

THE DETERMINATION OF THE MELTING TIME OF THE PARTICLE BY SPRAYING IN THE PLASMA JET

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The quality of the deposited layers by spraying in the plasma jet is determined by several factors: the powder material and the surface of the base material, the thermo-physical properties of the material, the temperature of the particles, the particle condition at the interaction with the surface of the base material.

A basic element that influences the quality, constitutes the particles and especially the way of dosing in the plasma jet and the changes that occur [1].

The total period of particle maintaining in the plasma flow can be divided into the following steps:

1) The temperature increasing of the particle from the initial temperature up to the melting temperature.

2) The formation of a melted zone on the surface of the particle and penetration to the center of the particle. In this case two states of the particle are distinguished: the melted surface of the particle and the center of the particle in the solid state.

The goal is to determine the time of melting of the particle.

At the moment of impact (contact) with the base material, the particle must be completely molten.

The presence of the solid core in the particle leads to the formation of a layer with poor adhesion.

The overheating of the liquid particle, leads to the weight loss of the substance at evaporation.

The aim of the study is to determine the time of melting of the particle [2].

The whole process is divided into two stages: the heating and the melting.

Considering that the process is quite complicate due to plasma fluctuation and because it is not uniform and is unsteady, due to the presence of phase transformations, the dependance of the thermophysical parameters on the temperature, the irregular shape of particles; we can admit some simplifications [3].

1. The particle has a spherical shape

2. The heat flux on the surface of the particle is constant

3. The thermophysical parameters are constant and change at the phase transformations; and at the temperature ranges average values are used.

The energy equation for the particle is written as:

$$\frac{\partial T}{\partial x} = a \left(\frac{\partial T}{\partial R^2} + R^2 \frac{\partial T}{\partial R} \right) \quad (1)$$

where $\tau > 0$; $0 < R \leq R_0$
 Symmetric problem
 initial conditions

$$T(R, 0) = T_0 \quad (2)$$

we write the limit conditions as follows:

$$-\frac{\partial T}{\partial R}(R_0, \tau) + \frac{q_c}{\lambda} = 0 \quad (3)$$

where q_c - the heat flux on the particle surface (density) W/m^2

T_0 - initial temperature K

$\frac{\partial T}{\partial R}$ - the temperature gradient K/m

$$\frac{\partial T}{\partial R}(0, \tau) = 0 \quad \text{and} \quad T(0, \tau) \neq \infty \quad (4)$$

Equation (1) is solved by operational method [1] and we present it in the following way:

$$\begin{aligned} T(R, \tau) = & \frac{3}{R_0^3} \int_0^R R^2 T_0 dR + \frac{3\alpha}{\lambda R_0} \int_0^\tau q(\tau) d\tau \\ & + \sum_{n=1}^{\infty} \frac{2}{\mu_n^2 \cos \mu_n} \frac{\mu_n \sin \mu_n \left(\frac{R}{R_0}\right)}{RR_0} \exp(-\mu_n^2 F_0) \\ & \int_0^R RT_0 \frac{\sin \mu_n \frac{R}{R_0}}{\mu_n} dR \frac{\alpha}{\lambda} \sum_{n=1}^{\infty} \frac{2}{\mu_2 \cos \mu_n} \frac{\sin \mu_n \frac{R}{R_0}}{\mu_n} \\ & \exp(-\mu_n^2 F_0) \int_0^\tau q(\tau) \exp\left(\mu_n^2 \frac{\alpha \tau}{R_0^2}\right) d\tau \quad (5) \end{aligned}$$

Where μ_n - the roots of the characteristic equation $\text{tg} \mu = \mu$

T - temperature, K;

λ - conductivity coefficient W/mK ;

α - thermophysical coefficient m^2/s ;

q_c - heat flow W/m^2 .

The problem is solved in general way and we admit $T_0 = \text{const.}$ and heat flow $q_c = \text{const.}$ Then (5) can be written as:

$$T(R, \tau) = T_0 + \frac{q_c \cdot R_0}{\lambda} \left[\frac{3\alpha \cdot \tau}{R_0^2} - \frac{3R_0^2 - 5R^2}{10R^2} - \sum_{n=1}^{\infty} \frac{2}{\mu_n^2 \cos \mu_n} \cdot \frac{R_0 \cdot \sin \mu_n \frac{R}{R_0}}{R \cdot \mu_n} \exp\left(-\mu_n^2 \frac{\alpha \tau}{R_0^2}\right) \right] \quad (6)$$

When $\tau > \tau_0$ some values can be ignored in considerations that do not influence the final result and (6) is written as:

$$T(R, \tau) = T_0 + \frac{q_c \cdot R_0}{\lambda} \left[\frac{3\alpha \cdot \tau}{R_0^2} - \frac{3R_0^2 - 5R^2}{10R^2} \right] \quad (7)$$

Time of the first stage can be determined from equation (7) introducing $R=R_0$ and admitting the values $T=T_n$ on the particle surface [4].

