Aleksander P. Woronczuk, Aleksander P. Żudra

The Effect of Temperature on the Hardness of High-Alloy Carbide-Chromium Alloys Surfaced with Flux-Cored Strips

Abstract: The development of surfacing materials deposited on elements exposed to extreme wear at high temperature is based on investigating the correlation between the hot hardness of the weld deposit and its alloy system. The article discusses the methodology and results concerning the hot hardness of deposited high-chromium cast irons characterised by various doping degrees, e.g. 450H30M, 500H22B7, 500H22B7M7W2F and 300H25S3N2G2 as well as nickel-carbide-chromium alloy 500H40N40S2GRC. Related tests revealed that the hot hardness of the weld deposit depends primarily on the presence and types of carbides formed in the weld pool. The hardness of relatively low-alloy high-chromium cast irons decreases along with an increase in temperature and increases along with an chromium content of up to 30% and a carbon content of up to 5%. Chromium, niobium, molybdenum, tungsten and vanadium-surface alloyed alloys retain their hardness up to a temperature of 650 °C. In terms of the above-named alloys, an important role is played by niobium, acting as a modifying agent and moderating the growth of primary chromium carbides and forming hard cubic niobium carbide. Because of the high content of higher chromium carbides in the nickel-based matrix, the nickel-carbide-chromium alloy is characterised by high hardness at a temperature of up to 650 °C.

Keywords: hot hardness, flux-cored strips, surfacing, high-chromium cast iron, stop nickel-carbide-chromium alloy

DOI: 10.17729/ebis.2019.4/4

Introduction

High-chromium cast iron type alloys play the leading role [1] among various surfacing materials used for increasing the operating properties and extending the service life of elements used in metallurgical, power generation, mining and other types of machinery exposed to abrasive and gas-abrasive wear at a temperature of up to 700°C. Because of a high filling coefficient and a vast possibility of providing the weld deposit with alloying components, these materials are surfaced using flux-cored strips [2, 3].

The development of electrode materials for surfacing alloys exposed to extreme conditions is based on investigating the correlation between the hot hardness of a given metallic material

Aleksander P. Woronczuk (MSc Eng.); Aleksander P. Żudra (PhD (DSc) Eng.) – E. O. Paton Electric Welding Institute, the National Academy of Sciences of Ukraine, Kiev

and its alloy system. The appropriate selection of alloying components can significantly affect the hardness of surfaced metal at high temperature and, consequently, influence the wear resistance of such a metallic material in actual conditions. Presented below are results of tests concerning the hot hardness of surfaced alloys characterised by various alloy systems.

Tests and results

Tests concerning hardness at high temperature involved the use of high-chromium cast iron surfacing alloys containing various amounts of alloying components. Such alloys are widely applied for the hardening of elements exposed to abrasive wear and gas-abrasive wear at ambient and high temperature, i.e. 300H25S3N2G2 (300Х25С3Н2Г2), 450H30M (450Х30М), 500H22B7 (500Х22Б7) and 500H22B7M7W2F (500Х22Б7М7В2Ф).

Equally interesting are tests concerned with the hot hardness of nickel-carbide-chromium alloy 500H40N40S2GRC (500Х40Н40С2ГРЦ), commonly used to harden machinery elements exposed to gas-abrasive wear at high temperature.

The tests concerning the hot hardness of the above-named alloys were performed in conjunction with the G.S. Institute for Problems of Strength of the National Academy of Sciences of Ukraine using a UVT-2 [4] machine. The UVT-2 machine is used for determining the hardness of materials within the temperature range of 300 K to 3300 K, in a vacuum or under gas-shielded conditions [4, 5]. The combination of inert atmosphere and vacuum makes it possible to measure the hardness of materials of various grades: pure metals, alloys and composites. The principal part of the machine includes a device for measuring hardness in a divided vacuum chamber (made of steel) provided with cooled walls (Fig. 1). The primary elements of the heating system, indenter system, the device for charging specimens etc. are fixed in the device chamber.

