V. I. Savuliak, Dc. Sc.(Eng), Prof.; S. A. Zabolotniy, Cand. Sc.(Eng), Assis. Prof.; M. S. Ukrainets

TEMPERATURE FIELDS EQUALIZATION IN THE PROCESS OF PLASMA SPRAYING

The paper presents the results of research studying the influence of additional thermal resistances in the system «piece-fixture» on the configuration of temperature fields and distribution of residual stresses after plasma spraying of «sleeve» type pieces.

Key words: *spraying, temperature fields, thermal resistances, internal stresses.*

Introduction

Heat flows and their distribution in the system play an important role in provision the quality of restoration or strengthening of pieces using gas-thermal methods of powders spraying (GTS). Heats flows form in material of the piece and applied coatings constantly changing temperature fields. Considerable temperature differences at different sections of coating are accompanied by corresponding internal stresses. This causes deformations, distortions of the geometry and formation of non-uniform structures in the coating and in the base. While spraying of long pieces of «sleeve» type it is especially important.

Negative consequences of non-uniformity of temperature fields and internal stresses, caused by them, are:

- flexing of the piece;
- the necessity to apply additional machining;
- different thickness of coating after machining;
- irregularity of hardness and wear resistance of the coating on the surface;
- boost of manufacturing or restoration cost.

The aim of the research is to study the possibilities of increasing the quality of restoration or strengthening of internal surfaces of «sleeve» type pieces by means of control of temperature fields of restoration process, in particular, by temperature differences minimization Research, carried out in this direction, are described in [1, 2, 3]. It was revealed that such factors as specific consumption of materials for piece blank, availability and characteristics of heat discharge in the environment and attachments, symmetry of piece construction play important role in formation of temperature fields and stresses configuration.

Materials and technique of investigation

Temperature fields of plasma spraying are calculated by means of programming package of finite-element analysis [4]. Modeling of spraying operation is carried out in the following sequence: creation of 3D model of the piece 1 (Fig 2 a), fixed in bushing 2 of spraying installation; determination of physical mechanical properties of the material; generation of finite-element analog of 3D model (Fig 2 b); determination of heat embedding in the sleeve from plasma jet and time of its action (Fig 2 c); execution of resulting values computations (temperature, deformation, etc.) with further presentation of the obtained data in the form of graphs, tables, fields, etc.

Temperature stresses emerge in heated body either as result of non-uniform propagation of the temperature or as a result of external factors influence or in case of their simultaneous impact [5]. Common deformation at each point of the heated body consists of two parts. The first part is a uniform expansion, proportional to temperature increase T. As for isotropic body this expansion is the same in all directions, then in this case only normal deformations emerge and tangent deformations are missing. If the coefficient of linear expansion is denoted by α, then this normal unit strain in any direction equals αT.

The second part comprises deformations, necessary for maintaining the integrity of the body and deformations, emerging under the influence of external loading. These deformations in elastic area are the function of stresses and adhere to Hooke's law of isothermal linear theory of elasticity. Complete deformations equal the sum of these two parts and correspondingly, in any orthogonal system of coordinates *x*, *y*, *z* are connected with stresses and temperature by such dependences [5]:

$$\left.\begin{aligned} \varepsilon_{xx} &= \frac{1}{E}\left[\sigma_{xx} - \nu\left(\sigma_{yy} + \sigma_{zz}\right)\right] + \alpha T; \\ \varepsilon_{yy} &= \frac{1}{E}\left[\sigma_{yy} - \nu\left(\sigma_{zz} + \sigma_{xx}\right)\right] + \alpha T; \\ \varepsilon_{zz} &= \frac{1}{E}\left[\sigma_{zz} - \nu\left(\sigma_{xx} + \sigma_{yy}\right)\right] + \alpha T; \\ \varepsilon_{xy} &= \frac{1}{2G}\sigma_{xy}, \quad \varepsilon_{yz} = \frac{1}{2G}\sigma_{yz}, \quad \varepsilon_{zx} = \frac{1}{2G}\sigma_{zx}. \end{aligned}\right\} \tag{1}$$

Dependences between stresses and deformations mathematically describe the behaviour of the considered material. Equilibrium equations in Cartesian rectangular coordinate system have the form:

$$\left.\begin{aligned} \frac{\partial\sigma_{xx}}{\partial x} + \frac{\partial\sigma_{xy}}{\partial y} + \frac{\partial\sigma_{xz}}{\partial z} + X = 0; \\ \frac{\partial\sigma_{xy}}{\partial x} + \frac{\partial\sigma_{yy}}{\partial y} + \frac{\partial\sigma_{yz}}{\partial z} + Y = 0; \\ \frac{\partial\sigma_{xz}}{\partial x} + \frac{\partial\sigma_{yz}}{\partial y} + \frac{\partial\sigma_{zz}}{\partial z} + Z = 0. \end{aligned}\right\} \tag{2}$$

