Developing and Studying the Methods of Hard-Facing with Heat-Resisting High-Hardness Steels

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Abstract: The authors develop the methods of hard-facing of mining-metallurgic equipment parts with heat-resisting high-hardness steels on the base of plasma-jet hard-facing in the shielding-alloying nitrogen atmosphere.

Introduction

Alloying materials developed on the base of chrome-tungsten heat-resisting high-speed steels are widely applied for strengthening mining-metallurgical equipment parts [1, 2]. The most common problem appearing when alloying with chrome-tungsten steels is formation of cold (tempering) cracks in the process of and after alloying. Crack formation is reduced with increase of the temperature of martensite transformation and slowing down the cooling rate. The easiest and the most efficient way to prevent cracking is to regulate the thermal cycle through choosing proper methods and conditions of alloying as well as through application of preheating if necessary. To prevent cracking, reduce internal stresses and obtain enough plastic structure of the hard-faced metal compulsory preheating of the parts up to 350–400°C is applied when they are hard-faced with highly-alloyed electrode wire PP-3H2V8 or solid-drawn EI-701 wire. To eliminate cracking, when hard-facing the high-speed steels the workpieces are to be preheated and additionally heated up to the temperature of 500–700°C [1,2]. The traditional technology of bimetallic products manufacturing (hard-facing with preheating – annealing – hardening – tempering) is unreasonably time and labor consuming. Compulsory application of high-temperature heating, retarded cooling and, as a result, of further hardening of the hard-faced part is a significant disadvantage of the technology. Retarded cooling of the parts which is recommended to prevent cold cracking generates a need for further hardening of the bimetallic item which, by itself, is a difficult task due to the difference between the properties of hard-faced highly alloyed metal and low alloy center. Hardening of some large-sized parts is almost impossible to complete. Current technological processes of tool steels hard-facing do not allow full use of the hard-faced metal properties [1-3]. That is why the problem of developing new methods of chrome-tungsten steels hard-facing is relevant as the new methods allow improving the mentioned above disadvantages of the traditional technology and taking the full advantage of high hardness and wear resistance of chrome tungsten steels as they have been designed by the metallurgists and metal physicists. It is practical to

combine the processes of metal hard-facing and hardening as it allows producing a hard-faced layer which state is close to that of a hardened metal. It is also necessary to avoid high-temperature heating or at least reduce its temperature applying new methods of cold cracking elimination.

The work objective is developing and studying the methods of hard-facing with heat-resisting steels high-hardness steels ensuring obtaining hard-faced metal which state is close to the state of the hardened metal and which has no cracks.

Hard-faced metal characterized by high resistance to cold cracking and high mechanical properties can be obtained immediately after the process of hard-facing is finished through regulation of the thermal cycle of hard-facing. The suggested thermal cycle for the multiple-bead deposit of chrome-tungsten hardening steels is shown in Figure 1 [3, 4].

The specific feature of the suggested methods of hard-facing is application of low-temperature preliminary and additional heating. To obtain hard-faced metal with reduced ability for crack formation we have to regulate the level of temporary stresses during the hard-facing process by their partial relaxation due to kinetic plasticity effect which appears at the moment of martensite or bainitic transformation. Relaxation of temporary stresses within the temperature interval of martensite or bainitic transformation prevents cracking during the process of multiple-bead hard-facing.

Cooling of the hard-faced layers and isothermal hardening within the interval of martensite transformation leads to thermal stabilization of austenite. It is worth noting that $70 - 90\%$ of the metal hard-faced in the process of depositing is stabilized austenite. When the amount of austenite increases the stresses reduce, plasticity grows, volumetric changes, deformations and crack sensitivity reduce. The duration of isothermal tempering depends upon the chemical composition of hard-faced metal and can be determined experimentally for each grade of steel or according to the diagram of undercooled austenite transformation.
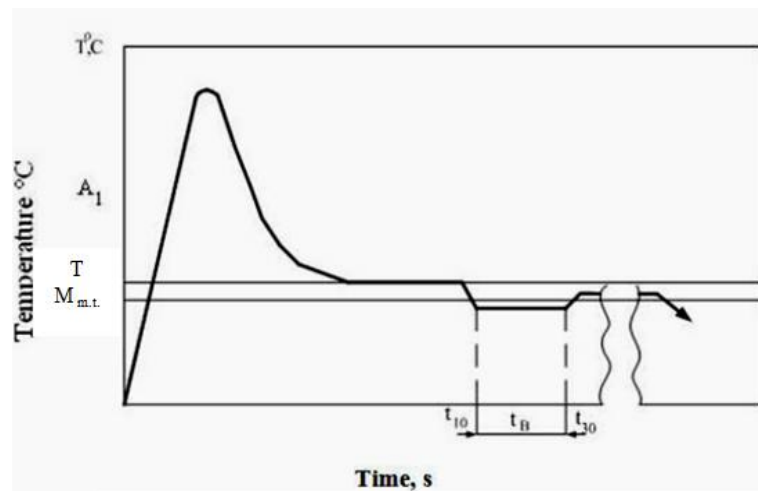
Figure 1. Diagram of the thermal cycle when hard-facing with heat-resisting steels

The level of relaxation of temporary stresses is determined by the time of isothermal hardening t_B under the temperatures below M the beginning of the martensitic transformation, which is found from correlation 1:

$$t_{10} < t_B < t_{30,} \tag{1}$$

where t_{10}- time required formation of 10% of martensite; t_{30} – time required for formation of 30% of martensite.

