MECHANICAL PROPERTIES OF STEELS UNDER CYCLIC LOAD

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Mechanical properties of steels determined under cyclic load are one of the criteria for the use of these steels as machine-construction materials. The properties of components can be improved by the use in their production of high-tensile alloyed steels and by enhancing the methods of their strengthening.

The investigations were concerned with alloy steels intended for parts working under the conditions of prolonged variable loads (Table 1).

The case-hardening steel 16KhN3MA-Sh is used in the oil industry for the manufacture of parts of drill bits intended for work under prolonged alternating static and dynamic loads.

D7KhFN-Sh and D5KhN2MFA-Sh steels were developed in the Gubkin Institute for the manufacture of heavily loaded parts of the oil industry and drilling equipment.

The 16KhN3MA-Sh steel specimens were case-hardened at 920°C and subsequently annealed at 100 to 500°C.

The carbon content in the surface layer was 0.8-1.0%. Such a case-hardening depth was selected which would ensure a relative core area, equal to 0.5.

The D7KhFN-Sh steel was hardened in oil at 840°C and the D5KhN2MFA-Sh steel at 870°C and subsequently annealed at 100-500°C.

The fatigue tests were carried out according to GOST 25.502-79 in pure bending with rotation using type 11 specimens. The test base was constant amounting to $5 \cdot 10^6$ cycles. The strength properties were determined according to GOST 1497-73.

The coefficient of cyclic viscosity of fracture (K^q_{Ic}) was calculated according to [1]:

$$K^q_{Ic} = \sigma_N \sqrt{\pi l_s},$$

where σ_N is the nominal bending stress for fatigue tests; l_s is the critical crack length.

The critical crack length was determined in the specimen fracture after its failure under a stress close to the fatigue limit; it corresponds to the maximum thickness of the zone covered by fatigue strips.

The effect of the annealing temperature or the fatigue limit of the investigated steels is shown in Fig. 1. The D5KhN2MFA-Sh steel has the maximum fatigue limit and 16KhN3MA-Sh the minimum after case hardening. The experience gained in the operation of parts from high-tensile steels shows that the fatigue limit does not always define the degree of their suitability for use.

TABLE 1

Steel	Content of elements, %								
	C	Mn	Si	Cr	Ni	Mo	V	S	P
16KhN3MA-Sh	0,15	0,45	0,16	0,72	3,5	0,28	—	0,015	0,010
D7KhN-Sh*	0,74	0,29	0,16	0,59	1,4	—	0,23	0,011	0,010
D5Kh2MFA-Sh†	0,47	0,68	0,33	0,95	1,4	0,26	0,19	0,015	0,010

*Inventor's Certificate No. 232506 USSR. MKI S 22 S 39/36. Steel.
†Inventor's Certificate No. 945221. MKI S 22 S 38/46. Steel

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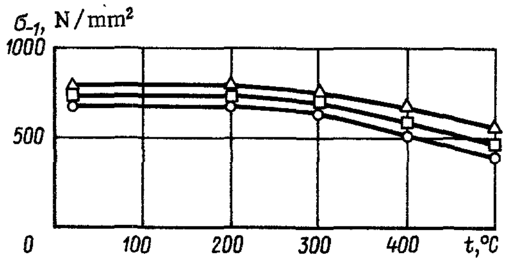

Fig. 1

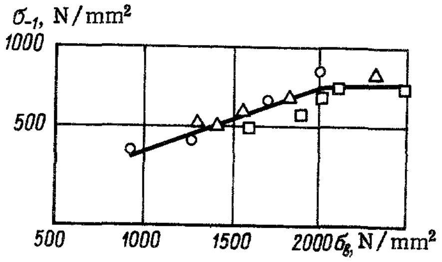

Fig. 2

Fig. 1. Effect of annealing temperature on fatigue limit of steels: ○) 16KhN3MA-Sh; Δ) D5KhN2MFA-Sh; □) D7KhFN-Sh.

Fig. 2. The link between ultimate strength and fatigue limit of the investigated steels. For denotations see Fig. 1.

The link between the ultimate strength and the fatigue limit of hardened alloy steels is shown in Fig. 2. An improvement in the ultimate strength to 2000 N/mm^2 causes an increase in the fatigue limit regardless of the chemical composition of steels. After a further increase in the ultimate strength the fatigue limit shows practically no change. This relation is a common feature of the alloyed high-tensile steels.

