TOOL STEELS AND ALLOYS

INVESTIGATION OF THE CARBIDE PHASE IN W–Mo HIGH-SPEED STEELS

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At the present time tungsten (R18, R9, R12), molybdenum (M8), and tungsten–molybdenum high-speed steels (R6M5, R6M3) are used. The tungsten and molybdenum form isomorphous carbides of the M₆C type, and therefore the replacement of tungsten with molybdenum probably also leads to changes in the carbides with no substantial changes in the properties. However, there are no data in the literature on this question.

We investigated four steels (see Table 1) in which the total concentration of tungsten and molybdenum and also the concentration of carbon remained unchanged (at. %). The chemical composition of the steels matched the composition of the solid solution of high-speed steel in terms of tungsten, molybdenum, and carbon after quenching from optimal temperatures [1].

The steels were melted in a basic furnace. All the ingots weighed 8 kg. After forging to a section of 15 × 15 mm, the bars were annealed at 700°C for 10 h. For carbide analysis the carbides were separated in an electrolyte of 5% HCl + 5% citric acid at room temperature. The current density was 0.03 A/cm² for annealed samples and 0.02 A/cm² for quenched samples, and the time was 1.5 h. Part of the carbide was dried in vacuum (10 mm Hg) at 100°C. Phase analysis was conducted with the URS-50I diffractometer equipped with a scintillation counter, with use of K$_{α}$-Co radiation. The lattice constants of M₆C carbides were measured with recording of lines (1133; 973). The melting point was measured by the pyrometric method.

Figure 1 shows the change in the composition, amount, and properties of carbide phase with replacement of tungsten by molybdenum. It should be noted that when tungsten is replaced with molybdenum (up. to K = 0.7) the composition of the carbides in terms of carbon, iron and total W + Mo remains unchanged. With further replacement of tungsten by molybdenum (K > 0.7) the concentration of carbon, molybdenum, and total W + Mo increases, and the iron content of the carbide decreases. The x-ray analysis showed that the carbides consist mainly of M₆C, which is confirmed by Fe–W–C [2] and Fe–Mo–C [3] phase diagrams.

The chemical composition of the carbide residues corresponds to the formula Fe₃.₅(W, Mo)₂.₅C up to K = 0.7 [more precisely, Fe₃.₅(W, Mo)₂.₅C]. In the molybdenum steel the composition of the carbide (rounded) is 20 at. % C, 55 at. % Mo, and 25 at. % Fe, which corresponds to the formula Fe₃.₅Mo₂.₅C.

M₆C carbide has a lattice incompletely filled with carbon atoms [4]. When all sites are filled with carbon atoms the formula of the carbide should be M₄C. It can be assumed that for K > 0.7 the M₆C carbide gradually changes to M₄C with no change of the lattice constant. The lattice constant of the carbide decreases with a change of K from 0 to 0.7, and increases with K > 0.7 (Fig. 1c). The lattice constant of the carbide decreases, since the total W + Mo remains unchanged (Fig. 1a), but the molybdenum replacing the tungsten has a smaller atomic diameter and thus the lattice.

The amount of carbide phase (wt. %) increases monotonically up to $K = 0.7$ due to reduction of the density when tungsten is replaced with molybdenum, and decreases greatly with changes in the composition of the carbide at $K > 0.7$ (Fig. 1b). Simple replacement of tungsten with molybdenum (up to $K = 0.7$) reduces the thermodynamic stability of the carbide, which is indicated by the melting point of the carbide (Fig. 1d) and the solubility in austenite (Fig. 1c) (the latter was determined from the difference in the amount of carbide in the annealed steel and the steel quenched from 1150°C). The changes in the carbide with $K > 0.7$ lead to an increase of the thermodynamic stability.

The lower thermodynamic stability of $M_6C$ containing tungsten and molybdenum with $K < 0.7$ leads to high saturation of the solid solution of ferrite with tungsten and molybdenum in the annealed steel and austenite in the quenched steel (Fig. 2).

Since the cutting properties of high-speed steels depend on the concentrations of alloying elements in the solid solution [5], partial replacement of tungsten with molybdenum in high-speed steel ($K = 0.7$, which corresponds to approximately the same concentrations of these elements in the steel, in wt. %) is advisable.

Conclusions. 1. Equiatomic replacement of tungsten with molybdenum up to $K = 0.7$ also leads to equiatomic replacement in carbides; with further substitution the percentage of molybdenum in the carbide increases. 2. The solubility of the carbide in the steel is highest with $K = 0.7$. 3. The replacement of tungsten with molybdenum in high-speed steel is advisable.

Taking into account the solubility of carbide in austenite, the properties are optimal with $K = 0.7$, which is numerically equal to the same wt. % of tungsten and molybdenum in the steel.