# THE VARIATION OF YOUNG'S MODULUS AND THE HARDNESS WITH TEMPERING OF SOME QUENCHED CHROMIUM STEELS

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Hardening and tempering of quenched steels are accompanied by decomposition of the $\alpha$- and $\gamma$-solid solutions and also by carbide transformations. The composition and conditions for the formation and transformation of iron carbides have still not been studied in detail [1]. There are data on the existence in chromium steels of chromium carbides, the stoichiometric composition of which does not match the phase diagram of the Fe–C–Cr system [2-4]. The processes occuring in steels are very complex, as is confirmed by the ferromagnetic and paramagnetic components observed in the carbide phase studied in greatest detail – cementite [5].

Measurements of Young's modulus are a great help in studying phase transformations in steels [6-8]. The elastic characteristics are sensitive to distortions of the crystal lattice. A monotonic increase of Young's modulus was observed on tempering of quenched steel [9]. After careful study of the variation of Young's modulus on tempering of quenched steel the conversion of hexagonal $\varepsilon$-carbide into orthorhombic carbide was established [6].

The purpose of this work was to determine the variation of Young's modulus, the hardness on tempering of quenched steels alloyed with chromium, and the connection between these two phenomena.

We investigated standard steels 7Kh3, 4Kh13, and 9Kh18 with chromium concentrations of 3.5, 13, and 18% respectively. Young's modulus was measured on plates $1.8 \times 16 \times 112$ mm and the hardness on samples 15 mm in diameter and 20 mm high. After normalizing annealing at 900°C for 30 min with the necessary measures taken to prevent oxidation and decarburization the samples were quenched from 1200°C in oil. The quenched samples were tempered for 1 h at temperatures from 150 to 700°C (every 25-50°C).

Young's modulus was determined by the dynamic method by comparing the natural frequency of vibrations with the frequency of a string stretched by a weight [10]. From the averaged data we plotted the variation of the hardness and Young's modulus with the tempering temperature.

In accordance with Born's theory, when any process leading to distortion of the crystal lattice occurs in a crystalline system it leads inevitably to a reduction of Young's modulus.

The small change in hardness and Young's modulus at low tempering temperatures for steel 7Kh3 (Fig. 1a) is due to the reduction of stresses induced by sharp cooling during quenching. Around 250°C one observes a peak on the hardness curve. Young's modulus begins to increase after tempering at 150-200°C. On the basis of x-ray data one can assume that the slow rate of increase of Young's modulus between 150 and 200°C is due to the microdistortion [11, 12] induced by decomposition of martensite and the formation of low-temperature $\varepsilon$-carbide with a hexagonal lattice coherently bound to the mother phase [13, 14]. In the region of "secondary hardness" (400-500°C) one observes a second peak on the hardness curve and a plateau on the curve of Young's modulus. The increase of Young's modulus is slowed down in this temperature range by phase transformations, and only after they are completed does Young's modulus increase again, accompanied by a sharp reduction of the hardness. Obviously this cannot be explained by the decomposition of residual austenite, since, according to [15], in steels with 2-3% carbide-forming elements the residual austenite is completely decomposed in tempering at 300-350°C. For example, steels with 0.5% Cr and 1.0-1.5% V have no residual austenite after quenching, although a peak of secondary hardness is observed during tempering. According to [16], in purely carbon steels no traces of residual austenite remain after tempering at 300°C. It was shown in [6] that after tempering at 400-450°C a slight reduction of Young's modulus occurs. Analysis of all the data, including magnetic and other studies [17-20] indicates that the plateau on the curve of Young's modulus and the corresponding peak of secondary hardness are due not to decomposition of residual austenite but to carbide transformations.

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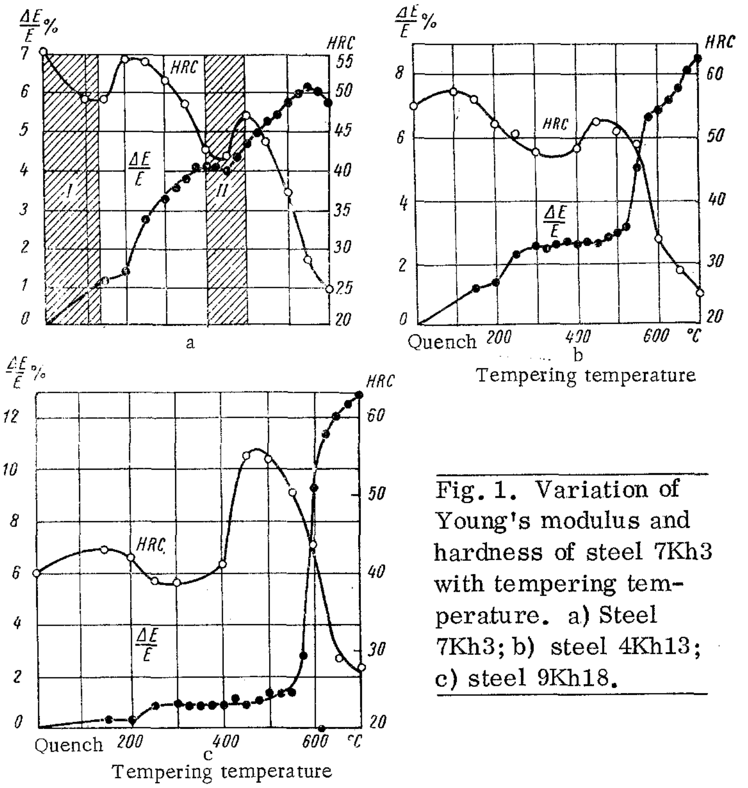


