Journal of Engineering Physics and Thermophysics, Vol. 77, No. 4, 2004

INFLUENCE OF LASER TREATMENT ON THE KINETICS OF COMPACTION OF COATINGS OF THE Fe–Cr–B–Si SYSTEM

N. N. Dorozhkin,[a] M. A. Kardapolova,[b] O. V. D'yachenko,[b] T. M. Abramovich,[c] S. A. Donskikh,[c] and Yu. A. Simonov [c]

UDC 621.793.74

The characteristics of the change in the porosity of coatings of the Fe–Cr–B–Si system as a function of the velocity of motion, the diameter, and the temperature of the spot of a laser beam have been studied.

Deposition of coatings makes it possible to most rationally and efficiently employ materials depending on their properties, to simplify, in some cases, the technology of manufacture of parts, and to replace expensive and rare metals by ones that are less scarce.

Deposition of a wide range of coatings by the plasma method enables one to produce layers with a prescribed set of properties on the surface of parts, which is determined by the operating conditions of the parts. However, these coatings have a high porosity, as a rule. The reasons for the presence of pores in the sprayed layer are the insufficient heating of individual particles, the possible elastic deformation of particles on impact on the surface, the insufficient plasticity of particles, the mutual influence of gases and the particle to be sprayed, etc.

In operation of sprayed parts, the pores improve the conditions of friction of the parts operating with a lubricant by absorbing the lubricant, when the lubricant is insufficient or the friction is boundary or dry. However, as the number of pores in the material increases, its mechanical properties — plasticity, viscosity, and others — become much more degraded.

The coatings produced possess a relatively high porosity and an insufficient strength of cohesion of the coating to the base and represent, as a rule, a porous conglomerate consisting of a metal and oxides. One method of elimination of the above drawbacks is the application of laser treatment [1]. Fusion by a laser beam makes it possible to measure out energy supply, whereas the character of the structure produced determines the quality of the hardened layer.

Computational Procedure. We consider two cases of a porosity change. In the first case, the change in the porosity of a coating with variation of the velocity of motion of a part relative to a laser beam for a constant power of the laser has been considered theoretically according to the procedure of [2]. In the second case, by increasing the diameter of the spot d, we have calculated the porosity for a constant power and for the velocity V of movement of a part relative to a laser beam with the use of the expression from [3].

Procedure of Experimental Investigations. Investigation has been carried out on ∅50 mm specimens from 40Kh steel. As the material for spraying, we employed self-fluxing alloy from PR-Kh4G2R4S2F powder of the following chemical composition (in %): Fe (83.1–87.6), B (3.3–4.3), Cr (3.5–4.5), Si (2.0–2.5), Mn (2.0–2.5), C (1.0–1.2), V (0.5–0.9), Al (0.05–0.5), and Cu (0.05–0.5). It was deposited on the surface by plasma spraying with the use of a UPU-3D unit with an IPN-160/600 power supply and a PP-25 plasmatron in the regime I = 250 A, U = 80 V, and P = 2 atm. The layer thickness was 0.6 mm.

Fusion was carried out with an LGN-702 continuous laser of power N = 800 W for a diameter of the laser-beam spot of $d = 1.0 \cdot 10^{-3}$ m with velocities of movement $V_1 = 0.83 \cdot 10^{-3}$ m/sec, $V_2 = 1.67 \cdot 10^{-3}$ m/sec, $V_3 = 3.33 \cdot 10^{-3}$ m/sec, and $V_4 = 5 \cdot 10^{-3}$ m/sec and an overlap coefficient of 0.8 with the aim of obtaining a single phase composition and prescribed properties throughout the thickness of the coating. For the second series of experiments we

[a]A. V. Luikov Heat and Mass Transfer Institute, National Academy of Sciences of Belarus, 15 P. Brovka Str., Minsk, 220072, Belarus; [b]Belarusian National Technical University, 65 F. Skorina Ave., Minsk, 220013, Belarus; [c]Taganrog Pedagogical Institute, 48 Initsiativnaya Str., Taganrog, 347926, Russia. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 77, No. 4, pp. 92–95, July–August, 2004. Original article submitted December 11, 2003.

also varied from $1.0 \cdot 10^{-3}$ m to $5.0 \cdot 10^{-3}$ m the diameter of the laser beam for the velocity of movement of a part relative to the laser beam V_2.

The porosity was investigated by the metallographic method on a Polyvar microscope (Reichert Company) with a ×200 magnification with an MOR-AMOZ semiautomatic image analyzer on transverse unetched metallographic sections and on the surface.

To study the microstructure we etched the microsections in a 5% alcoholic solution of picric acid and subsequently in a 5% alcoholic solution of nitric acid.