Dependences between deformations and displacements have the form:

$$\left.\begin{aligned} \varepsilon_{xx} &= \frac{\partial u}{\partial x}, \; \varepsilon_{yy} = \frac{\partial v}{\partial y}, \; \varepsilon_{zz} = \frac{\partial w}{\partial z}; \\ \varepsilon_{xy} &= \frac{\gamma_{xy}}{2} = \frac{1}{2}\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right); \\ \varepsilon_{yz} &= \frac{\gamma_{yz}}{2} = \frac{1}{2}\left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right); \\ \varepsilon_{zx} &= \frac{\gamma_{zx}}{2} = \frac{1}{2}\left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right). \end{aligned}\right\}, \tag{3}$$

where *u*, *v*, *w* – are components of displacement vector in the directions *x*, *y*, *z* correspondingly.

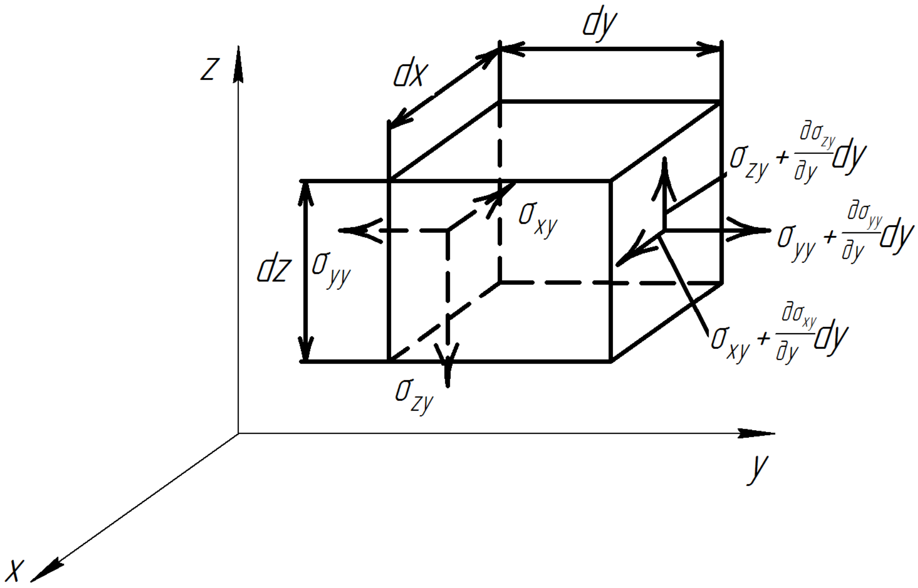
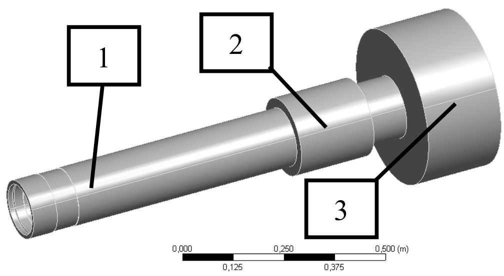
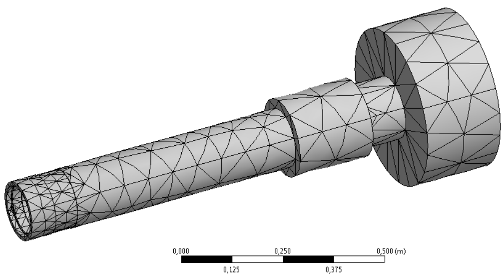


Fig 1. Volume element, used for writing equilibrium equations

Research are carried out on the example of cylinder sleeve of jack КД-90, manufactured from steel 20X. While spraying the sleeve is fixed in bushing.



a)



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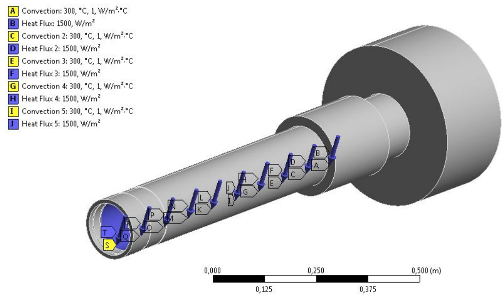

c)

Fig 2. Stages of model development: a) 3D model of a sleeve: 1 – sleeve; 2 – bushing of spraying installation; 3 – flange, modeling heat capacity of the fixture and machine-tool; b) division of the piece into finite elements; c) scheme of heat embedding

While determining heat embedding, previous activation of the surface prior to plasma spraying by previous heating to 300 °C is taken into account.

