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A Simplified Method to Determine Resistance to Rapid Crack Propagation in Polyethylene Pipes

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Abstract. A new simplified experimental testing method for the determination of resistance to rapid cracks propagation in PE pipes is developed and tested. The method is based on the experimentally observed phenomenon of degeneracy when the "shear lip pattern" temperature is lowered on the fracture surfaces of samples of polyethylene pipe sheets during fracture toughness testing of a notched sample in the temperature and speed range. Approbation of the method confirms a significant difference in the values of the lower permissible temperature limits for the operation of gas pipelines made of PE80 ($T \approx -5$ °C) and PE100 ($T \approx -20$ °C).

INTRODUCTION

A concept has been formed according to which the reliability of a polyethylene pipe, primarily a gas pipeline, is determined by a combination of three key parameters – minimum required strength (MRS), resistance to slow crack growth (SCG) and to rapid crack propagation (RCP). The latter factor plays a decisive role in choosing a brand of polyethylene pipeline material for cold climate conditions and imposes a limitation on the permissible lower limit of operating temperatures. The proposed (developed) method is based on the idea of using the experimentally recorded degeneration phenomenon with a decrease in the "shear lip pattern" temperature on the fracture surfaces of polyethylene pipe samples during fracture resistance testing in the temperature and speed range admissible for commercially available standard test machines equipped with an environmental test chamber.

EXPERIMENTAL PART

An established fact is the existence of a temperature boundary (transition temperature, T_{trans}), which determines the possibility of rapid crack propagation (area $T < T_{trans}$) associated with the formation of so-called "shear lips" on the fracture surfaces of PE pipes [1]. They appear at a test temperature slightly below T_{trans} and have a limited width of less than 0.5 mm [2]. When $T \geq T_{trans}$, the lip of the shear rapidly grows, and this results in crack deceleration and stopping.

Figures 1 and 2 illustrate the fracture surfaces of polyethylene samples made from PE80 and PE100 pipes (SDR11, ø110) in the form of strips with the following parameters ($h \times b \times L$): 9×26×120 mm, type 2, edge unilateral notch. A notch with a depth l is applied with a hacksaw blade followed by sharpening with a safety razor blade.

Tensile tests are accomplished on a UTS 20K machine at a loading speed of 500 and 1000 mm/min, in the temperature range of 0 to −30 °C, with a grinding distance of 60 mm.

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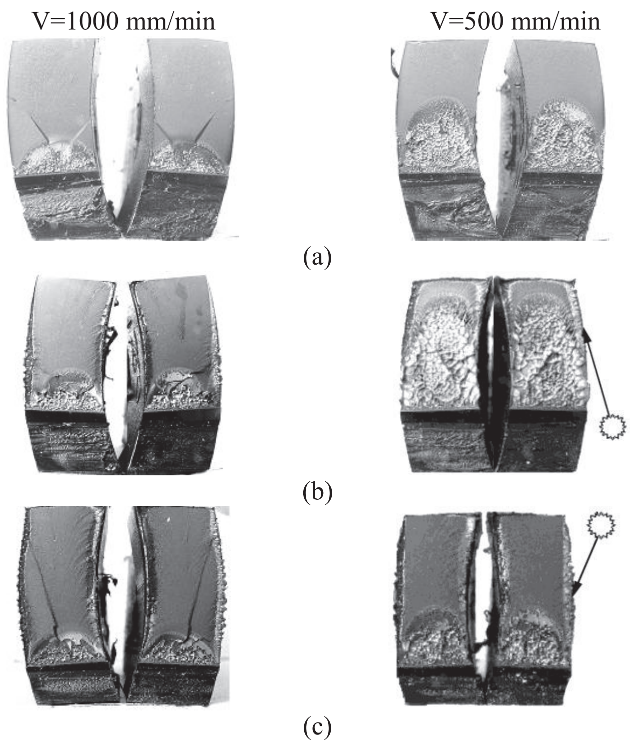

FIGURE 1. Fracture surfaces of PE80 samples (the size of samples 2) tested at the following temperatures: $T = -15$ °C (a), $l/b = 0.35$; $T = 0$ °C, $l/b = 0.35$ (*b*), $T = 0$ °C, $l/b = 0.2$ (c) and two speeds (V_{test}): 1000 mm/min and 500 mm/min; ☼ - shear lips

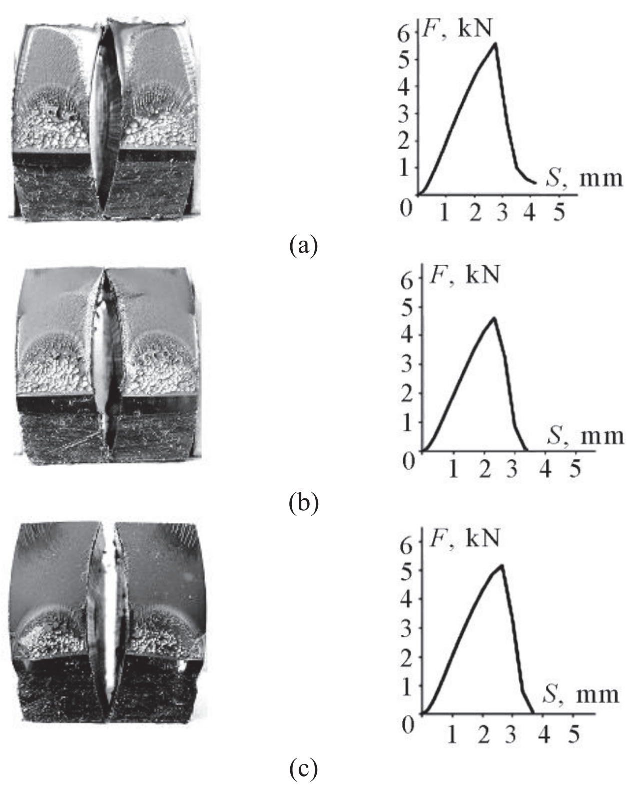

FIGURE 2. Fracture surfaces and load-displacement diagrams of PE100 samples (sample size 2; $l/b = 0.35$) tested at 1000 mm/min and temperatures $T = -15$ °C (a), $T = -20$ °C (b) and $T = -30$ ° C (c)

