International Journal of Emerging Engineering Research and Technology
Volume 4, Issue 9, September 2016, PP 1-7
ISSN 2349-4395 (Print) & ISSN 2349-4409 (Online)

Thermal Field of Basic Material in the Process of Coating Formation by Thermal Application

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ABSTRACT

Paper presents the latest knowledge acquired in the process of the coating formation applying by the thermal spraying. This effect has been studied from the point of the thermal effect on the base material from the side of the coating. Provided are the results of the solution gained by the mathematical numerical methods application, particularly Finite Elements Method. The separate part of the paper represents the simulation of the thermal effect on the base material in the area of microstructure of the applied coating. The information's acquired from the cooling time determination of the ceramic particle with the dominant proportion of Al2O3 are presented. The cooling time differs due to various shape and mass of particles. The cooling time of particle with diameter approx. 70 μm and the average thickness of approx. 15 μm reach up to 0.8 sec after its individual impact on the basic material.

Keywords: thermal application, coating, thermal field.

INTRODUCTION

The technology of thermal spraying (in particular plasma one) enables the application of practically all technically usable materials having the suitable properties, shape and size of particles, both metal and ceramic ones. Using this technology, it is possible to create the layer with good adhesion, characterised with specific properties, such as high hardness, abrasion-resistance, resistance against wearing and tearing at normal and increased temperatures, resistance against corrosion or cavitation, on the base material.

The great majority of applied additive materials is on ceramic basis. These are ceramic materials, the dominant portion of which is Al_2O_3 [1-3].

The present papers analyse the new knowledge obtained in the process of coating formation by thermal plasma spraying from the point of view of thermal influence of the base material from the side of the coating. When investigating, numerical mathematical methods based on the final element method [4] are used.

THERMAL THERMAL PLASMA SPRAYING

Plasma spraying is one of the most progressive technological processes of coating application [5-7]. The coatings applied using the given technology are used in many fields of industry and they enable the increase of the scope of application, working characteristics, as well as the operation life of the products of various specifications [8-10]. The plasma application of coatings has certain advantages over the other application technologies. One of them is that in the case of plasma application of coating onto the base material it comes to its negligent thermal influence.

For plasma spraying, the recognized limiting value of thermal influence of the base material is temperature 120 – 300 °C [1]. Some authors state this spread up to 400 °C.

Thermal Influence of Base Material in Plasma Application of Coatings using Final Element Method

In addition of the investigation of thermal field in three base materials (steel, copper and duralumin), thermal influence of the base material from the point of view of material microstructure was investigated. For this numerical experiment, steel with temperature of 23 °C was selected as the base material. The ceramic material was alpha modification of corundum Al_2O_3 with the supposed temperature of 2050 °C. The investigation should have:

- Determined the depth at which the coating shall cause the heating of the base material to the temperature of ca 400 °C,
- Determined the impact of the microgeometry of the base material surface on the distribution of thermal field in it, and
- Determined the time of ceramic material particle cooling down to temperature of ca 400 °C

The investigation was carried out for the simplified conditions with regards to the fact that after the individual impact of the particle onto the surface of the base material, the particle is impacted by another and subsequently the other and next particle within very short time. This process of particle impact is chaotic and non-stationary from time point of view. In addition, it comes to partial cooling down during the trajectory of the impact of the ceramic material particles from the mouth of plasma burner onto the base material, therefore the condition on temperature of impacting particle of 2,050 °C is not fully in accord with the real temperature of the particle. None of the analytic methods of investigation may be applied in this case.

The geometric model was constructed for the investigation using the final element method and it reflects the real surface of the base material. The real surface was obtained by light microscopy with 500x magnification (Fig. 1). The elements of ceramic particle after its impact on the base material are marked on Fig. 2 and 3. The model for numerical analysis is in first solution of 2D type and it has the dimensions of 180 x 50 μm.

