*Metal Science and Heat Treatment* *Vol. 43, Nos. 1 – 2, 2001*

UDC 621.9.048.7:621.793.7

# TREATMENT OF WEAR-RESISTANT METALLIC COATINGS WITH HIGHLY CONCENTRATED ENERGY SOURCES

**A. O. Tokarev**[1]

Translated from Metallovedenie i Termicheskaya Obrabotka Metallov, No. 2, pp. 18 – 21, February, 2001.

## INTRODUCTION

When a wear-resistant coating is deposited on the functional surface of parts, it is important that the structure and properties of the materials of the core, the surface, and the transition zone between them be in optimum combination.

The following problems of structure "design" are to be solved in the development of technological processes for reinforcing parts by the method of deposition of wear-resistant coatings.

1. Formation of a wear-resistant structure in the coating. The wear resistance of the coating is provided by the presence of hard reinforcing particles of carbides, borides, and other compounds in its composition.

2. The transition zone between the substrate and the coating should possess enough ductility and toughness. This is possible in the case of formation of a continuous series of solid solutions as a result of the interaction between the components of the substrate and the coating. If chemical and structural inhomogeneity appears in the transition zone, its embrittling effect should be minimized.

3. The structural changes in the substrate due to the deposition of the coating on it should not worsen its structure and, consequently, its mechanical properties.

The thermal cycle of the treatment for obtaining coatings with optimum structure involves (*1*) heating and a hold at a temperature close to the solidus (regime of solid-phase sintering) and (*2*) heating and a hold in the liquidus – solidus temperature range (regime of liquid-phase sintering) or heating above the liquidus temperature, which corresponds to a melting regime.

The most favorable regime removes the structural inhomogeneity and provides segregation of disperse hardening phases from the solid solution, coagulation of pores, and removal of internal stresses. In the case of self-fluxing nickel-chromium coatings, such a treatment requires heating to 930 – 1080°C. At these temperatures the structure of the steel substrate undergoes phase recrystallization and its grains coarsen. In addition, the elements of the coating diffuse into the substrate. All these factors decrease the hardness of the coating and the crack resistance of the substrate.

In order to preserve and improve the structure of the substrate, the temperature and time parameters of the thermal cycle to which the part is subjected when the coating is deposited onto preliminarily quenched steel should not exceed the range of short-term tempering. If the substrate contains structurally free ferrite, the heating can be performed to the temperature range $A_1 - A_3$ that provides preservation of the tough ferrite component.

It is possible to combine optimum thermal cycles in one technological process by subjecting the surface of the coating to the action of a highly concentrated energy beam. The efficiency of the treatment of wear-resistant alloys with short-term high-power beams is shown in [1, 2]. The fine-grain structure of the hardening phases is inherited without a change in the chemical composition of the initial powder charge. In the present work, we made an attempt to use one more substantial advantage of heating by highly concentrated energy sources, namely, the presence of a temperature gradient that appears due to their action on the surface. Control of the temperature gradient by regulating the treatment parameters promises new possibilities in the formation of the structure and properties of alloys with a hardened surface. Specifically, the use of concentrated energy beams can provide an optimum regime of thermal action on the surface, the transition zone, and the substrate. Controlling the parameters of the energy effect and the thickness, composition, and state of the deposited coating, we can provide a distribution of the temperature over the cross section under which the heating temperature of the coating will create conditions for its melting or sintering and the substrate will undergo short-term tempering or partial quenching.

## METHODS OF STUDY

We obtained wear-resistant coatings from powder alloy PG-10N-01 (15% Cr, 3% B, 4% Si, 0.9% C, 5% Fe, the remainder Ni) and steel R6M5-PM (0.8% C, 3.9% Cr, 6.1% W, 4.9% Mo, 1.8% V).

---

[1] Novosibirsk State Academy of Water Transport, Novosibirsk, Russia.