If the duration of isothermal hardening is smaller than the duration required to form 10% of martensite no significant relaxation of temporary stresses occurs leading to temporary stress accumulation in the process of multiple-bead hard-facing which, in its turn, may result in crack

formation. Besides, relaxation of stresses is important to stop the martensite transformation and to stabilize the austenite. That is why hardening with the time t_B is needed for partial relaxation of temporary stresses in the process of hard-facing and obtaining stabilized austenite. When hardening time exceeds t_B the metal ductility is significantly deteriorated due to formation of a large amount of martensite which results in crack formation. Besides, longer hardening increases the duration of the hard-facing and, thus, reduces the productivity of the process. If the amount of martensite formed in the process of hard-facing exceeds 30% more intense breakdown of martensite occurs. During the process of martensite breakdown carbides are precipitated, that is why high hardness cannot be achieved during further hardening. To obtain homogeneous metal structure of all hard-faced layers cooling and hardening are completed after depositing every single layer.

The special features of the suggested thermal cycle of the hard-facing also include limited time of the hard-faced metal exposure to high temperature heating, high rates of metal cooling in the area of minimal austenite stability, keeping the metal in the austenitic state until the end of the hard-facing process through application of preheating with the temperature $M_{\text{the beginning of the martensitic transformation}} + (50\text{-}100)°C$ (Figure 1). To reduce the temporary stresses accumulated in the austenite region we suggest short-term lowering of the preheating temperature by $(20\text{-}100)°C$ below $M_{\text{the beginning of the martensitic transformation}}$. Preheating temperature reduction in the process of multiple-bead hard-facing leads to partial relaxation of temporary stresses which happens mainly due to superplasticity effect which happens in the moment of martensite of bainitic transformation. Relaxation of temporary stresses within the temperature range of martensite or bainitic transformation prevents formation of cracks in the process of multiple-bead hard-facing. The level of temporary stresses relaxation is ensured by hardening time t_B under the temperatures below $M_{\text{the beginning of the martensitic transformation}}$

Plasma-jet hard-facing with non-current-carrying filler flux cored wire was chosen as the method of hard-facing. Choosing plasma-jet hard-facing as the basic method of depositing wear-resistant coating to produce new and renew the worn-out parts is explained by a number of advantages laser-jet hard-facing has in comparison to other hard-facing methods such as: high productivity, wide opportunities of alloying the hard-faced metal, opportunity of applying various alloying metals. The wide range of regulation of the heat input into the base and the hard-faced metal allows implementation of the suggested thermal cycle of the hard-facing. The enumerated advantages of plasma-jet hard-facing methods not only significantly increase the technological opportunities of their application but also allow substantial economic effect due to hard-facing of layers with minimal penetration and retaining original physical and mechanic properties of the hard-faced metal. The specific feature of a constricted arc as a heat source is also the opportunity of easy regulation of its thermal and gas-dynamic characteristics within a wide range. Application of a constricted arc with reverse polarity allows avoiding labor consuming operations of preliminary surface preparation complicating the process of hard-facing. The surface of the hard-faced part is cleaned directly in the process of hard-facing due to cathode spattering effect, thus, ensuring the necessary conditions of wetting the surface of the part with the hard-faced metal and producing a defect-free deposit layer. Under plasma-jet hard-facing with reverse polarity we also observe less dilution of the hard-faced metal with the base one [3-7].

The most efficient method for solving a number of process tasks when hard-facing parts of metallurgic equipment like bodies of rotation (rollers, forming rolls, shafts) is application of plasma-jet hard-facing with reverse polarity in shielding-alloying nitrogen atmosphere with non-current-carrying filling flux cored wire. Nitrogen used as a shielding gas as compared to argon allows not only reducing the costs of the hard-facing but also efficient alloying the hard-faced metal with nitrogen from the gas phase immediately in the process of hard-facing, thus, significantly improving its (hard-faced metal) hardness and wear-resistance. Porosity of the hard-faced metal can be prevented by introducing elements with affinity for the nitrogen and fixing it within stable nitrides into the flux cored wire. Introduction of certain amounts of aluminium into the mixture for the flux cored wire has a positive effect on the hardness improvement of the hard-faced metal and porosity prevention. In the