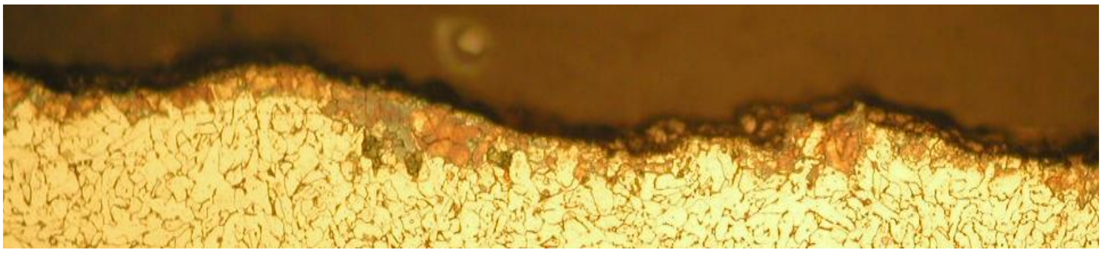

Figure1. *Steel material surface geometry magnified 500 times*

Fig. 2 displays the impact of ceramic particle onto the "excavation". Fig. 3 displays the impact of the particle on the surface projection.

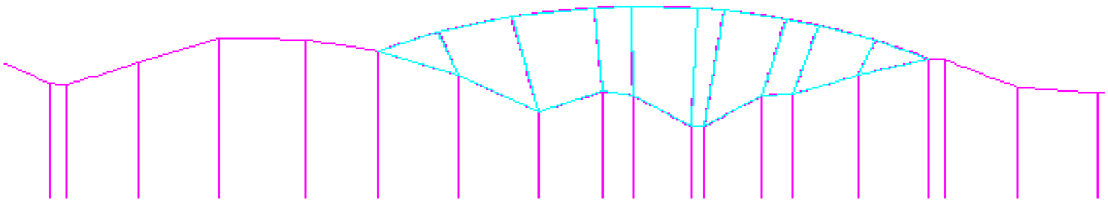

Figure2. *Geometric simulation model of surface depicting ceramic element in the excavation magnified 500 times*

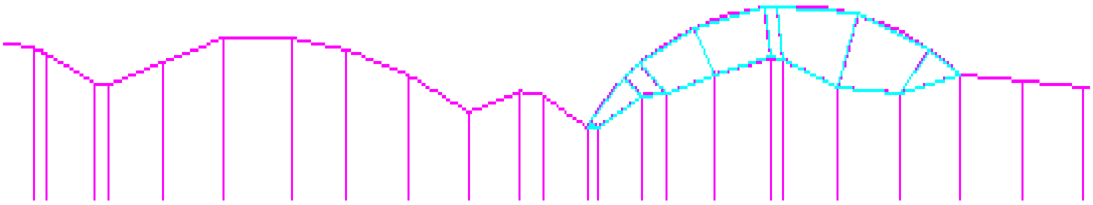

Figure3. *Geometric simulation model of surface depicting ceramic element on the ledge magnified 500 times*

The Analysis of the Impact F Unevenness on Thermal Field

The geometric simulation model was investigated in COSMOS/M as planar using the elements of SHELL type with 4 nodal points per 1 element. The total number of elements, the basic sample was divided to, was 8509. The number of nodal points corresponding to these elements is 10949. It is possible to obtain the information on temperature on every element node from the solution. Identically, the model was dealt with as well as the volume one, formed b SOLID elements with 8 nodal points per 1 element.

Keramická Častica Dopadla Do Priehlbiny Základného Materiálu

Ceramic Particle Impacted the Excavation of Base Material

The distribution of thermal field after the impact of the ceramic particle on the base material is displayed as detail on Fig. 4. As it can be seen, isotherms show a moderate shift to the left from the imaginary centre of gravity of the particle. This condition is visible only within the temperature range of 2050 and 1200 °C. At lower material temperatures (at greater distance from surface), this phenomenon ceases to exist. The figure implies heat transfer from the surface of the base material would not be uniform. Heat was more easily transferred by the adjacent material projection (to the left) than in the excavation spot (to the right). This knowledge is unimportant from macroscopic point of view.

In the case of ceramic material coating onto the microscopic geometry of the base material, the result of investigation on the basis of numerical methods represents the substantial knowledge that the unevenness projection shall transfer more heat than the excavation to the environment and the base material during the same time.

In such numerical solution, the particle had the maximum height 20 μm (above the deepest place of base material unevenness). The base material had temperature 410 °C, at which the change in the structure of the base material is not supposed yet, at the depth 210 μm, perpendicularly under the centre of gravity of the impacting particle.