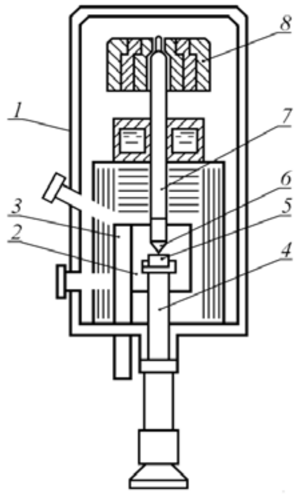

Fig. 1. Schematic diagram of the UVT-2 device for hardness measurements: 1 – body, 2 – chamber, 3 – heating element, 4 – table, 5 – specimen, 6 – indenter, 7 – piston rod, 8 – weight

The hardness of materials within a wide temperature range is determined using a method where an indenter (a regular pyramid having an angle of 136 degrees between two opposite sides) is pushed statically into a specimen [5, 6]. The value of hardness measured using the above-named method is referred to as mean pressure on the surface of indentation. After including the bulge, it acquires the significance of the mean contact pressure.

$$HV = \frac{P}{F} = \frac{2P\sin\gamma}{b^2} = 1{,}8544\frac{P}{b^2}, \text{ МПа},$$

where

P – load affecting the specimen transmitted by the pyramid-like indenter;

F – area of pyramid indentation, mm²;

2γ- angle between opposite sides of the pyramid;

b – arithmetic mean of the lengths of two indentation diagonals, mm.

Indentations made by the pyramid are geometrically similar. For this reason, during a measurement performed using the aforesaid method, the condition of mechanical similarity is satisfied and test results do not depend on the value of load P. The specimen was subjected to a load of 9.81 N. The above-named load was transmitted by a pyramid. The tests were performed in a vacuum, using pressure not exceeding 0.7 MPa. The hardness values of alloys were determined within the temperature range of 290 K to 1200 K, with a range of 50 to 100 degrees for the specimen material deformation rate under a load of $10^{-3}\ s^{-1}$, using method [4]. The heating rate was restricted within the range of 20 to 40 degrees/min. Before making an indentation, the specimen and the indenter were located 1 ÷ 2 mm away from each other and heated up to the same temperature through radiation emitted by a tungsten radiator. The hold time at a given temperature before making the first indentation was not shorter than:

- 10 minutes within the temperature range of 293 K to 670 K;
- 6 minutes within the temperature range of 670 to 1070 K.

The hold time under the load amounted to 60 seconds.

The test temperature limit depends on the indenter tip material. The indenter tip was made of the monocrystal of synthetic corundum Al_2O_3 (leucosapphire), working well up to a temperature of 2033 K. The hardness of refractory carbides, up to a temperature of 2273 K, is tested using indenters made of boron carbide B4C and boron carbide-based alloys.

Because the of difficult mechanical treatment of the test materials and the geometric features of the test objects, the specimens used in the tests were as presented in Figure 2, where:

- non-parallelism of planes A and B did not exceed 0.01 mm;
- surface roughness of plane A is not lower than 10 purity class;
- electrolytic polishing of surface A is acceptable.

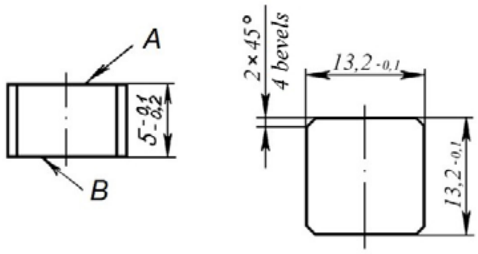

Fig. 2 Specimen used in the hardness tests

The specimens used in the tests of temperature-dependent hardness of surfaced metal were deposited in two layers on plates made of steel St3 in accordance with GOST 380-88 (equivalent of steel S235), using optimum parameters for a given type of electrode material. All three types of surfacing materials had the form f flux-cored strips (16.5 x 4.0 mm in cross-section). The core of the flux-cored strips was the mechanical mixture of ferroalloys and chemical compounds of various chemical elements. The process of surfacing was performed using self-shielded arc. After surfacing, specimens were sampled using mechanical cutting. Afterwards, the specimens were subjected to gridding (to obtain required dimensions). In addition, the surface of the specimen to be used in hardness measurements was subjected to polishing.