Results of Theoretical Investigations and Their Discussion. We consider the kinetics of buildup of the density of a sprayed layer with fusion of its surface. For this purpose we employ the kinetic equation [2]

$$\Delta F = F(\Pi) - F(\Pi_0) = (A_1 - A_2)\left(1 - \exp\left(-\frac{1}{\tau}\right)\right) P_{\text{layer}} \tau + A_2 P_{\text{layer}} t \,. \tag{1}$$

According to [2], the porosity function $F(\Pi)$ will be written in the form

$$F(\Pi) = \Pi - \ln \Pi \,, \tag{2}$$

and the quantity t/τ will be written as

$$\frac{t}{\tau} \approx \frac{d}{V\tau} \,, \tag{3}$$

where A_1 and A_2 are the kinetic constants of the process of baking of the layer; we have

$$A_i = A_{i0} \exp\left(-\frac{E_{ai}}{kT}\right). \tag{4}$$

Then Eq. (1) takes the form

$$\Delta F = C_1 \left(1 - \exp\left(-\frac{t}{\tau}\right)\right) + C_2 t \,. \tag{5}$$

It is noteworthy that we have taken the average temperature in the region of the coating layer as the sintering temperature $T \approx 1509$ K.

Next, we consider the second case where the diameter of the spot d increases for a constant velocity V of movement of a part relative to the laser beam and a constant power of the laser.

To study the kinetics of compaction we have taken the formula

$$\Delta F(\Pi) \approx A \exp\left(-\frac{E_0}{kT}\right) P t \tag{6}$$

as the basis of calculations. Here t/τ has been determined according to (3), and the approximate relation allowing for the diameter of the heat source

$$T \approx \frac{2 N_{\text{ef}}}{\pi \lambda d} + T_0 \tag{7}$$

is employed for calculation of the layer temperature. Now expression (6) takes the form

$$\ln[\Delta(\Pi)] = C_1 - \frac{C_2 d}{C_3 + T_0 d} + \ln\left(\frac{d}{v}\right). \tag{8}$$

The results of computations of porosity according to (8) and a comparison of them to experiment show that when C_1 = 1.79, C_2 = 1696.7, C_3 = 1.206, and $V_2 = 1.67 \cdot 10^{-3}$ m/sec they are different just for $d = 4 \cdot 10^{-3}$ m and are

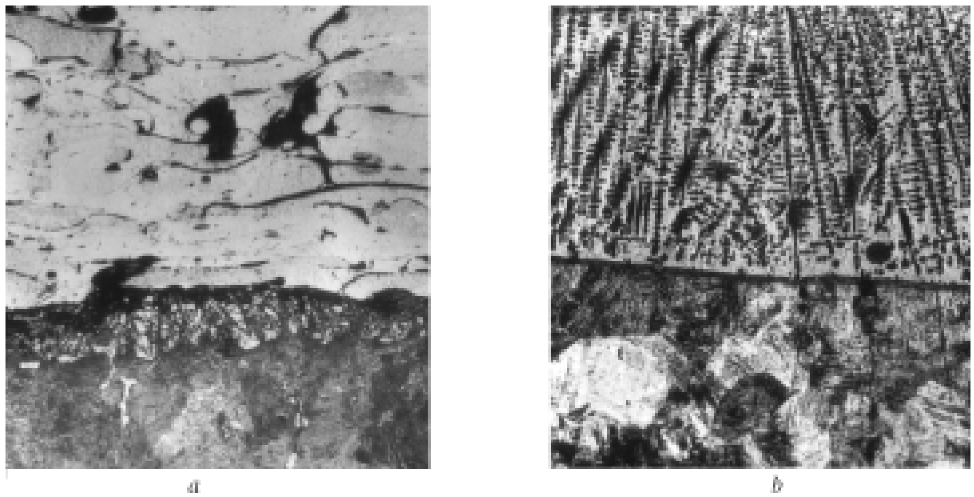

Fig. 1. Microstructure of coatings produced by spraying of PR-Kh4G2R4S2F powder without fusion (a) and with fusion for the velocity of motion of the part relative to the laser beam V_1 (b).

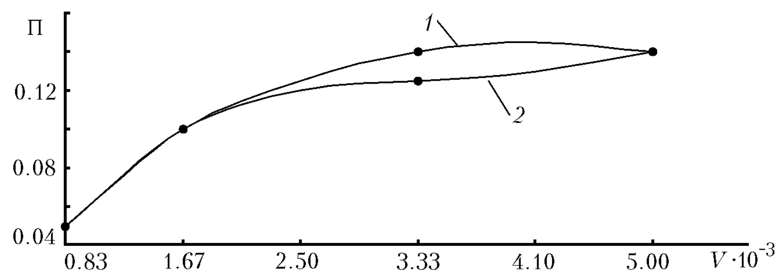

Fig. 2. Porosity of the fused coatings vs. velocity of motion of the part relative to the laser beam: 1) theory; 2) experiment. $d = 10^{-3}$ m, $C_1 = 0.48$, $C_2 = 1.046$, and $\tau = 0.057$ sec. V, m/sec.

