In recent years a great deal of attention has been given to exploring the possibility of improving the cutting properties of steels by additionally alloying them with carbide-forming elements. In the manufacture of high-speed steels by the powder metallurgy technique, this can be accomplished by adding fine particles of, e.g., titanium carbide or carbonitride to the charge. The effectiveness of carbide strengthening depends to a large extent on the particle size of the strengthening phase and on its uniformity of distribution in the steel matrix. Data on the effect of such additions on the service properties of P/M R18 and R9* high-speed steels together with optimum conditions for their manufacture will be found in [1, 2].

The present work was undertaken with the aim of investigating the effect of titanium carbide on some properties of sintered 10R6M5 high-speed steel and determining process parameters enabling material of high density to be produced by cold pressing and sintering. The starting materials were a 10R6M5 powder manufactured at the Tulachermet Scientific-Production Association by the atomization of molten metal with nitrogen and a titanium carbide powder manufactured at the All-Union Scientific-Research Institute of Hard Alloys. The starting carbide, whose mean particle size was not more than 7 μm, had total and free carbon contents of 19.38 and 0.6 wt.%, respectively, and a density of 1.22 g/cm³.

High-speed steel powders produced by gas atomization cannot be pressed cold because their particles have a spherical shape, smooth surfaces, and high hardness. Pressing with a plasticizer (a solution of synthetic rubber in benzine) enables compacts to be obtained having a density of 65-70% of theoretical at a pressing pressure of 600-700 MPa.

An attempt was made to improve the compressibility of the atomized powder by subjecting it to additional comminution in a wet fall mill and in a Vibratom vibratory mill. The particle size distribution of the starting 10R6M5 steel powder was characterized by the existence of two maxima, corresponding to 200 and 45 μm (Fig. 1). Wet milling in the ball mill for up to 48 h failed to eliminate the 200-μm maximum. Owing to a difference in starting hardness between the large and small powder particles (their microhardnesses were 6500 and 8200-9000 MPa, respectively), preferential comminution of the less hard large particles was observed. However, it proved impossible fully to comminute the large particles, and, apart from this, the majority of the powder particles remained spherical in shape.

Different results were obtained with the powder processed in the Vibratom vibratory mill. To determine the dynamics of milling, a quantity was used equal to the ratio of the weight of a fine powder fraction to the total weight of the sample employed. On the basis of experiments, the following conditions were chosen for comminuting the 10R6M5 powder: ratio of the weight of the milling elements (14-mm-diameter steel balls) to that of the batch of material being comminuted, 16:1 and time of milling under ethyl alcohol, 20 h. Sedimentation analysis showed that the mean particle size of the powder after milling did not exceed 15 μm.

The addition of between 1 and 12.5 wt.% of titanium carbide intensified the milling process owing to the higher hardness of the carbide grains and led to mechanical alloying of the steel matrix by fragments of carbide grains embedding themselves in the high-speed steel particles. This promoted a more even distribution of the strengthening phase in the matrix—a phenomenon which must have had a beneficial effect on the properties of the resultant sintered material.
Fig. 1. Particle size distribution of 10R6M5 steel powder (sieve analysis): 1) starting condition; 2) after ball milling.

Fig. 2. Variation of mean pore size $D_m$ (1) and total pore volume $V_p$ (2) with amount of titanium carbide in sintered material.

Fig. 3. Microstructures of sintered composite with 5% TiC, $x400$. $T_{sint}$: a) 1260; b) 1280°C.

Fig. 4. Variation of density of sintered specimens ($T_{sint} = 1260°C$) with pressing pressure.

The variation of the mean pore size $D_m$ and relative pore volume $V_p$ with titanium carbide concentration in the mixture after sintering at a temperature of 1280°C is shown in Fig. 2. As can be seen, raising the titanium carbide content to 7.5 wt.% did not have a significant effect on $D_m$, but at higher titanium carbide concentrations the porosity sharply grew. In view of this, further experiments were carried out with a composite containing 5 wt.% TiC. It should be noted that, during milling, the powder experienced appreciable oxidation (to 0.22% $O_2$), while in the starting, as-atomized powder the amount of oxygen did not exceed 0.03%. To minimize the deleterious effect of the oxygen, suitable amounts of lampblack were added to the milled mixture.

A study of pressing conditions revealed that, after being milled in the ball mill, which imparted to it better compressibility than did processing in the Vibratom mill, the powder could be compacted to a comparatively high density (not less than 80%) by pressing under a pressure of 300 MPa in a steel die set with a plasticizer (a 4% solution of synthetic rubber in benzine). However, the marked particle size nonuniformity of this powder (Fig. 1) made it impossible for the required structure to form during sintering.