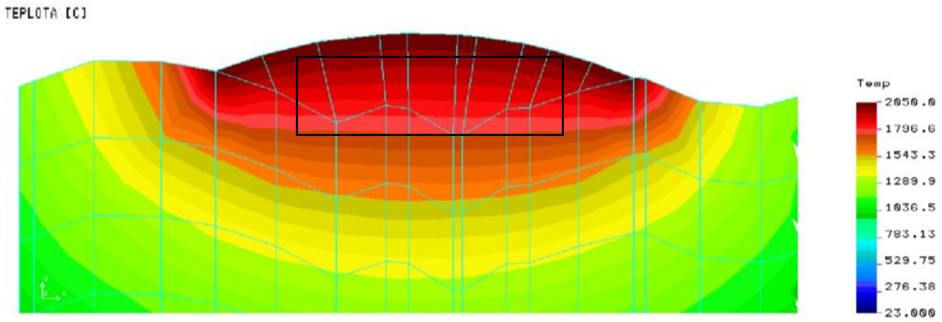

Figure4. *Temperature field detail of element in the excavation*

Ceramic Particle Impacted the Projection of Base Material

The distribution of thermal field after the impact of the particle on the projection of base material (Fig. 3) is recorded on Fig. 5. From the point of view of subsequent cooling down of material, isotherms are more favourable for right side, where the surface is almost planar from the place of the contact of the particle with the base material. Left side is characteristic with the absence of material on the place of the contact of the particle with the excavation, from where heat is less intensively spread out to the left side of the base material. In this case, the identical temperature (410 °C) was reached at the depth 233 μm, which is by 23 μm more than in the case of the solution of the impact of the particle onto the excavation. This is the unimportant enlargement of depth, however the particle is smaller in this case, from volumetric point of view, its maximum height is 12 μm. With the same volume of the particle as in the case of the excavation (20 μm), the depth of thermal influence of the material would be increased.

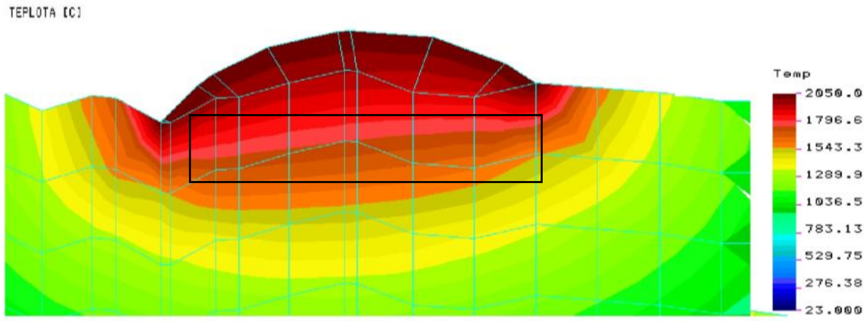

Figure5. *Detail of thermal field of the particle on unevenness projection*

Ceramic Material Particle Cooling Down to Temperature 410 °C

The initial conditions in the investigation of the non-stationary phenomenon of ceramic particle cooling down after its impact on steel material were as follows:

- The temperature of ceramic particle is 2050 °C in its entire volume upon the impact on the base material, which is steel (a simplified condition).
- The ambient temperature and temperature of the base material prior to the impact of the particle are identical (23 °C).

When investigating the time of particle cooling down, heat transfer by free surface of the particle to atmosphere is not considered, which does not reflect the real condition after the impact of the particle (a simplified condition).

The change of temperature in time was investigated for 10 seconds since the particle impacted the base material, totally in 100 steps with the interval of 0.1 s.

After time step 10 (i.e. at time $\tau = 1$ s from the impact of the particle onto the base material excavation (pursuant to Fig. 2), the temperature of particle shall drop down from 2050 °C to ca 251 °C. This condition is displayed in 2D on Fig. 6. The shape of isotherms is identical in every time step, the thermal level of isotherms is lower and it corresponds to the time of cooling down in the relevant time interval. Particle temperature is the highest in the thickest part of the particle (20 µm) located in the base material excavation, however with regards to the dimensions of the particle, specified in 20 µm, temperature shall differ from temperature of the remaining part of the particle to the minimum extent. Temperature 410 °C shall be reached by the particle even after 0.75 s since it impacted the base material.