Fig. 1. Variation of Young's modulus and hardness of steel 7Kh3 with tempering temperature. a) Steel 7Kh3; b) steel 4Kh13; c) steel 9Kh18.

Above the region in which phase transformations of the previously precipitated carbides occur, Young's modulus begins to increase again. This occurs because additions of molybdenum, vanadium, and chromium substantially inhibit decomposition of the supersaturated $\alpha$-solid solution, extending it over a wide temperature range. Thus, in high-carbon steels with additions of molybdenum and vanadium about 0.1% C is still retained in the $\alpha$-solid solution after tempering at 500°C. Therefore, the increase of Young's modulus and simultaneous reduction of the hardness we observed after tempering at 450-500°C are due to the continuing decomposition of martensite and gradual transformation into pearlite of this most stable metallographic structure.

Despite the higher chromium content of steels 4Kh13 and 9Kh18, the variation of the hardness and Young's modulus with the tempering temperature has the same character as in steel 7Kh3 (Fig. 1b, c). At tempering temperatures of 100-150°C we observed a small peak of hardness and then a decline. Here, Young's modulus increased, slowly in steel 9Kh18 and more rapidly in steel 4Kh13. Above 250°C a horizontal section is observed on the curves of Young's modulus, the length of the section increasing with the chromium content of the steel.

At 450-500°C a secondary hardness peak is observed, after which the hardness begins to decrease rapidly. After a long slow increase, Young's modulus begins to increase rapidly. In this section the increase or Young's modulus amounts to about 6% for steel 4Kh13 and 12% for steel 9Kh18.

The variations of Young's modulus and the hardness reflect the processes occurring in the steels during tempering at different temperatures, including those in which the lattices of the $\alpha$- and $\gamma$-solid solutions are coherently bound. In the boundaries between martensite needles and grains of residual austenite the crystal lattices of the supersaturated solutions are in the most unstable condition and decomposition begins earlier in these areas than in others. But the decomposition of $\alpha$-solid solution and subsequent structural transformations to pearlite lead to reduction of the distortion of the lattice, and thus an increase of Young's modulus. The decomposition of austenite, involving large changes in volume, induces a reduction of its concentration. The decomposition of austenite slows down the increase of Young's modulus: the more residual austenite in the quenched steel the greater the retarding influence of its decomposition (see Fig. 1). The decomposition of $\alpha$- and $\gamma$-solid solutions, beginning in regions of coherent binding, spreads into the phases and is accelerated with increasing temperatures. After decomposition of the solid solutions is completed the subsequent processes in quenched steels will be only of the relaxation type. The reduction of lattice distortion and coalescence of carbide particles lead to a system with a higher equilibrium, due to which Young's modulus increases continuously and the hardness decreases after tempering at 450-500°C.

## CONCLUSIONS

1. After low-temperature tempering of high-alloy chromium steels Young's modulus begins to increase and then remains almost constant up to tempering temperatures of 525-550°C. The higher the chromium content of the steel, the smaller the initial increase and the longer the horizontal section of the curve.

2. On the hardness curves one observes a small peak at 150°C and then a drop of the hardness. At 450-500°C one observes another peak, which is the result of processes in the carbide phase.

3. After tempering at 525-550°C the hardness decreases and Young's modulus increases. Up to 700°C the increase of Young's modulus for steel 4Kh13 averages 6%, and 12% for steel 9Kh18.

4. The rapid increase of Young's modulus after tempering at 525°C and the simultaneous decrease of the hardness confirm the data in [14] indicating that the decisive factor in the retention of the high hardness of alloy steels up to high temperatures is the inhibition of the decomposition of the $\gamma$-solid solution and the increased temperature of relaxation processes that induce a reduction of lattice distortion.

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