same — martensite and a small quantity of residual austenite. The microstructure of the core was sorbite. The hardness profile across the thickness of the carburized case is shown in Fig. 3. The microhardness was measured on a PMT-3 tester with a load of 0.5 N and then converted to the HRC scale. The surface hardness of the samples of continuously cast billets and hot-rolled metal was the same, 59-60 HRC; at a distance from the surface of up to 0.25 mm it also did not differ, and then, with distance from the surface, at a distance of more than 0.25 mm the hardness of the continuously cast billet samples was more than the hardness of the samples of hot rolled metal, which was the result of the increased content of the basic alloy elements in the continuous cast billets.

Conclusions. 1. The hardenability and strength properties of continuously cast billets of 30KhGT steel meet the requirements of GOST 4543-71. The characteristics of plasticity and impact strength were below these requirements even after rolling with a reduction of $\lambda = 6.24$.

2. After drop forging of an experimental lot of billets for ZIL-130 automobile rear axle driven gears from continuously cast billets of 30KhGT steel first rolled with a reduction of $\lambda = 1.48$ the macrostructure was satisfactory and the combination of mechanical properties was sufficiently high. Therefore, drop forging may be recommended for wider production testing.

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MAGNETIC PROPERTIES AND ELECTRICAL CONDUCTIVITY OF 58 (55PP) AND 47GT STEELS AFTER HARDENING AND TEMPERING

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The purpose of this article is an investigation of the magnetic properties and electrical conductivity of steels of reduced and controlled hardenability in relation to hardening and tempering temperatures and their quantitative relationship to the individual structural constituents.

The 5-mm-diameter 100-mm-long samples of 58 (55PP) and 47GT steels were induction heated to 800-1000°C at a rate of 800 deg/min, hardened in a 10% aqueous solution of NaOH, and then tempered at 150-550°C.

To determine the static magnetic characteristics, the coercive force (H_c), the magnetic permeability (μ_{max}), the saturation induction (B_s), and the residual induction (B_r), a magnetometer was used and the specific electrical conductivity ($1/\rho$) was measured on a special stand.

Preparation of the samples for metallographic analysis and measurement of hardness were done according to the standard methods.

The content of the individual structural constituents was determined by the intercept method and the second-order residual stresses (σ_{II}) and residual austenite content by the x-ray diffraction method.

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TABLE 1

Hardening temp., °C	H_c, kA/m	μ_{max}	B_r	$B_s \cdot 10^4$	1/ρ, MS/m
			T		
800	2,0/1,7	175/180	1,8/1,9	116,8/119,5	4,2/4,4
850	2,4/2,0	156/170	1,8/1,9	116,3/117,4	4,0/4,28
900	3,0/2,8	130/150	1,8/1,9	116/116	3,89/4,1
1000	3,0/2,8	130/150	1,8/1,9	116/116	3,85/4,1

Note. The first figure is the properties of 58 steel and the second of 47GT steel.

TABLE 2

Tempering temp., °C	H_c, kA/m	μ_{max}	B_r	$B_s \cdot 10^4$	1/ρ, MS/m
			T		
150	2,6/2,18	150/160	1,8/2,0	115/117	3,9/4,1
250	2,0/1,9	210/240	1,85/2,0	115/118	4,1/4,3
350	1,5/1,8	250/280	1,85/2,0	116/118	4,2/4,5
450	1,5/1,8	270/320	1,85/2,0	116/118	4,35/4,6
550	1,5/1,8	290/320	1,85/2,0	116/118	4,55/4,8

Note. First and second figures are the same as in Table 1.

An increase in the hardening temperature of 58 steel accompanied by a decrease in the excess ferrite content in its structure leads to an increase in the coercive force (Table 1). At 900°C ferrite is not observed in the structure of 58 steel. The disappearance of the magnetically soft constituent of the structure is accompanied by a decrease in magnetic permeability. At the same time, the values of saturation and residual inductions, which depend only upon the number of domains in a unit of volume, show practically no change. This data agrees with the results of x-ray diffraction investigations indicating (with an accuracy of 3%) the absence of residual austenite in the structure of the steel after hardening from 900°C.

With an increase in the level of second-order internal stresses with an increase in hardening temperature a large amount of energy is necessary for reorientation of the domains in the direction of the magnetic field.

Two factors may have an opposite influence on the electrical conductivity. A decrease in carbon content in the martensite must promote an increase in electrical conductivity while an increase in hardening temperature accompanied by an increase in the density of crystalline structure imperfections, including vacancies and dislocations, must cause a decrease in electrical conductivity. The results presented in Table 1 show that in this case the second factor is predominant; with an increase in hardening temperature the values of 1/ρ decrease according to a relationship close to linear.

There is a similar change in the properties of 47GT steel in hardening from different temperatures but the general level of H_c is lower and of μ_{max}, B_s, and B_r higher than for 58 steel; that is, 47GT steel is a more magnetically soft material as the result of the lower carbon content.

The magnetic properties of the investigated steels after tempering at different temperatures are shown in Table 2. Before tempering the samples were hardened from the optimum temperature, 900°C, which provided a uniform structure of fine acicular martensite in the steels after hardening.

Tempering at 150°C does not cause a significant change in the magnetic properties of 58 steel. An increase in tempering temperature to 350°C leads to a significant decrease in coercive force and an increase in magnetic permeability and specific electrical conductivity. With a further increase in tempering temperature to 550°C the magnetic permeability continues to increase although somewhat more slowly than after tempering in the 150-350°C range while there is practically no change in the coercive force.

For 47GT steel the minimum values of H_c are reached after tempering at 250°C and the highest values of μ_{max} after tempering at 450°C while with a further increase in tempering temperature the magnetic permeability does not change.