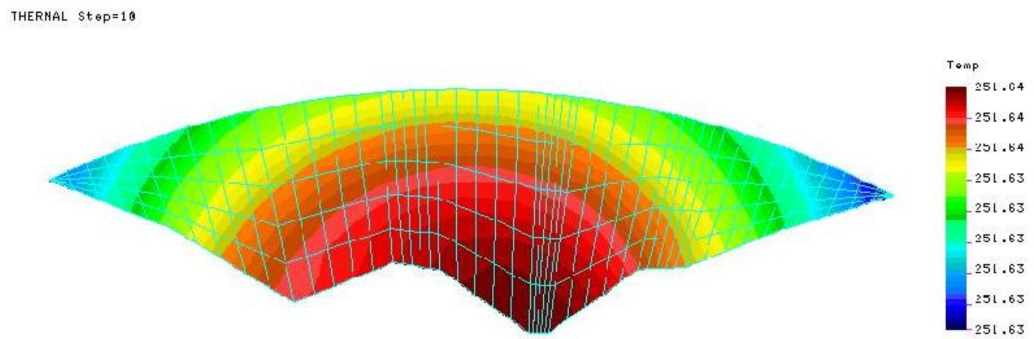

Figure6. *Two-dimensional thermal field of particle located in excavation after 1 s*

Fig. 7 displays 2D thermal field, corresponding to the geometric simulation model of surface, displaying the ceramic particle at the projection of unevenness according to Fig. 3. At time $\tau = 0.1$ s, temperature of ceramic particle is just 1476 °C, which is by 157 °C less than in the case of the impact of the particle onto an excavation. At time $\tau = 0.5$ s, temperature of ceramic particle dropped down to 416.9 °C, which is by 171 °C less than in the case of the impact of the particle onto an excavation.

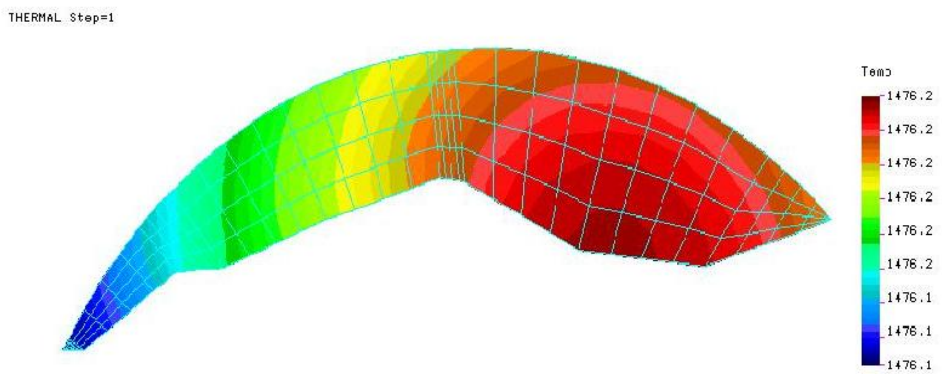

Figure7. *Two-dimensional thermal field with ceramic particle image on the jog after 0.1 s*

After 1 s from the impact of the particle, particle temperature is just 104.7 °C (thermal field is on Fig. 8). This temperature is by 147 °C lower than in the case of the impact of the particle at the same time onto the excavation (Fig. 6). Temperature of 410 °C was reached by the particle after time $\tau = 0.51$ s.

The impact of smaller weight of the particle is demonstrated b its faster cooling down.

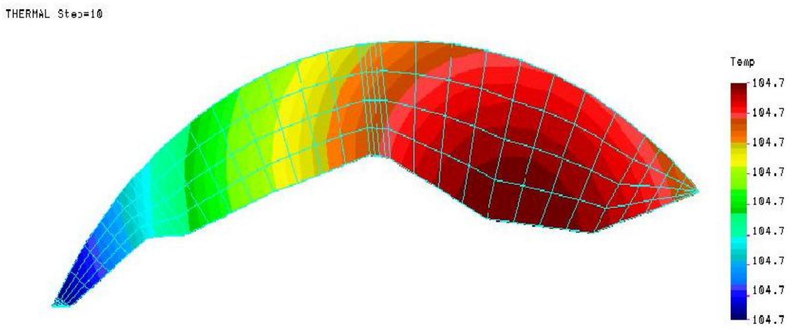

Figure8. *2D teplotné pole keramickej častice na výstupku nerovnosti podľa po 1 s*

RESULTS AND DISCUSSION

In the papers, there is the analysis of thermal load of steel sample after the application of alpha modification of corundum Al_2O_3 to its surface area.

