Publishing House
AKAPIT

COMPUTER METHODS IN MATERIALS SCIENCE
Informatyka w Technologii Materiałów

Vol. 7, 2007, No. 2

COMPUTER MODELING OF THE FACING BY RESISTANCE SINTERING OF METAL POWDERS

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Abstract

Pure, alloy and composite metal powders are used for facing by resistance sintering (based on resistance welding principles). Facings produced in this way are characterized by unique properties which are difficult to obtain by traditional methods. This kind of facing process has no limitations as to the type of base and facing material. The quality of the facing depends on the facing process parameters. The process was modelled using the finite element method (FEM). The simulation covered coupled complex electrical, thermal, mechanical, metallurgical and surface phenomena. The compression of nickel powder subjected to resistance heating on a steel base between two copper electrodes was simulated. The base was made of 3 mm thick low-carbon steel sheet S235JR. The mechanical and physical material properties and their change with temperature were investigated. Although the phenomena which occur during facing by resistance sintering have a three-dimensional character, a two-dimensional model was adopted to simplify the analysis. The FEM calculations were performed using the MSC.Marc&Mentat 2005 software with an additional Marc-Electrical module. The numerical simulations were run for a coupled electrical-thermal-mechanical analysis. The aim of the mathematical modelling of the facing process was to identify the parameters which for the physical properties of the materials used for the facing and the base allow one to obtain a high quality facing continuous with the base. The numerical simulation results are compared with experimental results.

Key words: facing by resistance sintering, metal powders, finite element method

1. INTRODUCTION

The durability of constructions is limited by the operating wear of their components. An increase in durability is commonly achieved by weld surfacing the components both while they are manufactured and regenerated. Attempts have also been made to face such components by resistance sintering using fusion welding equipment (Bartnik, 1999; Bartnik&Derlukiewicz, 2004; Lüdorff, et al., 1991). The facing produced in this way preserves the properties of the facing material and the method is environmentally friendly since there are no harmful gas or smoke emissions and the noise level is low.

The facing material can have the form of a strip, a wire or a metal powder. The metal powders can be pure metal powders, alloy powders and powder mixtures (composites). Exemplary facings produced by resistance sintering of alloy powders are shown in figure 1. Figure 2 shows powder grains and hardness distribution in the facing-base zone.

Facings should be characterized by metallic continuity with the base and preserve the properties of the facing material. In order to obtain a high quality facing one must take into account several data about both the facing material and the base when setting the facing process parameters. An FEM model of the facing process would allow one to determine the proper process parameters for each type of material.

The aim of this research was to develop a preliminary calculation model for facing by resistance sintering. A nickel powder with purposefully enlarged grains was used for the analysis. Furthermore, a long

ISSN 1641-8581

heating current flow time was adopted to increase the accuracy of thermovision measurements.

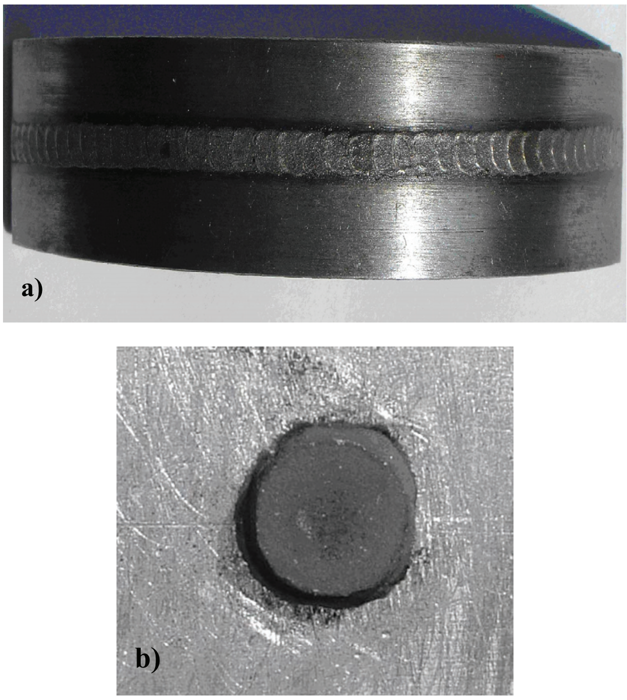

Fig. 1. Facing produced by resistance sintering on steel base (a) and on aluminium base (b).