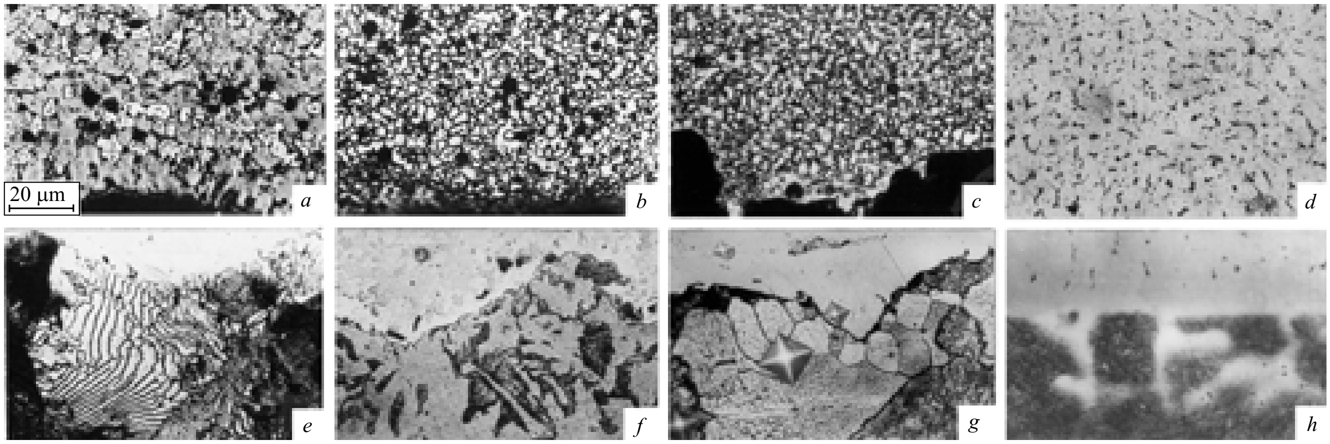

**Fig. 1.** Structure of iron-carbon alloys with wear-resistant coatings obtained by depositing a powder material on the surface and heating the surface until it fused at various rates: *a*, *e*) $v_h = 18 – 20$ K/sec (in a salt bath); *b*, *f*) $v_h = 35 – 45$ K/sec (by plasma jet); *c*, *g*) $v_h \cong 100$ K/sec (by the method of electrocontact heating); *d*, *h*) by $CO_2$-laser beam (with a power density of 2 $MW/cm^2$); *a* – *c*) PG-10N-01 coating; *d*) R6M5-PM steel coating; *e* – *h*) substrate: *e*) cast iron SCh25; *f*, *g*) steel 20; *h*) steel 65G.

The self-fluxing alloy PG-10N-01 was deposited on reinforced surfaces by the method of plasma spraying with the use of a plasma generator with a quasi-laminar plasma jet [3, 4]. The reinforced specimens and parts were fabricated from low-carbon steel 20 (0.21% C, 0.5% Mn, 0.24% Si, 0.04% P, 0.01% S) and gray cast iron SCh25 with a pearlite matrix.

In order to form an optimum structure and properties, the specimens with the deposited coating were heated by different regimes, namely, in a salt bath, by the electrocontact method, and by a plasma quasi-laminar jet.

Powder high-speed steel R6M5-PM was deposited by the method of laser facing on a substrate from preliminarily quenched steel 65G (0.63% C, 1.1% Mn, 0.32% Si). The powder was deposited onto the surface of the preform with the help of a special batcher designed by Novosibirsk-NIIkhimmash without any adhesive binder. Then we performed laser treatment [5]. This technology was used to fabricate inexpensive reliable tools with a body made from low-alloy steel and cutting edges made from faced high-speed steel.

In order to detect the thermal cycles in the process of facing and treatment of the coatings, a chromel-alumel thermocouple was mounted on the surface of the specimens. When the coating was deposited, the junction of the thermocouple was located on the interface between the substrate and the coating. In other regions of the coating and the substrate, the thermal cycles were detected from the structural changes in them.

The structure of the substrate and the wear-resistant coating differed greatly in their composition and chemical properties and therefore were studied successively. At first the structure of the substrate was determined by etching in nital. Then the structure of the coating was determined with the help of more aggressive reagents and the method of color thermo-oxidizing etching. When the structure of the coating was determined, the substrate corroded and looked dark on the photographs.

## RESULTS AND THEIR DISCUSSION

When specimens with sprayed-on coating were treated in a salt bath (molten BaCl, $t = 1020°C$), the mean rate of their heating was 18 – 20 K/sec. Given that the hold of the treated specimens in the salt bath was controlled, we obtained a temperature gradient over their cross section at which the coating acquired a solid-liquid state and the pearlite in the structure of the substrate recrystallized [6].

