case of an isolated defect at $s = 66$ mm, $c = 40$ mm, $a = 14$ mm, $p \approx 0.05$ according to [2] that corresponds to $B = 470$ MPa. Considering such B value, p values were calculated by (2), which are given in Table 2 at different d and P.

CONCLUSIONS

1. Interaction of defects at force loading of welded structures largely depends on defect geometry and their position relative to the direction of force load application.

2. The most studied is the interaction of material discontinuity defects of the type of cracks and thinning, which are located in one loaded section of the item, so-called collinear defects. There are the respective schematics of combining such defects, depending on overall dimensions of defects and distance between them.

3. Unlike collinear defects, parallel defects of the type of cracks and groove thinning, located in different, but parallel sections of the item, usually unload each other. Therefore, they are less critical when they draw closer to each other, compared to similar collinear defects.

4. At present, owing to development of information technologies and computer engineering means, it is possible to assess the interaction of the found defects in welded structures based on the respective solutions of deformation mechanics for elasto-plastic continua with cracks or thinning defects.

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APPLICATION OF POWDERS OF COBALT AND NICKEL ALLOYS FOR PLASMA SURFACING OF EXHAUST VALVES OF INTERNAL COMBUSTION ENGINES

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Properties of alloys based on cobalt and nickel for plasma surfacing of exhaust valves of gasoline and diesel engines of cars and lorries as well as engines of diesel locomotives and ships are considered. Recommendations on application of powders of various compositions for valve surfacing are given.

Keywords: *plasma-powder surfacing, powders of cobalt alloys, powders of nickel alloys, valves of internal combustion engines*

Exhaust valves of internal combustion engines (ICE) suffer from high temperature cycling, power loads as well as corrosion in operation. Operating temperature of valve head of ICE of a car reaches 700 °C and that for a lorry makes 800 °C. Multiple heating and cooling, non-uniform distribution of temperature over a valve section and cyclic power loading result in damage of contact surface of a valve face. Surfacing of the face by alloys with high heat resistance, thermal stability, hot hardness and corrosion resistance is the most effective method for a burn-out and wear-out preventing.

Nickel and cobalt based alloys are used for surfacing of contact surfaces of the faces depending on operating conditions of ICE valves. Cobalt-chromium-tungsten alloys (stellites) Nos. 6 and 12 as well as stellite F and VZK (domestic analog of stellite No.6) (Table 1) are the most widely used for surfacing of the valves among the stellites.

All these alloys differ by high wear resistance, thermal stability and heat resistance at standard and elevated temperatures as well as high corrosion resistance in many aggressive media. Corrosion resistance of the stellites exceeds approximately 10 times resistance of steel used for ICE valves. It is usually evaluated on weight loss in molten plumbic oxide PbO at 910 °C in engine construction.

Characteristic of the stellites is the possibility to preserve sufficient hardness at high temperatures. As can be seen from Figure 1, hardness of alloy of stellite F has the most intensive decrease starting from 500 °C. Properties of solid solution and carbide eutectics as well as relationship of these main constituents determine hardness being an integral characteristic of the stellites. Significant decrease of hardness of F stellite alloy at 700 °C is related with softening of the solid solution enriched with nickel.

Table 1. Chemical composition (wt.%) and alloy hardness applied for surfacing of exhaust valves of ICE [1–4]

Alloy grade	C	Mn	Si	Cr	W	Ni	Fe	B	Co	Others	Hardness *HRC*
110K65Kh28V4 (stellite No.6)	1.1	0.5	1.1	28	4.5	≤ 3	≤ 3	–	Base	–	44
140K60Kh30V8 (stellite No.12)	1.4	≤ 1.0	≤ 2.0	30	8.0	≤ 3	≤ 3	–	Same	–	50
110KKh30VS (VZK)	1.1	–	2.0	30	4.5	≤ 3	≤ 3	–	»	–	42
180KKh25N20V12 (stellite F)	1.8	0.3	1.1	26	12.0	20	≤ 2	–	»	0.5Mo	43
90KKh30N6VSR (PN-AN34)	0.8	–	1.7	30	4.5	6	≤ 3	0.8	»	–	45
EP-616A	0.9	0.4	2.5	26	–	Base	≤ 3	1.5	–	0.2Ti 0.8Al 0.25Cu	40
150N40Kh25V6	1.5	–	0.6	26	6.0	Same	25	–	–	–	35
50NKh25S5R	0.5	–	5.0	25	–	»	8	0.9	–	–	46

