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Mechanical Properties of Micro-Injection Moulded Components

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Summary: Micro-injection moulded specimens and components were investigated using instrumented indentation testing and tensile testing. Conventional nano indentation testing, from which hardness and modulus can be obtained, is useful for the characterization of thermoplastics and filled thermoplastics. The difficulties of indentation measurements on LCPs can be overcome by a cantilever beam arrangement. Optical strain measurement is suitable for the description of the (local) deformation behaviour of micro scaled polymeric components.

Introduction

Micro-injection moulding is a method to produce small polymeric components and the influence of processing conditions on the material properties is a topic of ongoing research.

The results of micro-injection moulding are parts having a mass of only a few milligrams.[1-4] Due to this fact it is obvious that conventional material testing methods cannot be used. For the mechanical characterization of miniaturized specimens or prismatic and cylindrical geometries the classical methods like tensile, bending or compression test can be used in a miniaturized, downscaled manner using special micro testing devices.[5-7] Testing of typical micro-injection moulded components is more difficult due to the frequently complex geometries. Instrumented indentation testing in the low load range is a suitable method. There are two advantages: material properties can be determined with high spatial resolution from small volumes and the obtained values are independent of geometry conditions.

In the presented work results of measurements on micro-injection moulded tensile specimens, films, gear wheels, click wheels and case parts of hearing aid sensors are shown. For this measurements instrumented indentation testing and tensile testing were used. Additionally, the application of optical strain measurement and bending tests using the indentation device will be shown.

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Experimental

Two different kinds of micro-injection moulded test specimens were tested, miniaturized tensile bars (length 22.5 mm, parallel length 10 mm, parallel width 1.25 mm, thickness 0.5 mm) and films with dimensions of 10 x 5 mm and thicknesses of 100, 50 and 30 µm. Film materials were polypropylene (PP), poly(oxymethylene) (POM) and a liquid crystalline polymer (LCP).

Testing of the tensile bars was done on a conventional tensile testing machine Z050, (Zwick GmbH & Co, Ulm) using an extensometer with very low drag force (≤ 0.015 N) which is situated on a guide linkage (Fig. 1a). Modulus and hardness of the micro-injection moulded films were measured on the surface and over the cross section using a Nanoindenter XP (MTS, Oak Ridge) and the calculation procedure of Oliver and Pharr.[8] Figure 1b shows a schematic graph of a load-indentation curve.

For bending experiments using the indentation apparatus narrow stripes were cut from the films. One end of the strip was fixed on the specimen holder in order to act as a cantilever beam.

Additionally, the films were tested in tension. Strain distributions were measured and calculated with an optical system Aramis 3d (G.O.M.mbH, Braunschweig).

To investigate the micro-injection moulded components having a more complex geometry, the nanoindenter was used to measure on surfaces or on cross sections. The components were gear wheels (material: POM), case parts of hearing aid sensors (POM) and click wheels (Nylon with 30% glass spheres).

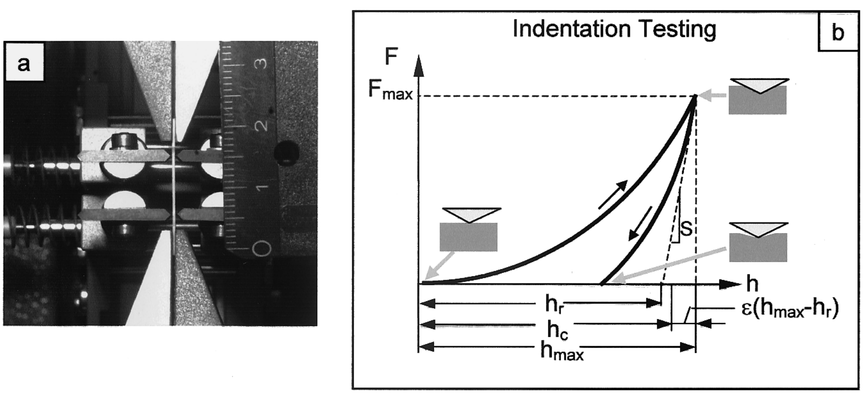

Figure 1. a) Miniaturized tensile specimen in the tensile test arrangement, b) principle of the instrumented indentation test.