Hardness measurements involved the use of the three specimens. Afterwards, the arithmetic mean was determined for each temperature. Next, the statistical processing of averaged experimental results in relation to hardness was performed. Calculations performed in relation to each temperature included the average value of specimen HV_{cp}, ($\bar{x}$), the standard deviation of specimen S, variation coefficient w and confidence intervals Δ HV (Δ x) in relation to mathematical expectation for significance level α = 0.05 [7]. The results obtained in the tests concerning the hot hardness of high-chromium cast iron alloys and nickel-carbide-chromium are presented in Table and Figures 3÷7.

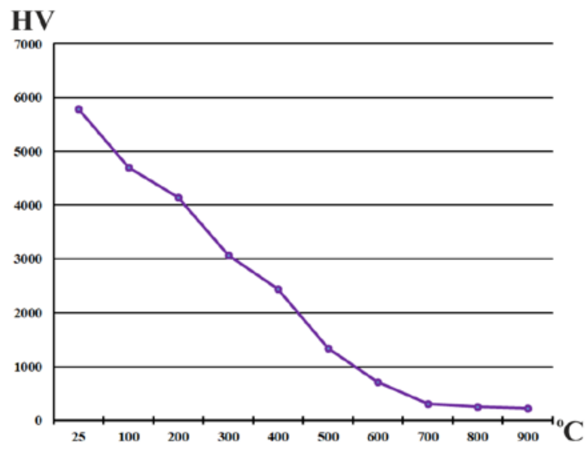

