EFFECT OF SULFUR AND PHOSPHORUS ON THE PROPERTIES OF STEEL 18B

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The Ukrainian Scientific-Reserach Institute of Metals, in collaboration with the E. O. Paton Institute of Electric Welding of the Academy of Sciences of the Ukrainian SSR, has developed low-carbon steel 18B, microalloyed with niobium, with good weldability [1, 2].

The use of steel 18B in place of St3sp reduces the weight of structures and increases the strength and reliability.

We investigated the possibility of using steel 18B with a concentration of sulfur and phosphorus at the upper limit established for steel St3sp (<0.05% S, <0.04% P).

The chemical composition of the steels is given in Table 1.

We investigated steel 18B with 0.030% S and 0.025% P and with 0.055% S and 0.050% P in comparison with steel St3sp with the same chemical composition. Ferroalloys FeS and FeP were added to increase the sulfur and phosphorus concentrations. The steel was rolled to strips 12 × 170 mm in section.

The mechanical properties of the steel were determined after hot rolling and after normalization, and also after aging (10% deformation + tempering at 250°C for 1 h).

Raising the sulfur and phosphorus concentrations has essentially no effect on the strength and ductility; the reduction in section decreased slightly (by 2-6%) and the hardness of both steels increased somewhat.

The toughness was determined on longitudinal samples of type I (GOST 9454-60). The tests showed that with increasing sulfur and phosphorus concentrations the toughness at +20°C for steels 18B and St3sp

TABLE 1

Steel	Composition, %			
	Mn	Si	S	P
18B	0,50	0,32	0,030	0,025
	0,57	0,31	0,030	0,025
	0,53	0,34	0,055	0,050
	0,54	0,32	0,055	0,050
St3sp	0,53	0,32	0,030	0,025
	0,53	0,33	0,030	0,025
	0,55	0,35	0,055	0,050
	0,54	0,33	0,055	0,050

Note: The carbon content of both steels was 0.18%; steel 18B also contained 0.05% Nb.

TABLE 2

Steel	Condition	a_1	a_p	H_{20}
		kg-m/cm²		
St3sp	hot rolled	4,0/5,0	12,0/8,5	261/304
18B		5,0/4,0	5,0/2,5	295/362
St3sp	normalized	6,5/5,5	13,5/9,5	236/264
18B		5,5/6,0	11,5/6,5	270/318

Note: Numerators refer to steel with 0.030% S and 0.025% P; denominators to steel with 0.055% S and 0.050% P.

Ukrainian Scientific-Research Institute of Metals. Translated from Metallovedenie i Termicheskaya Obrabotka Metallov, No. 12, pp. 50-52, December, 1974.

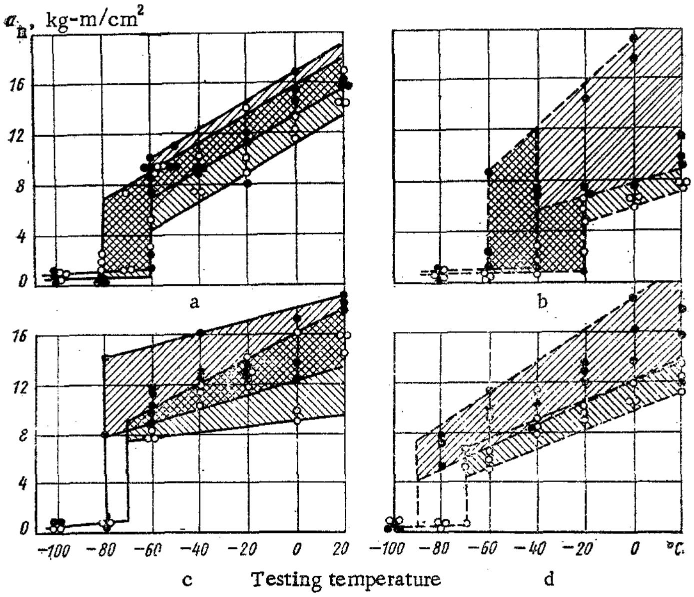

Fig. 1. Toughness as a function of testing temperature for steels St3sp (solid lines) and 18B (dashed lines) after hot rolling (a, b) and after normalization (c, d). ●) With 0.030% S and 0.025% P; ○) with 0.055% S and 0.050% P.

decreases by 20-35% after hot rolling and normalization, while the ductile—brittle temperature, determined from the point at which scattering of the toughness values begins, shifts to positive temperatures. The ductile—brittle temperature of steel 18B increases by 20-30°C and that of St3sp by 10-20°C; in the hot rolled condition these temperatures are −20 and −60 to −70°C respectively, and after normalization they are −60 to −70°C for both steels (Fig. 1).