Results

With the help of the micro-injection moulded miniaturized tensile specimens a quality control of the used material and a basic check of the used mould equipment can be realized. Figure 2 shows stress-strain curves of POM. Compared to the results of standard tests on the bulk material there is a somewhat smaller yield strength and modulus of elasticity and a larger elongation at break. This should be due to the higher relative amount of highly undercooled parts, yielding to a higher amount of amorphous phase compared to the standardized specimens (type 1A, EN ISO 527-2 [9]).

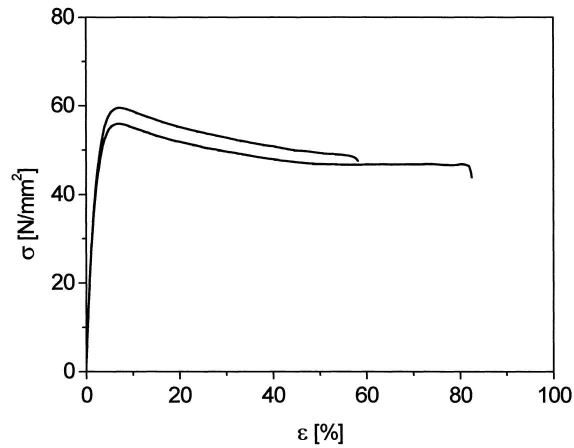

Figure 2. Stress-strain curves of miniaturized tensile specimens showing the range of results, Material: POM.

The film specimens are suitable to simulate the effect of different cavities. Due to the large ratio of flow distance to thickness, changes in the process parameters should result in quality changes. Therefore, the films can be used for a check-up of the process stability and process optimization. The first check of the film quality was done with an optical microscope, where sometimes flow lines can be observed. To find possible changes of materials properties in dependence of the flow distance, indentation measurements were done at different distances from sprue. Results of the instrumented microindentation tests on the films are shown in Figure 3. Reducing the film thickness of polypropylene copolymer (PP) from 100 μm to 50 μm does not result in visible changes of modulus (Fig.3a). The values of modulus of elasticity are comparable to the bulk Young's modulus. Note, that the films were produced in a variothermic process where the mould is tempered at a high temperature ($T > T_m$) during injection and is cooled down afterwards. This prevents quenching effects which would influence the whole thickness of the films and could lead to a blocking of the cavity.

In the case of poly(oxymethylene) (POM) a variation of the injection speed (POM 1: 5 cm^3/s, POM 2: 27 cm^3/s) has no influence on the values of modulus. Looking at the distribution of hardness values on the surface deviations can be seen (POM 2, Figure 3c). These deviations are relatively small. The values far from the sprue tend toward smaller values.

a)

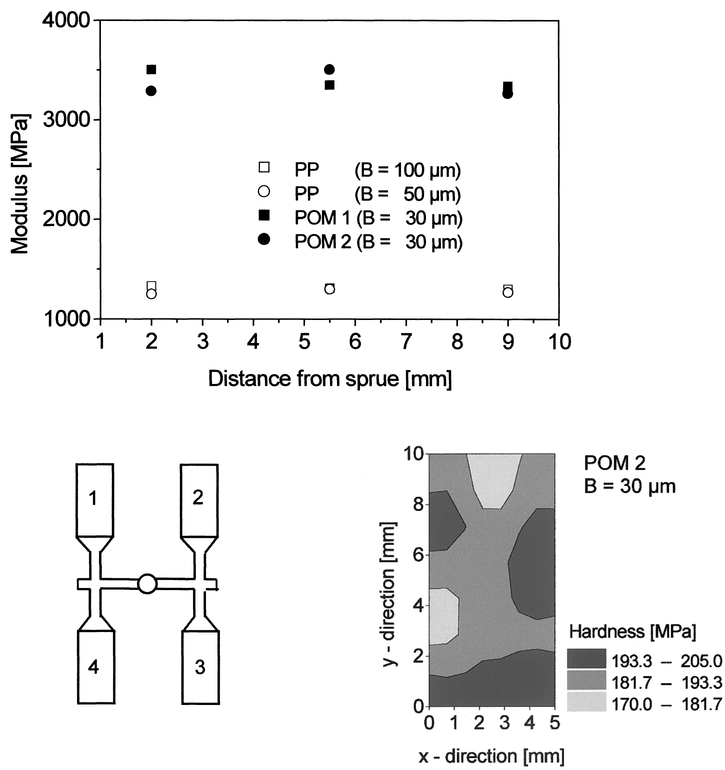

Figure 3. Examples of results of instrumented microindentation tests on films of thicknesses B (a, c) and arrangement of the specimens in the mould (b).