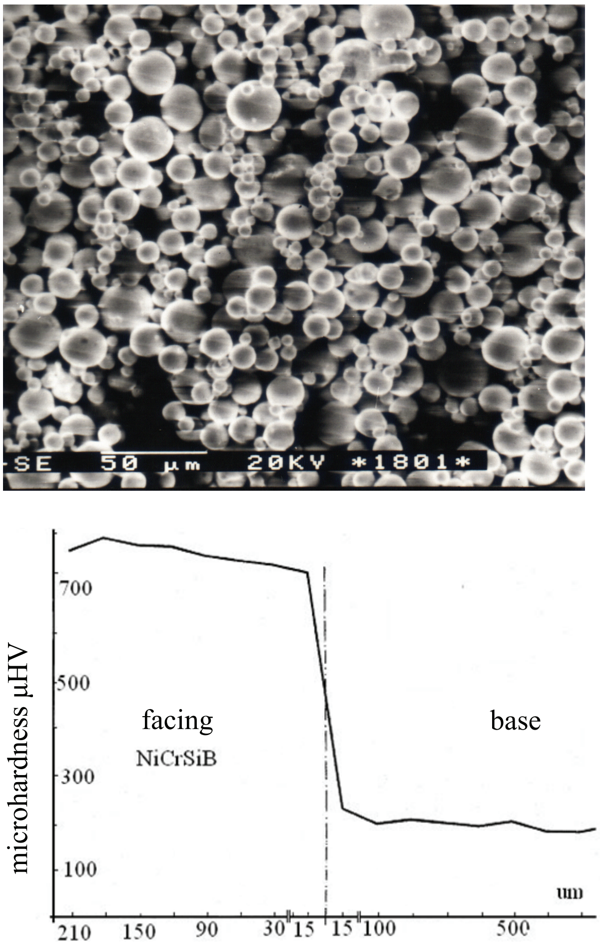

Fig. 2. Alloy powder grains and variation in hardness along line passing through facing and base.

2. EXPERIMENTAL

Nickel powder grains about 3mm in diameter were used to produce a facing on a steel base (3 mm thick steel sheet S235JR) using a ZPa-80 spot welder. The facing process was conducted on a test stand (figure 3) with a THV 550 thermal camera, a Pp-10 microprocessor instrument for measuring electrical parameters and an electrode movement registering system.

The data recorded by the camera were transmitted to a PC equipped with a card allowing image recording and play back at a rate of 60 Hz. Thanks to the measuring card's frequency several thermograms of the heating of the materials used in the experiment were obtained.

The Pp-10 instrument made it possible to continuously acquire full information about the facing process electrical parameters. The processed data were sent to the PC. The parameters were measured by the noncontact method using a measuring toroid.

Facing process parameters: current intensity – about 1.3 kA and current flow time – 1.7 s were adopted. The top electrode diameter was 9 mm and the powder layer height was 33 mm. An experimental graph showing changes in powder layer height (top electrode movement) during facing are shown in figure 4.

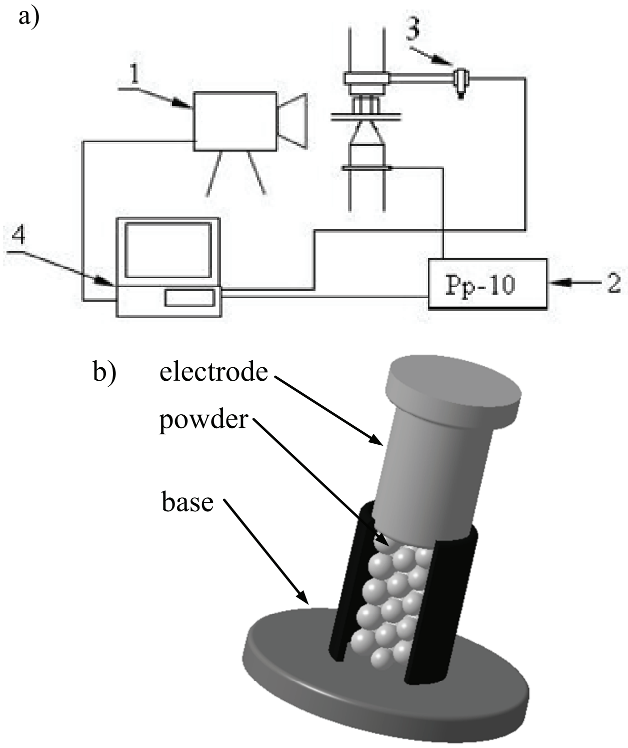

Fig. 3. Stand for facing by resistance sintering of powder grains (a), arrangement of elements (b).
1 – thermovision camera, 2 – microprocessor instrument, 3 – electrode movement registering system, 4 – PC.

