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Magneto-Thermal Model for Crimped Connections

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***Abstract*—In this paper numerical results coresponding to thermal regime of two types of superposed crimped connections has been obtained. The samples studied use copper wire crimped by two methods: the first method uses one crimp indents and the second method is with two crimp indents. The ferrule is a parallel one type. A 2D model of crimped connections has been created in QuickField Professional to obtain the numerical results. For obtaining temperature values, a coupled problem AC Magnetics – Steady-State Heat Transfer was solved. Numerical simulations were made considering the next values for electrical current intensity: 510 A, 682 A, 855 A, until the steady state regime is established. First, the AC Magnetics problem was solved to obtain the specific Joule heat. Then, the source term was imported in steady state heat transfer problem to solve it. Joule Heat and temperature values are presented and discussed. An important parameter in numerical simulations is heat transfer coefficient which depends on overtemperature. Knowing heat transfer coefficient law and using in numerical simulation can be obtained the real numerical temperature values. The temperature dependence of global heat transfer coefficient has been taking into account into numerical simulations. Finally, obtained numerical results are discussed and proposals are made.**

I. INTRODUCTION

Crimping is the most widely used method of pressure connection for permanent electrical contact between a wire conductor and a wire conductor terminating device. Due to technological simplicity and possible usage at temperatures above soldering temperatures, such connection are more and more used in electrical installations and equipments, particularly in electrical machines and various electrical apparatus. A good crimp connection can withstand high levels of temperature and vibration and it has excellent performance in corrosive environments, being reliable [1].

The large number of factors that influence the performance and reliability of connections made by crimping are discussed by many authors [2], [3], [4], [7], [8]. These factors include:

- material;
- finish surface;
- crimp depth;
- number of crimp indents;
- crimp solution;
- conductor size;
- tensile strength.

Many authors in their papers are using finite element method for creating numerical models of crimp connections.

In [8] a numerical model of crimping by finite element method is proposed and the concept of an instantaneous strain by a creep is introduced to this model.

A dynamic finite element analysis simulation of the terminal crimping proces was made in [9]. FEA models were created using the ABAQUS program. In order to simplify the study, the work was conducted using 2D and 3D models.

A 3D Numerical Simulation of Open-Barrel Crimping Process was made in [10]. The model was validated using experimental results. The numerical results indicate that elastic springback of the crimp is an essential design parameter engineering into a reliable crimped termination.

In this paper numerical results coresponding to thermal regime of two types of superposed crimped connections has been obtained. The samples (Fig. 1) use copper wire 7.1 × 3 mm^2 crimped by two methods: the first method uses one crimp indents and the second uses two crimp indents. The ferrule is a parallel one.

A 2D model of crimped connections has been created in QuickField to obtain the numerical results. For obtaining temperature values, a coupled problem AC Magnetics – Steady-State Heat Transfer was solved. The temperature dependence of global heat transfer coefficient has been taking into account into numerical simulations.

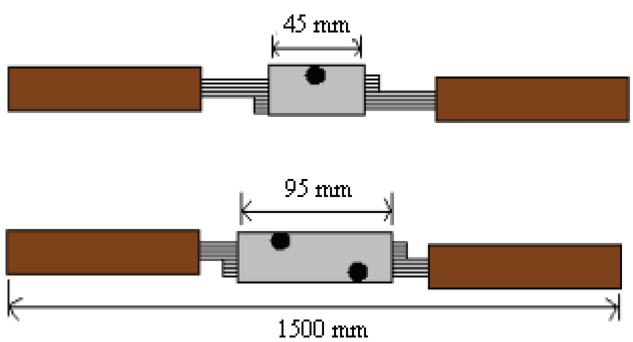


Fig.1. Two type of crimped connection.

II. Numerical Results

A. Problem formulation

For obtaining temperature values a coupled problem AC Magnetics – Steady-State Heat Transfer was solved. The used mathematical model has two components [11], magnetic model and thermal model, coupled through the source term (specific Joule heat):

$$S(\theta)=\rho(\theta)\cdot J^2(x,y). \tag{1}$$

The magnetic model is governed by equation:

$$\left(\frac{1}{\mu}\cdot\frac{\partial A}{\partial x}\right)+\frac{\partial}{\partial y}\cdot\left(\frac{1}{\mu}\cdot\frac{\partial A}{\partial y}\right)-\sigma(\theta)\cdot\frac{\partial A}{\partial t}=-J_S. \tag{2}$$

where:

σ - electric conductivity;

μ- magnetic permeability;

A- magnetic potential vector;

J_s - current density source;

ρ – resistivity.

