Materials Science, Vol. 37, No. 3, 2001

SPECIFIC FEATURES OF FRACTURE OF IMPROVED 40Kh STEEL UNDER CONDITIONS OF CONTACT INTERACTION

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UDC 669.14.018

Investigations of the effects of the quenching temperature and tempering conditions show that the development of a dispersion in grain sizes and precipitation of carbides along the boundaries of grains and subgrains decrease the wear resistance of 40Kh steel. Quenching from 1050°C and elimination of the development of temper brittleness enable one to obtain a microstructure that increases the serviceability of friction units.

Friction of metallic materials is accompanied by the deformation, formation, and fracture of bonds on certain regions of the surface. For specific pressures of 1.3–1.8 MPa, the actual diameters of contact zones in parts of machines is equal to 22–42 μm [1, 2]. For improved steels with grains 10–50 μm in size, the probability that grains, boundaries, and triple grain joints fall into a contact zone is large. For steels with greater grains, the probability of finding an entire grain in an actual contact zone is low, but the boundaries and joints of grains and subgrains are always present there. The influence of internal interfaces on deformation and fracture is related to their structure. However, the technology of processing that is based on a change in the state of atoms on grain boundaries of steels and intended to improve their wear resistance is of limited utility. Below, we analyze the influence of parameters of the microstructure and the structural and energy state of internal interfaces on the wear resistance of 40Kh steel after its improvement.

We investigated 40Kh steel of industrial smelting. We cut specimens of annealed bars, quenched them in oil after heating in a salt bath to temperatures of 860–1050°C, tempered them at 600°C with a 2-h hold, and cooled them in water. The structural and energy state of internal interfaces was changed by performing an embrittling treatment, namely: several specimens were repeatedly tempered at 520°C for 2 h and cooled together with a furnace. We estimate the susceptibility of this steel to temper brittleness on the basis of a change in the threshold of cold brittleness (ΔT_{50}) of specimens tested by impact bending at temperatures from – 196 to 100°C. To obtain a structure with various quantitative parameters, we held the specimens in the process of quenching in the austenitic range for 30 and 80 min. The dispersion in grain sizes and the area of the boundaries of grains and subgrains were determined with optical and electron microscopes after ion and plasma pickling [3]. We calculate the mean number of carbide precipitations per unit area of internal interfaces by the relation

$$\rho = \frac{n}{l \cdot r},$$

where n is the number of particles on a surface of length l and r is the mean size of revealed particles [4]. We determine the hardness, mechanical properties, and wear resistance. The specimens were tested for wear resistance with a 2070 SMT-1 machine according to the “disk–shoe” scheme in a mode of dry friction–sliding. The parameters of loading are close to the service parameters that appeared in the gears of gear-boxes made of

“L’vivs’ka Politekhnika” University, Lviv. Translated from Fizyko-Khimichna Mekhanika Materialiv, Vol. 37, No. 3, pp. 91–94, May–June, 2001. Original article submitted May 27, 2000.

1068–820X/01/3703–0473 $25.00

improved steels. The sliding velocity of specimens was equal to $0.5\ \mathrm{m \cdot sec^{-1}}$, the loading equaled 300 N, and the time of wear was equal to 10 h. The counterbody was made of 45 steel with hardness HRC 42–44.