F stellite alloy characterizing by reduced cobalt content and increased fraction of tungsten and, in particular, nickel is mostly used for surfacing of the valves of gasoline engines. The alloys of stellite No.6 and VZK are used for surfacing of the valves of diesel engines. Stellite No.12 with higher content of tungsten is rarely applied. However, high cost of cobalt and reduction of its production require it to be replaced by other materials.

Nickel-based alloys gain more and more spread as a substitute of cobalt alloys. Alloys of Ni–Cr–Si–B system as well as nimonic and inconel type alloys find an application in manufacture of the valves in the world practice. An important peculiarity of inconel is the fact that content of up to 20 % of iron provides a small change of its properties and the first deposited layer already has high corrosion resistance.

Two grades of nickel-based alloys, i.e. 150N40Kh25V6 and EP-616A (see Table 1) have been used in CIS countries till recently. Long-term experience of operation of the deposited valves confirms their good service characteristics. 150N40Kh25V6 alloy is mainly used for surfacing of the engine valves of heavy lorries, the sealing faces of which operate at 800 °C. The alloy is ductile and easy to machining. Structure of the alloy is austenite with carbide hardening. Chromium and tungsten carbides provide excellent mechanical wear resistance.

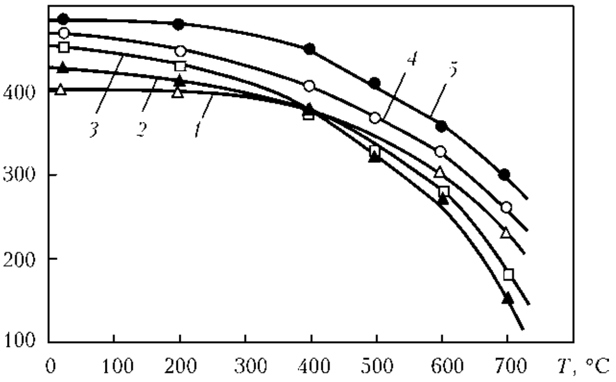

Figure 1. Hot hardness of alloys for surfacing of ICE valves: *1* — 150N40Kh25V6; *2* — EP-616A; *3* — stellite F; *4* — stellite No.6; *5* — 50NKh25S5R

Deposited metal of this type has high hot resistance, i.e. its hardness is approximately the same as in stellite No.6 (see Figure 1) at temperatures higher than 700 °C. Lower sensitivity to presence of iron, which significantly reduces properties of cobalt alloys, is sufficiently important advantage of 150N40Kh25V6 alloy in comparison with the stellites. This alloy does virtually not yield to cobalt-based alloys on the level of corrosion resistance in the melt of plumbic oxide.

Chromium-nickel alloy EP-616A refers to Ni–Cr–Si–B alloy system which is well known under the trade name «Colmonoy». These alloys have low melting temperature 960–1050 °C as well as the properties of self-fluxing brazing alloys. Boron and silicon promote excellent formation of the deposited layer. Tendency to formation of shrinkage porosities is a disadvantage of these alloys. Nickel and chromium borides are present in the structure of the deposited metal of this type together with complex eutectics.

Hardness of nickel alloys varies from *HRC* 20 up to 65. Chromium-nickel alloys with boron and silicon do not yield to the stellite on heat resistance at temperatures of 500–550 °C, however, their hot hardness characterizing by heat resistance to a certain degree is lower at higher temperatures than in the stellites (see Figure 1).

Alloys of Ni–Cr–Si–B system are close to the stellites on ductility and coefficient of linear expansion. As can be seen from Table 2, temperature of melting of nickel-based alloys 150N40Kh26V6 is lower than that of cobalt stellites and EP-616A alloy.

Automatic surfacing of the valves with 150N40Kh25V6 alloy was carried out using plasma arc over a stationary additive in a form of cermet ring.

