Novel Uniaxial and Biaxial Tensile Test Specimen for Polymer Materials

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Abstract

The geometry of the uniaxial tensile test specimen for polymer materials and the testing procedure are defined by the ISO norms. Depending on the type of polymer material, two types of norms are specified: ISO 37 for rubber-like polymers and ISO 527 for more rigid polymer materials. Although these norms defined the specimen geometries and testing procedures, both experiments and finite element simulations indicated that none of the geometries defined in these norms resulted in fracture within the zone with homogeneous stress and strain (i.e., the gage zone), thereby leading to inaccurate results. For hyperelastic materials this means that tensile strength and maximal strain are slightly underestimated; however, for elastoplastic materials, plastic strain mostly occurs outside the measured zone, and experimental results are completely unreliable.
On the other hand, biaxial test specimens are not defined by any norm, and a wide variety of biaxial test specimen geometries were reported in the literature. Although the geometry of biaxial test specimens has been the subject of extensive research, no geometry ensuring uniform stress and strain distribution in the central part of the specimen, with maximum stress in that region, has been developed.

To address this issue, the aim of this work was to develop a novel uniaxial test specimen with uniform stress and strain distribution and maximum stress in the gage zone. The development was guided by using the topology and shape optimization tools in ABAQUS software for finite element analysis. Although such simulations did not yield a satisfactory solution directly, they provided guidance for optimizing the geometry through a trial-and-error method. Several variations of uniaxial test specimen geometries were defined numerically and subsequently tested experimentally. To ensure independence of fracture location on the method of production and material type, uniaxial test specimens were 3D printed using three printing technologies (Fused Deposition Modeling (FDM), PolyJet, and Stereolithography (SLA)) and four different materials (poly-lactic-acid (PLA), ABS-like resin, Tango Black Plus, DM70)). The experiments demonstrated that for each technology and geometry type, fracture consistently occurred in the gage zone, thereby improving accuracy compared to specimens from the ISO norms. From the collected data, the elastic modulus, failure stress, and strain at break were calculated and compared with values reported in the literature.

Similar methodology was applied for biaxial cruciform specimens. Again, the optimization process did not yield a suitable geometry but provided direction for manual optimization. This process resulted in the development of a novel cruciform biaxial specimen. According

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to simulations, the resulting geometry exhibited maximum stress in the central region and uniform stress and strain distribution in that part of the specimen. Simulations were conducted for isotropic and anisotropic materials, and the results indicated that the positions of maximum stress were independent of material behavior. For validation, the developed geometry was 3D printed using PolyJet technology and experimentally tested. Due to the limitations of the load cells on the biaxial tensile tester, only specimens made of Tango Black Plus material were tested. The experiments revealed that fracture initiation occurred in the central region and propagated outward.

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