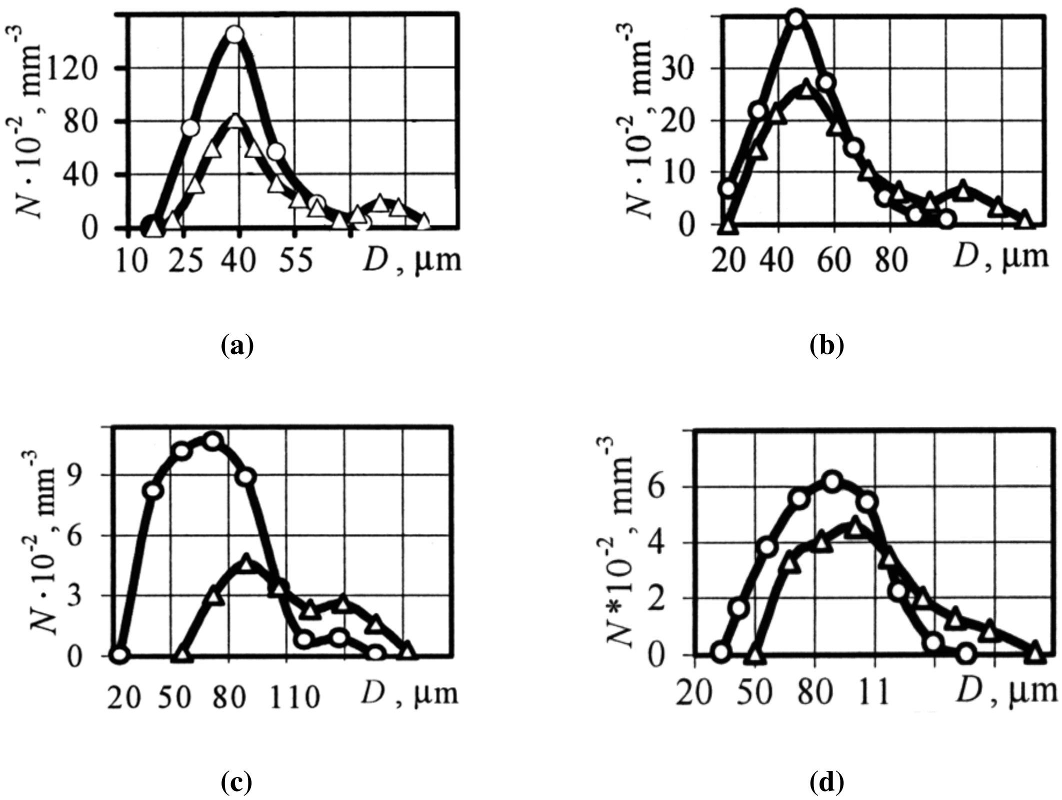

Fig. 1. Distribution of the grain size in 40Kh steel after its quenching from temperatures of 860 (a), 900 (b), 950 (c), and 1050°C (d); ○ and △ correspond to holding for quenching for 30 and 80 min, respectively.

After quenching from a temperature of 860°C and holding for 30 min, we obtain steel with a uniform grain 38–43 μm in size (Fig. 1a). For a greater holding time, grains with a size of more than 80 μm appear. As the quenching temperature increases to 900°C, grains 45–55 μm in size appear. For a holding time of 30 min, these grains are uniformly distributed (Fig. 1b). As the holding increases, there appear groups of grains 100–110 μm in size in the structure. After quenching from 950°C and holding for 30 min, we observed grains 70–80 and 130–150 μm in size (Fig. 1c). A greater holding leads to the appearance of grains 80–100 and 130–150 μm in size. Quenching from 1050°C favors the grain growth. Indeed, a part of the grains 150–170 μm in size increases with the duration of holding (Fig. 1d). Thus, after quenching from 860 and 900°C and holding for 30 min, we obtain a uniform grain. An increase in the quenching temperature and the duration of holding favors the variation in grain size.

After quenching from a temperature of 860°C and holding for 30 min, there appear spherical subgrains 1–2 μm in size and elongated subgrains 1–2 μm wide and 5–6 μm long in the structure (Fig. 2a). Quenching from 950°C leads to the appearance of solely elongated subgrains 2–3 μm wide and 8–10 μm long (Fig. 2b). After quenching from 1050°C, there appear spherical subgrains 2–3 μm in size in the steel (Fig. 2c). An increase in the holding time to 80 min in the process of quenching favors the growth of subgrains.