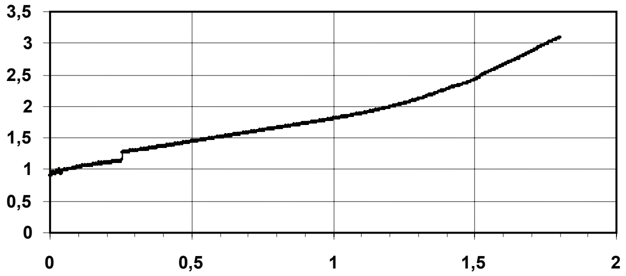

Fig. 4. Movement of top electrode during facing.

The experimental data were used to verify the FEM calculation results for the modelled facing of steel by sintering nickel grains.

3. FEM MODELLING OF FACING BY RESISTANCE SINTERING

Facing by resistance sintering of metal powders was modelled by the finite element method. The simulation covered coupled complex electrical, thermal, mechanical, metallurgical and surface phenomena. The compression of nickel powder subjected to resistance heating on a steel base between two copper electrodes was simulated. The mechanical and physical material properties and their changes with temperature were investigated. Although the phenomena which occur during facing by resistance sintering are three-dimensional, a two-dimensional model was adopted to simplify the analysis (figure 5).

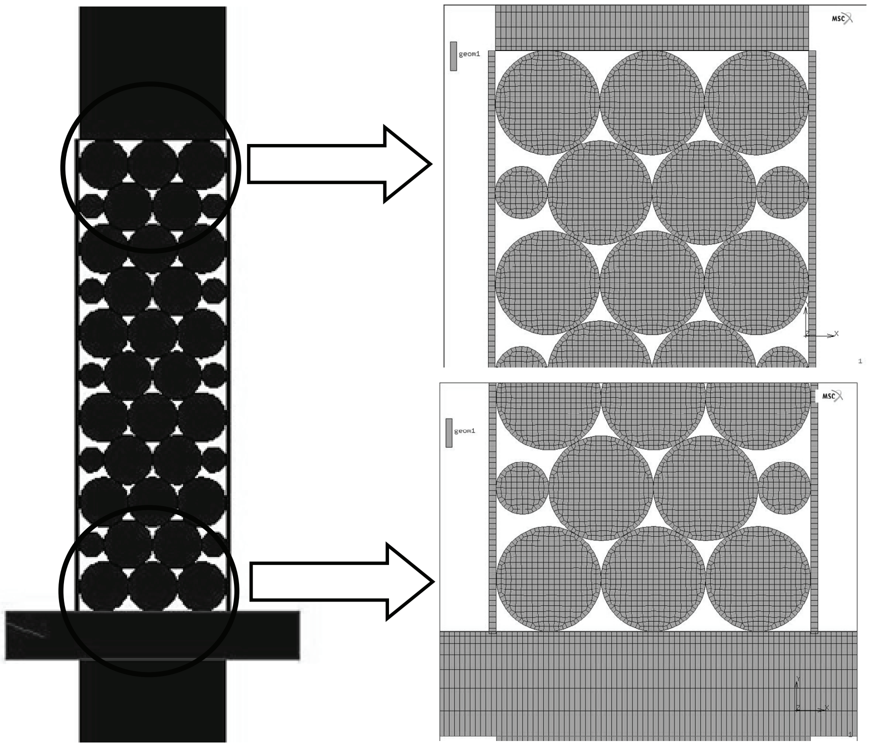

Fig. 5. FEM calculation model of facing by resistance sintering.

The FEM calculations were performed using the MSC.Marc&Mentat 2005 software with an additional Marc-Electrical module. The numerical simulations covered an electrical-thermal-mechanical analysis, i.e. an electric-thermal analysis (Joule heating) combined with a thermal-mechanical analysis, handled using a staggered solution procedure. In this approach, first the electrical problem is solved to determine the nodal voltages. Then the thermal problem is solved to obtain the nodal temperatures. Finally, the mechanical problem is solved to determine the nodal displacements. The electrical problem and the thermal problem are coupled through heat generation caused by electric flow (Joule heating). The thermal problem and the mechanical problem are coupled through thermal strain loads and heat generation caused by inelastic deformation and friction. The mechanical problem may involve geometric and material nonlinearities. If contact occurs between deformable bodies or deformable and rigid bodies in the mechanical problem, the boundary conditions of the electrical problem and those of the thermal problem are updated to reflect the new contact conditions (figure 6). The relevant matrix equations can be expressed as:

$$K^E(T)V = I \tag{1}$$

$$C^T(T)\dot{T} + K^T(T)T = Q + Q^E + Q^I + Q^F \tag{2}$$

$$M\ddot{u} + D\dot{u} + K^M(T,u,t)u = F + F^T \tag{3}$$

where V is a nodal voltage vector, T is a nodal temperature vector, u is a nodal displacement vector, $K^E(T)$ is a temperature-dependent electrical conductivity matrix, I is a nodal current vector, $C^T(T)$ is a temperature-dependent heat capacity matrix, $K^T(T)$ is a temperature-dependent thermal conductivity matrix, Q is a heat flux vector,Q^E is heat generation due to the electrical flow vector, Q^I is heat generation due to the inelastic deformation vector, Q^F is heat generation due to the friction vector, M is a mass matrix, D is a damping matrix, $K^M(T,u,t)$ is a temperature, deformation and time dependent stiffness matrix, F is an externally applied force vector and F^T is a force due to the thermal strain vector.

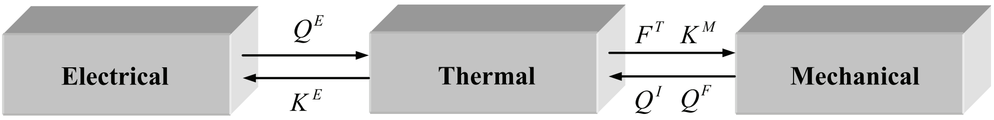

Fig. 6. *Coupled electrical-thermal-mechanical analysis.*

Through FEM simulations of facing by resistance sintering, performed using the above mentioned software, one can analyse the effect of: specific heat, thermal conductivity, specific resistance, current intensity and current flow time on the facing process. The solid-liquid transition was taken into account through the latent heat of fusion. The aim of the mathematical modelling of the facing process was to determine the parameters which for the physical properties of the facing and base materials allow one to obtain a high quality facing which is continuous with the base.

The discrete model of facing by resistant sintering (figure 5) consisted of 13272 elements and 15072 nodes. The contact resistances between nickel grains themselves and between nickel grains, the base and the top electrode are very difficult to define and practically impossible to estimate accurately. In the literature on the subject one can find only the dynamic resistances of the whole joint or the resistances of the whole contact area. The contact resistances and the nickel and steel base material data found in the literature were used in the simulations.

The results of the FEM simulations are shown in figures 7-8. Figure 7 shows the temperature distribution, after a current flow time of 0.1 s, in resistively heated nickel powder grains. One can see that the places of contact between grains are the hottest. For longer heating times a temperature increase extending over the powder layer's entire height is observed. Another simulation result (figure 8), also for a current flow time of 0.1 s, shows the distribution of effective strains within the area of nickel grains. One can see that the largest strains occur in the central area of the heated grains. In order to verify the calculation results they were compared with the results obtained by the thermal imaging method.

4. COMPARISON OF RESULTS

In figures 9-10 the FEM results and the heating isotherms recorded by the thermovision camera are shown respectively on the left and on the right. In figure 9 the calculated temperatures slightly differ from the recorded thermal images.

This applies to images observed in the thermovision camera's measurement window. Proper size of this window made it possible to simultaneously conduct the facing process and the thermovision recording.

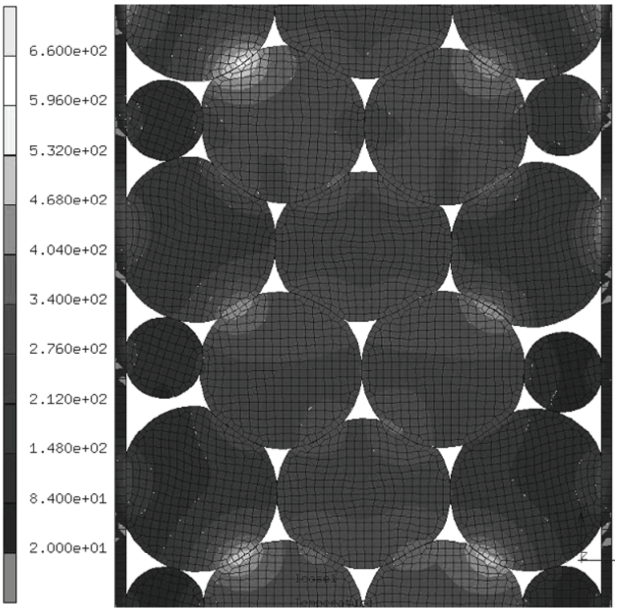

Fig. 7. *Temperature distribution in contact areas between grains (current flow time 0.10 s).*

