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A. Nota de constatare şi confirmare a indiciilor de plagiat prin fişa suspiciunii inclusă în decizie.

Fişa suspiciunii de plagiat / Sheet of plagiarism's suspicion	
Opera suspicionată (OS) **Suspicious work**	**Opera autentică (OA)** **Authentic work**
OS	PETRESCU, Doina; Niculae Napoleon ANTONESCU; Marian NEACŞU. Experimental investigations concerning the mathematical model of hard deposits by high-speed flame spraying. *The annals of University "Dunărea de Jos" of Galaţi. Tribology*. **14**(8). 2008. p.87-92. ISSN 1221-4590.
OA	PETRESCU, Doina; Niculae Napoleon ANTONESCU; Juan Alberto CALERO. The simulation of the dynamic processes at the thermal spraying of the Cr3C2-NiCr powder particles with high-speed flame. *Buletinul Universităţii Petrol – Gaze din Ploieşti. Seria Tehnică*. **59**(1). 2007. p.99-106.
Incidenţa minimă a suspiciunii / Minimum incidence of suspicion	
p.87:13d - p.88:13	p.99:01 – p.99:04
p.88:07s - p.88:13s	p.99:09 – p.100:02
p.89:04s – p.91:08s	p.102:01 – p.105:06
p.91:07d – p.92:06s	p.105:13 – p.106:14
p.88: Table 1	p.99: Tabel 1
p.88: Table 2	p.100: Tabel 2
p.88: Fig. 1, Fig. 2	p.101: Fig.1, Fig.2
p.89: Fig.3, Fig.4	p.102: Fig.3, Fig.4
p.89: Fig.5, Fig.6	p.103: Fig.5, Fig.6
p.90: Fig.7, Fig.7	p.104: Fig.7, Fig.8
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Note: By „p.72:00" one understands the text ending with the end of the page 72. By „p.00:00" one understands the taking over from the initial point till the last page of the current chapter, entirely.

B. Fişa de argumentare a calificării de plagiat alăturată, fişă care la rândul său este parte a deciziei.

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Notă:

a) Prin „provenienţă" se înţelege informaţia din care se pot identifica cel puţin numele autorului / autorilor, titlul operei, anul apariţiei.

b) Plagiatul este definit prin textul legii[1].

> „ …*plagiatul – expunerea într-o operă scrisă sau o comunicare orală, inclusiv în format electronic, a unor texte, idei, demonstraţii, date, ipoteze, teorii, rezultate ori metode ştiinţifice extrase din opere scrise, inclusiv în format electronic, ale altor autori, fără a menţiona acest lucru şi fără a face trimitere la operele originale…*".

Tehnic, plagiatul are la bază conceptul de **piesă de creaţie** care[2]:

> *„…este un element de comunicare prezentat în formă scrisă, ca text, imagine sau combinat, care posedă un subiect, o organizare sau o construcţie logică şi de argumentare care presupune nişte premise, un raţionament şi o concluzie. Piesa de creaţie presupune în mod necesar o formă de exprimare specifică unei persoane. Piesa de creaţie se poate asocia cu întreaga operă autentică sau cu o parte a acesteia…"*

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> *i) Cele două opere tratează acelaşi subiect sau subiecte înrudite.*
> *ii) Opera autentică a fost făcută publică anterior operei suspicionate.*
> *iii) Cele două opere conţin piese de creaţie identificabile comune care posedă, fiecare în parte, un subiect şi o formă de prezentare bine definită.*
> *iv) Pentru piesele de creaţie comune, adică prezente în opera autentică şi în opera suspicionată, nu există o menţionare explicită a provenienţei. Menţionarea provenienţei se face printr-o citare care permite identificarea piesei de creaţie preluate din opera autentică.*
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> *vii) In opera suspicionată se identifică un fir sau mai multe fire logice de argumentare şi tratare care leagă aceleaşi premise cu aceleaşi concluzii ca în opera autentică…"*

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[1] Legea nr. 206/2004 privind buna conduită în cercetarea ştiinţifică, dezvoltarea tehnologică şi inovare, publicată în Monitorul Oficial al României, Partea I, nr. 505 din 4 iunie 2004

[2] ISOC, D. *Ghid de acţiune împotriva plagiatului: bună-conduită, prevenire, combatere*. Cluj-Napoca: Ecou Transilvan, 2012.

