DIE STEELS WITH HIGH HEAT RESISTANCE AND TOUGHNESS

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The standard die steels do not ensure the necessary service life of dies for hot pressing of hard-to-work materials. Steels 3Kh2V8F, 4Kh5V2FS, 4Kh5MFS, and others retain high yield strength (100-110 kgf / mm^2) only up to 600-620°C. At 700-720° (during pressing) the yield strength drops to 20-40 kgf / mm^2.

The development of steel 2Kh6V8M2K8, which retains a yield strength of 100-110 kgf / mm^2 up to 700-730° due to logical alloying, substantially increased the service life of dies, but only in the case of pressing without substantial dynamic loads [1]. The toughness of this steel does not exceed 1.6 and 4 kgf-m / cm^2 at 20 and 600°, respectively (compared with 3-5 and 6-9 kgf-m / cm^2 for steels with 5% Cr).

Operation under dynamic loads and with intensive cyclic cooling requires a steel combining high heat resistance with high notch toughness and resistance to crazing.

We investigated steels with systematically varied concentrations of tungsten, chromium, and cobalt as the principal elements determining these properties (Table 1).

The tungsten concentration was varied from ~9 to ~4.8%; the possible reduction of the heat resistance in this case may be compensated by an increase of the toughness and thermal conductivity. The chromium content was reduced from 7-8 to ~4%; this is possible with use of inert lubricants, which reduces the requirements for scale resistance. Cobalt in steels with a low carbon content that are alloyed with ferrite-forming elements ensures the absence of excess ferrite. In some heats, part of the cobalt was replaced with nickel, which broadens the γ region, but less effectively than cobalt.

The molybdenum content was held constant (~2%); at this concentration the mechanical properties improve due to its refining effect on the grain boundaries during precipitation hardening, with no decarburization [2]. To improve the toughness and raise the temperatures of the critical points the carbon content was reduced to 0.2-0.25%.

The steels were melted in an open induction furnace and poured in ingots weighing 40 kg, which were forged to bars 140 mm in diameter and bars 12 × 12 and 16 × 16 mm in section.

The initial forging temperature was 1150-1180°, and final forging temperature 950°. The forgeability of all steels was good and somewhat higher than that of steel 2Kh6V8M2K8, since the carbon content did not exceed 0.23% and the tungsten and cobalt concentrations were lower.

Because of the high phase transformation temperatures the steels were annealed at 870-880° for 2 h, followed by cooling to 720° at the rate of 30 deg / h and holding at this temperature for 3-4 h. The hardness of the steels after annealing was HB 196-228 (HB 255 for steel 2Kh6V8M2K8), which ensures good machinability.

The structure of the steels after annealing consisted of sorbitic pearlite (except steel 2Kh5V8M2) and evenly distributed carbides, the size of which did not exceed 2-3 μ, in comparison with 4-9 μ in steels with 0.4% C and 5% Cr.

Steels containing over 5.5% W contained only M_6C carbides. With 4-4.5% Cr the carbide lattice constant was largest (11.05 Å); with 6 and 8% Cr it was 11.03 and 11.01 Å, respectively. When the tungsten content was reduced to 4.5-5.5%, $M_{23}C_6$ carbide was also formed.

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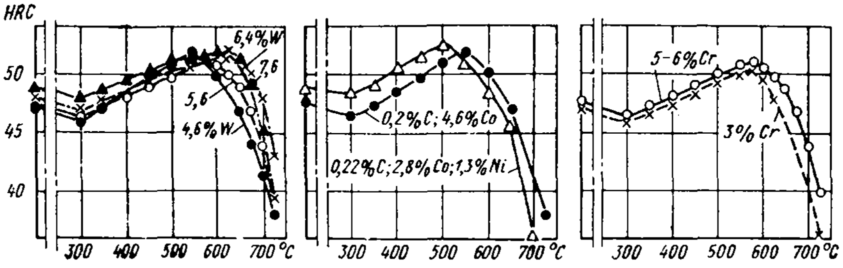

a b c

Fig. 1. Effect of tungsten (a), nickel (b), and chromium (c) on the hardness of steels after tempering.

TABLE 1

Heat No.	Steel	Composition, %				
		C	Cr	W	Mo	Co
1	2Kh6V8M2K8	0,26	7,3	9.00	2,12	8,05
2	2Kh5V7M2K5	0,21	5,3	7,58	2,31	4,68
3	2Kh5V6M2K5	0,22	5,3	6,39	2,33	4,68
4	2Kh5V5M2K5	0,21	5,3	5,62	2,36	4,50
5	2Kh5V4M2K5	0,22	5,4	4,80	2,34	4,63
6	2Kh4V6M2K5	0,21	4,1	6,21	2,32	4,42
7	2Kh3V6M2K5	0,23	3,2	6,10	2,28	4,20
8	2Kh6V5M2K3N1	0,22	6,0	4,88	2,59	2,85
9	2Kh5V8M2	0,22	5,3	7,97	2,36	—

Note. Steel 2Kh5V5M2K3N1 contained 1.35% Ni.

