STEELS FOR HOT WORKING DIES

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Hot working dies (for pressing, drawing, heading, forging) are made from steels 5KhNM, 5KhNV, 5KhGM, more heat resistant steels with 5% Cr (4Kh5V2FS in the USSR; 4Kh5MFS and 4Kh5MS, called H-11 and H-13, in the USA [1]), and recently steels with 3% Cr additionally alloyed with different amounts of tungsten, molybdenum, and silicon [1-3]. However, data on the mechanical and technological properties of these steels that are needed to choose the proper materials for dies for different purposes are still insufficient. Here we present the results of comparative tests of the properties of die steels 5KhNM, 4Kh3, 4Kh3V, 4Kh3M, 4Kh3VMS, 4Kh5MFS (H-11), and 4Kh5V2FS.

The steels were melted in an induction furnace and poured in ingots weighing 12 kg. The ingots were forged at 1150-900°C with cooling in air. The forgings were then annealed. The structure of the steels as annealed was sorbitic pearlite with sections of ferrite in steel 5KhNM and with carbide inclusions in the other steels. The hardness after annealing was HB 139-184.

The optimal quenching temperature was the temperature at which the steel retained a grain size of grade 10 (see Table 1); it provided a combination of good heat resistance, ductility, and resistance to erosion [4].

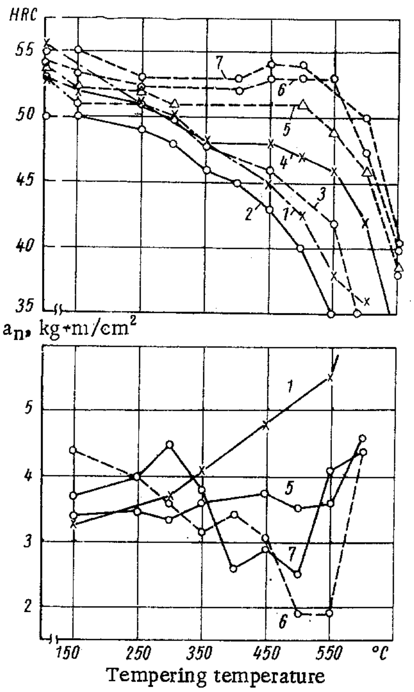

Fig. 1. Hardness and impact toughness of die steels in relation to tempering temperature. 1) Steel 5KhNM; 2) 4Kh3; 3) 4Kh3V; 4) 4Kh3M; 5) 4Kh3VMS; 6) 4Kh5MFS; 7) 4Kh5V2FS.

An increase of the chromium concentration in die steels requires an increase of quenching temperature — to 840-860°C for 5KhNM (5KhNV) and 1040-1060°C for 4Kh5V2FS — which increases decarburizing, particularly of large dies that require prolonged holding. Reducing the chromium content from 5 to 3% permits the quenching temperature to be lowered by 20-40°C.

Figure 1 shows the variation of the hardness of the steels with tempering temperature. The hardness of all the steels decreases with increasing tempering temperatures up to 300°C, while a further increase to 500-550°C leads to further reduction of the hardness for steels 5KhNM (5KhNV), 4Kh3, 4Kh3M, and 4Kh3V but no change in the hardness of the more alloyed steels or a slight increase due to precipitation hardening. This effect is most notable in the steels with 5% Cr. Tempering above 550°C leads to a sharp reduction of the hardness of all the steels. The heat resistance depends on the composition of the steel. Alloying 3% Cr steels with tungsten, molybdenum, and particularly silicon increases the heat resistance considerably. Thus, the heat resistance of 4Kh3VMS substantially exceeds that of 4Kh3, 4Kh3M, and 4Kh3V and is only slightly below that of steels with 5% Cr.

TABLE 1

Steel	Quench, °C	HRC
5KhNM (5KhNV)	840—860	55—59
4Kh3	940—960	50—52
4Kh3V, 4Kh3M	960—980	53—54
4Kh3VMS	1010—1030	53—54
4Kh5MFS	1010—1030	53—54
4Kh5V2FS	1040—1060	55—56

Moscow Machine-Tool Institute. Translated from Metallovedenie i Termicheskaya Obrabotka Metallov, No. 1, pp. 43-45, January, 1969.

