on the properties \((f_M < 0.5\%)\) (Fig. 2b). A further increase in the holding time is accompanied by a simultaneous increase in the strength and plastic properties and the strain-hardening characteristics. In medium- and high-carbon steels, the highest set of properties is achieved after quenching with a 7-min holding time at 735°C; in this case, \(f_M\) exceeds the optimal value (see Table 1).

The high plasticity is governed mainly by the combination of the superfine-grain polyhedral structure of the ferritic matrix and the uniform distribution of disperse segments of the martensitic phase, which are commensurate with the size of the ferrite grain (see Fig. 1).

By regulating the dissolution-process of the globular-shaped carbide phase, therefore, it is possible to achieve high plasticity, which is characteristic for ferritic-martensitic structures, in medium- and high-carbon steels when held in the intercritical interval.

**LITERATURE CITED**


**EFFECT OF HEAT TREATMENT ON THE AMOUNT OF CARBIDES IN BALL-BEARING STEELS**

M. Yakeshova

The distribution of carbon in steel, and the type, amount, and dispersity of the carbides affect its properties to a significant degree. A structure with a low-carbon matrix and disperse carbides is characteristic for rolling bearings [1]. The conventional methods of phase analysis have a number of drawbacks, which limit the possibility of their use in studying these structures [2]. The low sensitivity and accuracy of radiography, for example, do not make it very suitable for study of specimens with a negligible amount of certain phases - carbides for the case in question - and their high dispersity.

The sensitivity of Mössbauer spectroscopy to local neighborhoods of resonating \(^{57}\)Fe nuclei permits its use for the phase analysis of steels. The results of analysis are virtually independent of the material's deformation and the shape, size, and orientation of the particles, and depend on the standard to a lesser degree than with magnetometry.

Every iron-containing phase has its own fine structure corresponding to the component of the spectrum that permits its identification (qualitative phase analysis). Williamson et al., [3] cite parameters of iron-carbide spectra.

The ratio of the areas of the spectrum components makes it possible to approximate the distribution of iron throughout the phases (quantitative phase analysis). Complex relationships are obtained when other factors are taken into account (for example, the various Debye-Waller factors, the specimen thickness, the overlapping of lines, etc.) [4-7]. Calibrations are frequently used in this connection, especially for scattering techniques for which the penetrability is nearly constant.

Schwartz [8] proposes the expression

\[
A_{res} = \frac{S_A \times 100}{S_A + d(SS)_M}
\]  

(1)

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502 0026-0673/89/0708-0502$12.50 © 1990 Plenum Publishing Corporation
TABLE 1

<table>
<thead>
<tr>
<th>Material</th>
<th>Element content, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Steel</td>
<td>0.78</td>
</tr>
<tr>
<td>NLO</td>
<td>0.76</td>
</tr>
<tr>
<td>NLOm</td>
<td>0.74</td>
</tr>
<tr>
<td>SS</td>
<td>0.3</td>
</tr>
<tr>
<td>S5</td>
<td>0.3</td>
</tr>
</tbody>
</table>

for determination of the residual-austenite content ($A_{\text{res}}$, %), where $S_A$ and $ES_M$ are the areas corresponding to the austenite and martensite, and $d$ is a correction factor; $d = 0.86$ is established from comparison with radiographic data.

Transformation of Eq. (1) yields a general expression for calculating the distribution of iron between phases from the areas using the correction factors:

$$ p_i = \frac{S_i/d_i}{\Sigma(S_j/d_j)} $$

where $p_i$ is the proportion of the total amount of Fe in the specimen in the $i$-th phase.

The carbide composition was investigated on massive specimens of four steels - bearing steels and steels of similar composition (see Table 1); the heat treatment and structure of the steels are described in detail by Gridnev et al., [9]. The specimens formed from the NLO steel were treated in accordance with the following regimes; A - holding at 760°C for 4 h, and cooling in the furnace to 550°C and then in air (initial state); B - quenching from 820°C (10 min) in oil and tempering at 200°C for 1 h; C - rapid austenitizing (heating at a moderate rate of 600°C/sec to 900°C without holding) and tempering; D - same as in C with 10-min hold in liquid nitrogen prior to tempering; E - quenching from 820°C (10 min in oil; and, F - holding at 350°C for 4 h, rapid austenitizing, and tempering. The specimens formed from the remaining steels were examined in the initial state, after quenching from 900°C (30 min) in oil, and after quenching and tempering at 300°C for 1 h (regimes A', B', and C', respectively). The composition of the carbide deposits electrolytically segregated from two steels is presented in Table 1. The content of alloying elements in the carbides corresponds to their affinity for carbon: The amount of the elements Mn, Cr, V, and Mo is greater, while that of Si and Ni is smaller than their average concentration in the steels.

Only paramagnetic doublets are found in the Mössbauer transmission spectra of the carbide deposits (Fig. 1); they are most likely caused by cementite, which is paramagnetic with a high content of alloying elements at normal temperature [10, 11]. For type $(\text{Fe}_1-x\text{M}_x)_3\text{C}$ cementite, the Curie point corresponds to the normal temperature when $x_{\text{Cr}} = 0.08$, or $x_{\text{Mn}} = 0.13$ [12], and paramagnetic lines are observed even when $x_{\text{Cr}} = 0.044$ [10] and $x_{\text{Mn}} = 0.10$ [10]. In the carbide deposit from the NLO steel, $x_{\text{Mn}} = 0.088$ and $x_{\text{Cr}} = 0.076$, and the total amount of alloying elements $x_M = 0.169$. The spectrum of the deposit from the NLO steel could be divided into two components. Comparison with data derived by Huffman [10] enables us to propose that they correspond with the two positions G and S of the iron atoms in the lattice and to confirm the assumption concerning the fact that the carbide phase in these steels is alloyed cementite.

The magnetic component and paramagnetic doublet corresponding to the spectra of the deposits are observed in the spectra of massive specimens, and, moreover, the line of residual austenite is observed in the quenched specimens.

In analyzing the magnetic component, we assumed a binary distribution of alloying elements for the unhardened alloy. Chromium, silicon, and manganese diminish the effective superfine magnetic field by $\Delta = (7-8)%$; nickel increases the effective field, and the absolute value of the shift is significantly lower [13]. Neglecting the small value of $\Delta$ for Ni and the difference between $\Delta$ for Cr, Si, and Mn, we obtained three principal spectrum components, the values of which exceed 5%: for the NLO steel, Fe(8) yields 0.623, Fe(7) 0.304, and Fe(6) 0.0648. The ratio of these values 1:0.49:0.10 agrees well with the ratio 1:0.50: 0.10, which was obtained by decomposing the magnetic spectra into three components.