This technology was used to recondition and reinforce worn collars of a ship diesel of type G60 produced from cast iron SCh25 with a wall thickness of 10 – 40 mm. Powdered alloy PG-10N-01 was plasma-sprayed on the prepared surface of the collars. Then the collars were immersed into a salt bath. After a hold of 120 – 150 sec in the bath, the collars were faced with a coating that had a structure represented by regions of a carboboride eutectic uniformly distributed in the matrix of a Ni – Cr solid solution (Fig. 1*a*). During the hold in the salt bath, the pores coagulated and the porosity of the coating decreased. A short high-temperature hold did not lead to interdiffusion of the components of the coating and the substrate or a qualitative change in their structure.

A hold at a temperature somewhat exceeding $A_1$ provided phase recrystallization of the pearlite component of the substrate with formation of a finely dispersed pearlite structure (Fig. 1*e*) [6]. The wear resistance of the coated collar coupled with a sulfocyanided piston ring exceeded the initial value by a factor of 1.5 – 3.0.

Gasothermal fusion produces heating at a rate of 35 – 45 K/sec. The use of oxygen-acetylene torches for this purpose is not very effective and is expensive. The method of plasma-jet spraying is more adaptable to the process, but the commercial plasma generators with turbulent jets have disadvantages, i.e., the plasma jet produced by them is unstable and the pressure exerted by the jet on the coating causes its fracture. These disadvantages have been eliminated by using an electric arc plasma generator with an insert between the electrodes, which has been designed for operation in a laminar mode [3, 4].

We obtained a wear-resistant coating with disperse carboborides on a crack-resistant ferrite-pearlite substrate of steel 20 by treating the surface with a quasi-laminar plasma jet of such a plasma generator. In the treatment process, we controlled the speed of the plasma jet in order to heat the surface to the temperature of liquid-phase sintering. In visual control, this stage corresponded to the beginning of "sweating" of the treated surface of the coating. We did not observe noticeable interdiffusion of the components of the coating and the substrate. Regions cold-worked in the preliminary shot blasting recrystallized under the coating in the contact zone of the substrate. The developed relief of the surface of cohesion between the coating and the substrate was preserved (Fig. 1*b* and *f*). In order to evaluate the crack resistance of the obtained bimetal, we tested the specimens by applying local impact loads. After $3 \times 10^3$ loading cycles by a ball indenter 10 mm in diameter with an impact force of 0.57 J/cm$^2$, we observed plastic deformation of the coating and chipping of some fragments without crack propagation to the interface with the substrate or breakaway of the coating.

A localized action of the thermal and mechanical energy on the surface of interparticle contact in the powder coating and of contact with the substrate is provided by electrocontact treatment. The surface thermomechanical action appearing as a result provides the formation of an optimum structure in the coating and a high accuracy and quality of the treatment [2]. If the part with deposited wear-resistant coating has to be treated mechanically, this makes it possible to overcome the difficulties connected with its high hardness. Therefore, it is interesting to consider the methods of electrocontact deposition of self-fluxing coatings.

We studied the effect of the parameters of thermomechanical sintering (TMS) in electrocontact heating on the structure of parts with a wear-resistant Ni – Cr coating. The optimum treatment regime provides a homogeneous finely dispersed structure of a wear-resistant coating on a crack-resistant substrate. Specimens with a sprayed-on, self-fluxing, wear-resistant coating were treated by electrocontact rolls. The rate of feeding of the preform and the contact pressure of the rolls against the coating were controlled. The design current density was 300 A/mm$^2$. The contact pressure of the electrodes was changed from 20 to 80 MPa. The duration of the treatment of each unit area of the coating was 2 – 8 sec; the mean rate of heating was about 100 K/sec. At optimum treatment parameters [7], which provided full sintering of the coating, its structural inhomogeneity and porosity were eliminated. After the electrocontact treatment, the coating had the structure of a solid solution with uniformly distributed finely dispersed particles of carbides, borides, and silicides 0.7 – 1.5 μm in size. The cold-worked ferrite recrystallizes in the zone of thermal effect of the substrate, and the pearlite regions undergo austenization. When the thermal action ceased, this zone cooled rapidly (because the heat was transferred to the core). The austenite regions were hardened for martensite. The formed martensite had a twinned structure, because it contained about 0.8% C and its amount and position corresponded to the pearlite of the initial structure. Thus, the electrocontact treatment by an optimum regime yields a wear-resistant finely dispersed coating on a tough substrate (of steel 20) with a ferrite matrix (Fig. 1*c* and *h*).