Fig. 3. Correlation between hardness and temperature for alloy 300H25S3N2G2

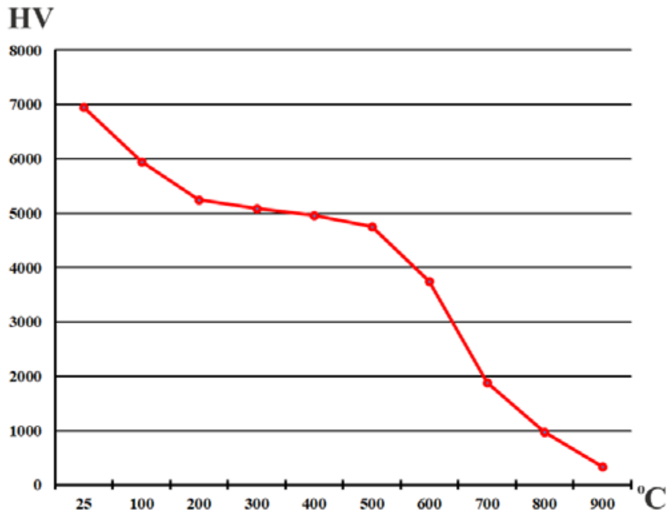

Fig. 4. Correlation between hardness and temperature for alloy 500H40N40S2GRC

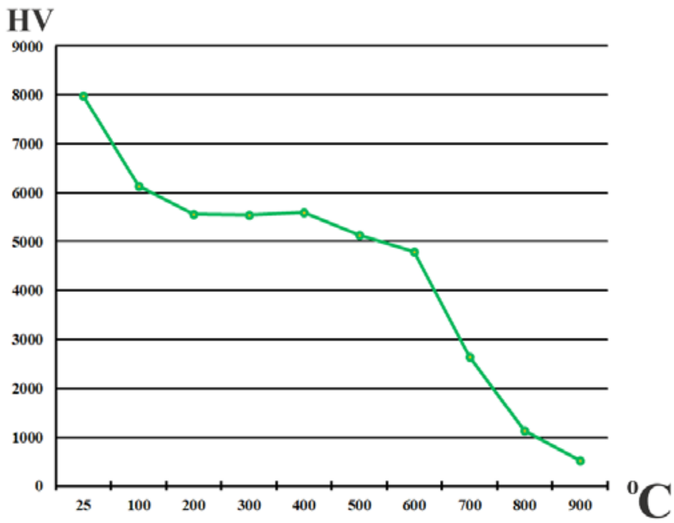

Fig. 7. Correlation between hardness and temperature for alloy 500H22B7M7V2F

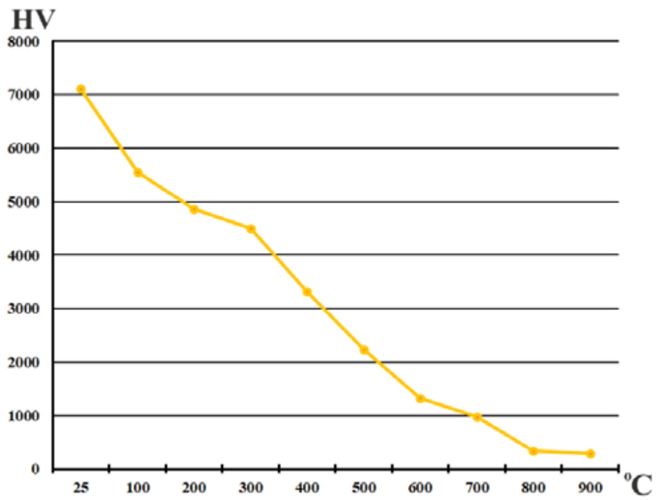

Fig. 5. Correlation between hardness and temperature for alloy 450H30M

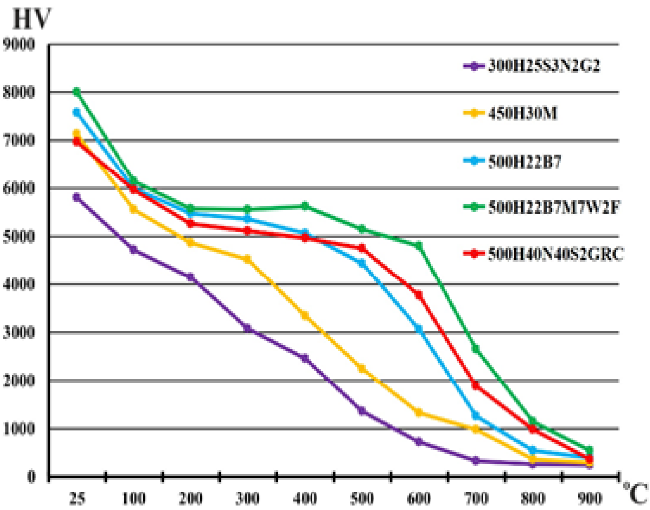

Fig. 8. Hardness of chromium cast iron alloys

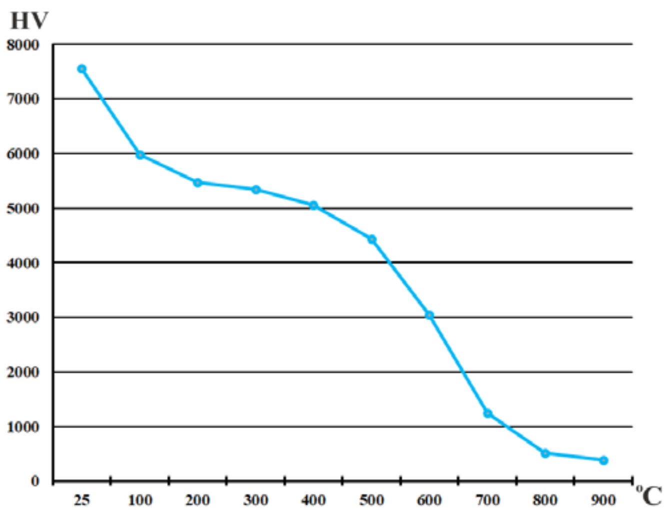

Fig. 6. Correlation between hardness and temperature for alloy 500H22B7

Hot hardness indicators are presented only as average values of tests of several specimens. Figure 8 presents generalised data related to all tested alloys.