The temperature distribution in the analysis domain is given by the thermal conduction equation in steady state:

$$\frac{\partial}{\partial x}\left(\lambda\frac{\partial\theta}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda\frac{\partial\theta}{\partial y}\right)+S(\theta)=0. \tag{3}$$

where:

θ – temperature;

λ – thermal conductivity;

S- source term;

Starting from cross section of samples used for testing the geometrical model of crimped connection was obtained in QuickField software (Fig. 2).

B. Numerical simulations

For obtaining numerical results, a 2D planar model was created in QuickField Professional. A coupled problem AC Magnetics – Steady-State Heat Transfer was solved. Analysis domain and boundary conditions are presented in Fig. 3.

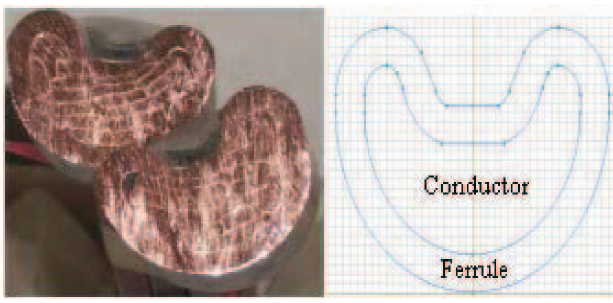


Fig. 1. Cross section of crimped connection.

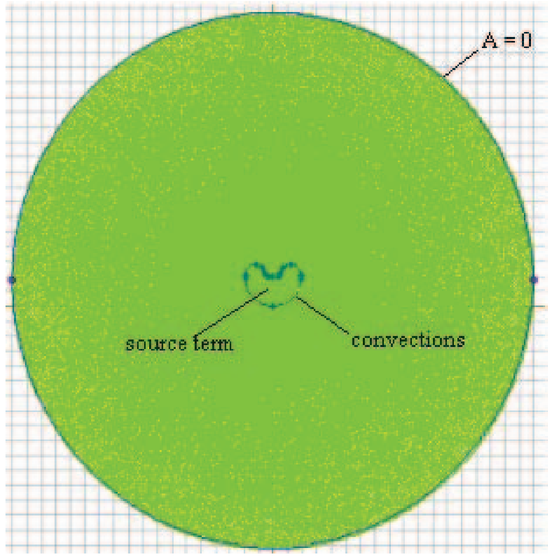


Fig. 2. Geometrical model of cross section crimped connection.

An important parameter in numerical simulation of thermal regime is global heat transfer coefficient whose law for the two types of crimped connection is given by (4) for samples with 1 intender and by (5) for 2 intenders [12].

$$h_\Sigma(\Delta\theta)=a+b\cdot\frac{4\cdot n}{(1+n)^2}, \qquad n=exp\left(-\frac{x-c}{d}\right) \tag{4}$$

In (4), the coefficients *a, b, c, d* take the next values: *a* = 1.5600717, *b* = 0.65996553, *c* = 106.9, *d* = 5.4241611. Graphical variation of h_Σ for samples with 1 intender is presented in Fig. 4.

For samples with 2 indents heat transfer coefficient law and graphical variations are given in (5) and Fig. 5.

$$h_\Sigma(\Delta\theta)=a+b\cdot\frac{\Delta\theta}{\ln(\Delta\theta)},\ \alpha=1.5297282,\ \beta=0.02063615 \tag{5}$$

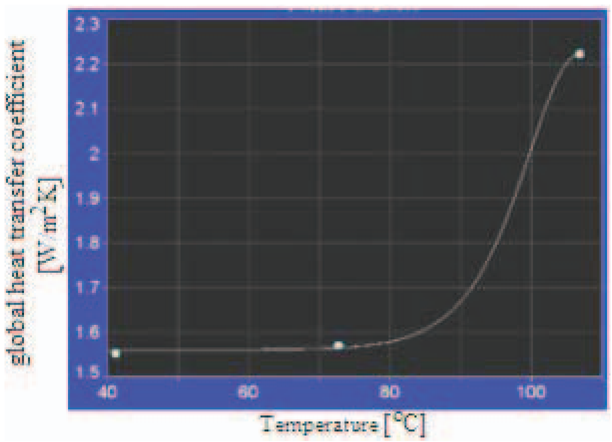


Fig. 3. Geometrical model of cross section crimped connection.