TABLE 2

Steel	a_n, kgf-m/cm^2		$1/\rho$, m/Ω·mm^2	Heat resistance (to HRC 45)
	HRC 49–51	HRC 44–46	HRC 44–46	
2Kh6V8M2K8	0,9–1,1	1,2–1,5	1,548	735–740
2Kh5V7M2K5	1,5–1,7	2,0–2,3	1,945	700–710
2Kh5V6M2K5	1,7–2,0	2,1–2,5	1,968	680–690
2Kh5V5M2K4	2,0–2,3	2,4–2,8	2,005	670–680
2Kh5V4M2K5	2,6–3,0	3,0–3,5	2,097	640–650
2Kh4V6M2K5	1,8–2,2	2,0–2,5	—	650–655
2Kh3V6M2K5	2,0–2,3	2,3–2,6	—	640–645
2Kh6V5M2K3N1	5,5–5,7	2,3–2,6	—	635–640
2Kh5V8M2	—	2,5–3,0	—	635–640

The steels without cobalt and nickel contained 25-35% δ ferrite after annealing and after quenching.

The initial $\alpha \rightarrow \gamma$ transformation temperature varies with the alloying – 880-890° for steels with 9% W and 7-8% Co; 835-850° for steels with ~5% W, ~5% Co, and ~5% Cr; and 810-820° when cobalt is replaced with nickel.

The grain size of steels with 5-6% Cr and no nickel is grade 9-11 at 1180-1230°. This is due to the high concentration of chromium, tungsten, and cobalt in the solid solution, which inhibits diffusion processes. Steels with nickel retain fine grains at lower temperatures – 1140-1160°. Steels with 3-4% Cr have grains differing in size – along with fine grains there are grains of grade 6-7, which is due to the change in the composition of the carbide phase.

Steels without nickel were quenched from 1180-1230°; the steel with 1.35% Ni, from 1140-1160°.

After quenching, the steels consisted of martensite and excess carbide. The hardness of the steels after quenching was HRC 48-50 (HRC 46 for the steels without cobalt).

The composition of the solid solution is determined by the conditions of the solution of M_6C carbide. The heating temperature for the solution of a large part of M_6C carbide rich in chromium (steels with 5-6% Cr) is 1200-1220°, which permits retention of fine grains. The solubility of M_6C carbide in steels with a lower chromium content (3-4%) is smaller at these same temperatures, which leads to lower alloying of the solid solution. The electrical resistivity of the steels with 5-6% Cr and 3-4% Cr after quenching to a grain size of grade 9-10 was 0.67 and 0.62 $\Omega \cdot mm^2/m$, respectively.

Precipitation hardening during tempering occurs in all steels (see Fig. 1). The rate of the process varies little with the composition of the steel; the increase in hardness as compared with the quenched condition is 3-5 units HRC.

The temperature at which the maximum secondary hardness is obtained depends greatly on the alloying of the steel – it is higher (625°) for steels with a high tungsten content (7-7.5%) and cobalt content (5-8%), lower (575°) for steels with 4-5% W and 4.5-5.5% Co, and does not exceed 500° for steels in which part of the cobalt is replaced with nickel. The secondary hardness is HRC 51-53. Lowering the chromium concentration to 5% has little effect on these temperatures. This is in good agreement with the assumption that the maximum hardening temperature is determined by the $\alpha \rightarrow \gamma$ transformation temperature [3].

The heat resistance, determined from the heating temperature (holding 4 h) after which the steel retains a hardness of HRC 45, depends primarily on the tungsten content and to a lesser extent on the cobalt content (Table 2). It was highest (735°) for steels with 9% W and ~8% Co. The heat resistance was lowest

(640-650°) for the steel containing nickel. It is higher when the hardening phase consists of M_6C carbide alone (M_2C in the process of precipitation). With formation of additional $M_{23}C_6$, which has a greater tendency to coalesce, i.e., in steels containing <5.5% W, the alloying of the solid solution decreases and also the heat resistance.

The thermal conductivity, characterized by the electrical conductivity, increases 35-40% – almost proportionally with reduction of the tungsten content from 9 to 4-5% (Table 2), which to some extent compensates the reduction of the heat resistance that occurs in this case.

The notch toughness (Table 2) at the two hardnesses established for dies (HRC 44-46 and 49-51) also depends more on the tungsten content – it increases 75-80% when the tungsten content is reduced from 8 to 5-6% and doubles when the tungsten content is reduced to 4-4.5%.

Because of its high heat resistance, steel 2Kh6V8M2K8 was tested at high temperatures and pressures without substantial dynamic loads and intensive cooling. In pressing austenitic alloys (at the All-Union Scientific-Research and Design Institute of Metallurgical Machine Construction) the service life of dies was 8-11 times higher than that of steel 3Kh2V8F.

In tests of steel 2Kh5V5M2K5 under high dynamic loads and intensive cooling in seamless dies for manufacturing high-speed steel blanks, the service life increased 7-10 times as compared with steels with 5% Cr (4Kh5V2FS, 4Kh5MFS).

CONCLUSIONS

1. Steels for pressing high-strength alloys must contain M_6C carbide in order to retain a high yield strength (80-120 kgf/mm^2) at temperatures up to 650-720°.

2. The heat resistance is highest (730-740°) and the notch toughness lowest (a_n = 0.8-1.5 kgf-m/cm^2) for the steel with ~8-9% W.

3. Steels of the first group (2Kh6V8M2K8 type) are intended for pressing without substantial dynamic loads and intensive cooling. They should be quenched from 1190-1210° and tempered at 700-710° (HRC 50-51) or 745-750° (HRC 45-46). Steels of the second group (2Kh5V5M2K5 type) are used for pressing with dynamic loads and intensive cooling. They are quenched from 1190-1230° and tempered at 620-625° (HRC 50-51) or at 680-685° (HRC 45-46).

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