[3] ISOC, D. *Prevenitor de plagiat*. Cluj-Napoca: Ecou Transilvan, 2014.

Paper presented at

ROTRIB '07
10th International Conference on Tribology - November 8-10, 2007
Bucharest, Romania

EXPERIMENTAL INVESTIGATIONS CONCERNING THE MATHEMATICAL MODEL OF HARD DEPOSITS BY HIGH-SPEED FLAME SPRAYING

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ABSTRACT

A complex study was done by the paper's authors using some independent models that take into account the combustion process, the particles' dynamics, the fluid dynamics and also the particle fluid transfer processes when they take place during the high-speed flame thermal spraying. In order to realize this study it has been started by a documentation of actual researches concerning the processes that take place in the combustion chamber.

In the present paper there were studied: the fluid parameters, the determination of the speed and fluid temperature values (the mixture formed from the particles and the combustible fluid fuel) taking into account the characteristic points that exist on the particle route, the particle-fluid moment transfer, the heat transfer, the mass transfer during the thermal spraying.

Keywords: modulation, hard coatings, high-speed flame, wear resistence.

INTRODUCTION

The high-speed flame deposit technology (HVOF) is based on utilization as powder containing agent of the hot gases (whose flow speed is of 1.5m/s, at a pressure a little higher than the atmospheric one) [4, 11, 13]. The powder particles during the spraying process suffer only just a softening, they do not melt, thus assuring a diminished oxidation and a minimal modification of the chemical composition in the deposited layer.

Using this procedure, in the deposited layer, there often appear compressive pressures that offer the guaranty of a good adhesion and an increased resistance to fatigue, even in the case of high pressures [1, 2, 3].

The high-speed flame deposit process is characterized by [11, 12, 13]: the low powder oxidation level, high productivity, as 9 kg/h, the thermal sprayed part does not suffer significant distortions, a very good adhesion of the thermally sprayed layer on the sub-layer, simple operation of the depositing installation, the interconnection between different elements is very easy done because it was built in order to be almost impossible to make a wrong connection; the deposits' costs are reduced in comparison to other deposits obtained by thermal spraying procedures; the layers deposited with this procedure have a good quality (there are dense and have a reduced porosity); the bond between the deposited layer and the sub-layer is strong; a high value for the hardness of the deposited layer, thus providing a good behavior to the wear.

THE PARAMETERS OF THE FLUID THERMAL SPRAYED WITH HIGH-SPEED FLAME

The thermal problem and the mechanical one have solution by the help of the algorithms described in [1, 2, 11]. For the mathematical simulation it will be considered the following reaction that takes place in the pistol combustion chamber:

$$C_3H_8 + 5O_2 \Rightarrow 4H_2O + 3CO_2 \qquad (1)$$

The combustion products properties (viscosity, density, specific heat, thermal conductivity) used for determining the fluid parameters are obtained as average values. There were calculated the fluid speed and the temperature following the points established in the paper [12].

The spherical particles have the dimension R_p between 10 µm and 60 µm. The properties of the studied powder that takes part in the simulation are presented in table 1. It is considered that the presence of the carbon in the Ni-Cr metal stage does not decisively influence the thermal and physical properties, and thus its influence is negligible.

Table 1. Powder properties.

