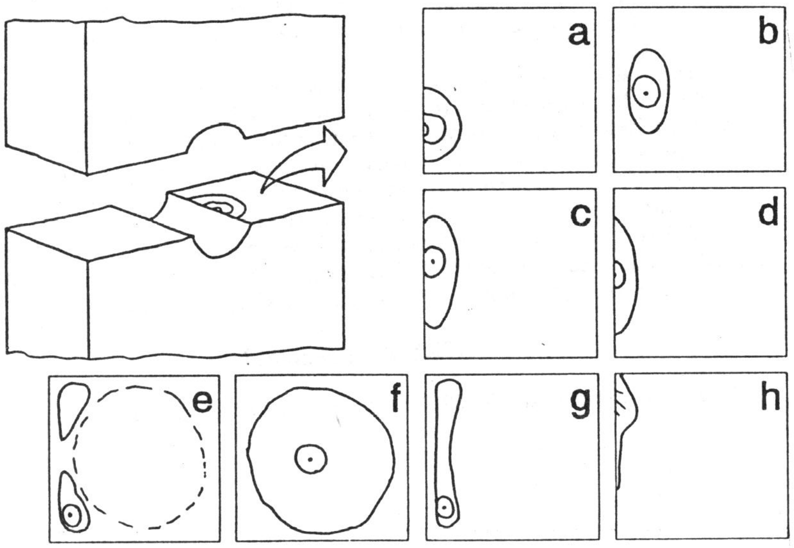

Figure 1 Schematic representation of the fracture surfaces. Explanation in the text.

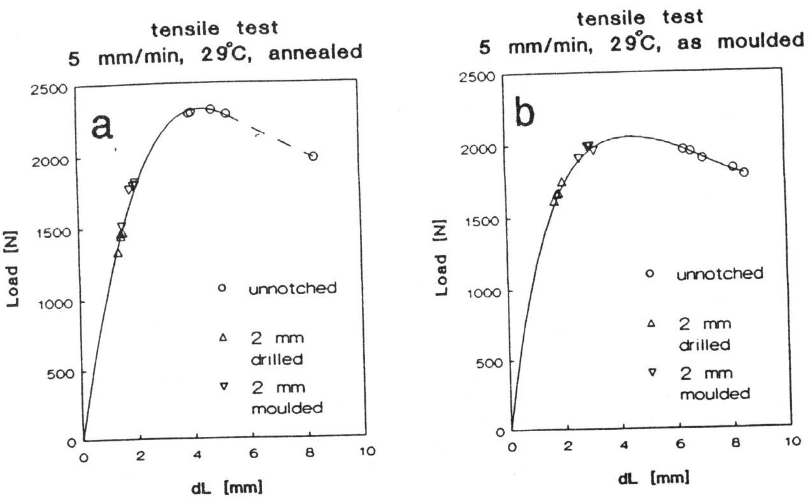

Figure 2 Load-elongation curves of the tensile test, annealed (a) and as moulded (b). The lines represent the typical deformation behaviour of an unnotched specimen. The symbols represent fracture.

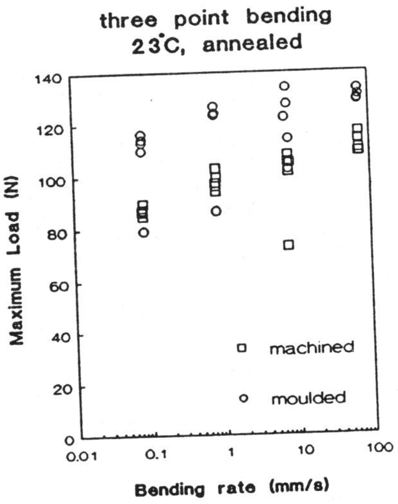

Figure 3 Maximum load vs. bending rate. The symbols represent fracture of the specimens.