As can be seen in the test results, the largest decrease in hardness along with an increase in temperature was observed in alloys 500H22B7M7W2F, 500H22W7 and 500H40N40S2GRC. The greatest decrease in hardness was observed in alloy 300H25S3N2G2. Alloy 450H30M was characterised by intermediate hardness.

The analysis of the test results revealed that the hardness of the weld deposit at high temperature depended primarily on types of carbides formed during the solidification of the weld pool. It was ascertained that in 300H25S3N2G2 type high-chromium cast iron alloys, the hardness of the weld deposit decreased considerably along with an increase in temperature. The microstructure of the above-named alloy is presented in Figure 9.

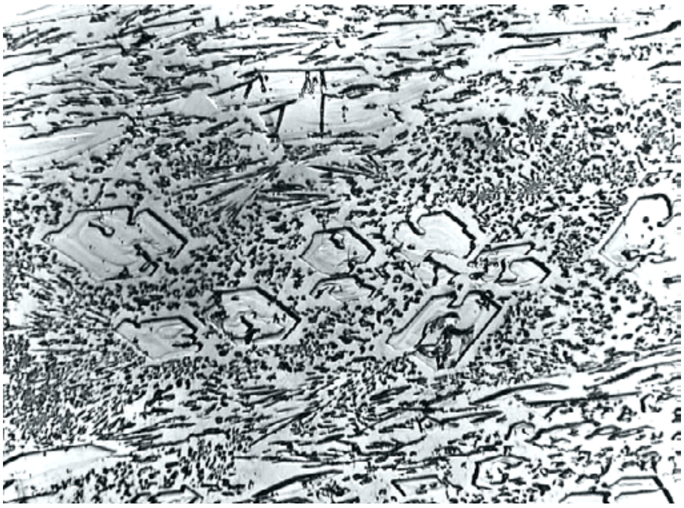

Fig. 9. Microstructure of alloy 300H25S3N2G2 (mag. 350x)

An increase in chromium content to 30% and carbon content to 5% was accompanied by the stabilisation of hardness to temperature restricted within the range of 350°C to 400°C. The foregoing could be ascribed to the presence of higher chromium carbides Cr_3C_2 in these alloys. The characteristic microstructure of the above-named alloys is presented in Figure 10.

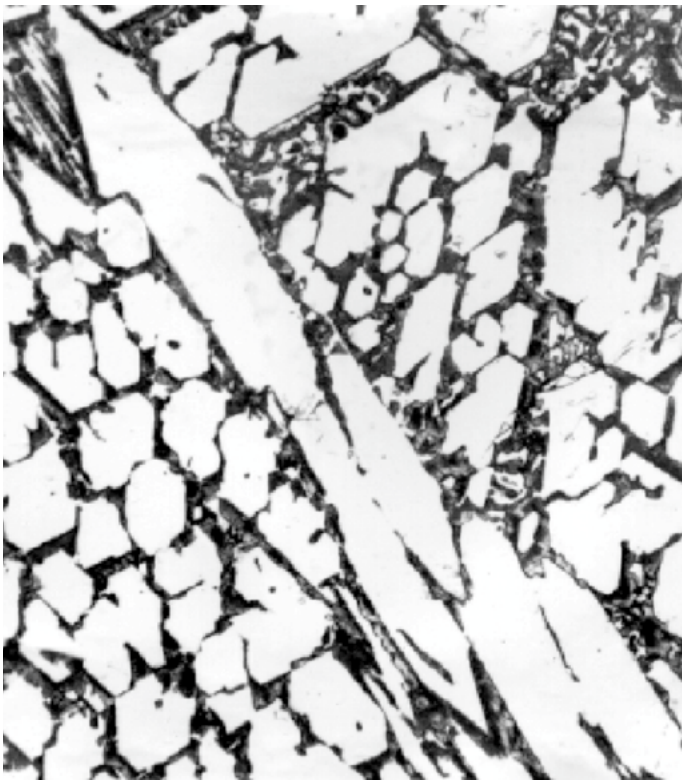

Fig. 10. Microstructure of alloy 450H30M (mag. 500x)

