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Fatigue Tests on High Density Polyethylene PE 100 Using Cracked Round Bar Specimens

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Abstract

The paper presents the methodology and the results of the fatigue testing of PE100 polyethylene used for pipelines construction. The fatigue tests were performed in air using cracked round bar specimens manufactured from the pipe wall, at variable tensile loads which stress ratio of 0,1. The circumferential crack is realized by machining followed by precracking using a razor blade.

The stress intensity factor vs. time to failure curve and the fracture surface analysis indicated a ductile failure mode at high stress levels and a brittle failure at low stress levels.

Key words: *polyethylene, slow crack growth, stress intensity factor, fatigue, long - term mechanical resistance.*

Introduction

High density polyethylene pipes represent a modern solution for water and natural gas distribution due to low pipeline construction cost as well as high reliability rustproof and maintenance free.

Designing of polyethylene piping systems is based on pipe long-term mechanical resistance of pipes under damaging operating conditions

The pipe resistance to slow or rapid crack growth (creep rupture) is experimentally determined by a series of well known laboratory testing methods that simulate the creep crack growth: the full notch creep test (FNCT), the notched pipe test (NPT), the Pennsylvania notch test (PENT), the resistance to point loading, etc.

The long - term resistance of the polyethylene pipes, i.e. the resistance to slow crack growth, is estimated by using the hydrostatic pressure test, obtaining the Long term Hydrostatic Strength (LTHS).

The rapid crack propagation in polyethylene pipes is specific the failure mode under high pressure and low temperature conditions. The ability to resist the rapid crack propagation is evaluated as the critical pressure beyond which crack initiated in a cooled area of the pipe propagates (advances) over more than 90% of the tested pipe length.

Because full scale long-term tests are time consuming and expensive a number of small scale quick test methods are proposed in order to extrapolate the fracture mechanics characteristics of polyethylene fatigue crack growth to the long term performance of the full size pipes.

This paper presents the methodology and results of fatigue testing of PE 100 cracked round bar specimens and macroscopic aspects of the fracture surfaces.

Experimental Procedure

In order to evaluate the long-term performance of PE pipes, notched round bar specimens machined from the pipe material were fatigue loaded in order to obtain an accelerated failure process reproducing the long-term failure mechanism of pipes.

Cracked round bar (CRB) specimens with the geometry presented in Table 1 and Fig. 1 were machined from the PE 100 pipe wall, with wall thickness of 34 mm. The cracked round specimens were notched with a razor blade up to a depth, *a*, presented in Table 1, to initiate the fracture process.

The fatigue tests were performed using a servo-hydraulic closed - loop INSTRON 8801 machine, at a frequency of 1 Hz, sinusoidal axial load with the stress ratio F_{min}/F_{max} =0,1 at room temperature.

The loading was described by the stress intensity factor K_I, in order to obtain useful data for the

PE 100 long-term performance evaluation based on the fracture mechanics characteristics and to compare the test results with data obtained by other researchers.

The stress intensity factor variation, ΔK_I, is calculated using the Benthem and Koiter equation:

$$\Delta K = \frac{\Delta F}{\pi b^2}\sqrt{\frac{\pi a b}{R}} f(\frac{b}{R}) \quad , \tag{1}$$

with

$$f(\frac{b}{R}) = 0{,}5\left[1 + \frac{1}{2}\left(\frac{b}{R}\right) + \frac{3}{8}\left(\frac{b}{R}\right)^2 - 0{,}363\left(\frac{b}{R}\right)^3 + 0{,}731\left(\frac{b}{R}\right)^4\right] \tag{2}$$

where : ΔF = Fmax – Fmin,

R - radius of the specimen;

b - radius of remaining ligament;

a - crack length (see Table 1 and Fig. 1).

The macro-fracto-graphic examination of the fracture surfaces of broken samples gives additional information on the fracture mechanism.

Results

The stress intensity factors and the corresponding cyclic fatigue life for every tested sample are presented in Table 1. It can be noticed that the lifetime increases significantly with stress intensity decrease.

Times to failure for different ranges of the initial stress intensity factor, ΔK_I are plotted in Fig. 1.

Depending on the loading conditions the mechanical behavior of polyethylene PE 100 can change from brittle to ductile (viscosity-plastic).

Table 1. Fatigue testing data

Sample	R, mm	a, mm	b, mm	F_{min}, N	F_{max}, N	ΔF, N	ΔK, MPa $\sqrt{m}$	Failure	
								cycles	Time to failure, h
OA 1	7,05	0,8	6,25	290	2900	2610	1,07	460	0,13
OA 2	6,95	0,95	6,00	250	2500	2250	0,951	1452	0,40
OB 1	6,95	1	5,95	200	2000	1800	0,795	13700	3,80
OB 2	6,9	0,9	6,00	200	2000	1800	0,748	19510	5,42
OC 1	7,05	1	6,05	180	1800	1620	0,685	46100	12,81
OC 2	6,8	0,75	6,05	180	1800	1620	0,627	75050	20,85
OA3	6,9	0,75	6,15	160	1600	1440	0,520	112320	31,20
OB3	6,9	0,7	6,20	140	1400	1260	0,455	136420	37,89
OC3	6,8	0,75	6,05	100	1000	900	0,344	224570	62,38