Properties	Ni	Cr	Cr_3C_2	Cr_2O_3
Density, [kgm^{-3}]	8 900	7 190	6 600	5 210
Specific heat [$Jkg^{-1}K^{-1}$]	471	460	300	880
Thermal conductivity [$Wm^{-1}K^{-1}$]	83	67	95	22
Thermal diffusivity [$10^{-5}m^2s^1$]	1.98	2.03	4.80	0.48
Latent fusion heat [10^6Jkg^{-1}]	0.3	0.27	-	-

Table 2. Fluids parameters in the critical points.

Fluids parameters	Point 1	Point 2	Point 3
Speed [ms^{-1}]	312	305	550
Temperature [^oC]	2 771	2 600	2 165
Pressure [bar]	3.37	2.50	1.0

The calculated values of the fluid speed, the temperature and the pressure in the critical points for the projection system with high-speed flame (fig. 1) are presented in table 2.

The fluid speeds and temperatures, in relation to the projection distance are calculated by interpolation. The calculus results as the particle speed in relation to the spraying distance, spreading time and particle diameter are presented in figures 1 and 5.

THE MECHANICAL BEHAVIOUR OF THE PARTICLE

In the projection with high-speed flame process, the particles speed from the spraying jet v_p is maximal in the direction of the sub-layer projection and then it decreases with the projection distance. The particles speed from the spraying jet decreases with the increase of the particles' diameter d_p. When the diameter d_p increases, the maximum speed $v_{p,max}$ corresponding to the foreseen diameter will decrease and will go towards the layer. That is why the particle with the highest diameter d_p varies the most uniformly with the speed along the projection distance. The $v_{p,max}$ value when it increases, leads to the increase of the volumetric fraction of chrome carbide and of the volumetric fraction of chrome oxide because these stages have smaller densities in relation to the metal phase.

The maximal speed corresponding to the position z_m is that of going out from the spraying pistol. A very important data for the high-speed projection system is the projection speed v_p to the recommended projection distance $L_s=z-L$, in this case $L_s=0.3$ m from the evacuating orifice of the high-speed flame spraying pistol. Also, it is important the spraying time of the particle, *t*. Experimentally, there were realized projections for recommended distances between 0.2 m and 0.4 m from the pistol out going.

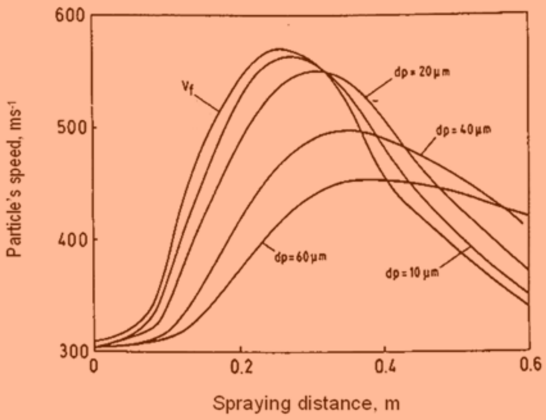

Fig. 1. Variation of the projection speed of the thermal with projection distance spraying particles.

The results are in relation to the obtained adherence by recovering and depend on the mass transfer that may take place during the spraying. The obtained adherence is essentially proportional to the existent pressure difference between the combustion chamber and exterior. This pressure difference depends on the particle speed, especially on the discharge to the highest density and on the fluid speed.

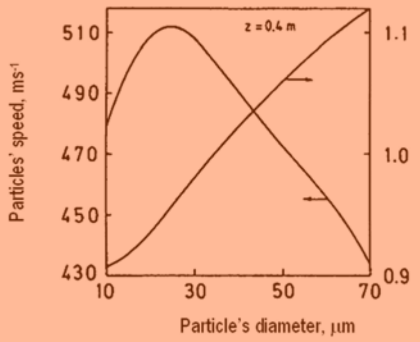

Fig. 2. Variation of the maximal speed of the thermal spraying particle and of the distance spraying time z=0.4 m depending on the particle diameter.