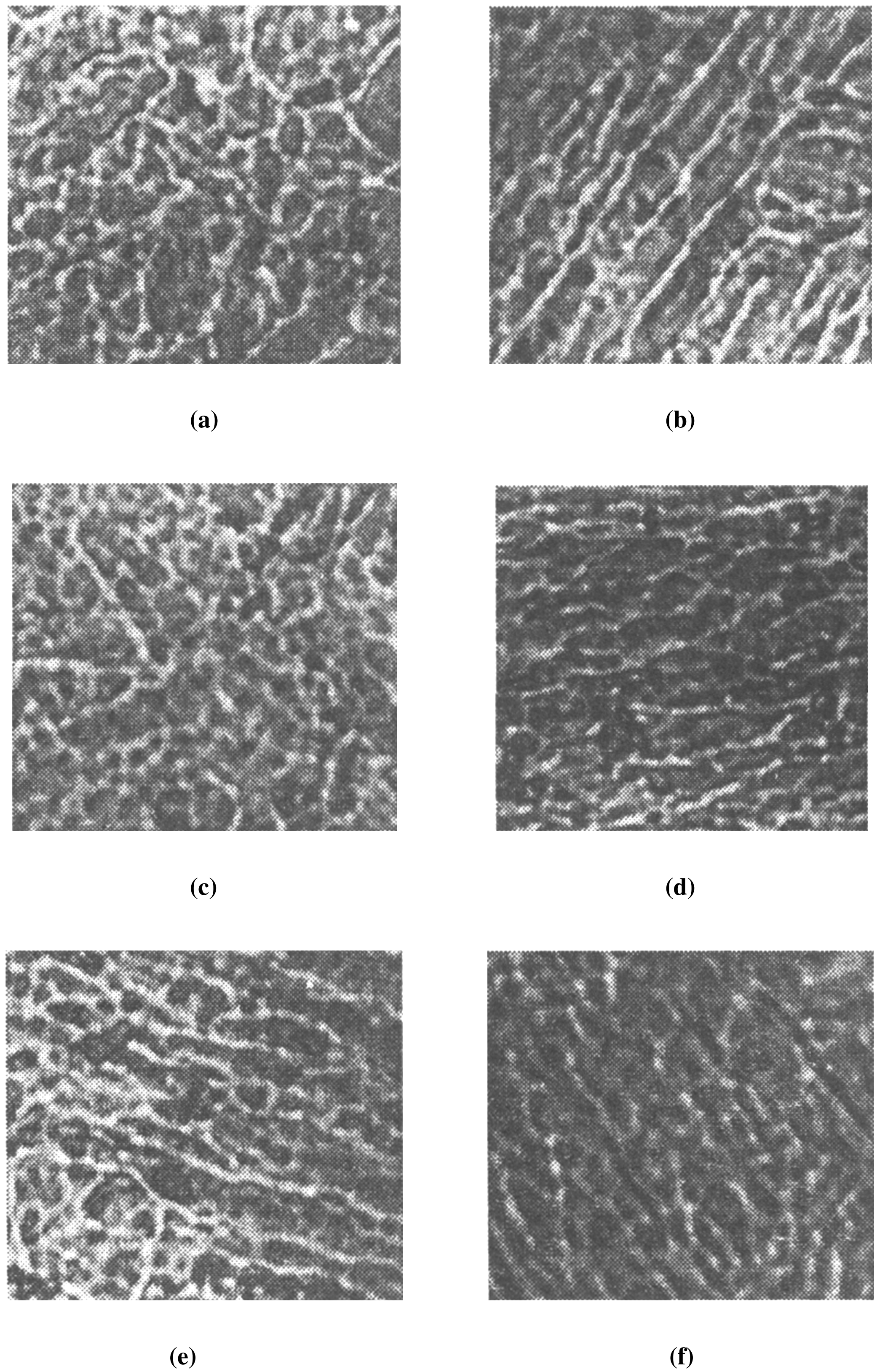

Fig. 2. Microstructure (×1500) of 40Kh steel quenched from temperatures of 860 [(a) and (d)], 950 [(b) and (e)], and 1050°C [(c) and (f)]; holding for quenching for 30 [(a), (b), and (c)] and 80 min [(d), (e), and (f)].

