HYPEREUTECTOID HIGH-SPEED STEELS

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It is known that approximately half of the tungsten and also of the molybdenum contained in R6M5 and R18 steels is combined in secondary carbides dissolved in hardening, which provides a hardness of HRC 63-64 and a heat resistance Cr_{58} of 620°C. The second half of the tungsten and molybdenum is concentrated in the undissolved eutectic carbides hindering austenitic grain growth in hardening and providing the necessary strength and impact strength. For 30-mm-diameter bars of R6M5 steel $\sigma_b \cong 3500$ MPa and $a \cong 320$ kJ/m^2. In addition, the nonuniform distribution of coarse eutectic carbides causes a reduction in the strength and impact strength of R6M5 and R18 steels.

The Moscow Machine and Tool Institute has developed the tungsten-free low-alloy high-speed steel 11M5F (ÉP980) with a chemical composition of (Technical Specification 14-1-2678-79 of Élektrostal' Plant) 1.03-1.10% C, 5.2-5.7% Mo, 3.8-4.2% Cr, 1.3-1.7% V, 0.3-0.6% Si, and 0.3% Ce (calculated). The composition of 11M5F steel is eutectoid and was selected from the phase diagram (Fig. 1a). Hardening of an alloy with 0.8% C and 4-5% Mo starts with precipitation of grains of austenite and not of ferrite as in R6M5 steel (Fig. 1b) or R18, which causes crystallization of a carbon enriched liquid with the formation of eutectic. Therefore, all of the molybdenum in 11M5F steel (the carbon content in it was increased to 1.05% in connection with the addition of vanadium) is precipitated from austenite in secondary carbides (Fig. 1), which makes it possible to obtain a hardness of 64-66 HRC and a heat resistance of 630°C in this steel.

The values of these properties are higher for 11M5F steel than for R6M5 steel. This may be explained by the high molybdenum content in solution of hardened 11M5F steel in comparison with the equivalent total content of tungsten and molybdenum in solid solution in R6M5 steel. As the result of the low temperature of solution (about 1160°C) of practically all of the molybdenum-base $\mathrm{M_6C}$ and $\mathrm{M_{23}C_6}$ carbides (Figs. 1a and 2b) in 11M5F steel the fine austenitic grain size (No. 12-10) is maintained in heating in the wide range of recommended hardening temperatures of 1140-1180°C (twice as wide as for R6M5 steel, 1210-1230°C) and for it $\sigma_b \cong 3800$ MPa and $a \cong 400$ kJ/m^2. The high values of these properties are promoted by uniform distribution of the small quantity of fine secondary carbides (primarily MC) migrating into the solid solution at higher temperatures than 1160°C. The low hardening temperatures of 11M5F steel (about 60°C lower than for R6M5 steel) provide minimum variations in grain size and high resistance to decarburization and oxidation. As the result of the low vanadium content (about 1.5%) the grindability of 11M5F steel is the same as that of R6M5 steel.

The uniform structure and high production properties of 11M5F steel provide increased stability of the cutting properties and reliability of the tool, which is especially important for automated production.

An increase in the tungsten content above 1.5% (R2M5 steel or Swedish D950) in steels with 5% Mo causes the formation of a eutectic and $\mathrm{M_6C}$ carbides which are insoluble in hardening (Fig. 2c) as in R6M5 steel (Fig. 2a). This leads to a reduction in hardness and heat resistance of a steel with 5% Mo and an increase in its carbide inhomogeneity and variations in grain size and also eliminates the possibility of use of high frequency induction hardening for tool hardening. Therefore, the addition of tungsten to 11M5F steel is not effective.

With about 1% of noncarbide-forming aluminum in 11M5F steel there is an increase in hardness to 65-67 HRC and in heat resistance to 630°C. The hardness increases particularly by 4-5 HRC in heating in the 400-600°C range, which is characteristic of the loading conditions of the cutting edge of high-speed steel tools (Fig. 3). This influence of aluminum may be explained by the fact that in its presence in the martensite there is an increase in the quantity of carbides by about 15% precipitated in tempering to the maximum secondary hardness and there is an increase of 50-100°C in the recrystallization temperature of the solid solution of the hardened steel.

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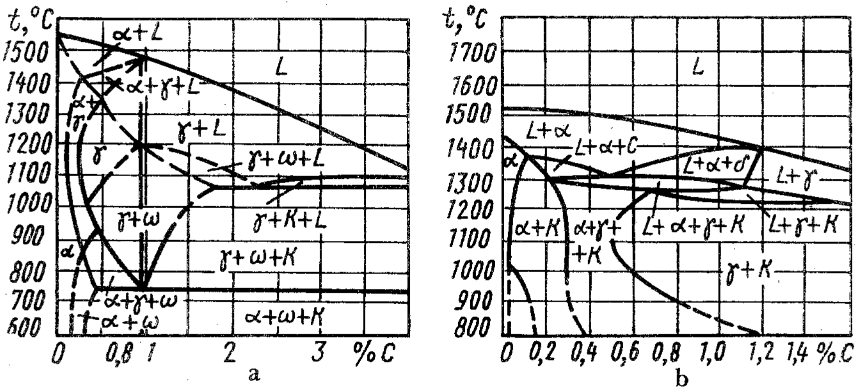

Fig. 1. Phase diagrams (K and ω are carbides) of steels containing about 5% Mo (a) and 6% W, 5% Mo, 4% Cr, and 2% V (b).