In figure 1 it may be noticed how the maximum of the fluid and particle speed, obtained as a result of using the mathematical model, is met in the range from 0.1m to 0.2 m. Figure 2 shows how the speed v_p initially increases as a result of the fluid acceleration, reaching the maximum value when $d_p=25$ µm and then it decreases as a result of the particle dimension increase. The spraying time increases with the particle diameter.

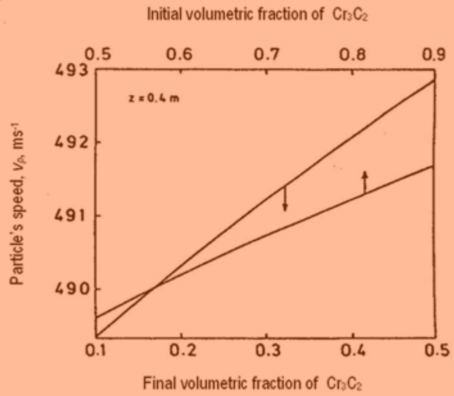

Fig. 3. Variation of the particle's speed at z=0.4 m depending on the initial and final volumetric fractions of chrome carbide Cr_3C_2.

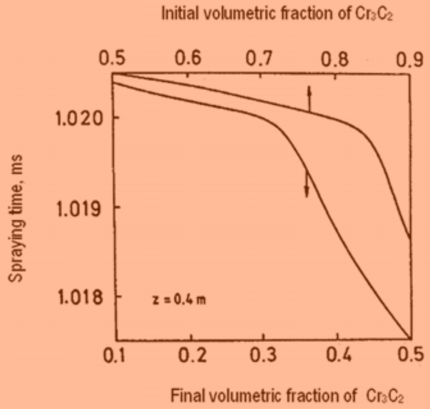

Fig. 4. Variation of the thermal spraying particle time depending on the initial and final volumetric fractions of Cr_3C_2.

The particle speed v_p increases with the increase of the final volumetric chrome carbide fraction (fig. 3). This speed increases with the final volumetric chrome oxide fraction. Both tendencies take place as a result of the fact that the oxide and the chrome carbide have greater densities than nickel and chrome in metallic phase. The thermal spraying time of the particle decreases during the increase of the volumetric chrome carbide fraction ε and the initial volumetric chrome carbide fraction ε_0 (fig. 4).

THE PARTICLE THERMAL BEHAVIOUR

Because of the heat and materials scattering coefficients that constitute bigger particles (without taking into account the chrome oxide which is present in a small quantity), the temperature variation inside the particle is in a narrow range. That is why it is considered only the temperature of the particle surface.

As it may be noticed in figure 5, during the high-speed flame spraying process the powder particles reach the fusion temperature of the NiCr metallic phase. During the fusion, the particle temperature slowly increases as a result of the fusion latent heat absorption. After this fusion, the particle temperature T_p rapidly increases reaching its maximal value $T_{p,max}$ in z=z_m and then it decreases. When it is reached the liquid temperature from the metallic phase the solidification starts and the particle temperature slowly decreases, this significant decrease of the fluid temperature taking place as a result of the latent heat loss. Once the solidification is finished, the particle rapidly cools. The heating of the particles with large diameter is relatively small. When increasing the particle diameter, the maximum temperature of the particles T_p goes towards the sub-layer surface.

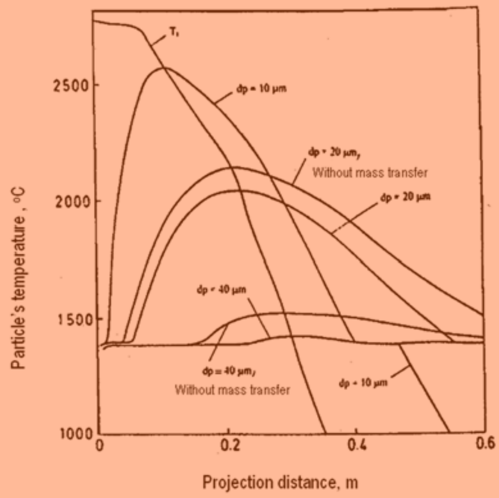

Fig. 5. Variation of the particle superficial temperature depending on the projection distance.