It is known that such carbides are characterised by a higher melting point and lower susceptibility to oxidation as well as by retaining their mechanical properties at high temperature [8, 9].

Table 1. Mean hardness in relation to temperature.

Type of weld deposit	300H25S3N2G2	450H30M	500H22B7	500H22B7M7W2FC	500H40N40S2GRC
T, °C	$HV_{av.}$, MPa				
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

An even higher increase in hardness was obtained in alloys subjected to complex surface alloying with chromium, niobium, molybdenum, tungsten and vanadium, the microstructure of which is presented in Figure 11.

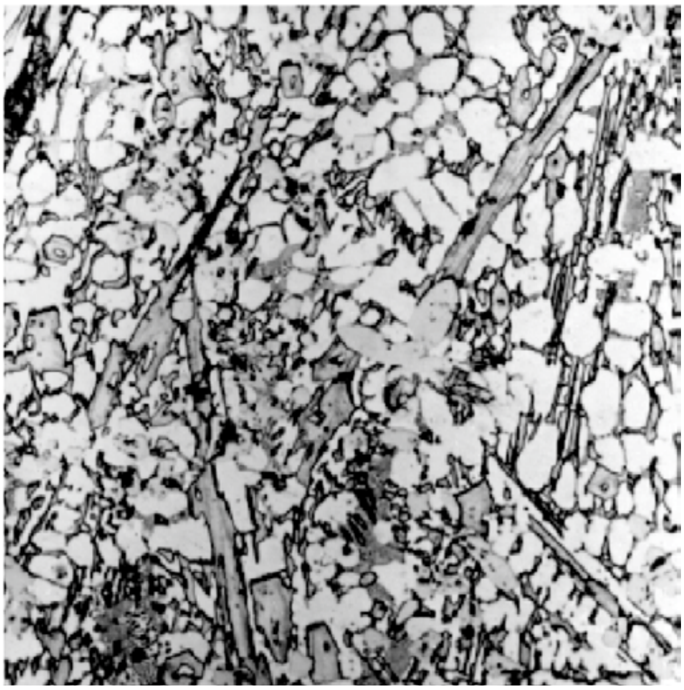

Fig. 11. Microstructure of alloy 500H22B7M7V2F (mag. 350x)

Such alloys retained hardness up to a temperature of approximately 650 °C. The alloys only containing chromium and niobium were characterised by intermediate hardness (Fig. 12).