Results of research

The research, carried out, revealed that the process of cooling of the piece with already applied coating plays an important role in formation of stresses and deformations in the piece. Distribution of temperature fields in the sleeve, fixed in the bushing of spraying installation and freely cooled in the atmosphere of protection chamber was investigated. Temperature fields of the piece, cooled after plasma spraying by four machining using spraying scheme from bushing to free end were determined.

Analysis of data, obtained as a result of studying temperature fields distribution, showed, that the difference temperatures between extreme points of sprayed coating surface is approximately 30 °C. This result is explained by the fact, that in the point of piece fixture convective heat transfer is more intensive, since heat is released across the fixture in installation nodes. As a result of this stresses are distributed non-uniformally (Fig 3, curve 1).

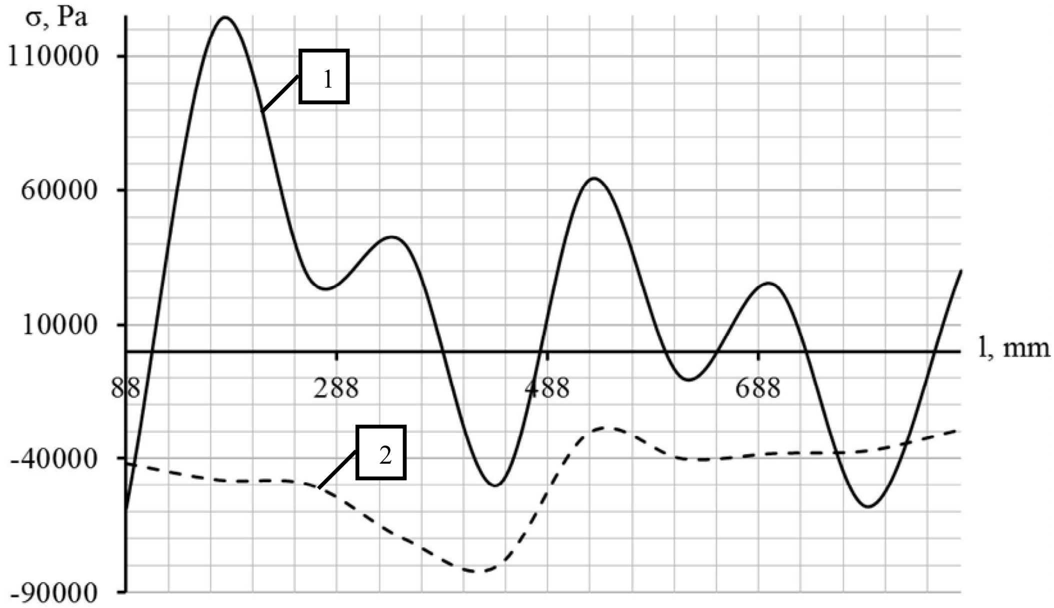

Fig 3. Distribution of stresses relatively axis of rotation of the piece: 1 – without installation of thermal resistance (spacer); 2 – with installation of thermal resistance (spacer)

In Fig 3 the curve 1 shows the change of stresses on the surface of coating spraying along the axis of rotation of the piece in the direction from fixed to free end. Greatest stress differences (approximately 170000 Pa) are observed in the area where the sleeve is installed in the bushing (the section 280 mm). Also negative factor is the presence of tension stresses in the coating. To avoid this it is necessary to decrease the intensity of heat removing in the nodes of spraying installation.

It is possible to decrease the intensity of heat removal by means of thermal resistance installation as the spacer between the sleeve and flange, and to decrease non-uniformity of temperatures distribution non-fixed part of the sleeve it is expedient to cool from without.

The results of research showed that installation of thermal resistance as thermal insulating spacer between the sleeve and flange and additional cooling of non-fixed part of the sleeve equalizez temperature fields in the piece.

As a result of temperature equalization, stresses in the piece and coating in the course of cooling are distributed rather uniformely (Fig 3, curve 2). Stresses differences become smaller (maximum difference is approximately 50000 Pa), distribution of stresses becomes rather uniform, and tension stresses are missing.

Conclusions

1. In the process of plasma spraying of long pieces orifices of "sleeve" type temperature fields are distributed non-uniformally, that leads to emerging of considerable stress differences in the piece.

2. Equalizing of temperature fields is possible by means of installation of thermal resistance between the piece and fixture, as well as additional cooling of non-fixed external surface of the piece. It is expedient to determine the characteristics of thermal resistances and cooling by computations, applying programs of finite-element analysis.

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Savouliak Valeriy – Dc. Sc. (Eng), Professor, Head of the Chair of the Technology of Wear Resistance Increase, E-mail: vsavulyak@mail.ru.

Zabolotniy Serqiy – Cand. Sc. (Eng), Assist. Professor, Chair of the Technology of Wear Resistance Increase, E-mail: zab82@mail.ru.

Ukrainets Maksym – Student, E-mail: maximukrainets22@gmail.com.
Vinnytsia National Technical University.