TECHNOLOGICAL PECULIARITIES OF CLADDING OF HIGH ALLOYS

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Parameters of the technological operations in cladding of alloys of ferrous and non-ferrous metals with a high content of alloying elements are analyzed and generalized. It is shown that the required minimum dilution of the base metal with the high-alloyed deposited one can be achieved only in their separate melting. The most promising technologies for cladding of such alloys are plasma powder cladding and hybrid technologies.

Keywords: *cladding, high alloy, technological peculiarities, melting of filler metal, heating of base metal, penetration of base metal*

Cladding as a technological process for restoration of dimensions of parts and correction of cast defects is known from the end of XIX century [1]. However, a hardfacing, which provides increase of resistance of the parts in several times in comparison with their manufacturing from structural metals, is more efficient. The high alloys and alloys of ferrous and non-ferrous metals with special service properties which can be divided in following groups [2, 3] are used for cladding:

- chromium steels (5–30 % Cr);
- high-manganese steels (11–18 % Mn);
- high-speed steels (2–20 % W, 2–10 % Mo, 5–15 % Co, 3–5 % Cr);
- chrome-nickel austenite steels (12–20 % Cr, 8–25 % Ni);
- high-chromium cast iron (2–5 % C, 18–35 % Cr);
- nickel alloys (15–21 % Cr, 2–5 % Si, 3–30 % Mo, up to 15 % Co);
- cobalt alloys (25–33 % Cr, 3–25 % W, up to 3 % C);
- copper alloys (bronze, brass); carbide compositions (up to 3 % C, 25–33 % Cr, 30–70 % Co, 3–25 % W).

Cladding of the alloys is the greatest difficulty since there is a necessity in technology, modes and materials different from widely used in welding engineering. This is a result of increased susceptibility to crack formation during cladding of the high alloys, necessity in sufficiently accurate representation of required chemical composition of the deposited metal, high sensitivity to crack formation, increased oxidation of the alloying elements and liquation. Widely used methods of arc cladding, in particular for non-ferrous metals, usually do not provide necessary quality and being carried out in three-four layers for obtaining the necessary chemical composition and allowance for machining. The following technological measures were developed and used for elimination of the negative effect of these factors in cladding of the high alloys:

- thorough surface preparation of the parts for cladding ;
- cladding technologies, providing minimum penetration of the base metal;
- secure protection of a weld pool from oxygen and hydrogen;
- preheating and delayed cooling after cladding;
- influence on initial structure of the deposited metal;
- heat treatment after cladding;
- deposition of intermediate sublayer.

Cladding of the high alloys, in particular, non-ferrous metals requires cleaning of the surface of the parts from oxide films and grease contaminations. Machining using metal cutting tools (cutters, millers and abrasive disks) with further degreasing by organic diluents or treatment by chemically active fluxes is used for this. Such a cleaning provides better spreading and wetting of the surface of part being deposited by liquid filler metal. This is, in particular, important in cladding with minimum and zero penetration of the surface when physics of the process becomes close to a brazing process.

Selection of a technology for cladding in most cases is caused by the necessity to provide accurate content of the alloying elements in the deposited metal from which the service properties of parts depend on. Penetration of the base metal and its dilution with deposited one should be close to zero. The following methods of cladding fulfill this requirement: plasma cladding; induction cladding by pouring of liquid filler metal; electroslag cladding by two electrode strips or using special activating fluxes; hybrid technologies of cladding.

Common physical and technological characteristic for these processes is division of melting of the filler metal and pre-heating of the base metal.

Cladding by means of liquid filler metal [4] was developed in the beginning of the 1940s. In it, the metal molten, for example, in an induction furnace or electric bowl, is poured on the surface of the part being heated up by low-current arc discharge. The efficiency is high at minimum penetration of the part but additional electric equipment is required for that. This method found limited application for cladding of the small parts by fusible alloys, for example, by babbits for the inserts and bushes of friction bearings. Today this technology is used as a spinning or cladding as well as freezing-on cladding using boride fluxes for cleaning of the part surface from oxide films and its activation [3].

The plasma cladding with powder filler significantly differs from other methods of cladding on type of applied equipment, materials and technological possibilities [5]. Its main advantages are a high quality of formation and obtaining of required chemical composition already in the first layer; minimum penetration and thermal influence on the base metal; fine grained structure of the deposited metal; possibility of cladding of an alloy of any composition using filler powder obtained by liquid metal spraying; secure protection of metal drops and weld pool by inert gas.