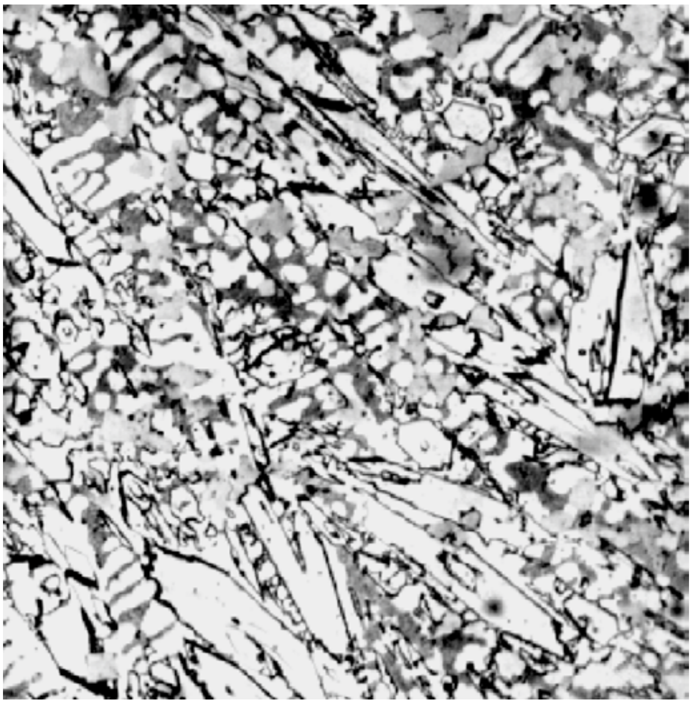

Fig. 12. Microstructure of alloy 500H22B7 (mag. 350x)

High hot hardness was also characteristic of the nickel-carbide-chromium alloy (Fig. 13).

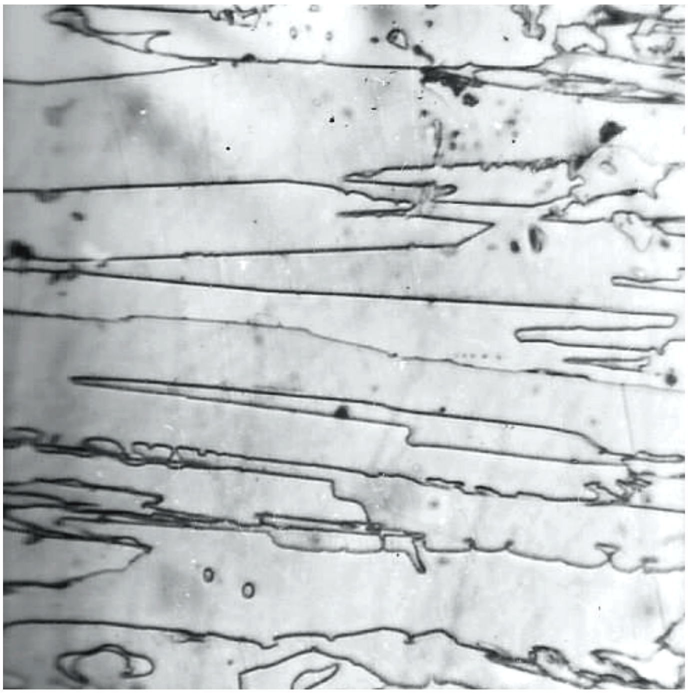

Fig. 13. Microstructure of alloy 500H40N40S2GRC (mag. 350x)

The combination of the high content of chromium carbides with the nickel-based matrix also enables the maintaining of stable hardness up to 650°C.

Particularly interesting is the effect of niobium in alloys 500H22B7 and 500H22B7M7W2F, the structure of which includes austenite with phases of chromium and niobium carbides (Fig. 11, 12).

In the above-named case, niobium plays the role of a modifier because the surface alloying of high-chromium cast iron with niobium slows down the growth of primary chromium carbides (Cr Fe)7C3, the large aciculae of which are crushed into fragments during wear and can be easily exposed and spalled. The authors [10] present test results concerning the wear of high-chromium cast iron type alloys without niobium, with niobium and additionally doped with Nb, Mo and W.

The X-ray analysis of the above-named materials revealed the presence of carbides Me7C3 and solid carbides (Nb, Mo, W, V) C and (Mo, W)2 C. The heat treatment of these alloys (T = 923 K, 1 hour, cooling in air) and subsequent tests revealed that the wear resistance of alloys such as high-chromium cast iron doped with Nb, Mo, W and V increased. The foregoing could be ascribed to re-hardening connected with the additional precipitation of carbides.

The tests of the microstructure and of the carbide phase composition in alloys 500H22B7M7V2F and 500H22B7 revealed that the primary amount of carbides was present in the mixed Me7C3 carbide (rich in chromium); its volume in the above-named alloys was nearly the same and restricted within the range of 40% to 43%. The content of the harder cubic carbide NbC in the aforesaid alloys amounted to approximately 8% and 10% respectively.

