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Material properties

Influence of manufacturing conditions on measurement of mechanical material properties on thermoplastic micro tensile bars

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ABSTRACT

Injection moulding of thermoplastic micro parts result in modified material behaviour due to process induced changes of the internal properties. Thus, a transfer of the mechanical material properties, determined and valid on standardized test specimens, to micro parts is only possible to a restricted extent. Tensile bars with scaled dimensions are used to investigate the influence of part size with injection moulded specimens (with size depending process conditions) and milled specimens (without size depending process conditions). Milled scaled tensile bars provide comparable and reproducible mechanical material properties due to their identical morphological structure. Injection moulded scaled tensile bars have a size dependent morphology which can lead to modified mechanical properties. It is shown that the mechanical properties of thermoplastic polymers react differently with reduced dimensions, especially due to the crystallisation behaviour.

1. Introduction

Microsystems technology is reputed to be a prospective key technology with estimated annual growth rates of about 10% [1]. The main fields of application of polymer micro parts are seen in the areas of biotechnology, as components of optical systems, as micro gears in micro fluidics, medical technology, electronics or as a micro-electromechanical system [2,3]. As a consequence of increasing requirements for these micro components, the demands on the part quality and reproducibility are also increasing [4].

A reduction of part dimensions causes an increase in cooling that affects the morphological and the mechanical properties [5,6]. Furthermore, the long term properties can also be affected [7]. To counteract this slow cooling of the melt using low conductive mould materials [8–10] or a dynamic temperature control of the cavity [11–13] can, for example, be used. Transfer of the mechanical material properties, determined and valid on standardized test specimens, to micro parts is only possible to a restricted extent [14]. As a consequence, it is necessary to investigate the effects of part dimensions on the usable material properties [15–17]

The mechanical behaviour of a material can be defined as the reaction to a mechanical load. The load on a part leads to stress and resulting deformation which depends on the mechanical behaviour of the material, the size and the direction of the force as well as the design of the part [18]. The deformation of polymers is divided into three superposed deformation components [18,19]: a) A purely elastic deformation takes place in polymers at very low loads. Under load, the deformation occurs spontaneously and is completely reversible. b) Viscous deformation is a function of time and is not reversible. c) The combination of elastic and viscous deformation is called viscoelastic or relaxing deformation. Under a constant load, the increase in component deformation is progressively lower. After removal of the load the recovery is at first rapid and then proceeds more slowly and is in principle reversible.

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For design and dimensioning of polymer parts, the material behaviour under mechanical loads has to be known [20]. Based on standardized testing procedures, appropriate strength and associated deformation characteristics provide a comparison of polymer materials as well as a basis for the design of polymer parts. A typical test method is the tensile test according to DIN EN ISO 527 and the corresponding characterization of the tensile properties of polymer materials [18,21].

As described above, the process conditions can influence the tensile properties of polymer materials. Orientation, which is always present in injection moulded parts, can increase the stiffness and the yield strength of the material with decreasing elongation at break in the direction of the orientation. The opposite behaviour is seen in the transverse direction [21]. The crystalline structure also has effect on the mechanical behaviour. An increasing degree of crystallinity leads to an increase of stiffness and yield strength [22]. Large spherulite size can reduce the strength and elongation [19]. Generally, a homogeneous crystalline structure is preferred, because inhomogeneous morphology can lead to local stress concentration and resulting part failure [23]. Residual stress as a result of inhomogeneous cooling can also lead to local stress concentrations, and thus to a decreasing stiffness or yield strength [24,25]. The environmental conditions during the tensile test can also affect the measured material properties. In ISO 291, the standard ambient conditions are a temperature of 23 °C and a humidity of 50%. Consequently, the test specimens have to be conditioned taking into account the specific material properties and test conditions [18,26]. Especially for hygroscopic materials such as polyamides, a defined conditioning procedure is needed due to decreasing stiffness and yield strength with increasing moisture content [19].

2. Experimental section

2.1. Materials

Three different thermoplastic polymers were investigated. As semi-crystalline polymers, a polyamide 66 (PA66, Ultramid A3K, BASF SE) and a polyoxymethylene (POM, Hostaform C9021, Ticona GmbH) were used. In addition, an amorphous polycarbonate (PC, Makrolon OD2015, Bayer MaterialsScience AG) was used as a material without cooling dependent crystalline structure.

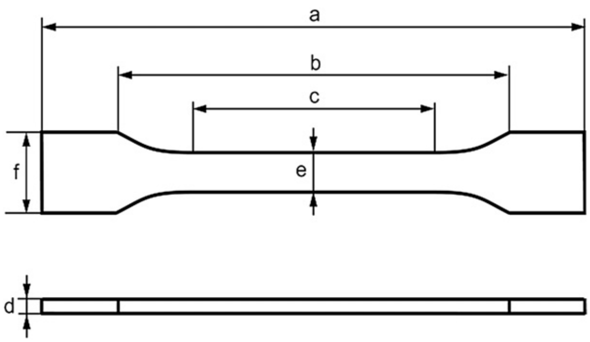

Fig. 1. Geometry of the tensile bar.

Table 1
Dimensions of tensile bars.

Tensile bar	a [mm]	b [mm]	c [mm]	d [mm]	e [mm]	f [mm]
1:1	170	108	80	4	10	20
1:2	85	54	40	2	5	10
1:4	48	27	20	1	2.5	5
1:8	28	13.5	10	0.5	1.25	2.5

Table 2
Processing parameters.

Material	Melt temperature [°C]	Mould temperature [°C]	Injection velocity [$cm^3 s^{-1}$]
PA 66	290	100	18
POM	230	100	18
PC	300	100	18

2.2. Specimens

To investigate the mechanical behaviour of the material, the standardized tensile bar (EN ISO 3167 Type A) was chosen. The dimensions of the smaller tensile bars were downscaled by a ratio of 1:8, as shown in Fig. 1 and Table 1. The shoulder lengths of the 1:8 scaled tensile bar were extended to assure safe clamping during tensile testing.

2.3. Processing

The standardized tensile bars (scaling 1:1) were injection moulded using an ENGEL ES 330H/200V/80HL with a screw diameter of 30 mm. For injection moulding the scaled tensile bars, an Arburg Allrounder 370U 700-30/30 injection moulding machine was utilized with a screw diameter of 15 mm. Relevant processing conditions for the three materials are shown in Table 2.

Scaled tensile bars without influence of different process conditions due to the different part dimensions were realized by milling. These scaled tensile bars were taken out of the normalized tensile bar, as shown in Fig. 2.

2.4. Characterization

2.4.1. Morphology and crystallinity

The crystalline morphology was investigated on 10 μm thick slices using polarised light microscopy. These slices were taken from the middle of the test specimen along the injection direction.

For characterisation of the crystallinity, infrared microscopy (Advantage, Spectra Tech Inc., Shelton, CT, USA) was applied to the PA parts. On each part, three transmission measurements of thin slices were carried out. The ratio r of extinction of the absorbance bands at 1199 cm^{-1} for the crystalline part and of 1180 cm^{-1} for the amorphous part describes the degree of crystallinity, shown by Kohan [27].

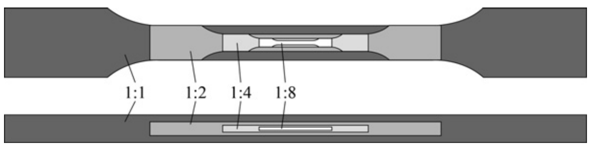

Fig. 2. Milling of scaled tensile bars from the standardized tensile bar.