The processes of interaction of liquid filler metal with tough base metal are influenced by temperature in a zone of cladding and chemical composition of metals. A depth of penetration is reduced using filler materials with lower melting temperature than in the part. The smaller depth of penetration can be obtained at higher temperature difference. An addition of the surface-active elements, for example, bore and silicon in cobalt-, nickel- and chromium-based alloys can significantly improve spreading of the liquid filler metal and wetting of surface of the part being deposited.

It was determined that melting temperature of the dispersed powder alloys is lower than that of the heavy-melting samples [6]. The reduction of melting temperature of the powder ΔT in comparison with melting temperature T of the solid (heavy-melting) sample can be determined by formula

$$\Delta T = 2T(\sigma_{1.3} - \sigma_{1.2})/[\sigma_{1.3} - (\sigma_{2.3} + \sigma_{1.2})d],$$

where $\sigma_{1.3}$, $\sigma_{1.2}$ are the coefficients of surface tension of solid metal and melt, respectively; $\sigma_{2.3}$ is the coefficient of interphase tension on the solid metal–melt boundary; d is the diameter (size) of the powder particle.

Therefore, application of powders requires lower heat input in the filler and base metal then into cladding wires and strips of solid section that results in lower overheating and melting of the part surface.

Heating and melting of the base metal by heat of constricted arc is estimated by an effective efficiency which at plasma cladding makes $\eta_s = 0.68$–0.72. Only part of the effective power is used for heating and melting of zone of penetration. It is evaluated by thermal efficiency the values of which are determined experimentally [7] ($\eta_t = 0.32$–0.34). An area of penetration can be determined from formula

$$\eta_t = S_{pen} v_{r.c} \rho H_{melt}/(IU\eta_s),$$

where S_{pen} is the penetration area, cm^2, equal Bh; B is the width of penetration zone, cm; h is the penetration depth, cm; $v_{r.c}$ is the resultant speed of cladding, cm/s; $IU\eta_s$ is the effective power of the constricted arc, W, equal q_s; ρ is the metal density, g/cm^3; H_{melt} is the specific enthalpy of molten metal, including latent heat of melting, J/mol.

The largest amount of the particles of metal powder, supplied through the constricted arc, is introduced in the weld pool in form of drops. The biggest fractions of powder are already melted in the weld pool, but they become additional centers of crystallization or «microcooler» under certain modes of cladding and ratios of sizes (mass) of particles of the small and large fractions. This peculiarity of given technology results in refining of the cast microstructure and increase of mechanical properties of the deposited metal (Figure 1). A structural heredity in the powder for deposition–weld pool–deposited metal system [8] is observed.

The minimum sufficient values of penetration of the part surface (not more than 0.5–1.0 mm) is achieved in the plasma-powder cladding at portion of the base metal in the deposited γ_0 in the ranges from 2 to 8 %. Moreover, formation of a joint of deposited metal with the base one can occur similar to brazing, i.e. virtually without melting of surface of the base metal, during cladding of self-fluxing nickel-chromium alloys of Colmonoy type, containing 2–5 % B