Determining the melting time of the particle, from the equation (1) we present it for a system of two spherical bodies [5].

The goal is to determine the spread of temperature in the sphere-sphere system.

ξ - the coordinate of the solid- liquid phase transformation

The equation in this case can be presented as:

$$\frac{\partial T_i}{\partial \tau} = a_i \left(\frac{\partial T_i}{\partial R^2} + \frac{2}{R} \cdot \frac{\partial T_i}{\partial R} \right) \quad (8)$$

where i- ventral sector (core) in the solid state.

α - the particle surface the liquid state

$$\begin{aligned} 1- \tau > 0 & \quad 0 < R < \xi \\ 2- \tau > 0 & \quad \xi < R < R_0 \\ T(\xi, \tau) &= T_{mn} - \text{constant} \end{aligned} \quad (9)$$

$$\lambda_2 \frac{\partial T}{\partial \lambda} (R_0, \tau) = q_c \quad (10)$$

where q_c - the energy flux density which contacts with the surface of the particle W/m^2 ,

The solution for the liquid peripheral sphere can be shown in equation (7) where thermophysical parameters are allowed for the liquid phase.

At the borders of liquid and solid phase, the equation of energy conservation can be written as:

$$\lambda_2 \frac{dT_2}{dR} \Big|_R + \frac{dT_1}{dR} \Big|_R = L \cdot \rho \cdot \frac{d\xi}{d\tau} \quad (11)$$

where L - the latent heat of melting of the solid particles J/kg .

ξ - melting zone, m

For solid phase the limit conditions for equation (8) admitting first-degree (9)

When $T(\xi, \tau) = T_{nno}$

The solving is known generally [2] and can be written in the following way:

$$\frac{T_2(R, \tau) - T_{nn}}{T_0 - T_{nn}} = \sum_{n=1}^{\infty} A_n \frac{\xi \sin \mu_n \frac{R}{\xi}}{R \cdot \mu_n} \cdot \exp(-\mu_n^2 F_0) \quad (12)$$

We use the first member of equation (12)

$$\frac{T_2(R, \tau) - T_{nn}}{T_0 - T_{nn}} = \frac{2R_0 \sin \mu_1 \frac{R}{\xi}}{\mu_1 \cdot \xi} \exp(-\mu_1^2 \cdot F_0) \quad (13)$$

Permeation rate of the melted zone in the spherical particle can be determined solving equations (7), (11), (13).

We admit that heating and melting of the particles occurs without loss and the heat transfer coefficient is a complex value which includes heat transfer through convection and radiation. Then the time of melting can be presented as:

$$\tau_{nn} = \frac{4 \pi R_0^3 \rho \cdot [c(T_{nn} - T_0) + L]}{9 (\alpha_{efec} - \alpha_{rad})} \cdot \left(\frac{1}{\alpha_{efec}} + \frac{R_0}{2\lambda_2} \right) \quad (14)$$

Solving (14) is suitable for the heat transfer processes when changing the state of aggregation.

Solving the problem more accurate leads to a groundless complication.

For engineering calculations the equation is quite appropriate.[6]

T_n - the temperature of the plasma jet.

The flow of the heat from the radiation is determined by Stefan-Boltzmann equation.

$$E = \varepsilon \cdot \zeta \left(\frac{T_n^4}{100} - \frac{T_m^4}{100} \right).$$

The effective value of the heat transfer can be written in the following way:

$$\alpha_t = \alpha_k + \frac{\varepsilon \cdot \zeta \left(\frac{T_n^4}{100} - \frac{T_m^4}{100} \right)}{T_n - T_m}$$

Preparing the surfaces for the formation of resistant coatings

The adhesive strength of the layer to the surface of the base material, depends on the mechanical linkages of the particles and physicochemical interaction between the roof and the base. The increasing of the adherence force is obtained through a preventive processing of the base surface. It has been shown that the maximum adhesion is achieved if the particles of the base surface after processing and the particles of the powdered material are approximately equal. This requirement is achieved if the surfaces are processed with air jet and abrasives, forming a proper roughness. All specimens examined at the adhesion and corrosion resistance and pump assemblies were processed with air jet and abrasives.

The coating was made with ПС-12НБК-01 powder. The plasma forming consists of argon gas and nitrogen in a proportion of 4/1. The distance to

the roof formation is 120-200 mm.