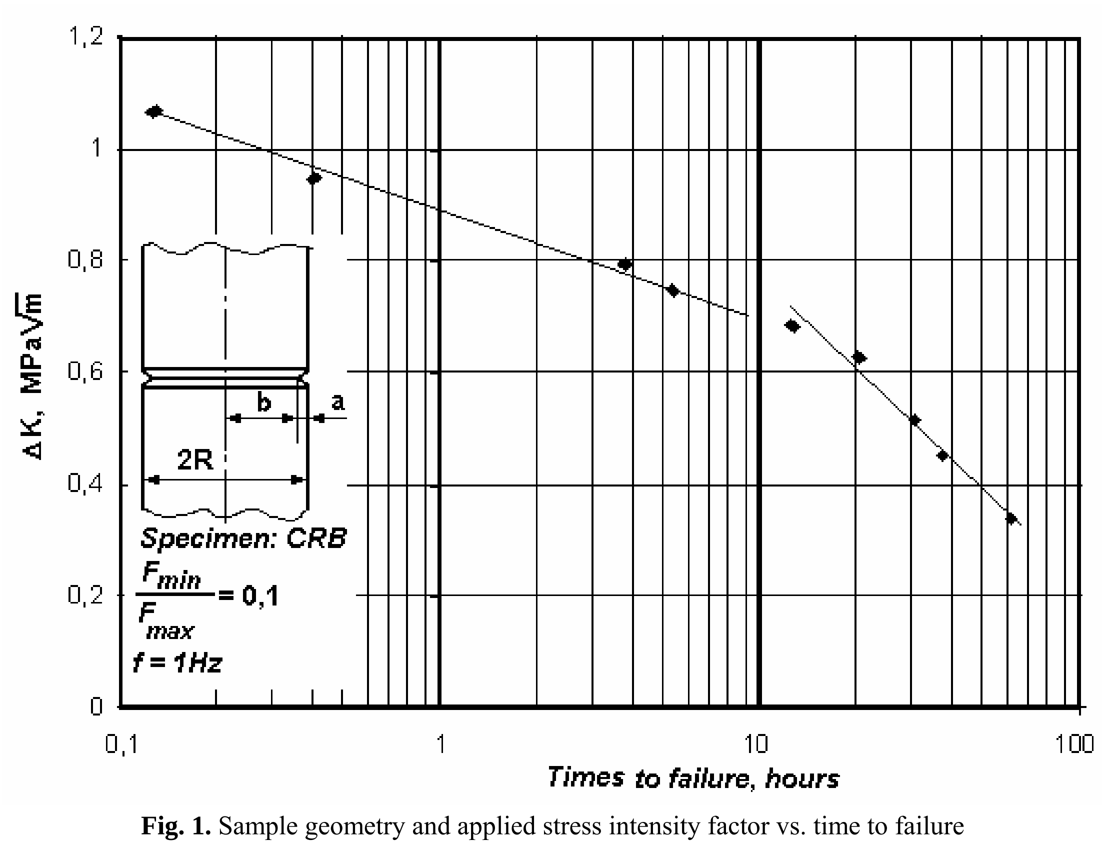

Fig. 1. Sample geometry and applied stress intensity factor vs. time to failure

The experimentally obtained data plotted in Fig. 1 make evidence for these two different failure modes, depending on stress level the latter of which altered the slope of the curve ΔK versus time of failure. At high loads the failure mode was ductile and below approximately ΔK=0,7 MPa the failure mode changed from ductile to brittle.

The macrofractografic analysis of the fracture surfaces of broken samples shows clearly the fracture modes. At high stress levels (high values for stress intensity factors), corresponding to samples OA1 and OA2 (Table 1), the fracture surface presented in Fig. 2 shows a typical aspect of ductile failure, usually called “parrot nose”. At low stress levels, the fracure surface, (Fig. 3), point out a relatively smooth and shiny appearance generated by rapid fatigue crack propagation without the macroscopic deformation of the material, which suggests brittle fracture. The remaining ligament is over loaded under crack propagation thus generating a ductile fracture for the rest of the fracture area, as can be seen in figure 3.

Fig. 2. Fracture surface of the OA1 sample

Fig. 3. Fracture surface of the OC2 sample

Conclusions

The experiments have proved the applicability of the fatigue testing on (of) cracked round bar specimens for the evaluation of stress and time dependent failure of high density polyethylene.

Although there are still effects to estimated concerning the pipe long term life based on fracture mechanics characteristics, the experimental method applied is a very accurate means in (of) comparing different available polyethylene piping materials.

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Incercări la oboseală a polietilenei de înaltă densitate PE100 folosind epruvete cilindrice prefisurate pe contur

Rezumat

In lucrare se prezintă metodologia cercetării experimentale a comportării la solicitări variabile a polietilenei de înaltă densitate PE 100 utilizată la fabricarea țevilor. Încercările la oboseală s-au efectuat în aer, utilizând epruvete cilindrice prelucrate din peretele unei țevi din polietilenă care au fost supuse la cicluri alternante de tracțiune cu coeficientul de asimetrie 0,1. Epruvetele prezintă în zona centrală un concentrator circular de tensiuni realizat prin strunjire şi adâncit cu ajutorul unei lame de ras (prefisurare).

Analiza dependenței dintre factorul critic de intensitate a tensiunilor şi durata până la rupere precum şi a suprafețelor de rupere a evidențiat faptul că la solicitări ridicate ruperea are un caracter ductil, la solicitări reduse ruperea are un caracter fragil, evidențiindu-se un nivel al solicitărilor la care are loc tranziția tipului de rupere.