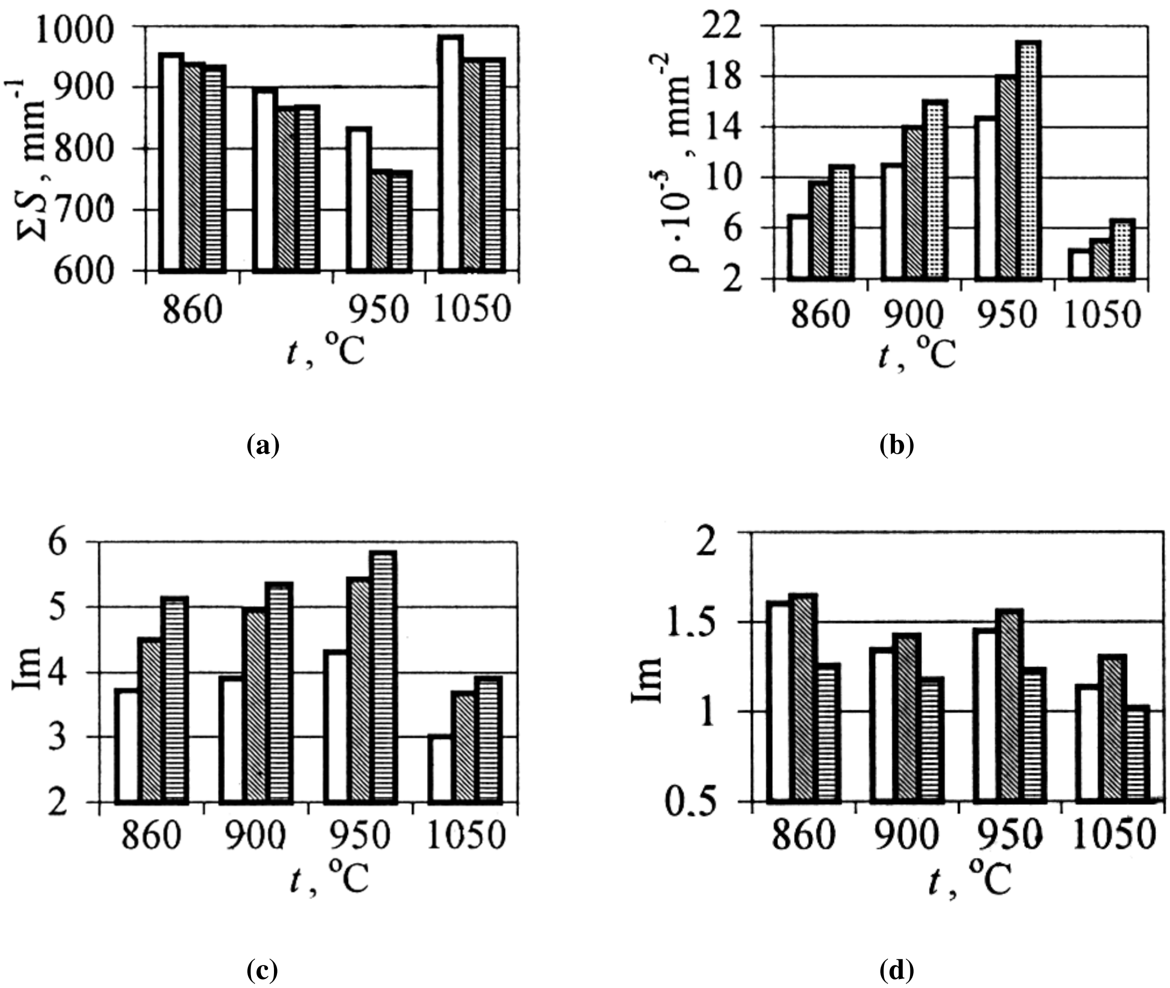

Fig. 3. Influence of the quenching temperature on the area of intersubgranular boundaries (a), the number of carbide precipitates on them (b), and the intensity of wear of specimens of 40Kh steel after improvement (c) and the counterbody (d): □ holding for quenching for 30 min, ductile state, ▧ holding for 80 min, ductile state, and ⊟ holding for 80 min, embrittled state.

