When cast G13L steel* is subjected to dynamic or high static loads, its surface layers undergo hardenening and strengthening, but the original ductility of its core remains unchanged [1-4, 7, 8]. Thanks to this combination of properties, the steel exhibits extremely high wear resistance in operation under impact load conditions.

However, the strong hardenability of G13L steel means that it is very difficult to machine, which severely restricts its use in engineering. As a rule, G13L steel articles are produced by casting or forging and are subjected only to heat treatment, although, if necessary, they can be machined with hard-alloy tools or ground. The range of applications of high-manganese steel could be substantially extended if a process were developed for producing parts in this steel without machining. A solution to this problem is offered by the techniques of powder metallurgy. It should be noted that the sintering of the majority of alloy steels poses considerable difficulties, because most alloying elements diffuse only very slowly, as a result of which it is not always possible to achieve homogeneous structures.

Benesovsky and Kieffer [5] carried out experiments on the preparation of low- and high-alloy manganese steels by the method of single pressing and sintering. Because of their porosity, such steels are greatly inferior to cast steels in strength properties. In this connection, great possibilities in the production of constructional parts in high-manganese steel are opened up by the dynamic hot pressing (DHP) process [9-12]. In the investigation described below, the following procedure was employed for producing G13M high-manganese sintered steel (this designation was chosen to distinguish it from G13L cast steel†).

Charge materials were prepared from PZh20M iron powder,$ made by the Sulinsk Factory, powdered ferromanganese, and carbon black. Instead of carbon black, it is possible to employ ground cast iron shavings. The iron powder was subjected to additional reduction in a technical hydrogen atmosphere at 650°C, after which it was ground and passed through a magnetic separator. After mixing, the charge powder had the following composition (in %): 13.5 Mn, 1.2 C, 0.27 Si, 0.039 P, balance iron. Cold-pressed compacts were produced under a pressure of 5 tons/cm² and had a porosity of about 25%.

The most important DHP parameters in the manufacture of G13M steel, determining the rate of diffusion and the quality of the steel, are the temperature and duration of heating of compacts (t, T) and the reduced work of densification (W). In contrast to the DHP of single-component compacts, where heating is employed for the sole purpose of making the powder particles as soft and ductile as possible, the heating of compacts from powders consisting of several components must ensure the latter's dissolution, resulting in a homogeneous structure and improved properties.

*The cast 13% Mn grade - Publisher.
†In Russian, the letters M and L stand for "sintered" and "cast," respectively - Publisher.
‡A very reduced iron powder of 98.0% purity - Publisher.
Heating was performed in a hydrogen atmosphere to which 15-18% of natural gas was added to protect the compacts against surface carburization. The effect of the duration of heating in the temperature range 800-1200°C on the tensile strength ($\sigma_B$) and elongation ($\delta$) of G13M steel specimens is illustrated in Fig. 1. The reduced work of densification in these experiments was maintained constant at 15 kg-m/cm³. It will be seen from this figure that the best combination of mechanical properties ($\sigma_B$ and $\delta$) is obtained after heating for 15-20 min at $t=1100-1200^\circ$C. To determine the optimum value of $W$, $\sigma_B$ vs $W$ curves were plotted for temperatures of 1100 and 1200°C at $t=20$ min (Fig. 2). It is clear from this graph that a reduced work of densification of $W = 20-25$ kg-m/cm³ is entirely adequate.

Thus, the optimum DHP parameters in the production of G13M steel parts are $t = 1200^\circ$C and $W = 20-25$ kg-m/cm³, the duration of heating being chosen depending on the shape and size of the parts being produced. With these parameters, a virtually nonporous ($\Pi \approx 2\%$) steel is obtained having an elongation of about 10% and $\sigma_B = 60-65$ kg/mm². The impact strength of such a steel is $\alpha_k = 3-4$ kg-m/cm². For the same steel produced by casting, $\sigma_B = 60-80$ kg/mm² and $\delta = 20-30\%$ [3]. Compared with cast and forged metals, sintered materials invariably exhibit lower values of $\delta$, which may be attributed to insufficient purity of the charge employed in their manufacture.

The microstructure of a specimen produced under the optimum conditions is illustrated in Fig. 3, from which it can be seen that the austenitic grain size of G13M steel is about one-hundredth that of the cast steel. In addition to austenite, the microstructure contains areas depleted of manganese, inclusions of manganese and iron oxides, and other nonmetallic particles. The structure has a typical cellular character, the austenite grains exhibiting twins and numerous shear planes. This structure, occupying the whole cross section of compacts, forms immediately after DHP. To obtain a similar structure in the cast steel, it is necessary to resort to additional plastic working.

Fine-grained structures are usually produced as a result of DHP. The grain size obtained is finer than in sintering and hot static pressing. The process in fact involves thermomechanical treatment (TMT) [13, 14] at the temperatures of stable austenite and subsequent quenching during densification in a relatively cold die. As a result, the austenitic structure is retained, with no appreciable precipitation of excess carbides. DHP in this case effectively combines several processes which normally require separate technological operations, namely, the shaping and sintering of parts, employed in powder metallurgy, preliminary deformation of metal to achieve a TMT effect, and quenching.

In the shaping of G13M steel, a characteristic thermal after-effect is observed after densification. While in the cold pressing of metal powder and the subsequent ejection of the compact the latter grows in size as a result of an elastic aftereffect, DHP is characterized by substantial shrinkage, which produces a decrease in the size of the compact. This facilitates the removal of the finished part from the die and reduces the wear of the latter.

Ksenofontov's findings [15] concerning the effect of austenitic grain size on the wear resistance of G13L steel led the authors to expect that the fine-grained G13M steel produced in this work would exhibit increased wear resistance. To verify this, wear tests were carried out under dry sliding friction conditions, using an MI machine. Test specimens were made to rub against a Type 45 steel* roller of 50-55 HRC hardness, the load at the point of contact being 100 kg. Some of the test steel specimens were used in the unmachined conditions, i.e., as produced by DHP (curves 2 and 3), while others were ground before testing (curve 4). The results of these tests are illustrated in Fig. 4, from which it will be seen that, after the first thousand revolutions of the roller, G13M steel produced under the optimum conditions (without surface

*0.45% C grade – Publisher.