Laser radiation is a concentrated source of thermal energy. Scanning of the surface of a specimen by a beam of a continuous CO$_2$-laser with a power of up to 2 kW with simultaneous feeding of a powder layer forms a fused wear-resistant Ni – Cr coating on a tough ferrite-pearlite substrate. We controlled the temperature gradient by changing the rate of feeding of the powder, the protective gas, and the laser radiation. The power density on the treated surface was up to 2 MW/cm$^2$.

The high concentration of energy in laser treatment makes it possible not only to face self-fluxing alloys but also powders of tool steel [5]. A powder of high-speed steel of type R6M5-PM was deposited on the surface of a preform from steel 65G by the method of laser facing. The powder layer, the protective gas, and the laser radiation were dosed in order to control the temperature gradient in the treatment of the powder by a continuous CO$_2$-laser with a power of 2 kW. The power density on the treated surface was up to 2 MW/cm$^2$. The layer faced in one pass had a dendrite-cellular structure. Over the branches of dendrites of the solid solution we observed phases of chemical compounds that composed eutectics, which often formed a closed skeleton. In the subsequent pass, these layers got into the zone of laser effect and heated to a temperature of the "solidus – liquidus" range. As a result of the transition to a solid-liquid state, the eutectoid net crushed into separate particles (Fig. 1*d*). The coalescence and partial dissolution of carbides thus observed increase the doping level in solid solutions. Diffusion processes developed in the matrix steel (Fig. 1*h*). The alloying elements from the high-speed steel of the coating transferred into the substrate over the roots of easy diffusion, i.e., over the boundaries of austenite grains. When the action of the laser beam ceased, the rapid removal of the heat into the substrate caused quenching of the high-speed steel of the coating and second quenching of steel 65G in the zone of the laser effect in the substrate. The regions of the substrate located around the boundaries of "former" austenite grains were etched less due to the diffusion of the alloying elements from the coating. The faced layer of high-speed steel had a hardness of 63 – 64 *HRC*. After a standard triple tempering its hardness increased to 66 – 67 *HRC*.

We tried to laser-face high-speed steel R6M5 onto the body of disk saws for cutting wood produced from steel 65G.

The tests of one batch of saws in woodworking shops proved their high service properties.

## CONCLUSIONS

The use of intense heat and thermomechanical action provided by sources of concentrated energy increases the efficiency of the deposition and treatment of wear-resistant coatings. Control of the process parameters provides an optimum thermal cycle that gives requisite structures both in the coating and in the substrate.

## REFERENCES

1. L. I. Tushinskii, *The Theory and Technology of Hardening of Metallic Alloys* [in Russian], Nauka, Novosibirsk (1990).
2. N. N. Dorozhkin, *Hardening and Reconditioning of Machine Parts by Metallic Powders* [in Russian], Nauka i Tekhnika, Minsk (1975).
3. L. K. Arab'yan, V. I. Kuz'min, A. O. Tokarev, et al., "Structure of low-carbon steel with a wear-resistant coating after heat treatment by a laminar jet of nitrogen plasma," *Izv. Sib. Otd. Akad. Nauk SSSR, Ser. Tekh. Nauk*, Issue 2, 99 – 104 (1990).
4. V. I. Kuz'min and A. O. Tokarev, "Thermal treatment of plasma-sprayed coating. Plasma jets in the development of new technology," in: *Proc. Int. Workshop, USSR, Utrecht, The Netherlands, Tokyo, Japan*, pp. 375 – 382.
5. V. V. Krasheninnikov, A. M. Orishich, A. S. Tokarev, and V. S. Demin, "A study of the technological possibility of the production of cutting tools by the method of laser facing," *Metalloved. Term. Obrab. Met.*, No. 6, 6 – 9 (1998).
6. N. F. Golubev and A. O. Tokarev, "Microstructure of cast iron parts with a wear-resistant plasma coating from self-fluxing alloy PT-KhN80SR4," in: *A Study of the Structure and Properties of Volume- and Surface-Hardened Steel, Coll. Works* [in Russian], NÉTI, Novosibirsk (1987), pp. 59 – 65.
7. A. O. Tokarev, "Effect of electrocontact heating on the structure of wear-resistant nickel-chromium coatings," *Poroshk. Met.*, No. 5, 47 – 52 (1990).