Indentation measurement of liquid crystalline polymers (LCP) is difficult because of the strong anisotropy of this material. Bending tests using the nanoindneter are a possibility to solve the problems of modulus determination. Bending tests using instrumented hardness measurement devices have been applied to measure properties of thin metallic and anorganic non-metallic films for more than ten years.[10,11] Narrow specimens, taken from the LCP-films, were measured in a single cantilever test arrangement. In the load-deflection diagram the very good linearity of the curve can be seen (Figure 4), which shows that the method is suitable for this type of application. Note, that the curve has been corrected because the measured way results from the deflection of the cantilever beam and an impression of the indenter tip in the beam material. This can be done by indenting in the material which is glued on the sample holder and subtracting this indentation depth from the apparent deflection value. The determined value of modulus of elasticity (7500 MPa) is comparable to values measured by dynamic-mechanical analysis in tensile mode (1 Hz) but low compared to the modulus of the bulk material (11000 MPa, producer's data, standard test specimen). The reason for this could be a lower anisotropy of the material or the destruction of molecules.

To check the homogenity of the orientations in the LCP films two-dimensional strain fields can be measured by an optical measurement system. Figure 5 shows the distribution of the strain perpendicular to the tensile direction (x-component). The strain field of the film having bad quality is inhomogeneous compared to the film of good quality.

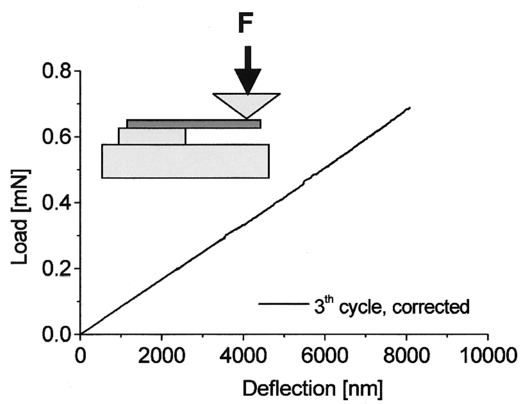

Figure 4. Test arrangement and load-deflection behaviour of bending test using the nanoindenter, material: LCP, bending length 3 mm, width 1 mm, thickness 0.03 mm.

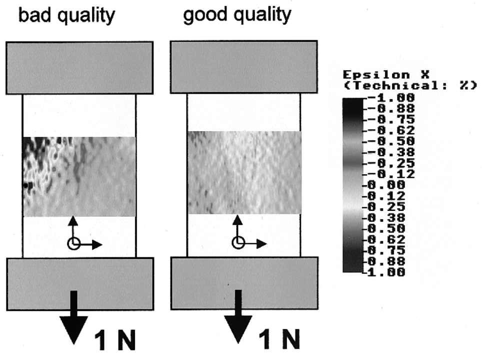

Figure 5. Strain distribution (x-direction) during tension; LCP-films, thickness 0.03 mm.

Miniaturized gear wheels are "classical" micro-injection moulded components, for example applied in watch industry. To check if the materials properties are remaining constant in the small parts measurements were performed on the cross section of some tooths of such gear wheels (Figure 6; material: POM). The modulus, 3000 MPa, is in good agreement with the values of the bulk material. The somewhat smaller values compared to the film test specimens should be due to the colder mould temperatures and the faster cooling rates in the production process.

Click wheels (Figure 7; material: Nylon + 30 % glass spheres) are used in PC keyboards. Indentation testing was performed in two ways: 1. with small indention depths (0.2 µm) to measure matrix properties and 2. with higher indentation depths (10 µm) to get properties of the composite. The measured values, E_{matrix} = 3109 MPa and $E_{composite}$ = 4369 MPa, are in very good agreement with producer's data of the bulk material.