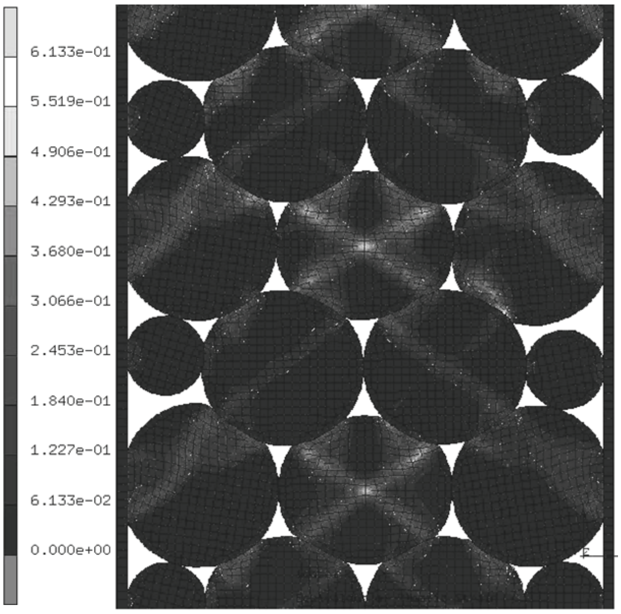

Fig. 8. *Distribution of effective strains in facing (0.10 s).*

The theoretical and experimental results for a longer heating time of 0.25 s are compared in figure 10. In this case, the temperature distribution is more uniform and the contact surface area is much larger. The theoretical temperatures are comparable to the thermal images.

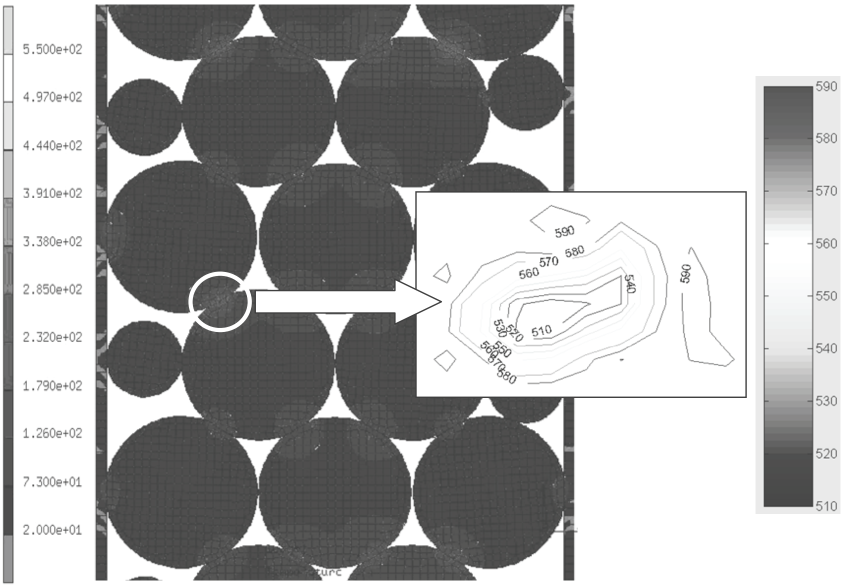

Fig. 9. Calculated temperature distribution (0.1 s) compared with thermal image.