Table 2. Physical-mechanical properties of alloys based on nickel and cobalt [1, 5, 6]

Alloy grade	Density, g/cm^3	Temperature of melting, °C	Coefficient of linear expansion, $K^{-1}\cdot10^{-6}$	Friction coefficient	Ultimate strength, MPa
110K65Kh28V4 (stellite No.6)	8.42	1290	14.9	0.07–0.13	740
140K60Kh30V8 (stellite No.12)	8.47	1285	14.4	0.07–0.13	530
110KKh30VS (VZK)	8.49	1280	15.5	0.08–0.11	620
180KKh25N20V12 (stellite F)	8.68	1300	13.8	0.07–0.13	660
EP-616A	8.51	1230	15.0	0.07–0.09	536
150N40Kh25V6	8.55	1100	15.1	0.07–0.10	550

The latter is manufactured by means of pressing of the fine-dispersed powders of nickel, chromium, tungsten, graphite and other materials and their further sintering in a vacuum. Industrial production of the cermet rings was stopped on series of organizational reasons in the resent years that made impossible the application of plasma surfacing over the stationary additive in bulk production of the automobile valves.

Plasma method using additive in a form of metal powder opens new possibilities for automatic surfacing of the valves. It is differ by high efficiency at low penetration of a base metal [1]. Efficiency of the plasma-powder surfacing is determined in many respects by quality of additive powder. The latter should have good flowability, low gas-saturation and specified grain-size distribution. The powders with 45–63 μm particle size (for valves of cars) or 80–200 μm particle size (for valves of diesels of locomotives and ships) are used depending on structure of a plasmatron as well as the deposited valves and saddles. They are obtained, as a rule, by spraying of liquid metal using inert gas.

Wider range of the additive materials can be used in plasma-powder surfacing, and this method meets the increased requirements made to valve control gears of ICE to a higher degree due to rising of specific power of the engines and increase of their ecological characteristics.

Cobalt- or nickel-based alloys with high service properties 110KKh30VS (VZK), 90KKh30N6VSR (AN34), 180KKh25N20V12 (stellite F), EP-616A, 50NKh25S5R are used for the plasma-powder surfacing depending on operation requirements, dimension-types of the valves and saddles. 50NKh25S5R is of interest since it exceeds EP-616A (see Table 1) on the level of initial and hot hardness and, besides, it is more sparsely alloyed. This alloy differs by high corrosion resistance, thermal fatigue resistance, and shows good behavior in metal-to-metal friction even at high pressures [1]. Investigations on Shevenar dilatometer in heating to 900 °C at 150–170 °C/h rate provide a representation of structural changes taking place in 50NKh25S5R alloy at working temperatures.

Alloy 50NKh25S5R has no structural transformations as can be seen form Figure 2. Insignificant inflections of the curves at 650 °C are, apparently, connected with a dissolution of carbide and chromium boride particles in the nickel-chromium solution. Alloy 50NKh25S5R is recommended for application in surfacing of the heavy-loaded valves of 5D70 diesel locomotive engines instead of cobalt alloy VZK based on evaluation of the service and welding-processing characteristics.

Quality of the deposited meal and economic indices of the process of plasma-powder surfacing mainly depend on the structural peculiarities of a groove of working face for surfacing. Two types of grooves are used in industrial practice for the plasma-powder surfacing of the valves, i.e. trapezoid and radius ones. Trapezoid groove (Figure 3, *b*) has the specific advantages since allows depositing layers of smaller thickness and, thus, reducing consumption of the additive powder, obtaining minimum machining allowance as well as stabilizing the heat input over the groove width and improv-