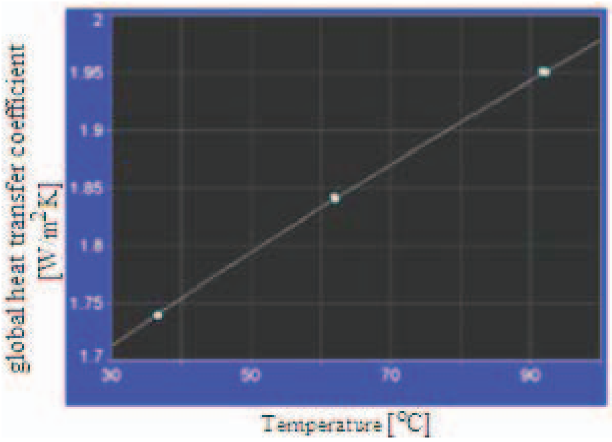


Fig. 4. Graphical variation of h_Σ, samples 2 intenders.

Numerical simulations were made considering the next values for electrical current intensity: 510 A, 682 A, 855 A, until the steady state regime is established.

First, the AC Magnetics problem was solved to obtain the specific Joule heat. Then, the source term was imported in steady state heat transfer problem to solve it.

Joule heat and temperatures values for samples using 1 and 2 indents for different electrical current values are presented in Fig. 6-16.

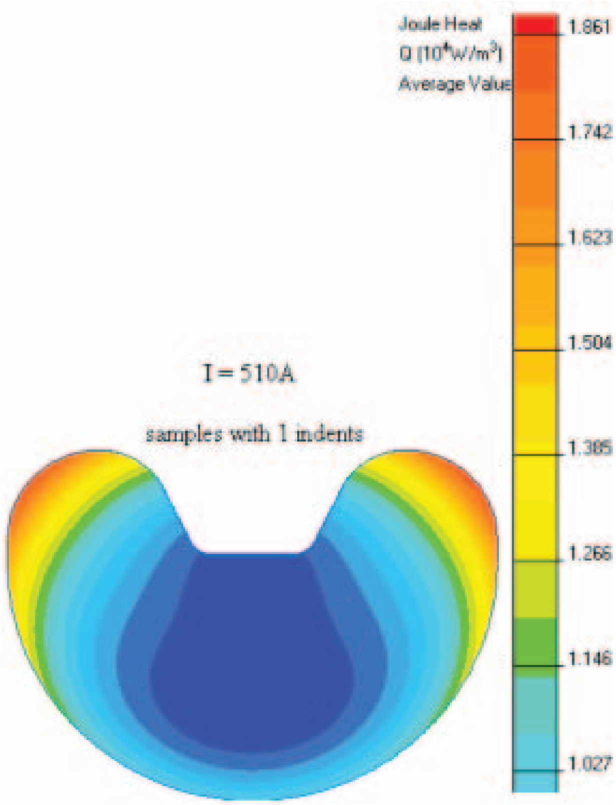


Fig. 5. Specific Joule heat for 510 A, sample with 1 indents.

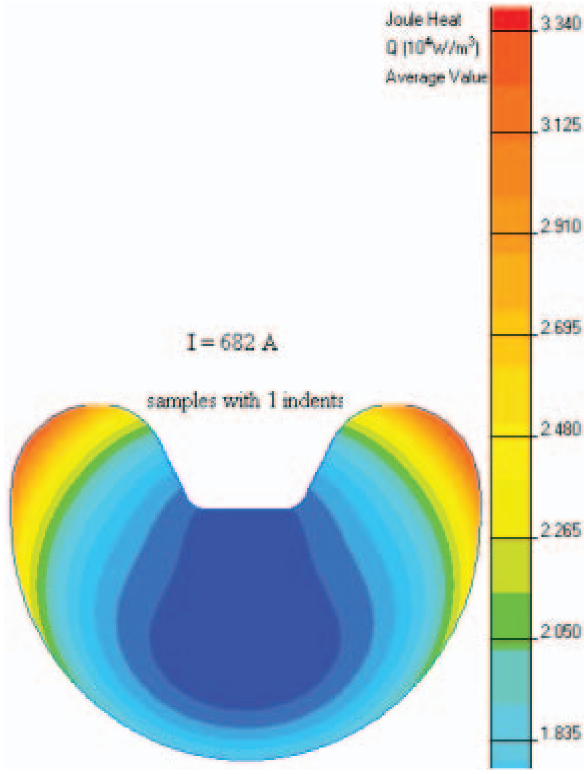


Fig. 6. Specific Joule heat for 682A, sample with 1 indents.