process of hard-facing the deposit metal is alloyed by the nitrogen directly from the gas phase which allows additional increasing of the working layer hardness. Aluminium is introduced into the mixture for the flux cored wire to avoid porosity. Aluminium fixes the excessive nitrogen into compounds which cannot be solved in the molten metal and can provide additional strength due to fine disperse nitride particles formation. Additional improvement of the properties of the hard-faced highly alloyed metal as well as ensuring favorable stressed state can be achieved by application of high temperature tempering. Thus, hardness of metal after hard-facing with flux cored wires PP-R18YuN is HRC 52-57 and, in terms of composition its structure is close to that of high-speed steel of R18 type in its tempered state and consists of martensite (about 70%), carbides (up to 20%) and retained austenite (up to 10%). 3-4-time high-temperature tempering under 580°C increases the hardness of the hard-faced metal up to HRC 62-64. Improvement of hardness is explained by transformation of retained austenite into martensite and effect of precipitation hardening. Hardness of the hard-faced metal after tempering for secondary hardness reaches HRC 64-66 [3 -9].

The typical structure of the hard-faced metal after multiple-bead laser-jet hard-facing and high-temperature tempering is shown in Figure 2 (microscope OLYPUS GX – 51, etching solution HNO_3, 3% spirit, magnification ×500).

To complete plasma-jet hard-facing with non-current-carrying flux cored wire we applied a unit assembled from serial equipment.
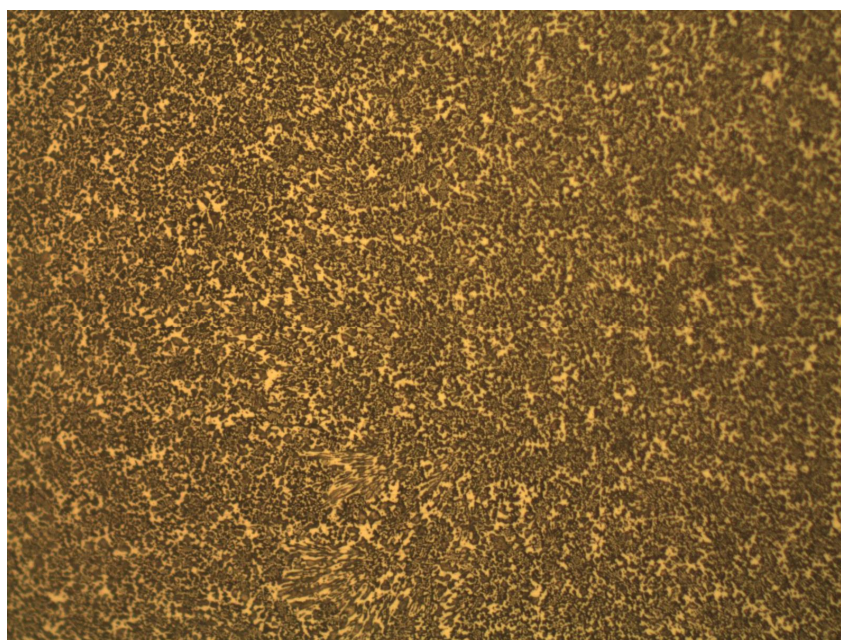
Figure 2. Structure of the hard-faced metal after multiple-bead plasma-jet hard-facing and high-temperature tempering, ×500

The suggested methods are efficient for hard-facing chrome-tungsten steels with low temperatures of phase transformation start (M $_{the\ beginning\ of\ the\ martensitic\ transformation}$ =180° − 380°C). This allows significant reduction of the preheating temperature for R18 steel: from 500–600°C to 230–280°C and even to 80–160°C according to the suggested methods and by itself simplifies the technology of chrome-tungsten steels hard-facing. The methods of hard-facing with heat-resisting steels ensure high resistance of the hard-faced metal to heat-treatment cracking and producing a hardened in the process of hard-facing layer with high hardness and high wear resistance.

Conclusion

1. The traditional technology of chrome-tungsten steels hard-facing with application of high-temperature preheating and retarded cooling is labor consuming, lacks efficiency and does not allow full use of high service properties of the hard-faced metal.

2. The methods of multiple-bead hard-facing were developed basing on following a certain thermal cycle. The specific feature of the suggested methods of hard-facing is application of low-temperature preheating and additional heating ($T_{heating} = 230 - 280°C$). to produce hard-faced metal with low ability for crack formation we can regulate the level of temporary stresses in the process of hard-facing through their partial relaxation due to the effect of kinetic plasticity in the moment of martensite or bainitic transformation.

3. Reverse polarity plasma-jet facing with non-current carrying flux cored wire in shielding-alloying nitrogen atmosphere was chosen as the process realizing the suggested above method of hard-facing.

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