The practical equivalence of the fatigue limit values of the alloy steels makes the selection of the chemical composition of a steel for the manufacture of equipment and tooling for real working conditions more difficult. This is important especially as experience has shown that the use of steels with high strength properties does not always result in an increase of life of various structures.

An important place among all the properties characterizing the suitability of a steel for the use as engineering material, alongside with the mechanical properties and wear resistance is occupied by fracture toughness.

The mechanical properties and cyclic fracture toughness of steels after hardening and low annealing are given in Table 2.

It can be seen that steels D5KhN2MFA-sh and D7KhFN-Sh surpass the case-hardening steel 16KhN3MA-Sh with regard to strength properties and D5KhN2MFA-Sh steel also in cyclic fracture toughness.

The differences between the values of K^q_{Ic} can be explained by the special features of initiation and growth of cracks during the cyclic loading process of the surface strain-hardened steels. As is shown by the fractographic investigations of the 16KhN3MA-Sh steel, the initiation of a crack takes place in the transition zone. The initiated crack grows at a high rate in the high-carbon layer, which is the reason for insufficiently high K^q_{Ic} values of the 16KhN3MA-Sh steel as compared with those of the D5KhN2MFA-Sh steel.

The effect of annealing temperature on the cyclic fracture toughness of steels 16KhN3MA-Sh and D5KhN2MFA-Sh is shown in Fig. 3. A rise of the annealing temperature of the D5KhN2MFA-Sh steel from 200 to 400°C causes no noticeable reduction of K^q_{Ic}. When the annealing temperature is raised to 500°C K^q_{Ic} slightly decreases which can be attributed to the annealing brittleness of the second order.

TABLE 2

Steel	Heat treatment	σ_B	$\sigma_{0,2}$	σ_{-1}	δ	ψ	K^q_{Ic}, N/mm$^{3/2}$
		N/mm^2			%		
16KhN3MA-Sh	1. Case hardening at 920℃ + hardening at 890℃ + annealing at 650℃. 2. Hardening at 780℃ + annealing at 200℃	2000	1700	660	10,0	40,0	1710
D7KhFN-Sh	Hardening at 840℃ + annealing at 200℃	2500	1800	700	7,5	25,0	1650
D5KhN2MFA-Sh	Hardening at 870℃ + annealing at 200℃	2500	1900	750	10,0	50,0	1820

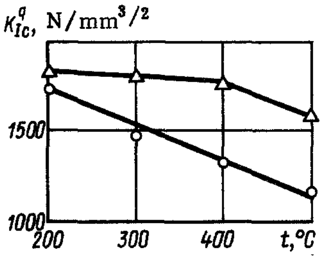

Fig. 3. Effect of annealing temperature on cyclic fracture toughness of steels 16KhN3MA-Sh (○) and D5KhN2MFA-Sh (△).

The effective reduction of K^q_{Ic} of the case hardened steel 16KhN3MA-Sh with rising annealing temperature can be explained by the fact that the critical crack length (l_s) does practically not change as a function of annealing temperature (l_s = 2.25-2.4 mm). At the same time a reduction in the fatigue limit and of the nominal bending stress close to it in value takes place, which causes the reduction in the cyclic fracture toughness of the case hardened steel.

The cyclic fracture toughness factor of the D5KhN2MFA-Sh high-tensile steel is less sensitive to a change in the structure and does practically not change within a wide range of annealing temperatures.

Thus, use of the medium-carbon alloy steel D5KhN2MFA-Sh (0.4-0.5% C) for parts working under cyclic load is preferable to the case-hardened steel 16KhN3MA-Sh and high-carbon steel D7KhN-Sh although their mechanical properties differ only little.

CONCLUSIONS

1. For work under alternating loads it is possible to use medium-carbon alloy steels whose ultimate strength reaches 2000 N/mm^2.

2. The use of case-hardened steel for work with prolonged alternating loads does not result in a marked increase of fracture toughness because of the presence of high brittleness of the superficial high-carbon layer.

LITERATURE CITED

1. V. S. Ivanova and V. F. Terent'ev, The Nature of Metal Fatigue [in Russian], Metallurgiya, Moscow (1975).