The weight of parts can be reduced by using new steels with a low density.

Recently developed steels of the Fermanal type (9G28Yu9) are 13-15\% lighter than common steels and have good mechanical properties. The density of these steels is reduced because of alloying with up to 9\% Al.

As-quenched, the steel is austenitic; the ferrite-forming effect of aluminum is compensated by austenite-forming elements – manganese (up to 30\%) and carbon (around 0.9\%).

These steels are cheaper than stainless steels and do not contain such scarce alloying additions as nickel and cobalt.

A combination of high strength and ductility in rods of steel 9G28Yu9MVB can be attained by quenching and precipitation hardening.

The mechanical properties of steel 9G28Yu9MVB rods after quenching in oil from 1050°C and aging at 550°C for 16 h are given in Table 1.

The optimal mechanical properties of the steel are attained by a suitable combination of alloying additions and heat treatment.

To attain good workability and high ductility it is necessary that the steel has a single-phase fine-grained austenitic structure after quenching, but the optimal amount of hardening phase after aging.

The data in the literature on steels of the Fermanal type, confirmed by x-ray analysis of steel 9G28Yu9MVB, indicate that aging leads to precipitation of a complex carbide of the (Fe, Mn)\textsubscript{3}AlC\textsubscript{x} type from austenite [1].

There are no dependable methods for quantitative analysis of phase (Fe, Mn)\textsubscript{3}AlC\textsubscript{x} in austenitic steels of this class, since the phase is difficult to separate. X-ray analysis does not permit quantitative measurement of the amount of phase precipitated because it is finely dispersed. Nor does metallographic analysis reveal the changes in the structure of the material after aging to the highest strength (550°C for 16 h).

To determine the quantitative relationships between the phase composition and the properties we have developed magnetic methods of phase analysis, since δ ferrite and (Fe, Mn)\textsubscript{3}AlC\textsubscript{x} are ferromagnetic.

To determine the magnetic properties of pure ferrite and (Fe, Mn)\textsubscript{3}AlC\textsubscript{x}, heats differing in chemical composition were

* S. P. Izotov, D. T. Lapkin, A. T. Tumanov, and others took part in the development of this steel.
The concentration of alloying additions in ferrite was < 0.05% C, 10-14% Al, 8-30% Mn; (Fe, Mn)$_3$AlC$_x$ contained 2.2-4.5% C, 11-14% Al, and 0-50% Mn.

The investigation of the saturation magnetization ($4\pi I_S$) and the Curie temperature ($\theta$) of the heats made it possible to plot calibration curves of $4\pi I_S = f(\theta)$ for δ ferrite and (Fe, Mn)$_3$AlC$_x$ respectively (Fig. 1).

The Curie temperature of δ ferrite and the hardening phase is respectively 190-200°C and 270-280°C, which, according to Fig. 1, gives $4\pi I_S \approx 6500 \pm 500$ G for δ ferrite and $4\pi I_S \approx 8000 \pm 500$ G for the hardening phase.

These data make it possible to judge the phase composition of as-quenched samples and determine the amount of phase in the presence of δ ferrite. It is also possible to determine the relationship between the mechanical properties and the amount of hardening phase.

As-quenched, the steel without ferrite is nonmagnetic; the magnetic permeability amounts to 1.01 G/Oe; after aging, the steel is weakly magnetic, with $4\pi I_S = 1000-2000$ G and the permeability $\mu = 3-4$ G/Oe.

The limit concentrations of alloying elements in steels of the Fermanal type were given in [1]: 0.85-1.0% C, 8-10% Al, and 25-30% Mn. As our studies showed, alloying with aluminum and carbon within such wide limits does not ensure consistent high values of ductility and toughness.

The aluminum content of the steel is an important factor. The aluminum must ensure reduction of the density and hardening during aging without inducing the formation of ferrite. The concentration of the hardening phase must be optimal.

With 9.5-10% Al, ~ 26.5% Mn, and ~ 0.85% C the castings contain 10-15% ferrite, which may induce cracking during hot working. Although hot deformation and subsequent quenching of samples with 9.5-10% Al reduce the amount of ferrite to 1-2%, the ductility and toughness of the aged steel remain low, since a large amount of hardening phase (~ 30%) is precipitated with increasing concentrations of aluminum.

The solubility of aluminum in steel of this type is around 7.5% at 550°C and 8.5% at 650°C. Since (Fe, Mn)$_3$AlC$_x$ contains no more than 13-13.5% Al, the amount of this phase precipitated during aging is large. Raising the aluminum content above the solubility limit by 0.5% increases the equilibrium amount of the phase by 10% at the respective aging temperature.

The amount of hardening phase depends on the aging condition. In the heat with 8.5% Al the maximum amount of phase (~ 17%) after holding for 8-20 h is precipitated at 550°C; at 650°C this phase is almost completely dissolved (Fig. 2). With increasing amounts of the phase the strength characteristics ($\sigma_B$, $\sigma_0.2$) increase, while the ductility ($\delta$, $\psi$) decreases (Fig. 3). The toughness depends not only on the amount of hardening phase but also the grain size and the presence of precipitates in the grain boundaries. Figure 4 shows the variation of the toughness with the amount of phase for a grain size of grade 4 without precipitates in the boundaries. The toughness decreases with increasing quenching temperatures and with an increase of grain size to grade 1, and also as the result of precipitates in the boundaries due to increasing the carbon content from 0.85 to 0.95-1%. The aging temperature was varied from 450 to 550°C, and the aging time from 3 to 20 h.

Thus, to obtain the optimal strength and ductile characteristics of steel 9G28Yu9MVB the upper limits of alloying should be reduced — to 9.2% Al and to 0.92% C. In this case the amount of hardening phase will be 15-20% after aging at 550°C for 16 h, and there should be no large precipitates in the grain boundaries.