The work described below was undertaken with the aim of establishing the optimum conditions for the tempering of quenched sintered steel produced by carburizing iron of 15% porosity. Starting specimens with 15% of pores for tensile, bend, compressive, and impact strength testing were pressed from PZh2M2 iron powder* (GOST 9849-61 standard) and carburized for 5 h at 1030°C in a mixture of the following, optimum composition: charcoal + 30% BaCO₃ [1]. As a result of carburizing by this process, the ratio of the carburized cross-sectional area to the total specimen cross-sectional area was, on the average, 1:5.

At a total carburized layer depth of 1.8 mm, the structure of such a layer changes with increasing distance from the specimen surface as follows: pearlite (0.25 mm), pearlite + cementite (0.8 mm), pearlite (0.5 mm), and ferritic pearlite. A slight decarburization of a thin layer adjacent to the specimen surface is characteristic of all high-porosity iron powder compacts cemented in a solid carburizer and is due to the following reasons:

a) variable composition of the gaseous carburizing atmosphere, especially the decrease in the CO/CO₂ ratio with falling temperature during the slow cooling of carburized parts in a solid carburizer.

b) strongly developed surface of the open, interconnected pores, which accelerates the diffusion decarburization process during the cooling of carburized specimens.

After carburization, the specimens were heated to 840°C in purified nitrogen and then quenched in water or in oil. Microhardness examinations (Fig. 1) demonstrated that the depth of a quenched layer with a microhardness of more than 550 kg/mm² (hardenability) was 0.7 mm after water-quenching and only 0.1 mm after oil-quenching. Water- and oil-quenched specimens differ also in the character of their microhardness curves. For water-quenched specimens, which exhibit greater hardenability, the microhardness rises with increasing distance from the specimen surface, attaining a maximum of ~ 1000 kg/mm² at a depth of 0.4 mm, which is linked with the character of the carburized structure prior to quenching (pearlite giving way to pearlite + cementite at some distance from the surface).

For oil-quenched specimens, the microhardness is a maximum at their very surface and falls very sharply, to less than 500 kg/mm², at a depth of more than 0.1 mm. In this case, in spite of the similarity between the initial structures, the slower rate of cooling attained in high-porosity specimens subjected to oil-quenching and the resulting negligible hardenability (0.1 mm) play the decisive part in structure formation

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*Fine reduced powder of 98.0% purity — Translator's note.
in the hard case, so that the free cementite inclusions located at some distance from the surface are in fact outside the quenched zone (in contrast to water-quenched specimens).

Two groups of specimens, subjected to water- and oil-quenching, were tempered for 1 h in a furnace with a hydrogen atmosphere at temperatures ranging from 200 to 700° C. The structural changes induced by raising the tempering temperature in quenched material of 15% porosity are identical with those observed in bulk steels of the same composition (Fig. 2). Figure 2 also illustrates the mechanical characteristics* of carburized iron specimens of 15% porosity after quenching and tempering at various temperatures, while Table 1 lists their hardness values.

A characteristic feature of the strength vs tempering temperature curves of quenched porous steel is that the tensile and bend strengths exhibit maxima at 300° C. These maxima are particularly pronounced for specimens quenched in water before tempering (in our study, the strength after tempering at this temperature rose by more than 100%). Cast carbon steels are, of course, characterized by a sharp increase in strength after quenching, while raising the tempering temperature decreases their strength and increases their ductility. In particular, on passing from the quenched condition to that produced by tempering at 300° C, the tensile strength of cast carbon steels generally falls.

While the strength characteristics $\sigma_t$ and $\sigma_b$ of cast carbon steel markedly increase as a result of quenching, the quenching of carbon steel with 15% of pores has practically no effect on its $\sigma_t$ and $\sigma_b$. The relief of structural stresses in sintered steels with 15% of pores after tempering at temperatures of up to 300° C sharply increases their strength characteristics, the strength ($\sigma_t$ and $\sigma_b$) after tempering at 300° C being more than twice that in the initial, quenched condition.

As the tempering temperature is raised to 200-300° C, a slight improvement in strength characteristics, brought about by relief of stresses set up by quenching, is exhibited also by some cast steels [2, 3]. For cast Type 40 (0.40% C) steel, for instance, tempering at 300° C raises its $\sigma_t$ by 2-3 kg/mm² compared with the initial, quenched condition [2]. The bend strength $\sigma_b$ of cast carbon steel with 0.88% C after quenching is 140 kg/mm² and rises as a function of tempering temperature as follows: 175 kg/mm² at 150° C, 230 kg/mm² at 200° C, and 175 kg/mm² at 300° C.

In contrast to cast steels, in porous steels the level of stresses generated as a result of quenching is apparently so high that the strength gain due to transformation into martensite is balanced by the strength loss due to the stressed state of the structure; the elimination of the stresses induced by quenching during subsequent tempering at up to 300° C ensures that the strength attained in porous steel is attributable to the formation of the stronger structure characteristic of heat-treated steel.

This strength maximum is much less pronounced in the case of porous steels subjected to tempering after oil-quenching. The reason for this

*Translator's note.

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**Table 1. Rockwell C Hardness of Carburized Iron of 15% Porosity as Function of Quenching and Tempering Conditions**

<table>
<thead>
<tr>
<th>Quenching medium</th>
<th>After quenching</th>
<th>After quenching and tempering at temp, °C</th>
<th>200</th>
<th>300</th>
<th>450</th>
<th>600</th>
<th>700</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>49</td>
<td>43</td>
<td>33</td>
<td>96</td>
<td>96</td>
<td>68</td>
<td>74</td>
</tr>
<tr>
<td>Oil</td>
<td>25</td>
<td>96</td>
<td>95</td>
<td>83</td>
<td>55</td>
<td>64</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 2.** Effect of tempering temperature on structure and mechanical characteristics of carburized and quenched iron specimens of 15% porosity. Specimens quenched from 840° C: solid lines) in water; dotted lines) in oil.