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Test Method

Complex yield behavior of polyethylene on oblique angle grooved tensile specimen

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Abstract

In the plane strain grooved tensile (PSGT) methodology of ASTM F2018 standard, a groove in the direction perpendicular to the loading axis allows a biaxial stress state to be generated under a uniaxial loading. The biaxial stress state produced very closely approximates internally pressurized pipes and, hence, is recommended as an alternate test method to actual pipe testing. In this work, the function of the groove in changing the stress state when allowed to vary the groove angle with respect to the loading axis is numerically and experimentally investigated. The results indicated that the yield load of polyethylene resin initially decreased from a plane strain angle of 0°, attained a minimum value at 35°, and then rapidly increased for higher groove angles. It was determined that at 35° a uniaxial stress state prevailed and a maximum value of von-Mises stress existed.

Keywords: Plane strain grooved tensile specimen; Oblique angle grooved tensile specimen; Yield behavior; Biaxial stress; Uniaxial stress

1. Introduction

Behavior of materials subjected to multiaxial stresses has been of scientific and engineering interests for some time. In particular, those in plastics pipe pressure testing for long-term performance have long been searching for a simple alternative method for use as a design basis for plastic resins. The adoption of a plane strain grooved tensile (PSGT) specimen by ASTM now allows a simple but effective alternative standard method for use as a design basis for plastic piping materials [1,2]. The PSGT specimen is in the form of a sheet having a local reduced section perpendicular to the loading axis, which is produced by means of placing equal grooves on exact opposite sides of the sheet (Fig. 1). On uniaxial loading in the direction perpendicular to the groove, a biaxial stress ratio that equals the material's Poisson's ratio is induced by the constraint on deformation of the groove material. Since the Poisson's ratios of polymers are time and strain dependent and known to approach 0.5 a short time after a constant load application [3], a stress ratio very close to that in hydrostatically pressurized pipes can be obtained. The key element in PSGT specimen is, thus, the groove and the method is made simple by the uniaxial loading.

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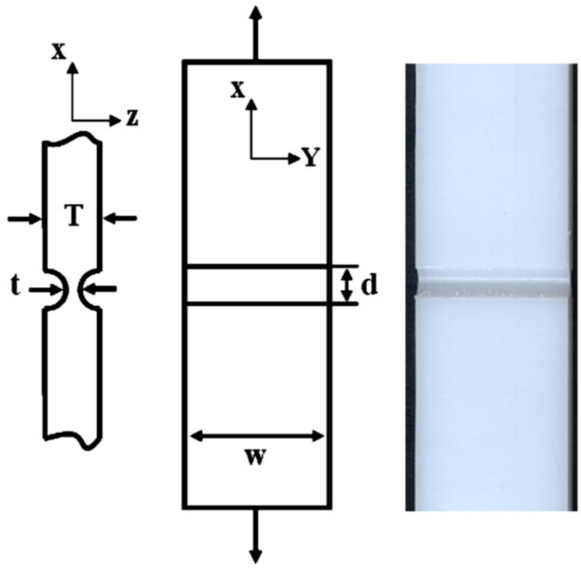

Fig. 1. PSGT specimen.

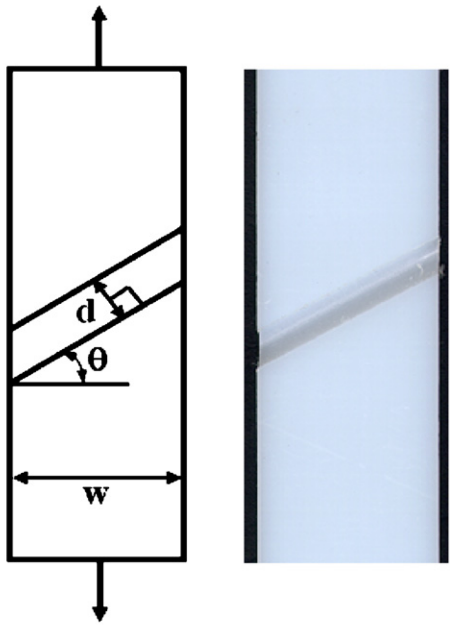

Fig. 2. OAGT specimen (thickness dimensions are the same as those of PSGT specimen).

In the early stage of PSGT methodology development, a uniaxial specimen to which the yield behavior of biaxial stress state PSGT specimens could be directly compared was needed without involving any secondary calculation or calibration. With a dogbone specimen this was not suitable as the strain rate developed under a constant crosshead speed was different from that of the much shorter gage length PSGT specimen. With a grooved tensile specimen, one method by which to produce uniaxial stress state was by making the specimen width small enough so as to remove deformation constraint in the groove. However, this method is also complicated by the specimen being difficult to handle as sample width is much reduced. The work indicated here may alleviate the aforementioned problems by utilizing the same size sample as the PSGT specimen and yet achieve test conditions equivalent to the PSGT specimen. This is done by having the groove angle different from 0° with respect to the loading axis (Fig. 2) and hence is called the oblique angle grooved tensile (OAGT) specimen. Better understanding of the working mechanics of the OAGT specimen in producing various biaxial as well as uniaxial stress states is presented in this paper.

2. Experimental

The material tested was pipe grade high-density polyethylene obtained from a local resin supplier. It was received in pellet form and compression molded to 8.5 mm thick plaques as per the ASTM method. The plaques were then stabilized at room temperature for 10 days prior to machining to produce PSGT and various OAGT specimens. The grooves on two opposite sides were made in each of the specimen by using a 6.0 mm diameter ball end-mill of the type described in ASTM F2018. The samples were grooved at 5° increments from 0° up to 65°. All samples were tested after at least 24 h of room temperature storage. To determine the proper limiting width dimension for the PSGT specimen, various width to groove thickness (W/t) ratio specimens were made and tested in a universal testing machine at a cross head speed of 10 mm/min. Similarly, the OAGT specimens were produced and tested for tensile behavior using the same sample width as predetermined for the PSGT specimen. The same test speed was also employed.

3. Results and discussion

The tensile yield stress of high-density polyethylene pipe grade resin determined from grooved tensile specimens ($\theta = 0$) of various W/t ratios are shown in Fig. 3. There is an increase of tensile yield stress with groove W/t ratio and, since the groove thickness was kept constant at 2.4 mm, the sample