In recent years considerable advances have been made in the field of manufacture of high-speed steels by powder metallurgy techniques. Among such steels, those made from atomized powders deserve particular attention [1, 2], since they are characterized by a uniform distribution of alloying elements and a small carbide particle size, as a result of which cutting tools in these steels have long life. However, atomized tool steel powders are generally difficult to press, and it is therefore more convenient to employ them for the production of large blanks of comparatively simple shape, but this entails a substantial waste of metal in machining, similar to that experienced in the manufacture of parts from cast-steel blanks.

It is conceivable therefore that better results will be obtained with composite mixtures of good compactibility, which may make it possible to produce directly actual parts or at least preforms closely approaching such parts in shape. In this connection, the object of the work described below was to examine the following methods of introduction of alloying elements for the purpose of producing sintered high-speed steels from compactible mixtures:

1. Addition of carbides of chromium (Cr$_2$C$_3$), tungsten (WC), and vanadium (VC) to 6% ferrotungsten prepared by coreduction of oxides.

2. Addition of carbide-forming elements in alloy powders, with the subsequent formation of carbides during their reaction with pencil-grade graphite introduced into the charge.

Compactibility tests on charge mixtures established that pressed compacts were capable of retaining their shape at porosities ranging from 20 to 50%. To obtain dense material, the following processing schedule was employed: mixing of starting components, pressing of compacts under a pressure of 6-7 tons/cm$^2$, heating-up to 1100-1200°C in a vacuum, and hot pressing under 5 tons/cm$^2$. Now hot pressing is a production operation which largely controls the properties of the resultant material, and consequently the temperature at which it is performed must be chosen with great care. In a case such as that under consideration, the optimum hot-pressing temperature is determined bearing in mind that the material being pressed must attain a state of "fluidity" under the action of the applied pressure and account is taken of any structural transformations occurring during hot pressing. The operation performed at the highest temperature—quenching— involves heating for not more than 1-2 min, which is clearly insufficient for the dissolution and uniform distribution of the starting carbides in the matrix, and it is therefore desirable to combine the densification of the material with the dissolution of the carbides in its matrix.

In view of this, a metallographic study was made of the processes of structure formation accompanying the heating of the following composites: ferrotungsten-chromium carbide, ferrotungsten-tungsten carbide, and ferrotungsten-vanadium carbide. The carbides were added to 6% ferrotungsten in amounts corresponding to the amounts in which they are present in R18 steel.* Specimens pressed from these com-

* A tool steel containing 0.7-0.8 C, 3.8-4.4 Cr, 17.5-19.5 W, and 1.0-1.4% V.—Translator.
Fig. 1. Microstructures of composites: a) ferrotungsten–chromium carbide heated to 1200°C, ×450; b) ferrotungsten–tungsten carbide heated to 1150°C, ×450; c) ferrotungsten–vanadium carbide heated to 1050°C, ×1500.

Fig. 2. Microstructures of ferrotungsten (a) and ferrotungsten–vanadium (b) powders pressed and sintered at 1200°C, ×450.

Fig. 3. Microstructure of annealed steel of composition R18 on base of ferrotungsten powder (30% W), ×450. Areas with particles of: a) chromium carbide; b) ferrovanadium.

Composites were heated in a high-temperature metallographic apparatus, which enabled the reactions of the carbides with the matrix to be observed during the actual heating operation. As a result of this investigation, it was found that diffusion zones formed around the chromium and vanadium carbides at temperatures as low as 800–900°C. At the same temperatures, the presence of Me₆C – a complex carbide characteristic of the structure of high-speed steel – was detected in the specimens with chromium carbide by x-ray structural analysis. Heating to 1100°C resulted in the formation of a liquid phase at the sites of the chromium carbide particles. On cooling, carbides were precipitated out of this liquid phase in the form of groups of fine, regular-shaped inclusions (Fig. 1a). In the tungsten carbide particles, heating to 950°C produced no