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Crack Resistance of a Welded Butt Joint of Polyethylene Pipes

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Abstract. The problem of predicting the indices of long-term strength of welded joints of polyethylene pipes is outlined in the present paper. Fracture mechanics methods allow determining crack resistance limit I_C of a welded butt joint of PE3PE, PE80, and PE100 polyethylene pipes at a temperature of 213 K. The I_C values in the junction area are less than in the base material for all the tested polyethylene pipe types. Herewith, PE100 has shown better weldability in comparison with the other specimens.

INTRODUCTION

The main express method to control the quality of welded butt joints (WBJ) of polyethylene pipes according to the current regulatory documents (Building Regulations 42-01-2002 *Gas distribution systems*, Set of Rules 42-103-2003 *Design and construction of gas pipelines from polyethylene pipes and reconstruction of outworn gas pipelines*) is testing of a specimen-blade with a welded junction for axial tension. The criterion for determining the quality of welding is the nature of specimen failure; namely, brittle rupture in the welding plane is inadmissible, herewith, at least 80% of the specimens must fracture in the base material (the rupture line must not cross the welding plane). Fracture of this kind is referred to as plastic in terms of WBJ quality control. Brittle fractures in the welding plane testify only to flagrant violation of welding technology. Consequently, the obtained test results do not characterize the material in terms of weldability [1]. Thus, the current technique for determining the quality of a welded joint should be recognized as being poorly informative in terms of its application when adjusting the technological modes of welding.

At present, the problem of predicting the indices of the long-term strength of welded joints is solved by the traditional method, that is, by the introduction of a safety factor [2]. An alternative approach is formulated as a solution to the problem of predicting the indices of the long-term strength of welded joints from the results of short-term strength tests. Its urgency is due to the need for an on-line inspection of the quality of welded joints, in addition to arranging optimal welding conditions, including welding at low temperatures.

The principal difficulty of the problem lies in the fracture of the specimen in the area of the welded joint. Such fracture occurs in tests for long-term strength, which reveal that the specimen is destroyed outside the area of the welded joint [3].

A number of studies [4, 5] aimed at improving express methods for mechanical testing of WBJ specimens of polyethylene pipes, discussed an approach to solving the problem in terms of fracture mechanics. In those studies, the authors found a significant difference in the values of such indices as critical crack opening [4] and impact toughness [5] of model WBJ specimens with notches in the areas of the base material and in the welding plane. At the same time, there is no comparison of the indicators for different modes of welding operations.

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EXPERIMENTAL PART

Incisions were pre-cut in order to make the fracture of the specimen with the welded joint in the short-term strength test occur in the area of the welded joint. The tests of incised specimens (smooth and suture) allow one to determine the crack resistance limit I_C , which is calculated by the formulas for K_{IC} [6]. These values were obtained by calculation and experiment at a temperature of 213 K in order to ensure a localized yield criterion at the notch tip and they are closest to the true values of $I_c = K_{IC}$.

The calculations are performed using the following relation [6]:

$$I_c = \sigma\sqrt{\pi l} \cdot \xi(l/b), \tag{1}$$

where σ is the destructive stress of the notched specimen, l is the length of the notch, b is the half-width of the specimen, and ξ *(l / b)* stands for the tabulated function.

RESULTS AND DISCUSSION

Table 1 shows the obtained I_C crack resistance values for the PE63, PE80 and PE100 materials at a temperature of 213 K and test speeds of 5÷500 mm/min with a confidence interval at 95% probability.

TABLE 1. The crack resistance limit (I_C) for the specimens of the main material and WBJ of the PE63, PE80 and PE100 pipe materials at a temperature of 213 K in the speed range of 5÷500 mm/min

V mm/min	PE63		PE80		PE100	
	I_C, MPa·m$^{1/2}$		I_C, MPa·m$^{1/2}$		I_C, MPa·m$^{1/2}$	
	M	F	M	F	M	F
5	5.65±0.12	4.31±0.55	5.73±0.12	4.89±0.51	6.05±0.46	5.55±0.41
50	5.32±0.81	4.26±0.19	6.06±0.06	4.90±0.33	6.33±0.13	5.55±0.42
100	5.99±0.16	4.28±0.39	6.06±0.39	4.53±0.13	6.84±0.15	5.79±0.21
500	4.87±0.05	3.61±0.18	5.40±0.15	4.10±0.04	5.82±0.09	5.27±0.53

* the abbreviations "M" and "F" denote the belonging of the indicated value to the zone of the main material and the fusion zone, respectively

Figure 1 illustrates the curve of the "temperature in the welded joint – distance from the welding plane" dependence obtained in our experiments at the initial moment of the formation (cooling) of the welded butt joint. The line parallel to the abscissa axis in the figure, corresponding to 353 К, cuts off the temperature range of the heating temperature of the compound, where $T > 353$ K, while the spatial length of this section is approximately 5 mm.

