

# EFFECT OF TEMPERATURE ON HARDNESS AND WEAR RESISTANCE OF HIGH-CHROMIUM CAST IRONS DEPOSITED WITH FLUX-CORED STRIPS

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The paper presents the procedure and results of investigation of hot hardness of the deposited high-chromium cast irons with different level of alloying of 450Kh30M, 500Kh22B7, 500Kh22B7M7V2F, 300Kh25S3N2G2 type, as well as nickel-chromium-carbide alloy 500Kh40N40S2GRTs. It is determined that hot hardness of deposited metal to a significant extent depends on the presence and types of carbides in metal structure. For relatively low-alloyed high-chromium cast irons, hardness drops at temperature rise and increases at the content of chromium up to 30 % and that of carbon up to 5 %. Alloys doped with chromium, niobium, molybdenum, tungsten and vanadium preserve high hardness up to 650 °C temperature. Niobium is important for indicated alloys. It plays a role of modifier delaying growth of primary chromium carbides, and forming hard cubic niobium carbide. Nickel-chromium-carbide alloy preserves high hardness up to 650 °C temperature due to the presence of high concentration of higher chromium carbides in a nickel-based matrix. Wear resistance of deposited alloys decreases with the rise of temperature in accordance with lowering of deposited metal hardness. 12 Ref. 3 Tables, 3 Figures.

**Keywords:** hot hardness, flux-cored strips, surfacing, high-chromium cast irons, nickel-carbide-chromium alloy, wear resistance

A considerable number of parts of blast furnace, metallurgical, power and other equipment operate under the conditions of abrasive and gas-abrasive types of wear at elevated temperatures. Improvement of performance of such parts is achieved due to their strengthening by surfacing with different alloys, having high wear resistance in extreme conditions. High-chromium cast irons with the content of carbon up to 5 % and of chromium from 10 up to 30 % take the leading place among such alloys. Based on advertising information, a number of foreign companies tend to modify such alloys by their additional alloying and increasing their carbon content up to 6 %. These are alloys of the type of sormite 300Kh25S3N2G2, as well as type 350Kh10M, 350Kh10G3, 500Kh30M, 500Kh30G2 and many others. Here, we should take into account the fact that increase of the degree of alloying and carbon content above 5 % gives rise to problems of producing thick deposited layers. This is associated with the risk of deposited metal spallation at surfacing in more than two layers [1–3].

One of the important factors of successful performance of such alloys is preservation of high hardness at elevated temperatures. Investigations of the relationship between metal hot hardness and its alloying system are important. Correct selection of alloying components can greatly affect the deposited metal hardness at elevated temperatures and eventually, its wear resistance under real conditions. Given below

are the results of studying the hot hardness of deposited alloys with different degree and system of alloying.

The following surfacing alloys of the type of high-chromium cast irons with different degree of alloying were selected for studying the high temperature hardness: 300Kh25S3N2G2, 450Kh30M, 500Kh22B7, 500Kh22B7M7V2F. These alloys are widely used for strengthening parts, operating under the conditions of abrasive and gas-abrasive kinds of wear at normal and elevated temperatures.

Also of interest is investigation of high-temperature hardness of nickel-chromium-carbide alloy 500Kh40N40S2GRTs, which was traditionally accepted for strengthening parts, operating under the conditions of gas-abrasive wear at elevated temperatures.

Investigation of hot hardness of the above alloys was conducted together with G.S. Pisarenko Institute for Problems of Strength of the NAS of Ukraine in UVT-2 unit [4], which is designed for determination of hardness of materials in the temperature range of 300–3300 K in vacuum or shielding gas atmosphere [4, 5].

A combination of inert atmosphere and vacuum allows measuring hardness of materials of different classes: pure metals, alloys and composite materials.

Hardness measurement instrument is the main part of UVT-2 unit. The instrument is a detachable steel vacuum chamber with cooled walls. The following main assemblies are mounted in the instrument chamber: heating system, indenter system, sample loading device, etc.

The method of static pressing of the indenter in the form of a regular tetragonal pyramid with the angle of  $136^\circ$  between the opposite faces [5, 6] is used for determination of material hardness in a broad temperature range.

By the method of static indentation of pyramidal indenter, the hardness value is determined as average pressure on the imprint area. Allowing for buckling, it acquires the meaning of average contact pressure:

$$HV = \frac{P}{F} = \frac{2P \sin \gamma}{b^2} = 1.8544 \frac{P}{b^2}, \text{ MPa,}$$

where  $P$  is the load on the sample, transmitted through the pyramidal indenter;  $F$  is the surface area of pyramidal imprint,  $\text{mm}^2$ ;  $2\gamma$  is the angle between the opposite faces of the pyramid;  $b$  is the arithmetical mean of the lengths of two imprint diagonals,  $\text{mm}$ .