$\Pi_{exp} = 0.14$ and $\Pi_{theor} = 0.15$, whereas for diameters of the laser beam of $1 \cdot 10^{-3}$, $2 \cdot 10^{-3}$, and $3 \cdot 10^{-3}$ m, and $5 \cdot 10^{-3}$ m they are the same and equal to 0.1, 0.11, 0.13, and 0.16 respectively. As we see, the results of the comparison of Π_{exp} and Π_{theor} are quite satisfactory.

Results of Experimental Investigations and Their Discussion. The quantitative analysis made has shown that the porosity of the coatings without fusion is maximum and attains 36–40%.

It is clear from the data given above that the porosity is affected by the velocity of movement of a part relative to the laser beam and by the diameter of the beam. The porosity is decreased by fusion of the coating by the laser beam. Varying the velocities of movement of a part relative to the laser beam, we obtain its different values. The porosity is the lowest for V_1. In this case a molten bath is formed on the coating surface; the bath, having an increased fluidity owing to the high temperature, streams to the substrate and dissolves powder particles lying below. Boron contained in the coating in combination with iron increases the fluidity of the melt. An additional amount of iron boride Fe_3B entering into the composition of the eutectic $\gamma Fe + Fe_3B$ is formed; the eutectic, freely moving between iron dendrites and crystallizing last ($T_f = 1200^oC$), "heals" the incipient pores and cracks, thus decreasing the tendency of the alloy toward pore formation and cracking.

The porosity increases with the velocity of motion of a part relative to the laser beam. The reason is that the eutectic $\gamma Fe + Fe_3B$ has no time to "heal" all the pores. As the diameter of the laser beam increases from $1.0 \cdot 10^{-3}$ m to $5.0 \cdot 10^{-3}$ m for the same velocity of motion of the part relative to the laser beam V_2, the porosity also increases. The reason is that the energy contribution decreases with increase in the spot diameter.

Figure 1 shows the structures of plasma-sprayed coatings without fusion and after laser fusion. Figure 2 gives theoretical and experimental dependences of the porosity on the velocity of motion of a part relative to the laser beam.

In the coatings after plasma spraying, we observe pores and flakings of the coating off the base, which indicates the insufficiency of the established chemical bonds. On the base surface immediately adjacent to the coating, we observe grinding of the structure.

The microstructure of the coatings fused by the laser can be characterized as a cast equilibrium structure with the axes of dendrites of first, second, and third orders. This indicates that the coating has stayed in the zone of laser irradiation for a fairly long time, and the elements have been redistributed in it. The hardening phase in the form of dendrites that are oriented at an angle of 45^o in the direction of heat removal threads the entire coating.

CONCLUSIONS

1. It has been established experimentally and theoretically that the porosity of gas-thermal coatings increases from 1 to 16% with the velocity of movement of a part relative to the laser beam and its diameter.

2. Satisfactory agreement between experimental and theoretical data has been obtained.

NOTATION

A_1, A_2, and A_i, kinetic constants of the process of baking of the layer; C_1, C_2, and C_3, effective averaged temperature in the 1st, 2nd, and 3rd cases; d, diameter of the laser-beam spot, m; E_{ai}, activation energy of the diffusion processes responsible for the baking of the ith subsystem of diffusion sources (i = 1, 2); ΔF, function of the kinematic law of compaction; $F(\Pi_0)$ and $F(\Pi)$, functions of the initial and final porosity; I, arc current in plasma spraying of the coatings, A; N, power of the LFN-702 laser unit, W; N_{ef}, effective power of the heat source (spot region), W; P, pressure of plasma-forming gases in spraying, atm; P_{layer}, external pressure on the layer, MPa; T_0, initial temperature in the region of the coating layer, K; T, average temperature in the region of the coating layer, taken as the sintering temperature, K; T_f, fusion temperature in the region of the coating layer, K; $t \approx d/v$, average time of baking in the region of the laser spot, sec; U, electric-arc voltage in plasma spraying, V; V and V_1–V_4, velocities of movement of a part relative to the laser beam; λ, thermal conductivity at $T_0 \approx 300$ K; Π, porosity of the coating; Π_0, initial porosity in the region of the coating layer; Π_{exp} and Π_{theor}, porosity of the coating, obtained experimentally and theoretically; τ, lifetime of the active (i = 1) subsystem. Subscripts: exp, experimental; theor, theoretical; layer, layer; ef, effective; f, fusion; a, activation; 0, initial value.

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