EFFECT OF SULFUR CONTENT ON THE RESISTANCE TO FRACTURE OF LOW-ALLOY PIPE STEEL

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We investigated the effect of the sulfur content and the quantity and geometry of sulfide inclusions on the resistance to fracture of low-alloy pipe steels 17GS and 16G2SAF, the chemical composition of which is given in Table 1.

Steel 17GS was melted in a 50-kg induction furnace from pure charge materials, with fractional casting in 10-kg ingots with 0.007, 0.015, 0.032, and 0.100% S. The ingots were forged to sheet bars and rolled to plates 12 mm thick. Samples were normalized at 930°C.

Fine sulfide inclusions (length ≤ 2.0 μ) were observed in the steel after deformation. With increasing sulfur concentrations the quantity of sulfides, distributed in clusters or stringers, increases, while the size of the inclusions remains almost unchanged.

Steel 16G2SAF was melted in a 30-ton converter and treated with liquid synthetic slag (SSh) in the ladle. To obtain an elevated sulfur content in one ingot (0.025%) powdered commercial sulfur was added to the mold under the stream of metal.

Ingots weighing 14.5 tons were rolled and cross rolled to plates 12 mm thick, which were normalized at 930°.

Metallographic analysis showed that the steel treated with liquid synthetic slag has fine (< 1 μ thick) sulfide inclusions with a ratio of length to width ~ 2 : 1. With increasing sulfur concentrations the shape of the sulfide inclusions remains unchanged, but the quantity and size increase.

Figure 1 shows the change in the fracture toughness and percentage of ductile components in the fracture of notched samples of type I and samples with a started fatigue crack of steels 17GS and 16G2SAF in relation to the sulfur content at different testing temperatures. The data indicate that with ductile or mixed fracture the fracture toughness of the steel decreases with increasing sulfur concentrations regardless of the type of sample.

From the fracture toughness of samples with a started crack it is possible to calculate the work of crack propagation (a_p), taking into account the work of crack propagation in relation to the character of fracture.

With increasing sulfur concentrations the dimpling at the tip of the stress concentrator (notch, crack) decreases, which points to a reduction of macroplastic deformation of the material in the zone of the stress concentration (and correspondingly the work of crack initiation a_i). This is also confirmed by measurements of the microhardness through the cross section of samples with a notch and a started crack.

TABLE 1

Steel	Composition, %								
	C	Si	Mn	S	P	Al	O	V	N
17GS	0,18	0,19	1,3	0,007; 0,015; 0,032; 0,1	0,002	0,038	0,010	–	–
16G2SAF (SSh)	0,16	0,49	1,5	0,004; 0,025	0,009	0,038	0,004	0,076	0,016

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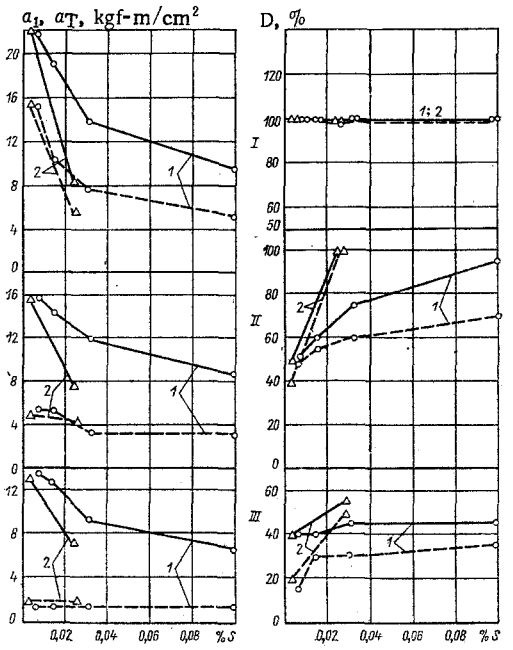

Fig. 1. Variation of the fracture toughness and percentage of ductile components in the fracture with the sulfur content of steels 17GS (1) and 16G2SAF (2). I, II, III) Testing temperature 20, −20, and −40°, respectively. —) Notched samples of type I; ---) samples with a started crack.

Examination of the fractures of samples with a notch or a started crack indicates that with mixed fracture the extent of ductile fracture (quantity of fibrous components) increases notably with the sulfur content of the steel (Fig. 1).

This effect of sulfur on the fracture toughness and the type of fracture in low-alloy steels was described in [1-3] and called the "sulfide effect" [1].

This phenomenon is due to the effect of sulfide inclusions on the characteristics of deformation and fracture of the steel. With decreasing sulfur concentrations the steel undergoes more plastic deformation before crack initiation in the bulk stress zone (near the notch or crack). For this reason, the main crack is formed and propagates in the zone of cold worked material with a high level of elastic energy accumulated in local volumes. The formation of new surfaces under these conditions is characterized by a reduction of the energy spent and is manifest in an increase of crystalline components in the fracture. There is evidently a relationship between the conditions of crack initiation and crack propagation.

LITERATURE CITED

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