At pyramid indentation, geometrically similar imprints are produced. Therefore, at hardness measurement by this method, the condition of mechanical similarity is observed, and test results are independent on load magnitude  $P$ .

The load on the sample, transmitted through the pyramid, was assumed to be equal to 9.81 N. Testing was conducted in vacuum at not higher pressure than 0.7 MPa.

Hardness values of the alloys were obtained in the temperature range of 290–1200 K with 50–100 K range for the rate of sample material deformation under the indenter of  $10^{-3} \text{ s}^{-1}$ , which was determined by the procedure of [4]. The heating rate was equal to 20–40 K/min.

Before making the imprint, the sample and the indenter were placed at the distance of 1–2 mm one from the other and were heated up to the same temperature by radiation from strip tungsten heater.

The time of sample soaking at the specified temperature before making the first imprint was not less than:

- 10 min in the temperature range from 293 to 670 K;
- 6 min in the temperature range from 670 up to 1070 K.

The duration of soaking under load was 60 s. Limit testing temperature depends on tip material.

Used as the indenter tip for hardness measurement was a single-crystal of synthetic corundum  $\text{Al}_2\text{O}_3$  (leukosapphire), which performs well up to the temperature of 2033 K. Indenters from boron carbide  $\text{B}_4\text{C}$  and alloys on its base are used for hardness testing of refractory carbides up to 2273 K.

The shape and dimensions of the sample were changed, in connection with the difficulty of machining the studied materials and geometrical features of the object of study. Samples for studying the deposited metal hardness, depending on temperature, were deposited in two layers. Surfacing of plates from St3 steel GOST 380–88 was performed in the modes optimum for each type of electrode material. All the types of surfacing materials were made in the form of flux-cored strips of 6.5×4.0 mm section. Mechanical mixture of ferroalloys and chemical compounds of various elements was used as the core of flux-cored strips. Sample surfacing was performed with open arc.

After surfacing samples were cut out of the obtained blanks by mechanical method, and were ground to the required size. The surface of the sample, on which hardness measurements were conducted, was further polished.

Hardness measurements were conducted on three samples, then arithmetical mean was determined for each temperature.

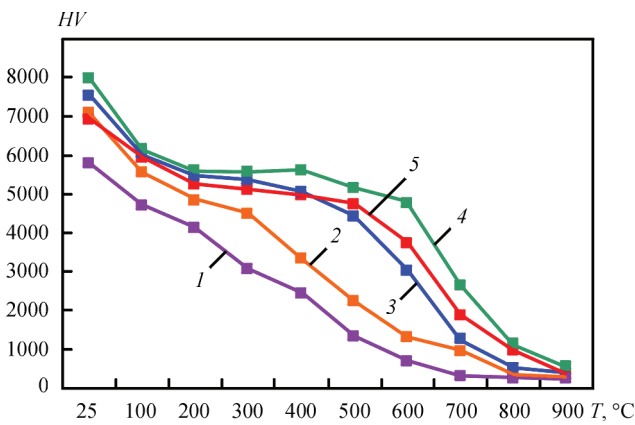
Statistical processing of generalized experimental samples for hardness was performed. Here, average sample value  $HV_{av}(x)$ , sample standard deviation  $S$ , variation coefficient  $w$  and confidence intervals  $\Delta HV(\bar{x})$  for mathematical expectation for significance level  $\alpha = 0.05$  were calculated for each temperature [7].

Results, obtained when studying hot hardness of alloys of the type of high-chromium cast irons and nickel-chromium-carbide alloy are shown in Table 1. Hot hardness values are represented by just average values by the results of testing several samples. Figure 1 shows generalized data for all the studied alloys.

As is seen from the given results of investigations, the smallest drop of hardness with temperature rise is observed in 500Kh22B7, 500Kh22B7M7V2F and

**Table 1.** Average hardness values ( $HV_{av}$ , MPa), depending on temperature

$T, ^\circ\text{C}$	Deposited metal type				
	300Kh25S3N2G2	450Kh2230M	500Kh22B7	500Kh22B7M7V2F	500Kh40N40S2GRTs
25	5793	7120	7561	7986	6960
100	4704	5546	5983	6145	5953
200	4143	4865	5473	5567	5250
300	3067	4506	5345	5545	5096
400	2450	3327	5054	5605	4956
500	1349	2231	4436	5134	4748
600	709	1321	3056	4789	3756
700	317	978	1243	2643	1878
800	256	346	521	1137	975
900	229	287	387	527	345



**Figure 1.** Hardness of alloys of the type of high-chromium cast irons (1 — 300Kh25S3N2G2; 2 — 450Kh30M; 3 — 500Kh22B7; 4 — 500Kh22B7M7V2F; 5 — 500Kh40N40S2GRTs)

500Kh40N40S2GRTs alloys. The most abrupt hardness drop is observed in 300Kh25S3N2G2 alloy. 450Kh30M alloy takes an intermediate position.