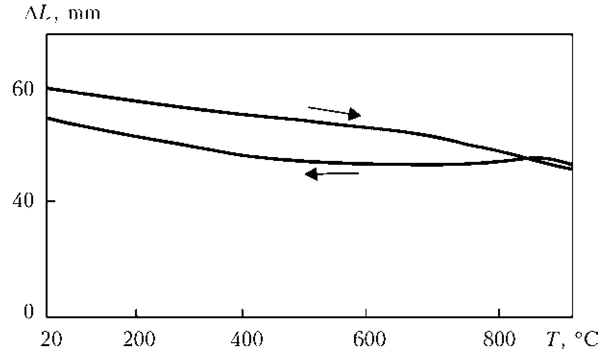

Figure 2. Dilatometric curve of heating–cooling of 50NKh25S5R alloy

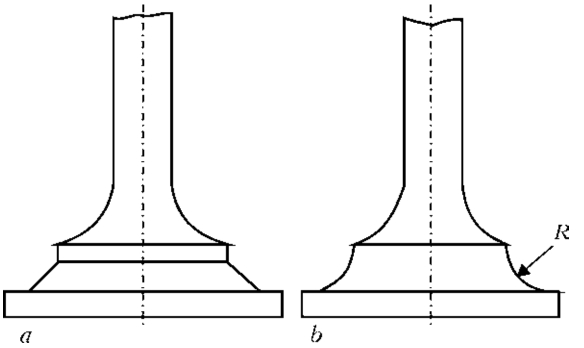

Figure 3. Schemes of trapezoid (*a*) and radius (*b*) groove of valve billets for surfacing

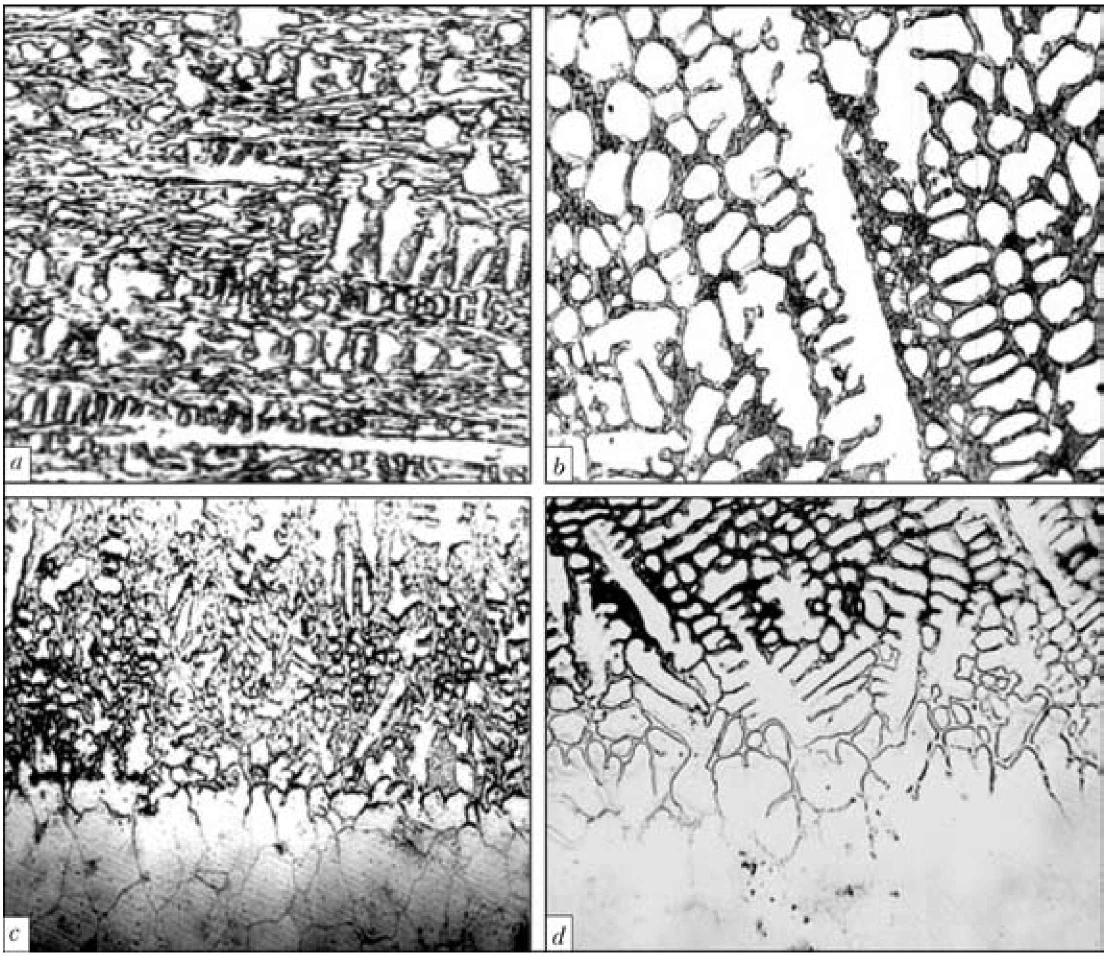

Figure 4. Microstructures (×480) of deposited metal of type of cobalt alloys K60Kh30VS (*a*) and K25Kh25N20V12 (*b*), and zones of their fusion with steel (*c*, *d*) for 55Kh20G9AN4 valves

ing formation of the deposited layer in comparison with radius one (Figure 3, *b*).