Cases of hearing aid sensors are also made of POM. Two case forms are discussed, one with relatively sharp and one with relatively blunt radii (Figure 8). In both variants the properties of POM are at the same level like in the bulk material.

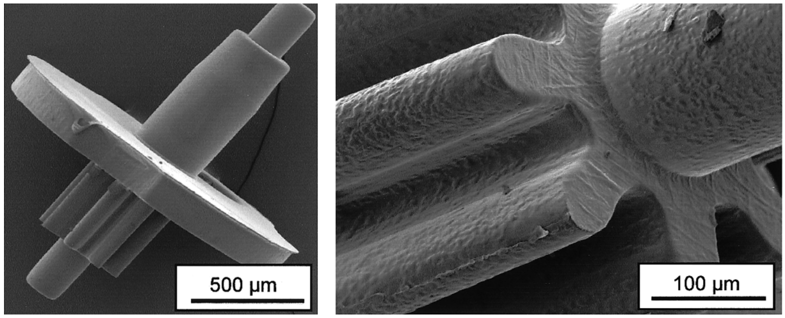

Figure 6. Micro-injection moulded gear wheel.

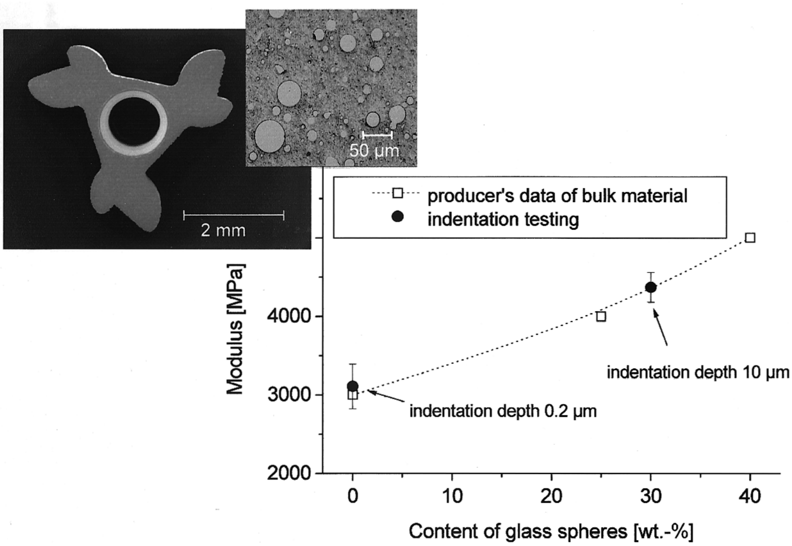

Figure 7. Click wheel with internal morphology and results of indentation testing.

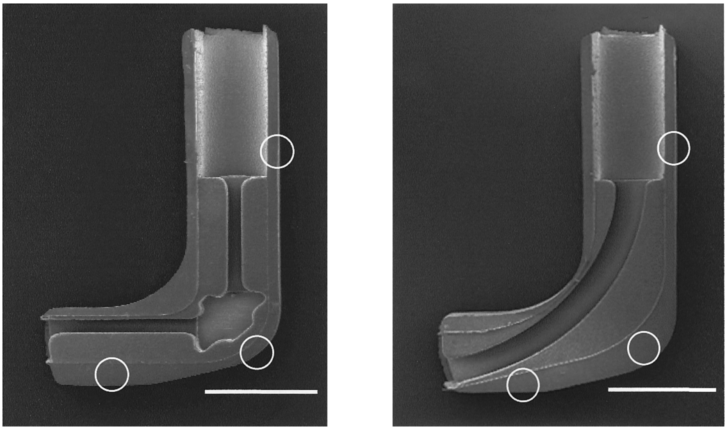

Figure 8. Possible shapes of case parts of hearing aid sensor and positions of indentation measurement; scale bar length 1 mm.

Summary

The presented methods are suitable for the characterization of the mechanical properties of micro-injection moulded components. No distinct changes of the modulus of elasticity and hardness of the investigated materials could be observed in small dimensions, especially in the case of a variothermic injection moulding process.

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