Analysis of the obtained results revealed that hardness of the deposited metal at elevated temperatures largely depends on the type of carbides, formed as a result of weld pool solidification. It was found that in alloys of high-chromium cast irons of 300Kh25S3N2G2 type deposited metal hardness drops abruptly with temperature rise. Microstructure of such an alloy is shown in Figure 2, *a*. At increase of chromium content to 30 % and of carbon to 5 % stabilization of hardness up to temperatures of 350–400 °C is observed. This is attributable to presence of higher chromium carbides of  $Cr_3C_2$  type in such alloys. Characteristic microstructure of this type of alloys is shown in Figure 2, *b*. As is known [8, 9], such carbides have higher melting temperature, are less prone to oxidation, and preserve their mechanical properties at higher temperatures.

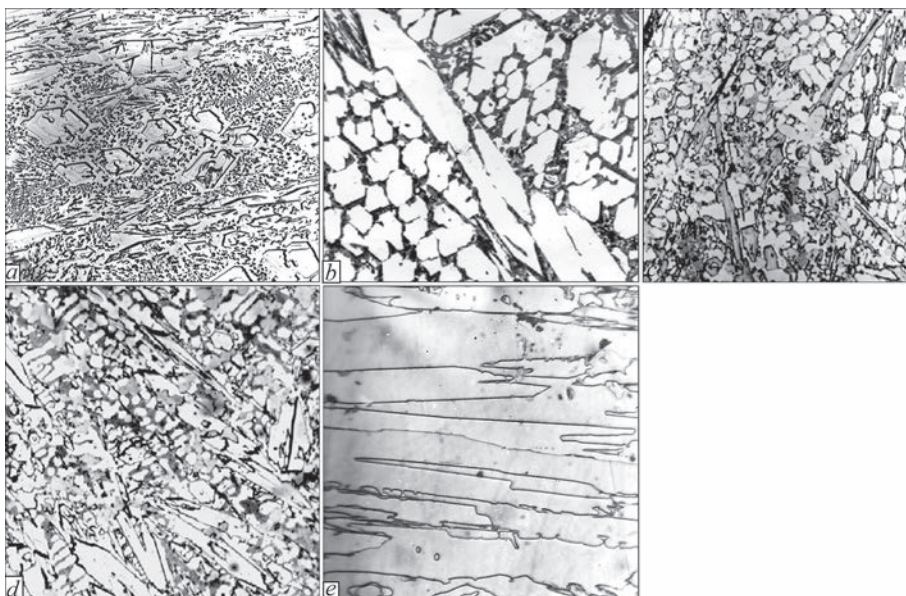
An even greater increase of hot hardness is achieved at complex doping of the alloys by chromium, niobium, molybdenum, tungsten and vanadium, the microstructure of which is shown in Figure 2, *c*. Such alloys preserve their hardness up to temperatures of about 650 °C. Alloys doped by just chromium and niobium, take up an intermediate position (Figure 2, *d*). Nickel-chromium-carbide alloy also demonstrated a high hot hardness (Figure 2, *e*).

A combination of high concentration of higher chromium carbides with a nickel-based matrix also allows maintaining stable hardness up to 650 °C.

Effect of niobium is of special interest in alloys of 500Kh22B7 and 500Kh22B7M7V2F type. Structure of such alloys, deposited on low-carbon steel, consists of austenite with chromium and niobium carbide phases (Figure 2, *c, d*).

In this case niobium plays the role of a sort of modifier, as alloying of high-chromium cast iron by niobium delays the growth of primary chromium carbides  $(Cr,Fe)_7C_3$ , the coarse needles of which are fragmented at wear, and can readily become exposed and crumble out. The authors of [10] give the results of investigation of wear of alloys of the type of high-chromium cast irons without niobium, with niobium and those additionally alloyed by Nb, Mo, W.