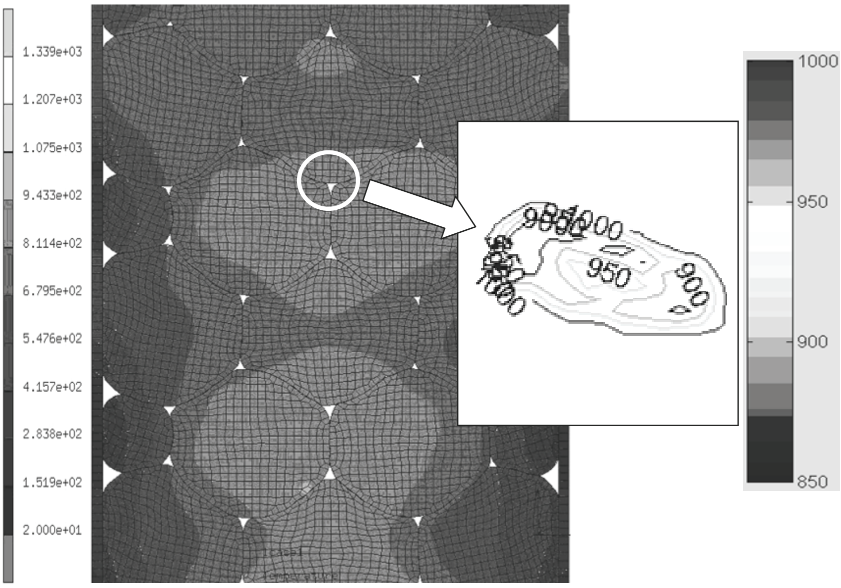

Fig. 10. Calculated temperature distribution (current flow time 0.25 s) compared with thermal image.

5. CONCLUSIONS

The main aim of the numerical calculations was to explore the possibility of determining in this way the parameters of facing by resistance sintering, in particular current intensity and current flow time. The preliminary FEM analysis of the 2D model (with purposefully increased grain size) showed that the above objective is achievable. The calculated temperature distributions show satisfactory agreement with the real process. Through such calculations one can select proper facing process parameters for a wide range of facing and base materials in order to obtain a high quality facing continuous with the base.

In order to simulate such processes more materials tests need to be carried out. Therefore in further research the properties of the materials used in facing by resistance sintering, as a function of temperature, will be more accurately (experimentally) determined. Special attention will be paid to the facing material. As a result, the accuracy of the simulation process will increase. In each case of facing by resistance sintering one must also determine the actual changes in facing height as a function of process duration.

For the real powder grain size (20-300 μm) it is necessary to make it technically possible to perform measurements by the thermovision method. In future calculation models the density of the finite element mesh will be increased whereby grains heating temperatures will be determined with a higher accuracy.

Acknowledgements. Calculations were carried out using MSC software and computers of Wroclaw Centre for Networking and Supercomputing.

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KOMPUTEROWE MODELOWANIE PROCESU NAPAWANIA ZA POMOCĄ REZYSTANCYJNEGO ZGRZEWANIA PROSZKÓW METALI

Streszczenie

Napawanie metodą rezystancyjną (opartą o zasady zgrzewania oporowego) pozwala stosować na warstwy proszki czystych metali, stopowe i kompozytowe. Uzyskiwane warstwy mogą odznaczać się unikalnymi właściwościami trudnymi do uzyska-

nia tradycyjnymi metodami. Istotnym elementem tego procesu wydaje się być brak jednoznacznych ograniczeń dotyczących tak rodzaju podłoża jak i rodzaju materiału użytego na warstwę. Jakość warstwy napawanej zależy w dużej mierze od zastosowanych parametrów procesu. Do modelowania procesu napawania zastosowano metodę elementów skończonych (MES). Przeprowadzona symulacja procesu napawania rezystancyjnego uwzględniała wzajemnie sprzężone złożone zjawiska elektryczne, cieplne, mechaniczne, metalurgiczne i powierzchniowe. Przedmiotem symulacji było nagrzewanie proszku niklu znajdującego się na podłożu stalowym, umieszczonego między dwoma elektrodami miedzianymi. Podłoże stanowiła blacha ze stali niskowęglowej S235JR o grubości 3 mm. Wprowadzane do modelu dane wejściowe materiałów uwzględniały właściwości mechaniczne i fizyczne oraz ich zmianę wraz z temperaturą. Podczas napawania oporowego zachodzące zjawiska są trójwymiarowe, do analizy przyjęto uproszczony dwuwymiarowy model. Obliczenia MES przeprowadzono za pomocą programu MSC.Marc 2005 z dodatkowym modułem Marc-Electical. Numeryczne obliczenia wykonano dla pełnej analizy elektryczno-termiczno-mechanicznej. Celem modelowania matematycznego procesu napawania było wskazanie parametrów, które przy uwzględnieniu właściwości fizycznych materiałów użytych na warstwę i podłoże pozwolą uzyskać wysoka jakość warstwy napawanej przy równoczesnym zachowaniu jej ciągłości metalicznej z podłożem. Przeprowadzono porównanie otrzymanych wyników numerycznych z uzyskanymi wynikami badań doświadczalnych.

Submitted: October 24, 2006
Submitted in a revised form: November 24, 2006
Accepted: November 24, 2006