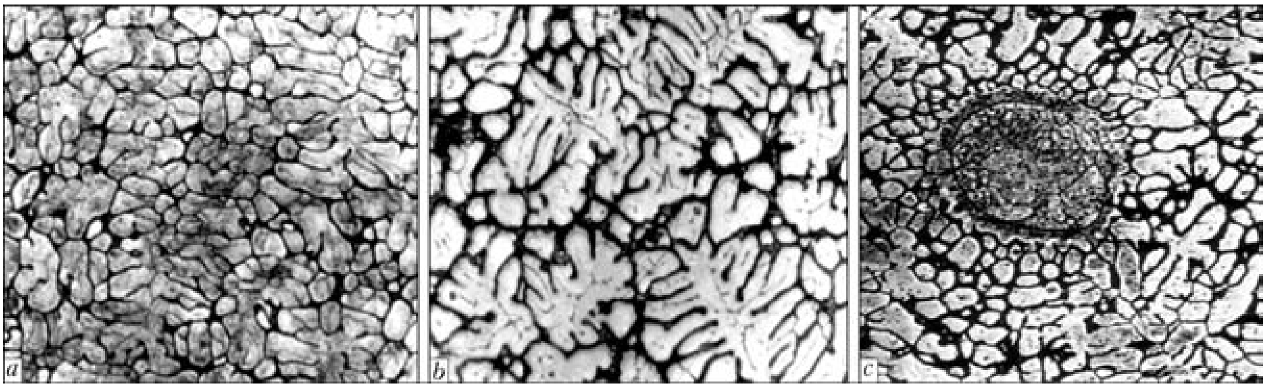

Figure 1. Microstructures (×400) of deposited high-speed steel 10R6M5 during introduction of the powder of large fraction into the filler powder of small fractions: *a*, *b* — cladding by mixture with addition of 30 % and 45 % of large fractions, respectively; *c* — non-melted particle of the powder (in the middle) at addition of large fractions

and 2–5 % Si and having melting temperature below than steel. Multiple tests and operation under industrial conditions of the parts of high parameter stop valves, metal-cutting tools (end-milling cutter, cutting taps, disk blades and cutters), parts of extruders, plugs and other parts, deposited with the help of plasma-powder technology, showed high adhesion strength of deposited to base metal.

Current intensity of a transferred arc has the most significant influence on value γ_0 in plasma-powder cladding as well as in all processes of arc cladding. This is, in particular, noticeable at small thickness of the deposited layer. Increase of mass velocity of the powder feed and thickness of the layer widens range of currents at which γ_0 lies in the ranges from 2 to 10 %, that is explained by reduction of direct influence of arc on the base metal.

Increase of consumption of the plasma gas has significant influence on penetration of the base metal. This is related with the level of arc constriction and, respectively, increase of the pressure of arc plasma on metal of the weld pool and penetration capability. Consumption of the transporting gas has similar but less influence. In this technology argon is used as a plasma, shielding and transporting gas.

There is no change of the penetration at reduction or increase of distance from plasmatron to part (arc length) in the plasma-powder cladding in comparison with traditional methods of arc cladding. Stability of transferred arc is preserved, but powder loss increases and shield of metal being deposited becomes worse at distance to the part more than 15 mm.

The mass velocity of powder feed is related with current intensity of the arc and cladding rate. The penetration rises at simultaneous increase of these three parameters of the process. The following formula [5] is proposed for determination of cladding rate:

$$v_c = G_f / \rho\mu B H,$$

where G_f is the mass velocity of powder feed, g/s; $\mu = 0.80$–0.85 is the coefficient of bead form at plasma-powder cladding; B, H are the width and height of deposited bead, cm.

The granulated powders of ferrous and non-ferrous metal, applied for plasma-powder cladding, are notable for variety of compositions and can be manufactured by spraying of any alloy, first of all alloys based on iron, nickel, copper and cobalt. Composition of the deposited metal in the first layer corresponds with chemical composition of the filler powder due to technological peculiarities of the plasma-powder cladding. At excellent formation of the deposited beads in most cases this allows using a single-layer cladding and significantly reducing allowances for further machining of the deposited part.

The fluxes for high-temperature brazing and alloys with melting temperature below than that of structural steels are used as a charge in induction cladding [9]. Heating in the high-frequency field firstly melts the flux and then filler materials is melted and spread over the activated surface. The flux consists of borax, boric anhydride and silico-calcium and cleans surface of the part from oxide film. The process of induction cladding similar in this case to brazing and the possibility of dilution of the base metal with the deposited high alloy of Sormait type is eliminated by difference in the melting temperatures. The plough shares manufactured on this technology successfully operate under conditions of intensive abrasive wear.

Technology of the horizontal elecroslag cladding by two strips, developed by Austrian company «Boehler» and PWI, is used for manufacture of the bimetal plates (low-carbon steel + stainless steel) [10]. Stable electroslag process takes place using fluoride low-silicon fluxes of AN-26P and 48-OF-10 types and weld pool level rises in 20–30 mm over the surface of the base metal in a gap between the strips. This allows reducing portion of the base metal in the deposited one up to 5–8 %. Smaller value of γ_0 can be obtained in electroslag cladding of copper on steel using fluoride and boride fluxes containing CaF_2, NaF, KF, $Na_2B_4O_7$, B_2O_3 which activate the surface of the part and melt the filler metal [11]. The crack formation in steel on the fusion line and propping action of liquid copper, entering in these cracks (Rehbinder effect), is eliminated at that. The latter effect takes place in simple arc cladding with significant penetration. The plate electrodes and consumable nozzles in vertical position are used during this process at temperatures below melting temperature of low-carbon steel (1200–1350 °C).

