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Measurement and FE-modeling of the Effects of Stress Triaxiality on the Neck Initiation and Failure of High-density Polyethylene

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Abstract

This study analyses the tensile deformation of neck i.e localization initiation, propagation and failure of injection-moulded polymer composed of high-density polyethylene (HDPE) as a function of initial stress triaxiality. Three different specimen geometries namely i) Simple tension, ii) Plane strain and iii) Shear specimens were punched from injection-moulded HDPE plates and tested experimentally in uniaxial tension to induced different stress triaxialities. Based on the major-minor strain paths from digital image correlation (DIC) measurements stress triaxiality has been calculated. It is challenging to follow the stochastic pattern at larger local strain in DIC and hence the strain at failure has been measured using orthogonal grid lines on the specimen surface. Strains at neck-initiation and failure at three different stress triaxialities for injection-moulded HDPE in two material orientations were implemented in finite lement model. ISIGHT with Abaqus was used for calibration of hardening behaviour, triaxiality dependent neck initiation and failure.

1. Introduction

High-density polyethylene (HDPE) is one of the most used polymers in the liquid food packaging industry. During manufacturing, liquid-filling, transportation and storage, a package experiences a wide variety of loading conditions. Finally, opening some packages requires intentional damage and failure in a thin layer of HDPE. In many package designs, part of the package, e.g. package top, is manufactured by injection-moulding. Produced part is a shell-like structure of HDPE plates thinner than 1 mm. During the filling stage in the injection-moulding cycle, material flow velocity into the mould varies largely along the thickness. The material properties of the HDPE studied in this work are a anisotropic, strain rate dependent and highly ductile reaching engineering strain of more than 10 [-]. Stress triaxiality, which is a measure of hydrostatic stress normalized by von Mises stress has an effect on neck-initiation and failure strain of many reported metallic and polymeric materials. To study the stress triaxiality effect in polymeric materials, axisymmetric notched tensile specimens are widely used where different notch radius initiates different triaxialities. The injection-moulded polymeric part in a liquid food package is seldom thicker than 1 mm hence in this study, 0.6 mm thick HDPE plates injection-moulded in the laboratory were cut with a metal tool to produce different test specimen geometries. Smaller thickness restricts the use of bar geometry for inducing different triaxialities. Literature reported to use geometry `A10', `PS' and `S45' to achieve different stress-triaxialities around uniaxial tension, plane strain and shear loading in nickel-based superalloy plates. Compact sized tension, plane strain and shear specimen geometries for the same purpose in dual-phase steels. Further studies are needed before using similar specimen geometries together with highly ductile HDPE which was covered in the current work.

In this article, the specimen geometries reported in earlier work were further modified and used to study stress triaxality in HDPE in two material orientations. Neck-initiation strain at different stress triaxialities were measured and reported. The challenge of measuring very large strains at failure in HDPE was addressed and failure strains were reported. HDPE material was modelled with Hill48 anisotropic yield function and stress triaxiality dependent neck-initiation and failure. Finally, ISIGHT with Abaqus was used for calibration of material parameters in FE-model.

2. Results

Measured stress triaxiality, neck-initiation and failure strain are reported in Table. 1. It was observed that within the elastic limit the stress triaxialities obtained from the experimental tests were close to the ideal values found in the literature and neck-initiation strain is strongly dependent on the stress triaxiality.

However, as neck initiates and propagates, the triaxialities for all geometries shift closer to the measured value in a simple tension specimen i.e. 0.33 limiting the effect of the initial triaxiality on failure strain.

Table 1: Average stress triaxiality and limit strains

Measurements / Geometry	Orientation	A10	PS	SH
Triaxiality- von Mises (η)	MD	0.41	0.48	0.20
	CD	0.39	0.50	0.35
Neck-initiation strain (ϵ_n)	MD	0.58	0.15	0.59
	CD	0.43	0.18	0.61
Failure strain (ϵ_f)	MD	2.23	2.14	0.67
	CD	2.96	2.57	0.64

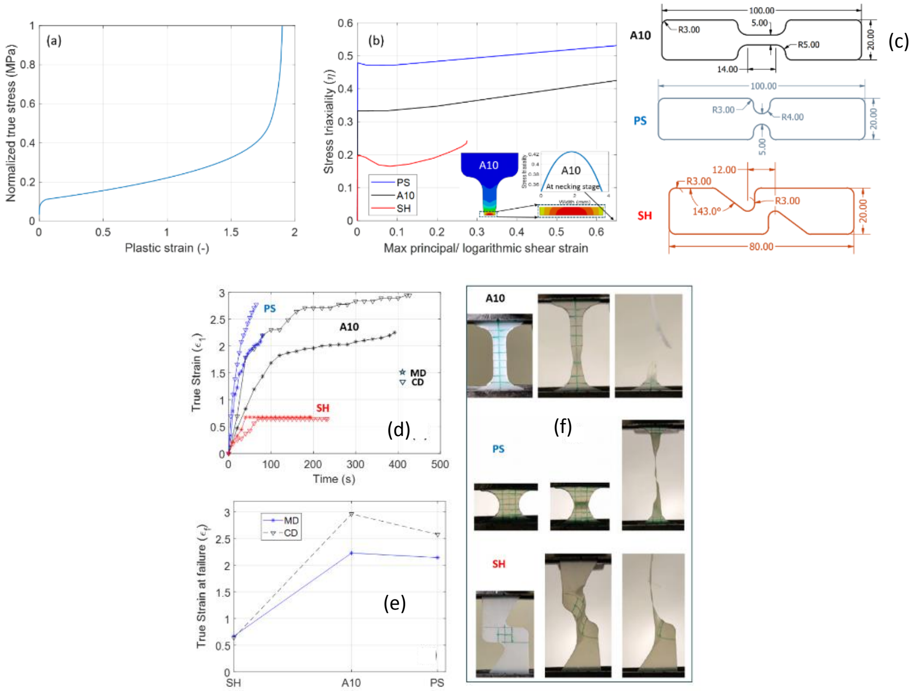

Fig.1 – (a) Optimized hardening of HDPE, (b) induced stress triaxialities in FE-model (c) proposed specimen geometries for triaxiality effect testing (d) measured failure strain using grid line (e) failure strains (f) experimental deformation.

Continuum and failure material model of the studied HDPE plate material could be represented by Hill48 anisotropy and stress triaxiality dependent ductile damage criterion in FE-model.

Conclusions

An experimental method and modified specimen geometries were used for measuring neck-initiation and failure strains at different stress triaxialities in anisotropic injection-moulded HDPE plates. Triaxiality levels were quantified from true major-minor strain path measurements of DIC at the centre of the initial neck with the help of von Mises and Hill48 yield criteria. FE-models parameters were optimized based on the experimental measurements and agreed well with the triaxiality and deformation in `A10', `PS' and `S45'.

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