With increasing sulfur and phosphorus concentrations the percentage of ductile components in the fracture of both steels decreases, while the ductile—brittle temperature, determined as 40% or less ductile components in the fracture, remains unchanged.

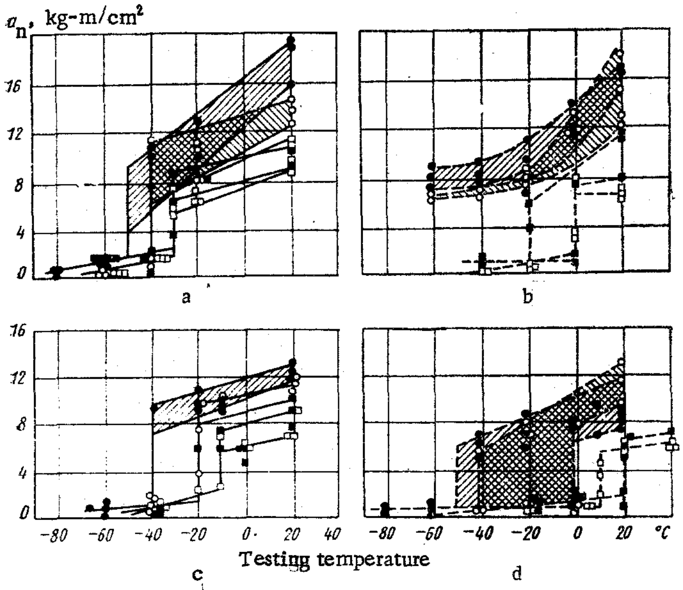

Fig. 2. Toughness of hot rolled (■□) and normalized (● ○) steels St3sp (solid lines) and 18B (dashed lines) after mechanical aging. a, b) 0.030% S and 0.025% P; c, d) 0.055% S and 0.050% P. ●■) 10% deformation; ○□) 10% deformation + tempering at 250°C.

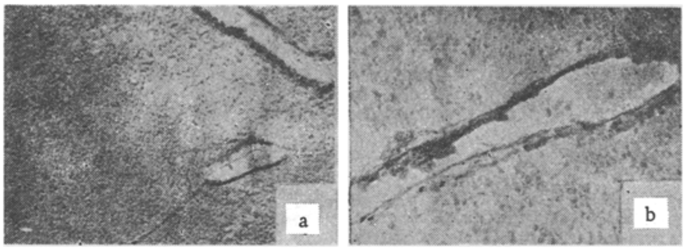

Fig. 3. Sulfide inclusions in steel 18B with 0.055% S and 0.050% P. a) × 4800; b) ×11,600.

The work of crack initiation a_i and crack propagation a_p were determined by Gulyaev's method [3, 4]. Raising the sulfur and phosphorus concentrations has the strongest effect on the work of crack propagation (Table 2).

A study of the susceptibility to mechanical aging showed that the strength of the steel increases after aging, while the ductility decreases. The yield strength of both steels increases to a greater extent than the ultimate strength. The increase in strength is considerably larger for steel St3sp than for 18B. The increase of the yield strength was 75-85% for St3sp and 44-54% for 18B in the hot rolled condition. In the normalized condition the increase in strength with aging is somewhat smaller. Raising the sulfur and phosphorus concentrations has a negligible effect on the mechanical properties after aging. The toughness of longitudinal samples after mechanical aging decreases – 25-35% for hot rolled 18B and 40-50% for St3p; 6.5-11.0% for normalized 18B and 27-38% for St3sp (Fig. 2).

The ductile—brittle temperature after mechanical aging, determined from the point at which scattering of the toughness values begin, rises 40°C for hot rolled 18B and 30-50°C for St3sp; it is 0°C for 18B and −30°C for St3sp. Raising the sulfur and phosphorus concentrations has a considerable effect on the susceptibility to aging (determined from the ductile—brittle temperature) of steel 18B in the normalized condition. With 0.030% S and 0.025% P the ductile—brittle temperature after mechanical aging is almost unchanged (down to −60°C there is no scattering of the toughness values, which remain higher than 6 kg-m/cm^2), while with 0.055% S and 0.050% P it rises from −70 to 0°C.

