COMPETITION BETWEEN NECKING AND PRE-CUT PROPAGATION IN FRACTURE OF HIGH-DENSITY POLYETHYLENE REVEALED BY TIME COURSES OF STRAINS

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Abstract

High-density polyethylene pipes are widely used in pressure pipe applications such as water and gas transportation, but both necking and pre-crack effects are still poorly understood. This paper presents experimental observations to highlight strain field evolutions to necking and effects of pre-crack on strain field evolutions in a high density polyethylene material deformed in tension through analyzing spatial distributions of time histories of strains. Necking and its growth along the tension direction dominate the failure behavior of the intact specimen. Necking and crack propagation are both observed in the pre-cut specimen, but the crack propagation eliminates the necking propagation along the tension direction. Energy releases from positions outsides the crack zone lead to the macroscopic load-displacement curve deviates from the trend of the intact specimen. These findings present new recognitions on strain fields evolving to necking and failure induced by the pre-crack that are significant for designing of theoretical models and simulations of polymeric materials and structures.

1. Introduction

Recognizing the process of deformation of High-density polyethylene (HDPE) materials evolving to failure is a fundamental requirement for modelling their constitutive behaviors and designing of this kind of structures. Necking and crack propagation are both key facts that dominate the failure process of HDPE materials, and should determine the differences of failure mechanisms in the intact and pre-crack polymer specimens. Understanding the deformation process evolving to failure suffering crack propagation in a HDPE material is key to explore methods to overcome the shortcomings induced by the pre-crack. Many researches focused on the differences of the macroscopic stress-strain curve induced by pre-notches. However, deformation field evolution properties leading these differences in average behaviors the intact and pre-notch HDPE specimens are still far from understood. Traditional extensometry methods cannot efficiently measure the strain rate in the specimen and provide little useful information, because these only measure the average strain over a gauge length by tracking the relative position of two points on a tensile specimen. This paper focuses on elucidating the differences of the strain field evolution to failure in intact and pre-notched HDPE specimens. Full-field strain analysis are performed through using the DIC technique to simultaneously measure the strain fields on two surfaces perpendicular to each other.

2. Results

With the softening of the specimens, the spatial distributions of the strains and strain rates become heterogeneous. The strain rates display various accelerations at different spatial positions. Increases in the strains in several areas (e.g., position 1 in Fig. 1 and positions 4 and 5 in Fig. 2a) become sharper than those in other areas and these strains exhibit rapid accelerations, although the strain rates at all positions still consistently accelerate. In the pre-cut specimen, after the peak stress point, the high longitudinal strain was mainly localized in the zone surrounding the pre-cut (Fig. 2). The strains at positions outside the crack zone began to decrease, which indicated that these regions were unloaded and released elastic deformation energy. This also resulted in rapid accelerations of the strain rates in the crack zone. Softening observed in the strain-time curve became sharp and rapid. Energy release from positions outside the crack zone led to the deviation of the stress-strain curve from that of the intact specimen.

The competition between necking and pre-cut propagation determines the deformation behaviors and failures of HDPE materials. The strains decreased (recovered) in parts outside the crack zone with crack propagation, which could be attributed to two factors: (1) the pre-crack largely decreased the cross-section at the necking zone and (2) the complicated deformation fields surrounding the crack tip severely influenced the orientations of the molecular chains in the necking zone, which limited the strain hardness in this zone. Consequently, the strengthening rate in a the load-bearing capacity of the necking zone could not compensate for its decrease owing to reduction in the cross-section. The second factor was the intrinsic cause of diminishing neck propagation in the intact specimen, because the fracture mode is independent of ligament length. In contrast, necking in an intact specimen did not induce unloading of outside zones although their strain rates decelerated, such that necking increased with elongation. Consequently, these results highlight a method of defining a crack zone based on strain evolutions and thus suggests a possible method of predicting failure.

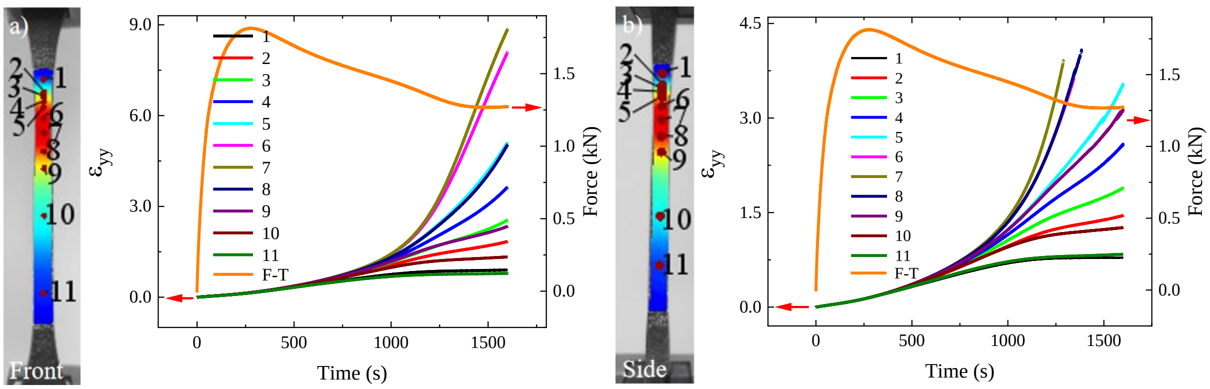

Fig.1 Time history of longitudinal strains at typical areas for Intact specimens.

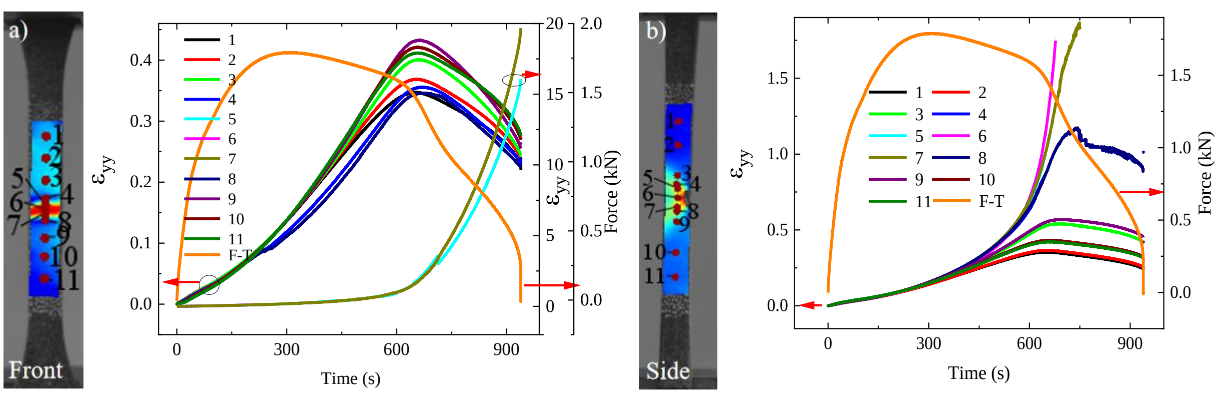

Fig. 2 Time history of longitudinal strains at typical areas for specimens containing pre-cracks.

3. Conclusions

Energy release from positions outside the crack zone caused the macroscopic stress-strain curve of the pre-cut specimen to deviate from that of an intact specimen. Necking and its propagation in the tension direction dominated the failure behavior of the intact specimen. However, the failure of the pre-cut specimen was dominated by crack propagation, which prevented neck propagation. The onset strain of necking may be defined as the faster increase in the strain rate at the necking nucleation zone. In contrast, the strain rates or their accelerations at other positions decrease.

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