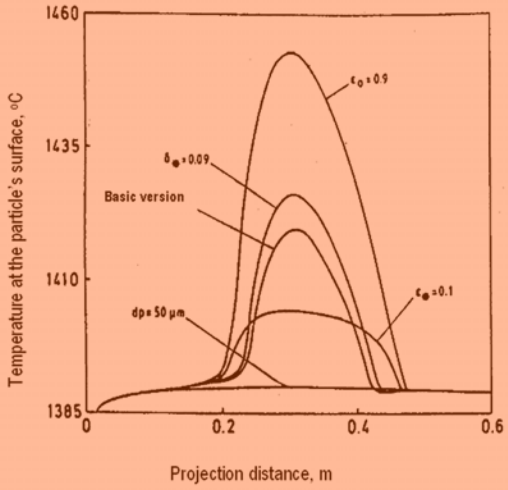

Fig. 6. Influence of the mass transfer process on the particle superficial temperature depending on the projection distance.

If it is not taken into consideration the carbide decomposition process, the thermal diffusivity of the particles is bigger than in the opposite case and that is why the particle reaches a higher temperature. Also, the carbides and oxides proportions have a great influence in recovering as it may be noticed in figure 6; at the increase of the carbides' initial content, ε_0 – the initial volumetric chrome carbide fraction, the particle temperature increases and determines an increase of the particle thermal diffusivity.

It is more complex the situation when the final volumetric carbide fraction ε decreases. On the other hand, the decrease of ε supposes an increase of the decomposition suffered by the carbides and that involves a decrease of the particles' thermal diffusivity and an increase of the temperature. Also, it involves a decrease of the particle speed as a result of the density increase that leads to the size of the stationary time interval where the fluid temperature is high. On the other hand, the decrease of the particle speed provokes, in turn, a decrease of the heat transfer coefficient α between the particle surface and the fluid ε.

The competence between these two factors will provoke the evolution of the particle temperature when the carbide final volumetric fraction ε decreases. First, the particle temperature is superior to that corresponding to the basic situation, when ε=0.3. Then, it occurs the situation opposite to the initial one, of cooling before solidification in the final moments. The increase of the chrome oxide final volumetric fraction δ leads to the decrease of the particles thermal diffusivity and of their density. This involves an increase of the particles' speed and the increase of the heat transfer coefficient α. When this factor is prevailing, the temperature of the particle increases. This situation is presented in figure 6. The temperature of the particles with large diameter, d_p=350 µm, varies slowly. As important as the mechanical behaviour for the high-speed flame projection process, there are the knowledge of the temperature maximal values $T_{p,max}$ and the longitudinal co-ordinate z_m where the particle arrives and also the temperature that a particle has to this projection distance.

In the thermal sprayings experimentally realized at distances z=0.2 m, z=0.3 m and z=0.4 m there are not observed significant differences among the decomposing thermal processes. In figures 5 and 6 it is presented how the maximal temperature $T_{p,max}$ for the particles with diameters between 20 µm and 40 µm depends on the projection distance that is approximately from 0.2m to 0.3m from the out going of the spraying pistol. The superheating of the small particles that justifies an increase of the porosity for smaller projection distances without taking into account the main factor of the porosity increase constitutes the decrease of the particles' speed, the decrease of the particles' kinetic energy. This effect is strictly related to the increase of the spraying distance.