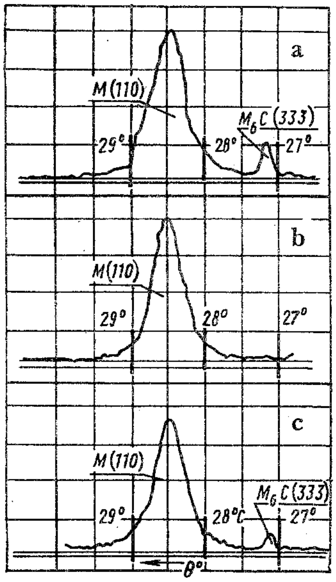

Fig. 2. X-ray diffraction patterns of R6M5 (a), 11M5F (b), and R2M5 (D950) (c) steels hardened from the optimum temperatures (No. 10 grain size) after tempering at 560°C for 1 h (M is martensite).

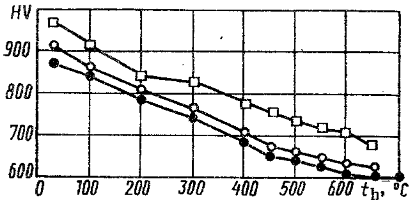

Fig. 3. Hardness of the steels in relation to the heating temperature after heat treatment using the optimum cycles: ●) R6M5 steel; ○) 11M5F; □) 11M5F + 1% Al.

Therefore, the influence of aluminum on certain properties of high-speed steels is similar to the influence of cobalt.

The results of production and laboratory tests of the cutting properties of tools of the steels developed showed their high effectiveness, especially of 11M5F steel with 1% Al. The life of tools of the tungsten-free steels is two or three times greater than the life of tools of R6M5 steel.

SYNCHRONOUS HEAT-TREATMENT TECHNOLOGY FOR HIGH-SPEED STEEL TOOLS

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In the mass production of high-speed steel tools great difficulties are caused by the difference between the time of holding and of hardening and repeated tempering. For instance, the total time of holding in salt baths τ_{tot} (the total time the tools remain in salt solution) and the equal time for each stage of hardening (preheating, final heating, and stepwise cooling) for drills with 6 to 50 mm diameter varies between 2 and 4.5 min, and in case of standard tempering at 560°C in furnaces or baths, holding in each tempering alone (not counting the time of heating) amounts to 1 h; this usually makes it necessary to use separate equipment and fixtures for hardening and tempering. This, in turn, requires the introduction of additional operations of transporting the tools and stacking them in large tempering cages where the tools are heated nonuniformly, in consequence their quality is impaired, and in addition this procedure entails unjustified consumption of electric power and lengthy dwelling of the tools at the tempering operation. Brief double tempering of tools at 580 or 600°C, described in [1], made it possible to reduce holding time to 20-30 and 10-15 min, respectively. However, such tempering conditions did not solve the problem.

For tools of steels R6M5, R6M5K5, R9M4K8 hardened under standard conditions, holding in tempering may be reduced to 4-6 min by raising the tempering temperature to 630°C, or to 7-8 min by reducing the tempering temperature to 615°C without impairing the mechanical properties [2, 3]. Tests showed that tool life at the same time increased by a factor of 1.2-1.3.*

As a result of this research the holding times in the salt baths in hardening and tempering of the same tool became so close to each other than it became obviously possible to make them equal to each other.

On this basis we worked out a technology of synchronous heat treatment enabling all stages of the operations of hardening and tempering to be carried out on the same plant or the same production line suitable for a fairly broad assortment of high-speed steel tools.

To carry out shorter tempering at 615, 630°C, or even at higher temperatures without risking reduced hardness of the tools and for extending their life in operation, it was necessary to increase the degree of alloying of the solid solution; this was attained by extending the holding time τ_{tot} in heating prior to quenching or by some increase of the hardening temperature.

In our investigation we increased the holding in heating prior to hardening τ_{tot}, determined by the well-known formula [3] $\tau_{tot} = \tau_{bp} + \tau_{dc}$, by increasing the standardized time of dissolving carbides τ_{dc} by a factor of 1.5-5 since the time of bulk preheating τ_{bp} did not change.

The tests were first carried out with specimens 6 × 6 × 60 and 10 × 10 × 55 mm of steel R6M5 and R6M5K5, and then with tools.

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*It may be assumed that it remains at the previous level (Editor's note).

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