We note (see Table 1) that the crack resistance limit in the fusion zone (determined at $T = 21$ K) is substantially lower (10÷20%) than in the main pipe material.

The specimens used in the experiments are in the form of strips (6.56×16.4×120 mm) with a transverse edge crack under uniaxial tension, cut from PE63, PE80 and PE100 pipes. The welded butt joint with the removed bead is in the middle part of the active zone of the strip. Incisions with a depth of 5.75 mm are made with a hacksaw blade and sharpened with a razor blade. Short-term tensile tests are accomplished at a temperature of 213 K and at a machine traverse speed of 100 to 500 mm/min.

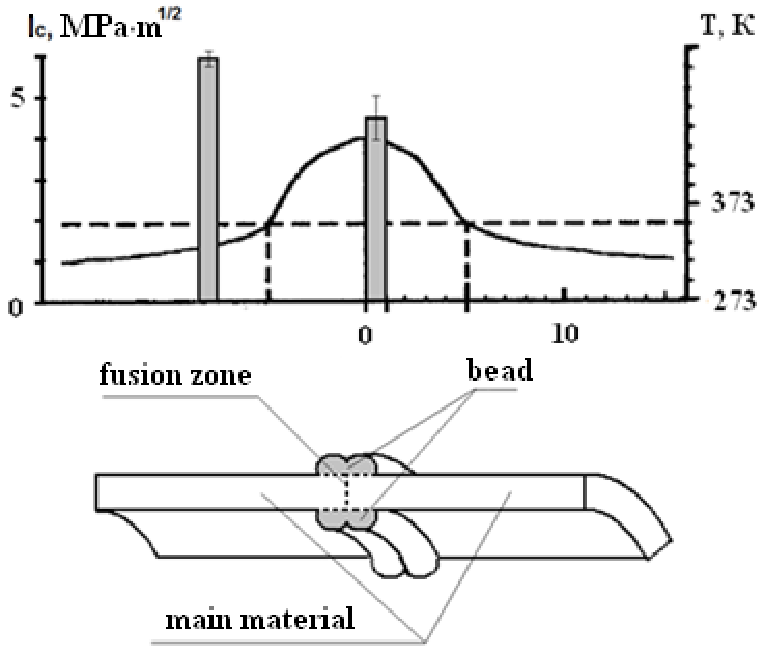

FIGURE 1. The temperature field at the initial moment of the formation of the welded butt joint

Figure 2 shows microphotographs of the fracture surfaces of incised model specimens of the base material and the PE100 welded butt joint at the test speed $V = 500$ mm/min.

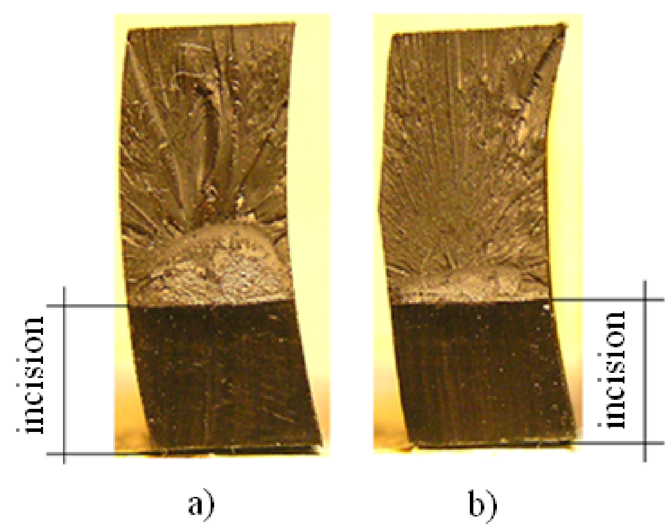

FIGURE 2. Microphotographs of the fracture surfaces of incised model specimens of PE100 WBJ in the zone of the main material (a) and in the welding zone (b)

CONCLUSIONS

The crack resistance limit of the PE80 material is higher than that of PE63 and lower than that of PE100 at a temperature of 213 K.

The I_C values for PE63, PE80 and PE100 in the weld region are smaller than in the base material. The decrease of the crack resistance limit I_C in the weld region relative to the main material of the pipe makes, on average, ~25% for PE63, for ~21% PE80 and ~11% for PE100. The smallest decrease in I_C for PE100 indicates its better weldability compared to PE80 and PE63.

These data confirm the hypothesis of embrittlement of the area of the welded joint with respect to the smooth body of the pipeline and explain the localization of specimen fracture mainly on the weld in the tests for long-term strength.

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