The temperature value $T_{p,\ max}$ increases with the initial temperature of the particle T_{p0} with the chrome carbide initial volumetric fraction ε_0 and with the chrome oxide final volumetric fraction δ. The maximal temperature of the particle decreases when the chrome carbide volumetric fraction increases. The parameter z_* decreases in the same time as the chrome oxide final volumetric fraction δ does, it increases with the particle initial temperature T_{p0} and ε_* behaves non-uniformly with the chrome carbide volumetric fraction ε_0 reaching its maximal value when ε_0~0.82.

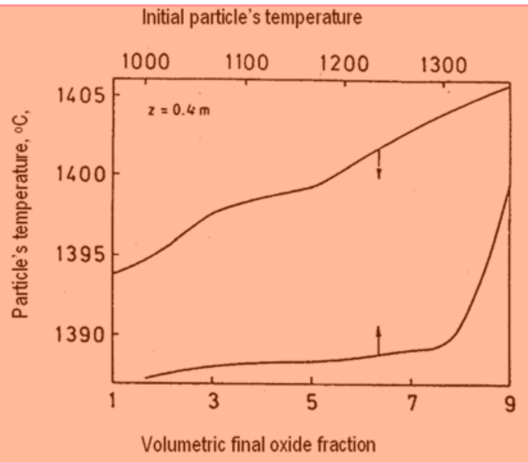

Fig. 7. Variation of the particle temperature at z=0.4 m depending on the final volumetric fraction of Cr_3C_2.

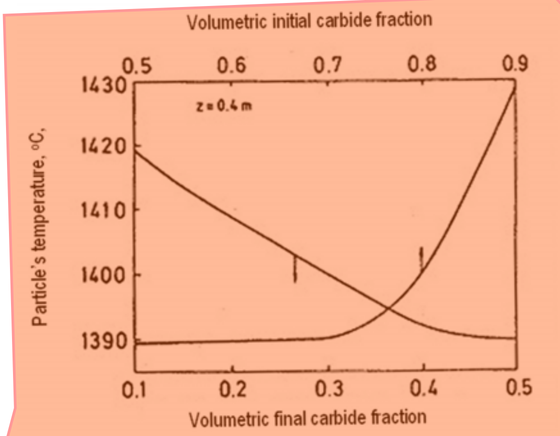

Fig. 8. Variation of the particle's temperature at z=0.4 m depending on the initial and final volumetricfractions of Cr_3C_2.

Figures 7 and 8 show how the temperature T_{p*} at a projection distance of 0.3 m from the out going of the spraying pistol increases with the parameters T_{p0}, δ, ε_0 and decreases with ε_*.

From the experimental point of view, the variation T_{p*} that depends on the particles' diameter d_p is very important and it may be observed how the temperature T_{p*} decreases when the chrome carbide dissolution takes place and when the projection distance increases. For the already described experimental results it seems obvious that the projection conditions are better when the spraying distance decreases considering the thermal point of view when the difference between the temperatures T_{p*} that correspond to different diameters of the particles in a particles' dimensions distribution interval is not very stressed there may obtained recovering better layers, then a better superheating and a better porosity.

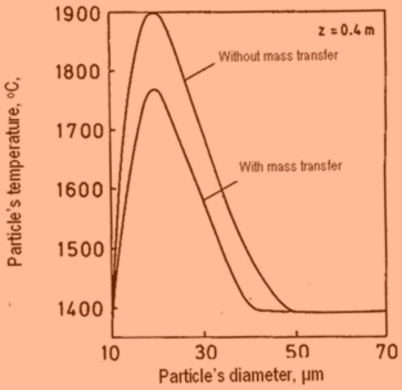

Fig. 9. Variation of the particle's temperature depending on its diameter (*z*=0.4 m).