X-Ray structural analysis of these materials showed the presence of carbides of  $Me_7C_3$  type and solid carbides  $(Nb, Mo, W, V)C$  and  $(Mo, W)_2C$ . Performed heat treatment of these alloys ( $T = 923$  K, 1 h, cooling in air) and subsequent testing showed that wear resistance of alloys of the type of high-chromium cast irons, doped by Nb, Mo, W and V, became higher, that is accounted for by secondary strengthening, associated with additional carbide precipitation.



**Figure 2.** Microstructure ( $\times 350$ ) of alloys of the following types: 300Kh25S3N2G2 (*a*); 450Kh30M (*b*); 500Kh22B7M7B2F (*c*); 500Kh22B7 (*d*); 500Kh40N40S2GRTs (*e*)

Investigations of the microstructure and composition of the carbide phase of 500Kh22B7M7V2F and 500Kh22V7 alloys show that the main amount of carbides are represented by mixed  $Me_7C_3$  carbide, rich in chromium. Its volume fraction in the given alloys is practically the same and equal to 40–43 %. The fraction of harder cubic niobium carbide of NbC type is equal to about 8 and 10 % for these alloys, respectively.

Molybdenum and tungsten do not form their own carbides. These elements are almost completely dissolved in the matrix that leads to increase of alloy high-temperature strength, and accounts for their high wear resistance at elevated temperatures. Niobium, having a higher affinity to carbon, than chromium, molybdenum or tungsten, promotes formation of hard, fine, uniformly distributed niobium carbides of a globular shape in alloys of 500Kh22B7MV2F type, that are responsible for higher viscosity and good resistance to impact loads in operation [11].

Thus, niobium is added to surfacing materials to increase the impact toughness of chromium cast irons, and metal wear resistance under the conditions of abrasive wear with shocks and improvement of hot hardness.

Conducted studies of hardness of surfacing high-chromium alloys at elevated temperatures allow optimizing selection of electrode materials for strengthening by surfacing a wide range of parts, operating in extreme conditions of wear at different temperatures.

Investigations of the relationship between hot hardness and wear resistance under the conditions of gas abrasive wear at elevated temperatures are of interest.

Samples of deposited metal of the following types: 300Kh22S3N2G2 (PLAN 101), 450Kh22B7M7V2F (PLAN 179), 450Kh30M (PLAN 180), 500Kh22B7 (PLAN 185), 500Kh40N40S2GRTs (PLAN 111) were made using appropriate flux-cored strips for comparative testing for wear resistance.

Surfacing was performed in A-874N unit, fitted with VDU-1201 power source and AD-167 attachment. The process was conducted in two layers at reverse polarity direct current, at unchanged value of extension equal to 50 mm, and flat external characteristic of the power

source. Used as the base metal were plates from St3 steel 30 mm thick of 300×400 mm size. Anode-mechanical cutting was used to cut out samples of the required size from middle sections of the beads. Modes of surfacing with all the given strips were as follows:

Current, A	750–850
Voltage, V	28–34
Electrode movement speed, m/h	33.1
Electrode extension, mm	50–60

Investigations of wear resistance were conducted in an upgraded stand OB-876Ts [12]. The stand provides a scheme of testing by the type of abrasive flow impact, which is as close as possible to the real conditions of strengthened parts operation.

In the stand abrasive particles are accelerated by a centrifugal accelerator in the form of a disc-rotor, in the center of which abrasive is gravity fed into the feed opening (in our case, it is quartz sand).

Sand particles are accelerated through four inner channels. Having reached the rotor outer diameter, the abrasive flow covers the air gap 25 mm long and produces simultaneous wear of working surfaces of six samples of 170×70×19 mm size, due to impact of abrasive particles. Cassette with the samples is located in the chamber, the temperature of which is adjustable in the range from 25 up to 450 °C.

#### Technical characteristics of OB-876Ts stand

Rotor diameter, mm	220
Number of rotor revolutions, rpms	6000
Angle of attack of abrasive flow, deg	5–70
Sample heating temperature, °C	up to 450
Duration of sample heating up to 400 °C, h	3.5
Abrasive consumption, cm <sup>3</sup> /s	0.5–0.3
Power of rotor drive electric motor, kW	0.75
Quantity of tested samples, pcs	6

Testing was conducted at temperatures of 25 and 450 °C. Quartz sand was used as abrasive.