The intergranular cracks usually propagating normal to the fusion line can be formed in the base metal during cladding of copper alloys on some steels. Application of a sublayer from chrome-nickel ferrite-austenite steel with content of not less than 40 % of ferrite phase in the structure completely eliminates possibility of formation of such cracks at further cladding of copper-based alloys on such a sublayer. Sometimes the necessity in sublayer can be caused by other reasons. For example, high thermal stresses, provoking failure as a result of thermal fatigue after effect of specific amount of cycles, appear during operation of the deposited part under conditions of thermal loadings due to differences in linear expansion coefficients of the base and deposited metals.

A method of cladding using a composite filler material, being developed in the Karaganda State Technical University, can be also referred to this group. Small penetration of the surface is observed only on the edges of the deposited bead of 23 mm width and 6.5 mm height (Figure 2, *a*) at distinguished fusion line in the middle part of the bead section. Hardness of the deposited metal (high alloy manganese steel) makes *HRC* 44–52 in the first layer. The microstructure contains quite fine dendrites growing form the surface of the base metal with high content of austenite and martensite (Figure 2, *b*).

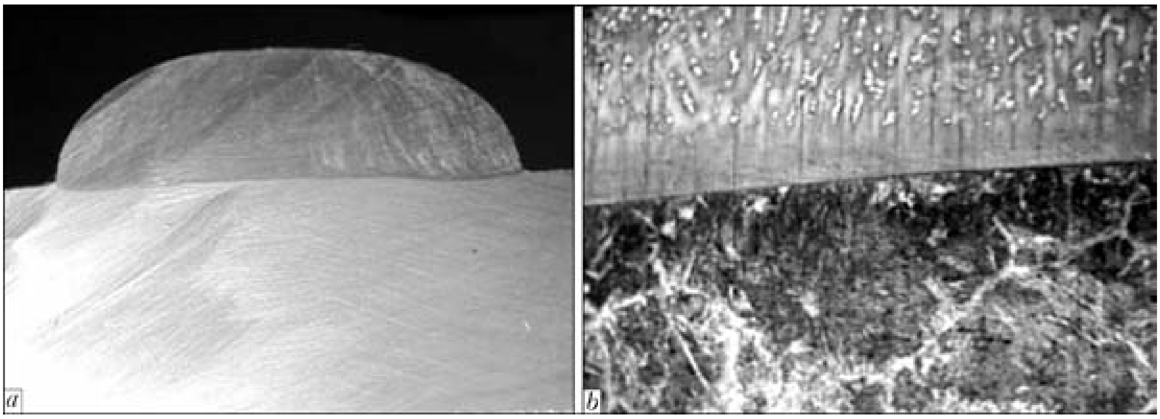

Figure 2. Macrosection of the deposited sample (*a*) and microstructure (×400) of high-manganese steel (on the top) deposited on St3 steel using combined filler metal

The heat treatment in the form of tempering is carried out in most cases after cladding of high alloys. A high tempering at 600–700 °C for 3–24 h is used for nickel-chromium alloys of NKh15SR2 type for redistribution of internal stresses in the dissimilar alloy joints. Short heat treatment in a form of two-, three-times repeated tempering at 560 °C is applied to high-speed steels after plasma-powder cladding of simple shape metal-cutting tools (disk cutters, cutters). Tempering reduces internal stresses in the high-speed steel, quenching in air during cladding, as well as increases secondary hardness up to *HRC* 63–64 for tungsten-molybdenum steels and up to *HRC* 66–67 for cobalt steels. Heat treatment of the high-speed steels is carried out at a complete cycle, annealing + quenching + + tempering, for such steels during cladding of work-pieces of multiedge cutter.

CONCLUSIONS

1. Cladding of high alloys with minimum penetration of the base metal can be realized technologically and justified economically.

2. Separate melting of the filler metal and heating of the base metal are necessary for obtaining minimum dilution of the base and deposited metals.

3. The plasma-powder cladding is the most preferable for high alloys allowing easily regulating penetration and depositing wide range of chemical compositions of ferrous- and non-ferrous based alloys with the help of powders, obtained by the liquid metal spraying.

4. Tempering is often used for reduction of the residual stresses in high alloy deposited metal.

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