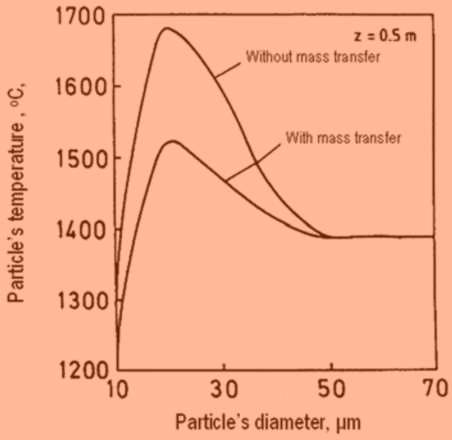

Fig. 10. Variation of the particle's temperature depending on its diameter (*z*=0.5 m).

If there are analyzed figures 10 and 11 from this final criterion, there will be obtained well spraying conditions when the distance from the out going of the pistol nozzle to the biggest layer. It may be also mentioned the fact that the projection distances' size from the mechanical point of view will substantially decrease the particles' speeds, provoking a sharp increase of the porosity if the mechanical factor prevails on the thermal factor, for this case.

Considering the same figures 9 and 10, it may be noticed that in the processes of mass transfer among the powder particles it results a difference of a much better temperature T_{p*} and the range of the particle optimal diameters is small. It results that for any distances there are taken into account the optimal thermal conditions and the distribution of particles' dimensions. For example, for L_s=0.4 m, the spraying optimal conditions include:

d_p=11…12 μm to d_p=34…44 μm;
ε_0=0.7…0.9; ε_*=0.10…0.45;
δ_*=0.02…0.08 and T_0=1320…1360ºC.

CONCLUSIONS

- There was realized a mathematical simulation in order to describe the dynamic processes that take place during the thermal spraying of the powder particles composed of metal matrix and phases with high point to fusion (in this case, the chrome carbide). In this model there are taken into consideration the combustion processes, the particles' dynamics and the fluid (inside and outside the spraying jet) and also the mass and heat transfer processes.
- At the increase of the chrome carbide and chrome oxide volumetric fraction, the maximal speeds that particles reach and the position in which these speeds are obtained go towards the out going of the thermal spraying pistol.
- The speed of the particles at recommended projection distance (L_s=0.3 m) varies depending on the size function and the powder particles' diameters. First, it increases till reaching its maximal value v_{max} for $d_p \geq 25$ μm and then it decreases. Also, this speed increases when the chrome carbide final volumetric fraction decreases and the chrome oxide final volumetric fraction increases. The particles' spraying time increases with the diameter and decreases with the initial and final chrome carbide volumetric fractions.
- The particle temperature increases, reaching its maximal value and decreases with the size of the spraying/projection distance. During metallic phase fusion and solidification the temperature slowly varies, as a result of latent heat absorption and desorption. The carbide decomposition causes the decrease of the particle temperature.
- The particle temperature increases with the chrome carbide initial volumetric fraction and chrome oxide final volumetric fraction. The decrease of the chrome carbide final volumetric fraction leads to the decrease of the particle temperature in the total fusion region, while in the anterior and posterior regions it increases.
- The maximal temperature of the particle increases with the initial particle temperature, with the chrome carbide initial volumetric fraction and with the chrome oxide final volumetric one. This maximal temperature decreases when the chrome carbide final volumetric fraction increases. The chrome carbide final volumetric maximal position increases with the initial temperature of the particle and with the chrome oxide final volumetric fraction.
- The particle temperature for the distance (L_s=0.3 m) in the sub-layer increases with the initial

temperature of the particle, with the chrome carbide initial volumetric fraction and the chrome oxide final volumetric one and decreases with the chrome carbide final volumetric fraction. If the thermal spraying distance modifies from L_s=0.3 m to L_s=0.4 m, the particle temperature decreases.

- The process of heat transfer among powder particles allows the increase of the diameters interval for particles. This situation is only possible when the spraying distance changes from z=0.4 m to z=0.5 m. Thus, when z=0.4 m the preferred diameters interval is from d_p=11…12 µm to d_p=34…44 µm, while for z=0.5m the preferred diameters interval is from d_p=14…19 µm to d_p=26…46 µm.

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