The presented photographs clearly depict the absence and presence of the shear lip on the fracture surfaces of the samples during the visual inspection of the moment of "pattern degeneration" of the shear lip during the tests. This fact is observed in the tests at temperatures below the transition temperature T_{trans}, Fig. 3. In this case, the "universality" of the method is observed with respect to the standardization of the size (depth) of the incision placed on the sample, and, consequently, to the level of the stored energy necessary for the initiation and propagation of the fast crack in the sample. The simplicity of manufacturing the sample for tests is another advantage of the developed method.

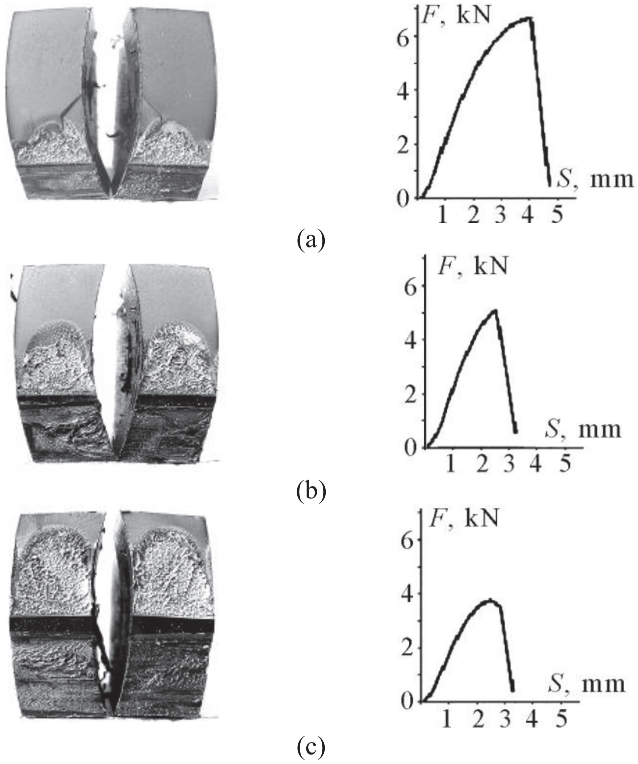

FIGURE 3. Fracture surfaces and load-displacement diagrams for PE80 pipe samples (sample size 2) tested at a speed of 500 mm/min and a temperature of −15 °C, with different incision depths: *l/b* = 0.20 (a); *l/b* = 0.35 (b); *l/b* = 0.50 (c)

RESULTS AND DISCUSSION

In view of the specific behavior of the amorphous-crystalline polymer (polyethylene), the interpretation of the results within the scope of the concepts (postulates) of fracture mechanics is as follows. There are straight sections (the conditions of the plane deformation state, PSS) and oblique (shear lips – the conditions of the plane stress state, PSS) of the fracture sites on the fracture surfaces of the samples at the moment of instability (the start of a fast crack). The material fracture toughness is determined to a decisive extent by the cost of energy for local plastic deformation at the top of the crack with its growth. In this case, plastic deformation in an amorphous-crystalline polymer can occur by two main mechanisms: forced-elastic shear strains, with the formation of shear bands, or forced-elastic tensile strains, with the formation of microcracks (craze formation).

In low-temperature tests, the visible pattern of the shear lip is not formed due to the relatively small extent of the propagation zone of the PSS conditions along the sample thickness, see Figs. 1a and 2c. They begin to appear at a temperature lower than T_{trans} and have a width of less than 0.5 mm, as indicated earlier. In this temperature range the total fracture toughness of the sample is controlled by fracture resistance in the plane strain field (PDS). The crack of normal detachment propagates in the sample as a "tunnel", from the notch in the center of the sample and, partly, along its thickness. The lateral bridges (PSS) are parted by a shear when fairly large displacements are reached at the crack tip, so that the crack as a whole propagates in a mixed way; namely, tunneling through cleavage in combination with deceleration through oblique fracture (shear lips, PSS). When $T > T_{trans}$, the shear lips grow rapidly resulting in the arrest of the crack.

CONCLUSION

A new simplified experimental testing method for the determination of resistance to rapid cracks propagation in PE pipes has been developed and tested. The method is based on the experimentally observed phenomenon of degeneracy, when the "shear lip pattern" temperature is lowered on the fracture surfaces of polyethylene pipe sheet samples during fracture toughness testing of a sample with a notch in the temperature and speed range.

The implementation of the methodology will decrease the complexity of testing equipment and the technical requirements imposed on it. The evaluation of the lowest permissible operating temperature for a polyethylene gas pipeline, which was made within the framework of the developed methodology, shows a significant difference in the parameter values for the PE80 ($T \approx -5$ °C) and PE100 ($T \approx -20$ °C) materials.

REFERENCES

1. C. F. Martins, M. A. Irfan and V. Prakash, Materials Science and Engineering A **465**, 211–222 (2007).
2. S. J. K. Ritchie, P. Davis and P. S. Leevers, Polymer **39** (25), 6657–6663 (1998).