INVESTIGATION OF FORGED ROTORS OF 1Kh12VNMF STEEL

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Two experimental forged rotors of steel 1Kh12VNMF (ÉI802) have been prepared for gas turbines (Fig. 1). In this article we give the results of testing the properties of these forgings.

The steel was melted in a 40-ton arc furnace with a basic lining by the method of oxidation without evacuation during pouring. The chemical composition of the melt was 0.17% C, 0.29% Si, 0.56% Mn, 11.60% Cr, 0.80% Ni, 0.66% Mo, 0.29% V, 0.81% W, 0.012% S, 0.016% P.

The rotors were forged from ingots weighing 17 tons (rotor 1, Fig. 1a) and 9.5 tons (rotor 2, Fig. 1b) with H/D = 1.5 and a taper of 10.6%.

The rotors were forged with intermediate upsetting at 1200-900°C on a 3000-ton press. The plasticity of the steel was high in all the forging operations.

The initial heat treatment consisted of supercooling to 300-350 and 200-250°C with subsequent soaking at 690-710°C for 60 h.

After rough machining the forgings were heated to the quenching temperature of 1050°C in a vertical furnace, cooled in oil, and tempered 20 h at 705°C with cooling down to 100°C in the furnace.

The mechanical properties of samples cut out of the rotors (from the places shown in Fig. 1) are given in the table. The consistent values of the ductility and impact strength through the cross section and at the edges of the rotor indicate the lack of any large metallurgical defects. The fractures of all samples were dark and fibrous; the microstructure was sorbite oriented toward martensite.

Sonic testing of the rotors and periscopic inspection of the center channels did not reveal any flaws.

Test samples were cut mainly from rotor 2. No defects were found after etching the faces of a diametric sample cut from the middle barrel of the rotor. However, in tangential samples from the

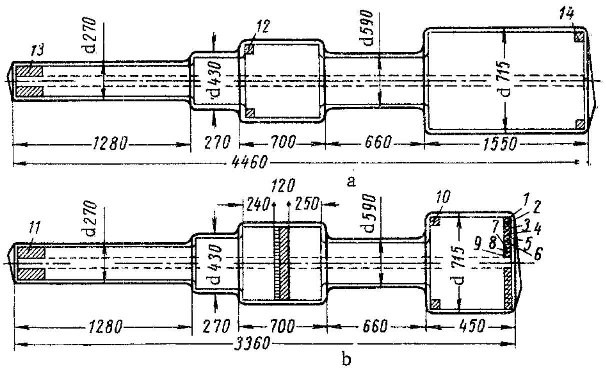

Fig. 1

Fig. 2

Fig. 1. Experimental rotors with diagram showing places where samples were taken for testing the mechanical properties. The thin lines indicate the final dimensions of the rotors.

Fig. 2. Fracture of sample from center of rotor 2. ×2.

V. I. Lenin Nevskii Plant. Translated from Metallovedenie i Termicheskaya Obrabotka Metallov, No. 8, pp. 51-54, August, 1967.

Rotor No.	Direction of cutting samples	Sample No.	$\sigma_{0,2}$	σ_b	δ	ψ	a_n, kgm/cm²	HB
			kg/mm²		%			
1	Tangential	12	65	79	17	39	6.1—5.8	255
	Longitudinal	13	63	78	21	53	7.5—8.4	255
	Tangential	14	61	76	21	51	6.0—6.1	241
2	Tangential	1	62	78	19	43	5.0—5.0	255
		2	60	78	18	43	5.2—5.0	255
		3	61	79	13	44	5.4—5.0	255
		4	62	79	13	43	4.8—4.8	255
		5	61	79	15	40	4.5—4.9	241
		6	62	78	15	43	4.3—5.1	241
		7	62	80	18	44	5.0—5.1	241
		8	62	79	17	45	5.1—4.5	241
		9	61	79	16	35	5.6—5.6	241
		10	58	78	19	40	5.5—5.1	255
	Tangential	11	61	80	23	52	7.8—8.1	255

center area the ductility decreased sharply; the impact strength remained fairly uniform. The ultimate tensile strength decreased sharply, almost to the level of the yield point. The same results were obtained in tests of radical samples. In the longitudinal samples the ductility did not decrease.

In the fracture of samples taken from the center of the diametric samples in both the tangential and radical directions we found light spots which in outward appearance resemble the spots in structural steel (Fig. 2). The fractures of tangential and longitudinal samples from the peripheral zone were fibrous and without visible defects. In the fractures of impact test samples no defects were found either.

The microstructure of the metal was identical through the cross section of the rotor. The reason for the formation of defects and the lowered ductility was hydrogen embrittlement. Heating the samples 300 h at 600°C raised the specific elongation from 6-7 to 15-18% and the reduction in section from 11-15 to 26-40% without changing the ultimate tensile strength. After this treatment the hydrogen concentration fell from 2.85 to 0.5 cm³/100 g. On prolonged tempering the plastic properties of samples taken from the embrittled zone of the rotor were restored; cracks and other discontinuities were completely absent. But in the fractures of samples taken 100-110 mm from the center, with a sharply reduced ductility, there were light spots.

It was interesting to determine whether these defects were segregates, since it is considered that high-chromium stainless steels are not affected by segregation. Neither examination of the zone of the rotor adjacent to the central channel after etching of the polished samples nor ultrasonic defectoscopy revealed the existence of any discontinuities in the metal in the unstressed condition.

Two tangential samples from the central zone were placed under a tensile stress near the yield point. After removal of the load no tears or other defects were found on the surface. These defects of the white spot type appear in the fracture of the tangential samples under loads above the yield point.

A group of tangential samples from the zone of the rotor adjacent to the central channel was subjected to prolonged tempering under the conditions given above. The hydrogen concentration was reduced from 3.25 to 1 cm³/100 g, while the ductility was not restored. Nor did improvement increase the plastic characteristics. We found light spots in the fractures of all samples.

It can be concluded that in zones near the central channel there are microcracks in the original steel which cannot be detected by the ordinary methods of checking – etching and ultrasonic defectoscopy.

Thus, the primary reason for the formation of microcracks in the steel is the presence of hydrogen, the amount of which increases toward the center section of the rotor. The nature of these defects and their effect on the mechanical properties of the steel are essentially the same as those of ordinary segregates. The difference is only that they are more difficult to find. Such defects are conditionally called "pseudosegregates."

In the presence of pseudosegregates there is great risk of premature breakdown and even fracture of the rotor. In certain periods of operation, during starting, for example, the most highly stressed sections of the rotor undergo local stress concentrations which sometimes reach values near the yield point. Such stress concentrations occur first of all in the central section of the rotor where the pseudosegregates mainly occur. In the presence of defects of the pseudosegregates type and extremely low reserve ductility large stress concentrations induce the formation of microcracks – dangerous stress concentrators which can lead to fracture of the rotor. Furthermore, the development of pseudosegregates can also occur at loads below the yield point under the influence of the alternating vibrational stresses occurring during operation of the rotor.

In view of the characteristics of the defects found in the center areas of the forgings manufactured from complex-alloyed high-chromium steels, the properties of the central zone of the rotors must be checked by other methods in addition to those regularly used.

In building rotors from such steels the possibility should be provided of taking samples from the central zone. The investigation of the rotors forged from basic electrosteel indicates the possibility of the formation of defects of the segregation type in large forgings of hardened high-chromium steels.

Vacuum pouring of high-chromium steels is obviously one way of reducing the hydrogen concentration. Attention must also be given to selecting the correct initial heat treatment to obtain forgings with high mechanical properties throughout the cross section.