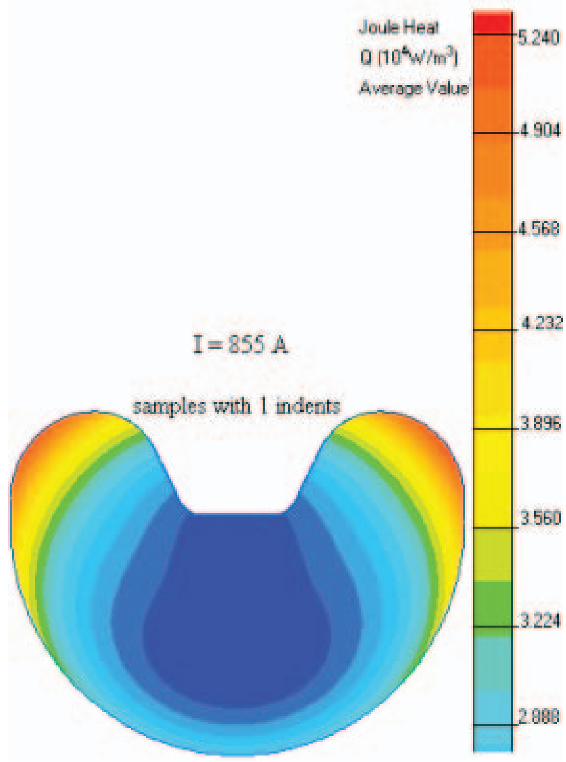


Fig. 7. Specific Joule heat for 855 A, sample with 1 indents.

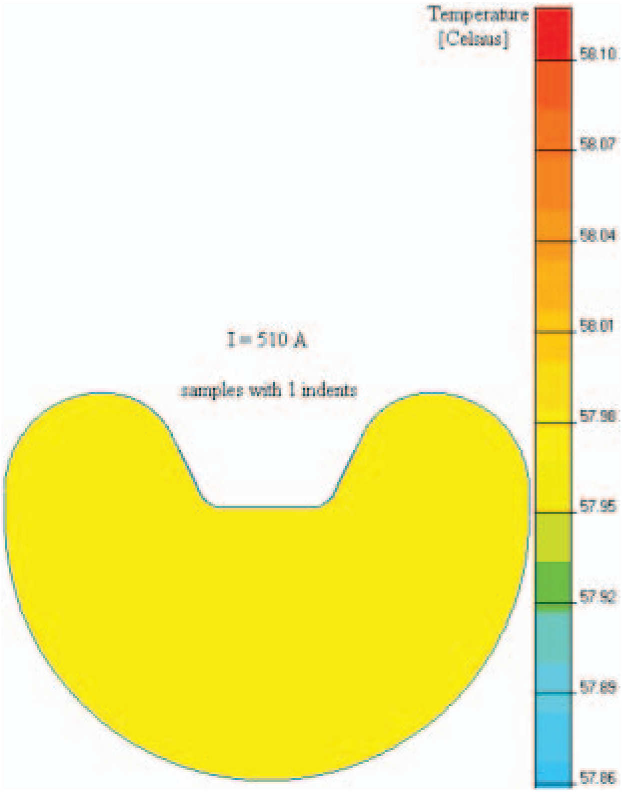


Fig. 8. Temperature for 510 A, sample with 1 indents, θ_a =21.2 ˚C.