Metallographic analysis revealed sulfides, oxides, and oxysulfides in 18B and St3sp, the oxides in 18B being finer than in St3sp. Steel 18B is also characterized by rose-colored inclusions of niobium carbonitride.

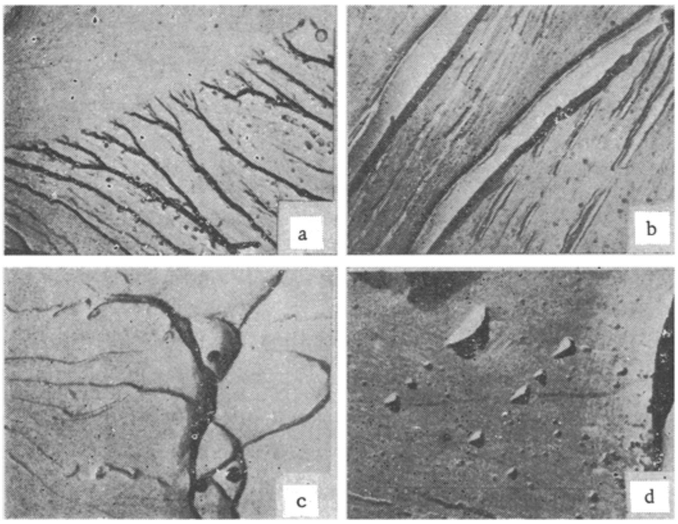

Fig. 4. Fractographs of steel 18B with 0.030% S and 0.025% P (a) and with 0.055% S and 0.050% P (b-d). a) Riverine pattern; b) tongues elongated in the direction of deformation; c) transition from brittle to ductile fracture; d) "scallops."

Electron microscopic examination of positive carbon replicas showed that the sulfides are located in the body of ferrite grains and are elongated in the rolling direction (Fig. 3a). With 0.055% S, inclusions are sometimes observed in the boundaries of ferrite grains or subgrains (Fig. 3b).

The ferrite grain size of steel 18B after hot rolling was grade 8-9, and grade 9-10 after normalization, while the grain sizes of steel St3sp were grades 7-8 and 8-9 respectively.

The microhardness of ferrite (Table 2) increases by 30-70 units (H_{20}) with increasing sulfur and phosphorus concentrations in both steels. This is evidently due to enrichment of ferrite with phosphorus, which has a hardening and embrittling effect.

Impact test samples were fractured at −196°C to determine the character of the fracture (intercrystalline or transcrystalline). The fracture of both steels in the hot rolled and normalized conditions was mixed in character – in the grain boundaries and through the body of the grains. With increasing concentrations of sulfur and phosphorus the percentage of transcrystalline fracture increased, which indicates increasing brittleness of the metal. The percentage of transcrystalline fracture of steels St3sp and 18B was 50 and 80% respectively with 0.030% S and 0.025% P and 60 and 90% respectively with 0.055% S and 0.050% P.

Fractographic analysis of both steels tested at −40°C showed sulfide inclusions. Most facets are characterized by a riverine pattern branching at grain boundaries, with steep terraces in steel 18B (Fig. 4a). White tongues extending in the direction of deformation (Fig. 4b), indicating considerable embrittlement of the metal [5], occur in steel 18B with increasing sulfur and phosphorus concentrations. Some cleavage faces have scallops (Fig. 4d), which are formed due to local extraction of metal on the surface between the main cleavage face and a twin occurring in the process of crack propagation.

CONCLUSIONS

1. Increasing the sulfur concentration from 0.030 to 0.055% and the phosphorus concentration from 0.025 to 0.050% lowers the toughness of steel 18B (by 20-35%), lowers the percentage of ductile components in the fracture and the work of crack propagation, and raises the ductile–brittle transition temperature (by 20-30°C).

2. The embrittling effects of sulfur and phosphorus are probably due to the increase in the number and size of sulfide inclusions, some of which are located in the boundaries of grains and subgrains of ferrite, and also the increase in the brittleness of ferrite with increasing phosphorus concentrations.

3. To prevent embrittlement of steel 18B the sulfur and phosphorus concentrations should not exceed the limits established for low-alloy steels.

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