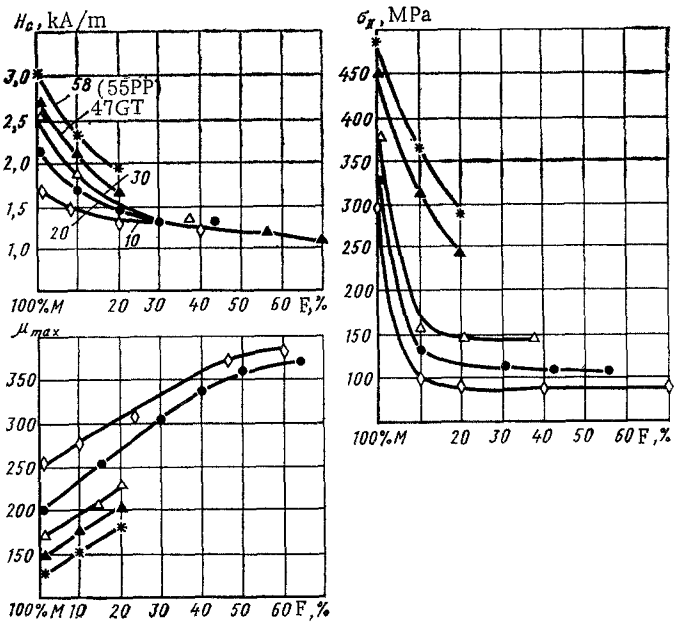

Fig. 1. Relationship of coercive force, second-order stresses, and magnetic permeability to the quantity of excess ferrite in the structure of hardened carbon steels (types of steels shown at the curves).

The rate of increase in the electrical conductivity of the two steels in the whole investigated tempering temperature range is approximately the same.

The decrease in coercive force after tempering at temperatures above 150°C is related to the formation of tempered martensite, a more magnetically soft phase than hardening martensite. The precipitation of finely dispersed carbides having a lower degree of magnetization causes the occurrence of magnetic leakage fields. Carbide inclusions prevent movement of the domain walls and as the result of precipitation of carbides in tempering the coercive force must increase. However, in the investigated tempering temperature range this factor apparently has a secondary influence. At tempering temperatures of more than 350°C coagulation of the carbides occurs and their size reaches the critical value at which they prevent remagnetization to the greatest degree [1]. On the other hand, a decrease in the degree of supersaturation of the α-solid solution with carbon leads to a significant reduction in the level of microdistortions of the crystalline lattice and second-order stresses and, as the result, in the hardness of the steel. Since the coercive force does not change these factors apparently mutually compensate the influence of one another.

The change in magnetic permeability with an increase in tempering temperature may be explained by the same factors.

A reduction or increase in the hardening temperature in comparison with the optimum does not cause a change in the character of the described rules and only the level of properties after tempering is different, as for directly after hardening (Table 1).

It is obvious that a fuller idea of the relationship of magnetic properties to the structure of the steel may be obtained in studying property—structure type curves. Such curves were constructed for the structures formed in hardening and tempering and reflect the influence on the properties of the quantitative relationship of the martensite and ferrite in the structure of the steel.

The relationships of the various properties of the investigated steels to the quantity of ferrite in their structure are shown in Fig. 1. For comparison the relationships obtained for straight carbon steels, 10, 20, and 30, are also shown. It may be seen that with full hardening the coercive force increases with an increase in carbon content in the steel while with incomplete hardening it decreases with an increase in ferrite content in the structure. This relationship, as a rule, is steady and for 10 steel is close to linear. For steels with a higher carbon content, a deviation from a linear relationship is observed only up to a ferrite content of 20-30%. With a ferrite content of more than 30% the values of H_c are the same for all of the investigated steels. It should be noted that with an increase in ferrite content the carbon content in the martensite increases rapidly and the martensite of 47GT steel contains 4.5 times more carbon than the martensite of 10 steel. This is an indication that the presence of diamagnetic carbon atoms in a quantity of up to 0.5 wt.% has a very weak influence on the coercive force of the α-solid solution. Apparently, internal stress has a significant influence on H_c. It is known that in strain hardening the coercive force increases significantly. The results of investigation of second-order stresses (Fig. 1) showed that the character of their decrease with an increase in ferrite content in the steel is similar to the character of change in coercive force. It is obvious that with a certain ferrite content the level of microstresses is determined by the yield strength of this structural constituent, which depending upon the degree of strain hardening is 100-220 MPa. These values of σ_{II} are critical. With lower values the second-order stresses have a weak influence on the coercive force.

From the standpoint of the domain theory of ferromagnetism [2] this may be explained by the following. The boundary between the domains in polycrystalline bodies is always formed in such a manner that the increase in free energy of the system caused by its appearance is a minimum; that is, the boundary appears in the areas with the minimum residual stresses or where their sign changes. With a high level of second-order stresses the number of boundaries and consequently the number of domains increase and their reorientation in the direction of the field is more difficult.

The structural curve for the magnetic permeability (Fig. 1) shows that with an increase in ferrite content in the structure to 40-50% μ_{max} rapidly increases. Then the rate of increase in magnetic permeability drops sharply and the difference in its values for steels with different carbon contents also decreases.

Conclusions. 1. As a structural criterion in nondestructive testing of the quality of hardening and tempering of parts of 58 (55PP) and 47GT steels on the basis of magnetic properties the selection of the excess ferrite content in the structure of the steel is recommended.

2. With the use of the recommended structural criterion the most reliable results for inspection of steel parts may be obtained with selection of magnetic permeability as the inspection characteristic.

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