The results are shown in Figure 1.

The research has shown that the strength of joining the roof (polished samples) to the coating distance of 160 mm, is about four times less than in specimens processed with sand and air jet and is 2.92 MPa and 12.3 MPa, respectively. The maximum adhesive strength was obtained for the steel 3 specimen (figure 1 curve 4) and is 15 MPa, for the given coating distance; 14.1 MPa for the 12X1810T stainless steel (Figure 1 curve 3). The rated current is $I=350A$ și $U=45V$

The adhesion testing of the layers made up of powders of Al_2O_3 based on the titanium alloy 3M are shown in (Figure 2).

The adhesive strength of Al_2O_3 layer to the base surface which has been processed by polishing and oxidized at a coating distance of $l = 160mm$ is 4.0MPa (Figure 2 curve 1). The base surface processed with the air jet and quartz sand, afterwards covered with Al_2O_3 has an adhesive strength of 5.2 MPa (curve 2 Figure 2). The base surface which has been processed with air jet and sand but has not been oxidized has an adhesive strength of 6.7MPa (Figure 2, curve 3).

The research results confirm that the preventive processing of the specimens surfaces, before coating, contributes to the increasing of the adherence strength 1.5-2.0 times, compared to the smooth surface which was not processed with air and sand (abrasives). Therefore, the processing with air jet and abrasives, constitutes an obligatory technological process.

Choosing the optimal regimes for the roof formation resistant to wear

Previously was noted that the resistance adhesion of the roof to the base material or to the intermediate layer, depends on several factors: firstly depends on the plasma forming (gas), the composition of fractional powders and materials from which it is constituted, the distance coating, pressure and intensity values.

When processing the coating technology to a fixed installation with a plasma-forming gas, the coating regime selection consists in determination of the optimal distance for each powder material and the current rate. This selection must provide the particles melting during the plasma jet.

The adhesive strength and high density of surfaces is obtained when the roof is made of completely melted particles of powder material. The coating regime is chosen preventively after the powders become melted on the surface of a glass. The molten particle, reaching the glass trickles on its surface. The coating regime is finally chosen

depending on the adhesive strength of the powdery material to the base material.

The adhesive strength was checked on special specimens with the adhesives method [1]. The coating specimens were made of materials widely used in construction of electric pumps, 12X18H10T stainless steel, titanium alloy 3M, carbon steel 3. When forming layers on the base material, an intermediate layer is created if the coefficient of linear expansion of the roof differs substantially from the coefficient of expansion of the base material. The properties of the intermediate layer are close to the properties of the base material. For certain bulk materials used in forming coatings, the intermediate layer increases the strength of the adhesion. The research has shown that at the coating formation from the powders ПС-12HBK-01 on the base material of carbon steel 3 with the intermediate layer ПТ-НA-01, the adhesive strength for the coating distance of 180 mm distance constitutes 16.2 MPa (Figure 3 curve 5).

The adhesive strength is 5.8 MPa lower and constitutes 10.4 MPa for the roof from the same powdered material, type ПС-12HBK-01 without an intermediate layer on the base material of steel 3 (Figure 4 curve1). The component of the intermediate layer has much influence on the strength of adhesion. When forming the roof of 90% Al_2O_3 + 10% Al, based on 12X18H10T stainless steel, two intermediate layers ПТ-НA-01 and ПН85Ю15 were checked.

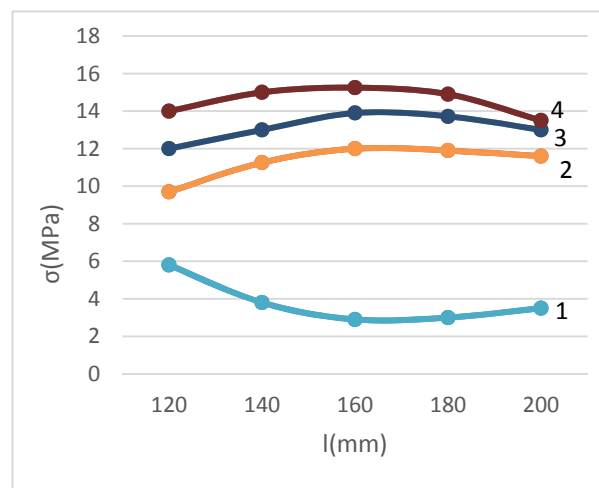


Figure 1. The dependence of the adhesion resistance of the roof formed by plasma jet on the distance forming the roof ПС-12 HBK-01: 1- base-material - 3M titanium alloy, prior to coating, the surface was polished up to $1.25 \mu m$; 2-3M base material, was processed preventively with air jet and sand; 3- The base material 12X18 H 10 T, processed with air jet and quartz sand; 4- the base material carbon steel 3, processed with air jet and quartz sand.