Assessment of wear resistance was performed by the mass method. Difference in mass before and after testing was determined for each sample. In order to obtain more valid results, three samples of each type of metal were

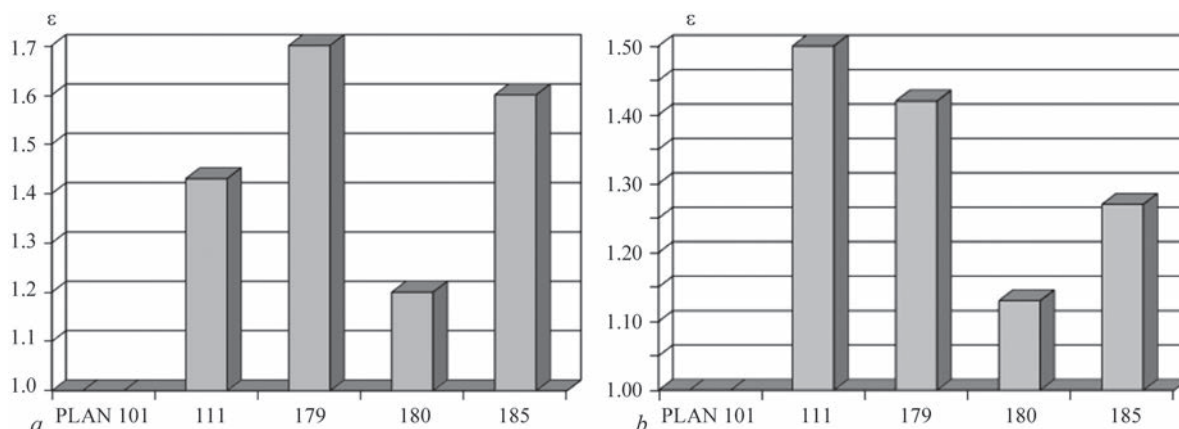


Figure 3. Relative wear resistance of the studied samples at room temperature (a) and at temperatures of 450–500 °C (b)

**Table 2.** Relative wear resistance at room temperature

Deposited metal type	Relative wear resistance $\epsilon$
300Kh22S3N2G2	1
500KhX40N40S2GRTs	1.43
500Kh22B7M7V2F	1.7
450Kh30M	1.2
450Kh22B7	1.6
250Kh10B8S2T	1.35

tested, which was followed by determination of average values. Assessment was based on relative wear resistance  $\epsilon$ , which was calculated by the following formula:

$$\epsilon = \frac{\Delta m_e}{\Delta m_n}$$

where  $\Delta m_e$  is the standard mass loss;  $\Delta m_n$  is the loss of tested sample weight.

300Kh22S3N2G2 alloy (sormite-1) was used as standard.

Results of studying the samples are shown in Tables 2, 3, as well as in Figure 3.

Thus, comparing the data, obtained under different temperature conditions, it was determined that wear resistance of the alloys drops with temperature rise, that correlates with the hot hardness data. It should be also noted that steel-based alloys, have a higher tendency to lowering of their wear resistance properties at temperature rise, than does nickel-chromium-carbide alloy. The most probable explanation for it, in our opinion, is the fact that testing was conducted under standard atmospheric conditions. Here, degradation of performance occurs not only due to hardness lowering, but also due to oxidation processes, which run on the deposited layer surface.

**Conclusions**

1. For alloys of 300Kh25S3N2G2 type with relatively low alloying by carbide-forming elements, deposited metal hardness drops abruptly with temperature rise. Increase of chromium content to 30 % and of carbon to 5 % allows stabilizing rather high hardness up to temperatures of 350–400 °C, as a result of formation of higher chromium carbides of Cr<sub>3</sub>C<sub>2</sub>.

2. Nickel-chromium carbide alloy 500Kh40N40S-2GRTs preserves a high hardness right up to the temperature of 650 °C, due to a combination of a high concentration of higher chromium carbides with nickel-based matrix.

3. At complex doping of alloys by chromium, niobium, molybdenum, tungsten and vanadium, alloys of 500Kh22B7M7V2F type preserve a high hardness up to the temperature of 650 °C.

**Table 3.** Relative wear resistance at temperatures of 450–500 °C

Deposited metal type	Relative wear resistance
300Kh22S3N2G2	37,735
500Kh40N40S2GRTs	1.5
500Kh22B7M7V2F	1.42
450Kh30M	1.13
450Kh22B7	1.27
250Kh10B8S2T	1.1

4. For 500Kh22B7 and 500Kh22B7M7V2F alloys, an important role is played by niobium, which is a sort of modifier, delaying the growth of primary chromium carbide (CrFe)<sub>7</sub>C<sub>3</sub> and forming hard cubic niobium carbide of NbC type.

5. Wear resistance of deposited alloys drops with temperature rise, in keeping with the drop of deposited metal hardness.

6. Drop of wear resistance of iron-based alloys with temperature rise runs somewhat more intensively, than that of nickel-chromium-carbide alloy that is obviously associated with oxidizing processes on the strengthened layer surface.

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