The results of calculation performed by the secant method [5] showed that the area of intersubgranular boundaries is minimum after quenching from 950°C and maximum after quenching from 1050°C (Fig. 3a). As the holding increases, the area decreases, and repeated tempering accompanied by slow cooling has no considerable influence on it.

At a quenching temperature of 950°C, the amount of carbides on intersubgranular boundaries of the steel increases by a factor of 2–2.2 (Fig. 3b), while after quenching at a temperature of 1050°C their number decreases. The embrittling treatment favors the precipitation of carbides on the boundaries of subgrains for all quenching temperatures.

The microstructure has a greater effect on the intensity of wear than the steel hardness. For example, a decrease in hardness from 2636 MPa after quenching from 860°C to 2499 MPa after quenching from 1050°C leads to an increase in the wear resistance of the steel (Fig. 3c). As the quenching temperature increases to 950°C, the intensity of wear of the steel increases. Quenching from a temperature of 1050°C increases the wear resistance. After holding for 80 min, the wear resistance of the steel always decreases. Specimens in the embrittled state wear more rapidly.

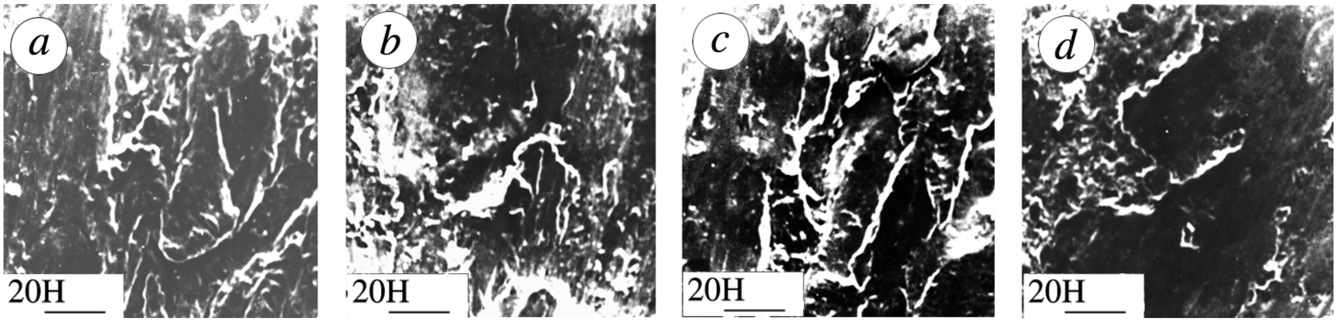

Fig. 4. Friction surfaces of specimens made of 40Kh steel after quenching from temperatures of 860 (a), 950 [(b) and (c)], and 1050°C (d): ductile [(a), (b), and (d)] and embrittled (c) states.

We observed a correlation between wear of specimens and the counterbody. As the intensity of wear of the specimens increases, the counterbody ages more slowly. Only after quenching from a temperature of 950°C, under conditions of maximal wear of the specimens, is an increase in wear of the counterbody also observed. Quenching from 1050°C simultaneously increases the wear resistance of the specimens and the counterbody (Fig. 3d). After the embrittling tempering, the intensity of wear increases for the specimens and decreases for the counterbody. On the surfaces of specimens quenched from 860°C, we see the zones of local plastic deformation and fracture elongated in the direction opposite to the motion of a specimen (Fig. 4a). Fracture proceeds due to cleavage and smooth plastic exfoliation.

After quenching from a temperature of 950°C, we see elongated pits, whose size corresponds to subgrains, on the friction surface (Fig. 4b). The part of cleavage decreases, whereas the part of smooth exfoliation increases. After the embrittling treatment, the number of elongated pits considerably decreases, and cleavage disappears. The friction surface mainly consists of the zones of intergranular exfoliation with minimum traces of plastic deformation in separate grains and subgrains of the steel (Fig. 4c). In the process of quenching from 1050°C, the part of smooth exfoliation decreases, and the area of pits, whose size does not correspond to subgrains, increases. In pits and near them, there are carbides. On the surfaces of exfoliation, we see the traces of plastic deformation (Fig. 4d).