Technological experiments showed that optimum angel of bevel of trapezoid groove makes 90°. A valve is set on a water-cooled bearing and smoothness of a surface contacting with the bearing should be not lower than grade 5 roughness for better heat removal.

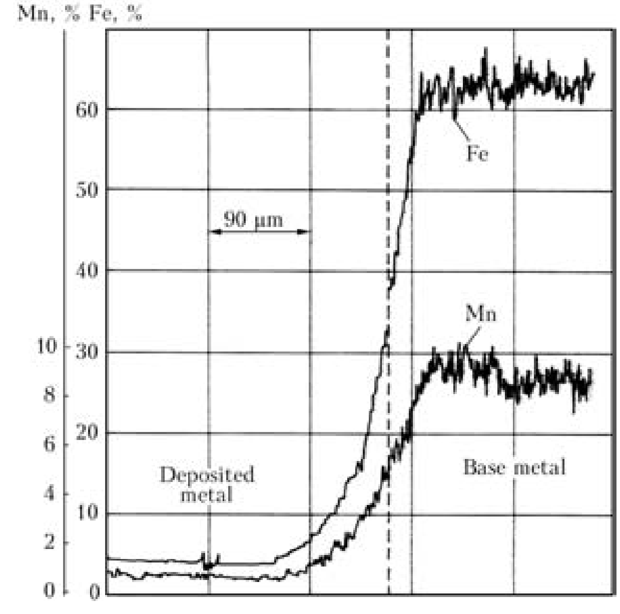

Figure 5. Distribution of iron and manganese in fusion zone of cobalt alloy K25Kh25N20V12 with steel for 55Kh20G9AN4 valves

Surfacing of the small passenger car valves are of particular difficulty. Rigid requirements are made to their quality, safety and service properties. This requires accurate selection of laws of variation of parameters and algorithm of technological process of surfacing in whole.

Selection of the mode parameters is based on a necessity of providing of maximum speed of surfacing at which formation of the deposited layer is not yet violated (15–22 m/h for car valves). Weight rate of a powder feeding should provide necessary dimensions of the deposited layer. Current of the main and pilot arcs was selected in such a way that safe and defect-free joining of the layer being deposited with billet material was provided and, at the same time, dilution of the deposited metal with the base one was minimum (5–7 %).

Values of current of the main and pilot arc, as well as efficiency of feeding of the additive wire, were changed on specific laws selected based on the methodological experiments for providing uniform and minimum penetration of the valve billet, since it is significantly and non-uniformly heated by the arc in the process of surfacing.

Only computer control of the main parameters of the process and high reliability of mechanical part of the equipment can provide required indices of quality

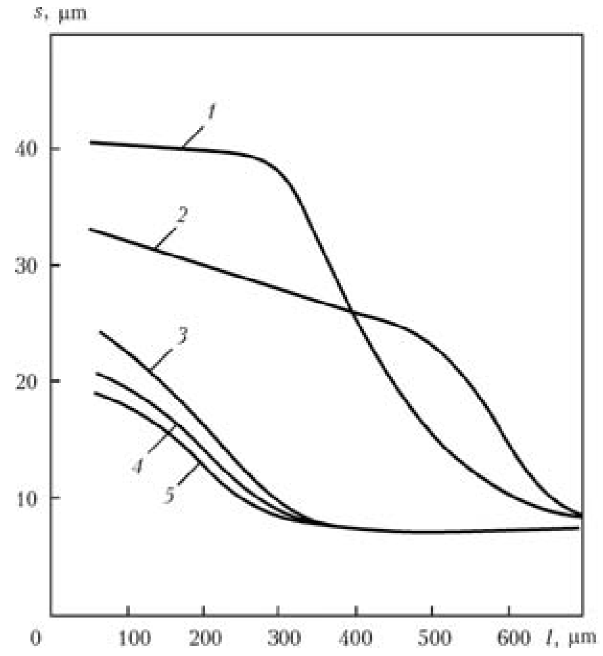

Figure 6. Dependence of grain sizes *s* on distance from fusion boundary *l* at induction (*1*, *2*) and plasma-powder (*3*–*5*) surfacing of valves with different alloys: *1*, *3* — K60Kh30VS; *2*, *4* — EP-616A; *5* — K25Kh25N20V12