Molybdenum and tungsten do not form their own carbides. These elements are almost entirely dissolved in the matrix, which leads to an increase in the heat resistance of alloys and explains their high wear resistance at high temperature. Niobium, having higher affinity for carbon than chromium, molybdenum or tungsten, contributes to the formation of small, hard and uniformly arranged globular niobium carbides in alloys 500H22B7M7V2F, which explains higher viscosity and good resistance to impact loads during operation [11].

In this manner, surfacing materials are provided with niobium in order to increase hot hardness, the toughness of chromium cast irons and the abrasive wear and impact load resistance of metals.

The tests concerning the hardness of high-chromium alloys used for surfacing at high temperature have made it possible to optimise the selection of electrode materials for surfacing-based hardening of a wide range of elements exposed to extreme wear conditions at various temperatures.

Concluding remarks

1. The hardness of high-chromium cast irons at high temperature depends primarily on types of carbides formed during the crystallisation of the weld pool.
2. In cases of alloys 300H25S3N2G2, characterised by relatively low doping with carbide-forming elements, the hardness of the weld deposit decreases significantly along with an increase in temperature. An increase in chromium content to 30% and carbon content to 5% enables the stabilisation of sufficiently high hardness to a temperature restricted within the range of 350 °C to 400 °C (through the formation of higher chromium carbides, e.g. Cr_3C_2).
3. As a result of the combination of a high amount of higher chromium carbides with the nickel-based matrix, nickel-carbide-chromium alloy 500H40N40S2GRC retains high hardness up to a temperature of 650 °C.
4. During complex surface alloying with chromium, niobium, molybdenum, tungsten and vanadium, alloys 500H22W7M7V2F retain high hardness up to a temperature of 650 °C.
5. An important role in alloys 500H22B7 and 500H22B7M7V2F is played by niobium, acting as a modifier slowing down the growth of primary chromium carbides $(CrFe)_7C_3$ and forming hard cubic NbC type niobium carbide.

References

[1] Под ред. Акулова А.И.: Сварка в машиностроении: Справочник в 4 томах. Том 2. Изд. Машиностроение, Москва, 1978, p. 462.

[2] Woronczuk A.P., Żudra A.P.: Taśmy proszkowe, technologia napawania warstw odpornych na ścieranie i zakres ich stosowania. Biuletyn Instytutu Spawalnictwa, 2019, no. 3, pp. 43-47.

[3] Рябцев И.А., Сенченков И.К., Турык Э.В.: Наплавка, материалы, технологии, математическое моделирование. Wydawnictwo Politechniki Śląskiej, Gliwice, 2015, pp. 362-365, 398-406.

[4] Алексюк М.М., Борисенко В.А., Кращенко В.П.: Механические испытания при высоких температурах. Изд. Наукова думка, Киев, 1980, p. 208

[5] ДСТУ 2434-94. Розрахунки та випробування на міцність. Метод визначення високотемпературної твердості вдавлюванням пірамідального та біциліндричного індентора. Держстандарт України, 1994, p. 10

[6] Борисенко В.А.: Общие закономерности изменения механических свойств тугоплавких материалов в зависимости от тепературы. Сообщение 1. Проблемы прочности, 1975, no. 8, pp. 58-63.

[7] Румшинский Л.З.: Математическая обработка результатов эксперимента. Изд. Наука, Москва, 1971, p. 192

[8] Хансен М., Андерко К.: Структуры двойных сплавов. Т. 1, 2. Металлургиздат, Москва, 1962, p. 1488

[9] Иванько А.А.: Твердость. Изд. Наукова думка, Киев, 1968, p. 128

[10] Gallo C., Hubert M.: A-Résistance à l'usure par abrasion rechargements en fontes au chrome. Soudage et techniques connexes, 1980, no. 11/12, pp. 371-386

[11] Schramm H.: Chrom-Niob-legierte Hartlegierungen für das

Auftragsschweißen. Industrieanzeiger
Essen, Jahrgang 1975, pp. 1567-1569.