X-ray spectral microanalysis with a probe $4 \times 4\,\mu\mathrm{m}$ in size showed that the chemical composition of the surface of contact varies depending on the temperature-temporal modes of treatment (see Table 1). After quenching from 860 and 950°C, the contents of silicon and chromium along the length of crests and cavities are almost constant, while the content of manganese decreases by a factor of two. After the embrittling treatment, this difference is constant, but the distinction along the length of the cavities increases. After quenching from 1050°C, the difference in the content of chromium increases along the length of the cavities, where as the content of manganese decreases. The results of the investigation show that carbides play a significant role. Due to the contact interaction, microcracks are formed, which leads to the separation of some particles. On the worn surface, we revealed carbides and their traces, which indicates their separation. A nonuniform distribution of carbides and their predominant location on intergranular and intersubgranular surfaces facilitate their separation. The regions of intersubgranular fracture after quenching from 950°C and regions of intergranular fracture after embrittling treatment testify to this fact.

A steel with small carbide particles uniformly distributed in the matrix is the most resistant against fracture and is obtained from 40Kh steel after its quenching from a temperature of 1050°C.

Table 1. Content of Elements on Regions of the Friction Surface of 40Kh Steel (%)

Quenching temperature and state of steel	Elements	Crest, beginning/middle	Cavity, beginning/middle	The original surface of the specimen
860°C, ductile	Si	0.53/0.43	0.69/0.56	0.50
	Cr	1.10/1.07	0.84/1.04	1.16
	Mn	0.65/0.38	0.70/0.44	0.84
950°C, ductile	Si	0.52/0.52	0.56/0.48	0.48
	Cr	0.83/0.98	1.14/0.94	1.27
	Mn	0.64/0.36	0.97/0.44	0.79
950°C, embrittled	Si	0.51/0.36	0.52/0.48	0.47
	Cr	0.90/0.84	1.15/0.79	1.23
	Mn	0.29/0.22	0.33/0.65	0.71
1050°C, ductile	Si	0.46/0.49	0.38/0.37	0.49
	Cr	0.83/1.16	0.66/1.12	1.01
	Mn	0.69/0.71	0.28/0.34	0.74

CONCLUSIONS

Development of the dispersion in grain sizes, a decrease in the area of intersubgranular boundaries, and an increase in the density of carbides on them with increase in the quenching temperature to 950°C lead to a decrease in the wear resistance of 40Kh steel after its improvement. Repeated tempering accompanied by slow cooling leads to an increase in the number of carbides on the boundaries of grains and subgrains and in the intensity of wear independently of the quenching temperature. Quenching from 1050°C favors the crushing of subgrains and the uniform distribution of carbides. As a result, this leads to a simultaneous increase in the wear resistance of both the specimen and counterbody.

REFERENCES

1. A. I. Sviridenok, S. A. Chizhik, and M. I. Petrokovets, *Mechanics of Discrete Frictional Contact* [in Russian], Navuka i Tékhnika, Minsk (1990).
2. S. B. Ainbinder and É. L. Tyunina, *Introduction to the Theory of Friction of Polymers* [in Russian], Zinatne, Riga (1978).

3. O. Kuzin, T. Meshcheryakova, and S. Bespalov, "The use of ion and plasma pickling for analysis of the structure and energy state of internal interfaces," in: *Bulletin of the "L'vivs'ka Politekhnika" State University. Ser. Optimization of Manufacturing Processes and Technical Control in Machine Building and Device-Making* [in Ukrainian], No. 359 (1999), pp. 73–76.
4. E. V. Nesterova, V. V. Rybin, and Yu. F. Titovets, "Statistical investigation of intergranular precipitations in commercially pure titanium," *Fiz. Met. Metalloved.,* No. 3, 81–88 (1992).
5. S. A. Saltykov, *Stereometric Metallography* [in Russian], Metallurgiya, Moscow (1976).