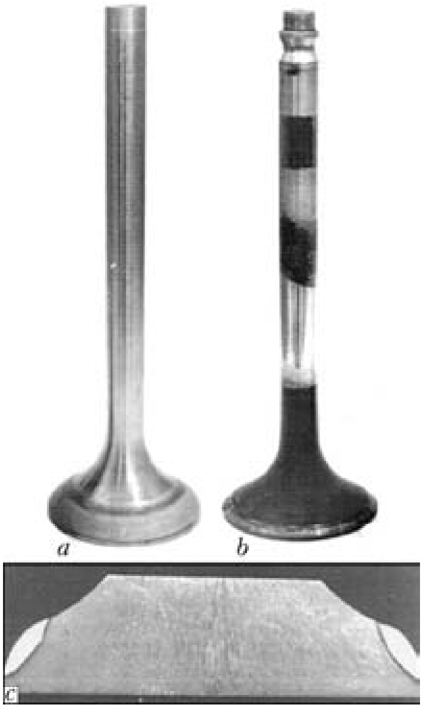

Figure 7. Surface appearance of 5D70 diesel engine valve, deposited using plasma-powder method with 50NKh25S5R alloy, immediately after surfacing (*a*) and after 5000 h of operation (*b*), and macrosection of deposited valve (*c*)

and efficiency of the plasma-powder surfacing of these parts considering that time of surfacing of car valve does not exceed 10 s.

Metallographic investigations showed that structure of the metal deposited on steel for valves 55Kh20G9AN4 using RP-K60Kh30VS and PR-KKh25N20V12 powders consists of a solid solution based on cobalt and eutectic constituent which is a mixture of carbides and solid solution, and there are no defects in their fusion zone (Figure 4, *a*–*d*). Transition zone between the base and deposited metals makes 100–150 μm in surfacing of the cobalt alloys and that for nickel alloy surfacing is 50–150 μm. Specified hardness of the deposited layer can be virtually achieved in a distance of 0.15–0.20 mm from the fusion zone line. Thus, if you have the deposited layer of 0.5–0.8 mm thickness the necessary serviceability of the valve after machining can be provided due to this that significantly saves consumption of the additive powder. Iron content in the deposited layer does not exceed 5 % (Figure 5).

Width of an overheating zone with coarse austenite grain makes only 0.2–0.3 mm in the plasma-powder surfacing. This is its profitable difference from induction surfacing at which the base metal suffers inevitably from strong overheating with large zone of the coarse austenite grain (Figure 6).

Plasma-powder surfacing is the most efficient, as a rule, in serial production of new valves and saddles of ICE. Surface appearance (Figure 7, *a*) and macrosection of the valve of diesel engine 5D70 deposited with 50NKh25S5R alloy (Figure 7, *c*) indicate good quality of formation of beads in the plasma-powder surfacing. This reduces laboriousness of machining due to allowance reduction. Figure 7, *b* shows the same valve after 5000 h of operation in the engine of diesel locomotive. Inspection showed that contact faces of the valve head have insignificant and uniform wearing and no signs of corrosion and other damages are observed.

Plasma-powder surfacing is sufficiently widely used in repair of the worn valves and saddles of large ship diesels (diameter of sealing surfaces 300–450 mm). Surfacing is performed in one pass with preheating and, sometimes, with concurrent heating. Delayed cooling of the deposited valves is provided after surfacing. Universal units for the plasma-powder surfacing can be used for manufacture and repair surfacing of the valves and saddles of various dimension-types in small-scale production and special units with computer control are to be used in a series production.