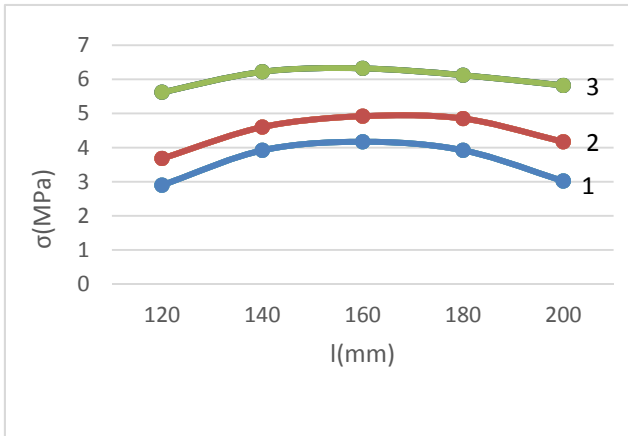


Figure 2. The influence of specimens processing before coating through the plasma jet, the adhesive strength: 1. basis - 3M alloy, before coating the surface was polished and oxidized. The roof consists of Al_2O_3 ; 2. Basis - 3M alloy prior to coating was processed with sand and oxidized. The roof consists of Al_2O_3 ; 3. Basis- 3M alloy, prior to Al_2O_3 coating, the surface was processed with air

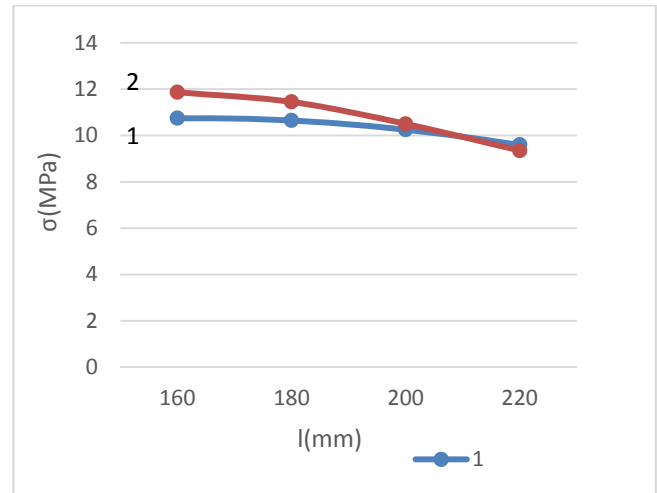
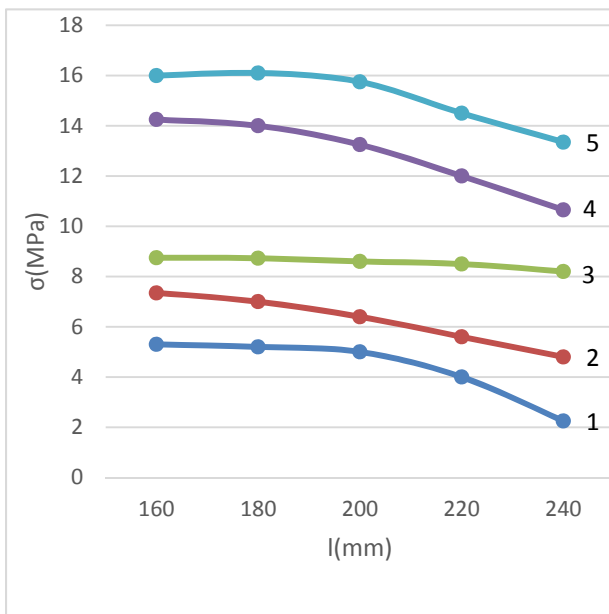


Figure 4. The dependence of the adhesive strength on the coating distance and on the base material: 1- The roof- ПС-12НБК-01 on steel 3 without intermediate layer; 2. The roof 50% TiC+50%ПН55Т45 on 3M titanium alloy without intermediate layer.



and sand. Oxidation has not been spent.

Figure 3. The dependence of the adhesive strength of the roofs: ПС -12- НБК-01 and СГ-Т (II) with the intermediate layer ПТ-НА-01, on the distance roof formation from: 1.- Base material- 3M titanium alloy with the roof СГ-Т (II); 2.- Base material Carbon steel 3 with the roof СГ-Т(II); 3.- Alloy 3M with the roof ПТ-19Н- 01; 4.- 12Х18Н10Т steel with the roof ПС 12- НБК- 01; 5.- steel 3 with the roof ПС 12 -НБК-01.

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