The analysis of the impact of unevenness of the base material on the distribution of thermal field in it provides new information. In the individual impact of the particle onto the material excavation, particle cooling is faster even if the surface area in contact with the base material is the same. The reason is smaller thermal resistance against the projection. In the case of an excavation, there are better conditions for heat transfer by convection. The particle and the base material cool down more rapidly as in the case of the impact of the particle of a comparable size onto the unevenness projection. The reason is higher thermal resistance of the projection in heat transfer from the particle to the volume of the base material.

Upon the impact of the particle of comparable size onto the unevenness projection, the particle shall be in contact with air with greater portion of surface area, whereby the heat transfer shall be reduced and therefore the depth of thermal influence of the base material shall be greater than in the case of the impact of the particle onto the unevenness projection. Temperature 410 °C may be expected at the depth around 200 μm.

In fact, temperature shall be lower at the depth 200 μm, since the simulation model is not able to incorporate into the investigation the condition of partial cooling down of the particle from 2050 °C during its flight trajectory in environment with atmospheric air until its impacts the base material. This fact shall affect the result towards lower values of temperature inwards the material.

The ideal case in coating application would be the ceramic layer covering all the unevenness of base material at one time. At that time, (Fig. 9), temperature of spraying would be 1602.5 °C after first step of the solution, i.e. after 0.1 s.

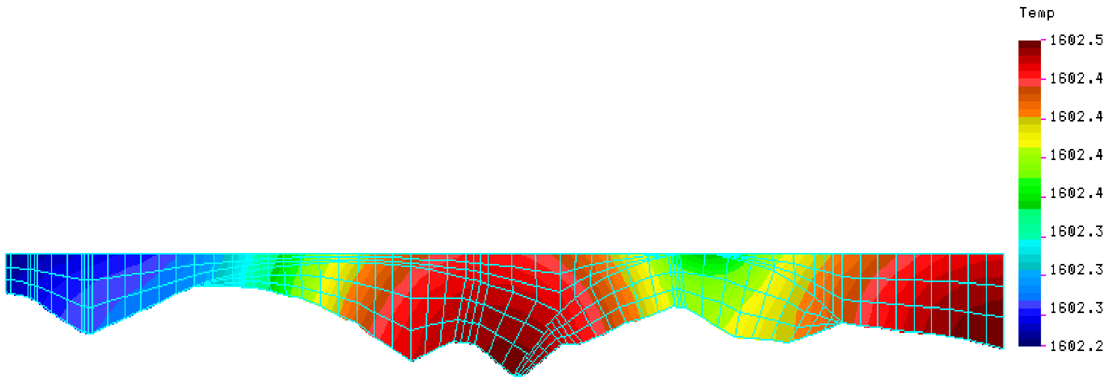

Figure9. *Thermal field of the entire spray application after 0.1 s*

After time $\tau = 0.5$ s, temperature of coating shall drop down to 617 °C and after 1 the coating shall reach maximum temperature 206 °C. Temperature 410 °C shall be reached after ca 0.65 s. It is the time greater than in the case of cooling down of the particle impacting the projection of the base material, but smaller than in the case of the particle impacting the excavation.

CONCLUSION

From the monitoring of the process of ceramic material particle cooling down from the maximum value of 2050 °C to ambient temperature, the decisive is the determination of time during which the particle cools down to the temperature that would not affect the structure of the base material, i.e. the temperature of max. 400 °C, yet. In the process of the monitoring of cooling down, the simplified conditions were incorporated in the numerical model and they would slightly affect the results of investigation. Particle cooling time shall be different for various shapes of particles and their various weights. For example, for the particle with the diameter of ca 70 μm and the average thickness after the base material impacting of ca 15 μm, the time till its cools down (considering the individual impact on the base material) would be up to 0.8 s. The given model of particle cooling down on the base material reflects cooling down just roughly. It is better to use the model that monitors the cooling down as the cooling of a continuous layer covering all the unevennesses of the base material at one time.

ACKNOWLEDGEMENT

The article was created with the support of Ministry of Education for EU Structural Funds Operational Program "Research and Development" project no. p. ITMS 26220220044 and project KEGA 003TUKE-4/2016.

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