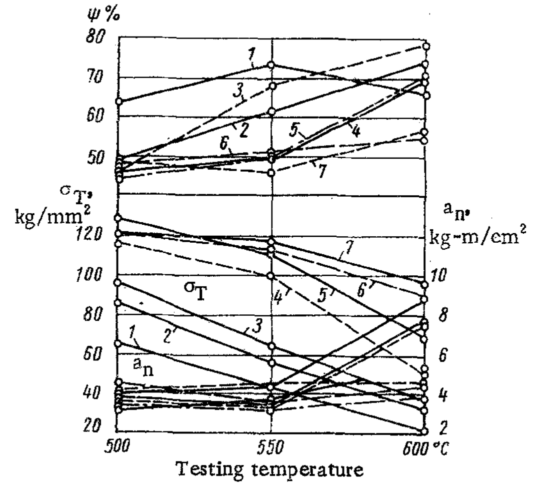

Fig. 2

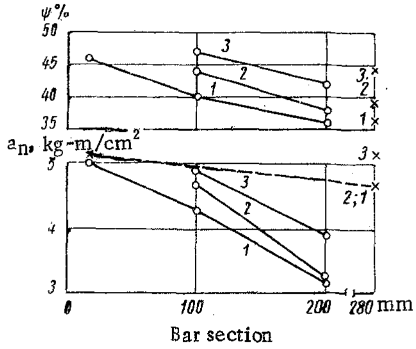

Fig. 3

Fig. 2. Mechanical properties of die steels at elevated testing temperatures. 1) Steel 5KhNM; 2) 4Kh3; 3) 4Kh3M; 5) 4Kh3VMS; 6) 4Kh5V2FS; 7) 4Kh5MFS.

Fig. 3. Impact toughness and plasticity in relation to the section of die steels. -×--) Steel 5KhNV (5KhNM); —— o ——) 4Kh5V2FS. 1) Samples from center; 2) halfway to center; 3) surface.

The impact toughness characterizes the most important property of die steels — the erosion resistance [4]. There is a general relationship between the erosion resistance and impact toughness for all the steels with 3 and 5% Cr (Fig. 1). On tempering at 300-400°C the impact toughness decreases as the result of first-order temper brittleness, and therefore tempering in this range does not provide the necessary erosion resistance. After tempering at 500-550°C the impact toughness decreases again due to precipitation hardening, the increase in hardness being inversely proportional to the decrease of impact toughness. At still higher tempering temperatures the impact toughness increases.

The mechanical properties at elevated temperatures are shown in Fig. 2. With increasing testing temperatures the yield strength decreases, while the plasticity and ductility increase. However, these changes are not identical for the different steels; the greatest change (decrease) of properties occurs in steels 5KhNM and 4Kh3.

With proper alloying, the heat resistance of the new steels with 3 and 5% Cr is high. The heat resistance of steel 4Kh3VMS is slightly inferior to that of steels with 5% Cr only at temperatures above 550°C.

The data presented were obtained with rolled or forged samples of small section (diam. 15-40 mm). However, many dies are of large size and the scale factor must be taken into account, since the mechanical properties decrease when the section is increased, particularly in hypereutectoid steels with 3-5% Cr. Therefore the properties of the steels with different sections from commercial heats were determined: steel 5KhNM (5KhNV) from a forged bar 280 mm in diameter and steel 4Kh5V2FS from a forged bar 16 mm in diameter, rolled bar 100 mm in diameter, and rolled bar 200 mm square.

Samples were taken 5 mm from the surface, halfway to the center, and 2 mm from the center of the bars. Impact test samples were taken also in the transverse direction (along the diameter).

The strength and plasticity of steel 5KhNV (5KhNM) change relatively little with increasing section of the forging. The impact toughness also changes only slightly with the size of the section (Fig. 3) and the direction — 4.7 kg-m/cm² for the longitudinal sample and 4.5 kg-m/cm² for the transverse sample.

In the hypereutectoid steel 4Kh5V2FS the plasticity and impact toughness decrease substantially with increasing section (Fig. 3).

The impact toughness of transverse samples of steel 4Kh5V2FS is only 30-40% that of longitudinal samples (2 kg-m/cm² for the bar 100 mm in diam. and 1.2 kg-m/cm² for the bar 200 mm square).

The difference between the mechanical properties of the steel in the samples and large dies is even greater, since the core of the die cools more slowly than the surface during quenching, which may be accompanied by precipitation of carbide particles in the grain boundaries and additional lowering of the impact toughness.

The results obtained indicate the expediency of using steels with 3-5% Cr for many dies, especially for dies working under low dynamic loads but elevated temperatures (pressing, extrusion, heading, etc.).

CONCLUSIONS

1. New die steels with 3-5% Cr surpass steel 5KhNM (5KhNV) in heat resistance and rigidity and have the same impact toughness in small sections. Steel 5KhNM (5KhNV) has better impact toughness and erosion resistance only in large sections (above 100 mm).

2. Steels with 3% Cr have almost the same heat resistance as steels with 5% Cr and a lower quenching temperature. Of the 3% Cr steels, the steel alloyed with silicon has better properties (4Kh3VMS).

3. Steel 4Kh5MFS has somewhat better heat resistance than 4Kh5V2FS but is more sensitive to decarburizing.

4. For commercial use (dies for presses, plungers and dies for extrusion, etc.) we recommend steel 4Kh5V2FS for sections no larger than 120 mm and steel 4Kh3VMS for the same purposes in sections up to 200 mm.

The heat treatments recommended are: 1) 4Kh5V2FS, quenching from 1040-1060°C in oil, tempering at 590-610°C (to a hardness of HRC 45-50); 2) 4Kh3VMS, quenching from 1010-1030°C in oil, tempering at 580-600°C (to HRC 45-50).

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