Plasma-powder method allows surfacing of all range of the valves. i.e. from valves of the engines of small capacity up to valves of the large ship diesels. This method is sufficiently flexible since allows easily transferring from one valve structure to another, using virtually any alloys independent on their melting temperature, capability to self-fluxing and other properties. Plasma-powder surfacing provides economical consumption of the additive materials (2–3 times lower than in induction surfacing), high quality of deposited metal, minimum heating of the valve and small allowances for machining.

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STRUCTURE AND WEAR RESISTANCE OF CHROME-MANGANESE DEPOSITED METAL

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Presented are the results of investigations into structure and wear resistance of low-carbon metal of different structural classes, deposited with flux-cored strips and containing approximately 13 % chromium and different amounts of manganese (from 2 to 12 %). The possibility of increasing wear resistance of the deposited metal by tempering and case hardening after hardfacing was studied. It is shown that achieving the optimal amount of meta-stable austenite, along with martensite, in structure of the deposited metal improves its wear resistance.

Keywords: *arc hardfacing, chrome-manganese deposited metal, structure, martensite, meta-stable austenite, tempering, case hardening, wear resistance*

To repair and strengthen parts operating under conditions of a mechanical wear combined with the corrosion effect at normal and increased temperatures, the industry widely applies hardfacing consumables that provide deposited metal of the type of low-carbon high-chromium steels (≤0.2 % C, ~13 % Cr) of the martensitic-ferritic grade. They are used to repair and strengthen plungers of hydraulic presses and hydraulic cylinders, continuous casting machine rollers, components of power and petrochemical fixtures, etc. [1].

Ferrite is characterised by the lowest fracture resistance, compared to martensite and austenite, which hampers achieving a high wear resistance of the deposited metal. To decrease the content of ferrite and provide mostly the martensitic structure, the deposited metal is alloyed with nickel in an amount of 2–4 %. Examples of such hardfacing consumables are PP-Np-12Kh13N2MFA and PP-Np-12Kh14N3. Along with nickel, formation of ferrite is also suppressed by alloying with less expensive manganese. Properties of the low-carbon deposited metal with approximately 13 % Cr and different contents of manganese have been insufficiently studied as yet. However, the data on structure and properties of this type of chrome-manganese steels can be found in studies [2–4].

Table 1. Chemical composition of deposited metal, %

Hardfacing consumable	C	Cr	Mn	Si	Ti
Sv-12Kh13	0.11	12.6	0.7	0.55	–
PL-OP1	0.12	12.5	2.3	0.73	0.14
PL-OP2	0.15	13.3	4.1	0.62	0.17
PL-OP3	0.13	13.1	6.2	0.71	0.15
PL-OP4	0.16	12.9	7.8	0.65	0.18
PL-OP5	0.17	12.6	12.2	0.66	0.16
Note. Content of S and $P \leq 0.03$ wt.%.					

The purpose of this study was to investigate structure of the low-carbon Cr–Mn deposited metal of different structural grades (martensitic, martensitic-austenitic, austenitic-martensitic, austenitic) and determine its wear resistance under different test conditions to define rational compositions of hardfacing consumables for different service conditions. The possibility of improving properties of the deposited metal due to tempering parameters and case hardening was also investigated.

One-lock flux-cored strips with a cross section of 10 × 3 mm and a fill factor of 48–50 % were manufactured for hardfacing of experimental samples. Cold-rolled strip of steel 08kp (rimmed) was used as a steel sheath. Manganese and chromium metals, iron powder and a small amount of ferrotitanium to refine grains and strengthen the deposited metal due to formation of dispersed carbides TiC were added in different quantities to the charge composition. Hardfacing was performed in three layers by the submerged-arc method using flux AN-26 on a 30 mm thick plate of steel VSt3sp (killed). The hardfacing parameters were as follows: current 450–500 A, voltage 30–32 V, and hardfacing speed 25 m/h. Chemical compositions of the metal deposited with wire Sv-12Kh13 and experimental flux-cored strips PL-OP (1–5) are given in Table 1.

As found at the preliminary stage of investigations, in hardfacing without preheating the deposited metal (~13 % Cr and ≥6 % Mn) was free from cracks. No cracks were detected in the metal deposited with wire Sv-12Kh13 either. However, they were detected at 2–4 % Mn. Preheating to a temperature of 250 °C made it possible to avoid cracks in all the cases. Al-