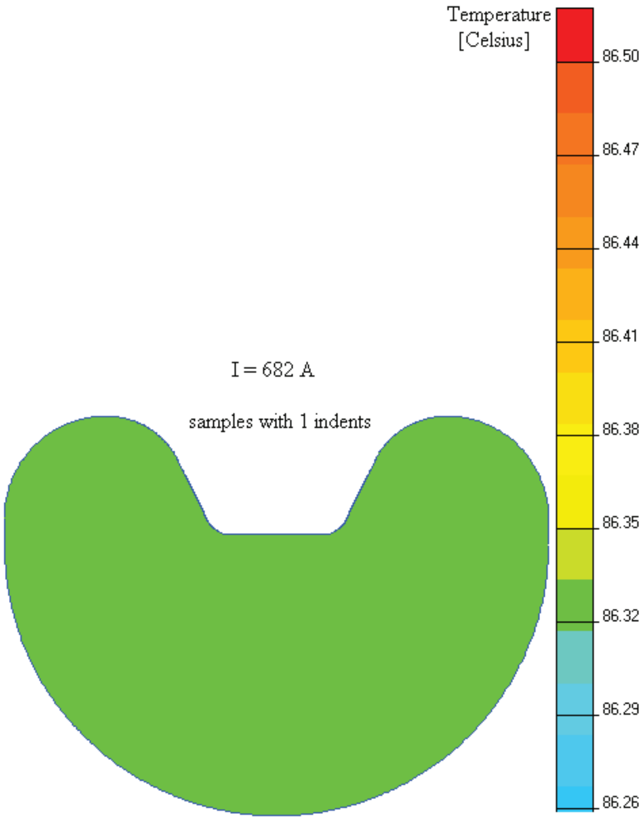


Fig. 9. Temperature for 682 A, sample with 1 indents, θ_a =21.8 ˚C.

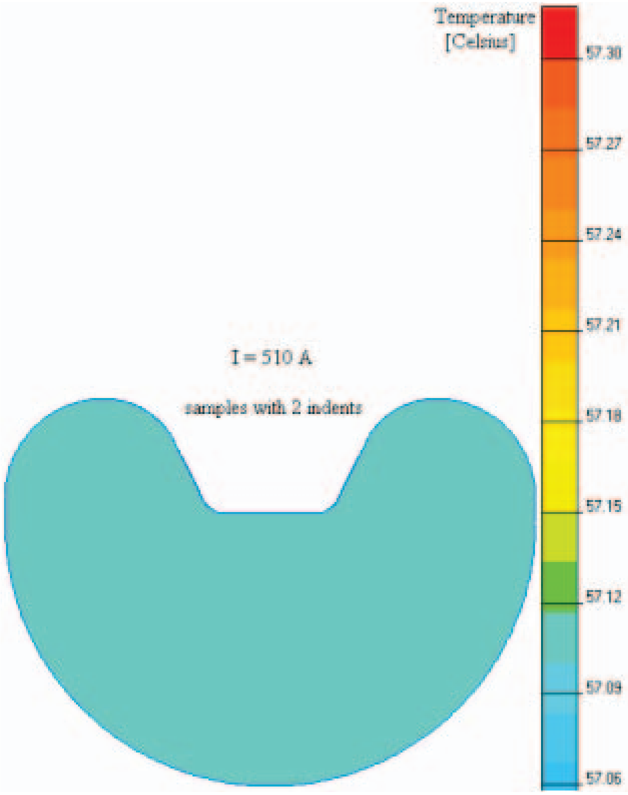


Fig. 10. Temperature for 510 A, sample with 2 indents, θ_a =21.2 ˚C.

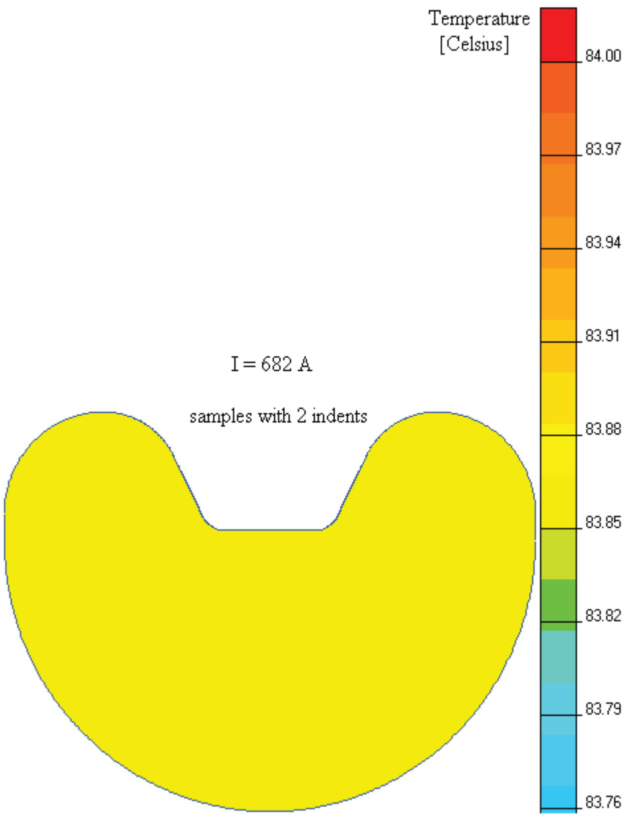


Fig. 11. Temperature for 682 A, sample with 2 indents, θ_a =21.8 ˚C.

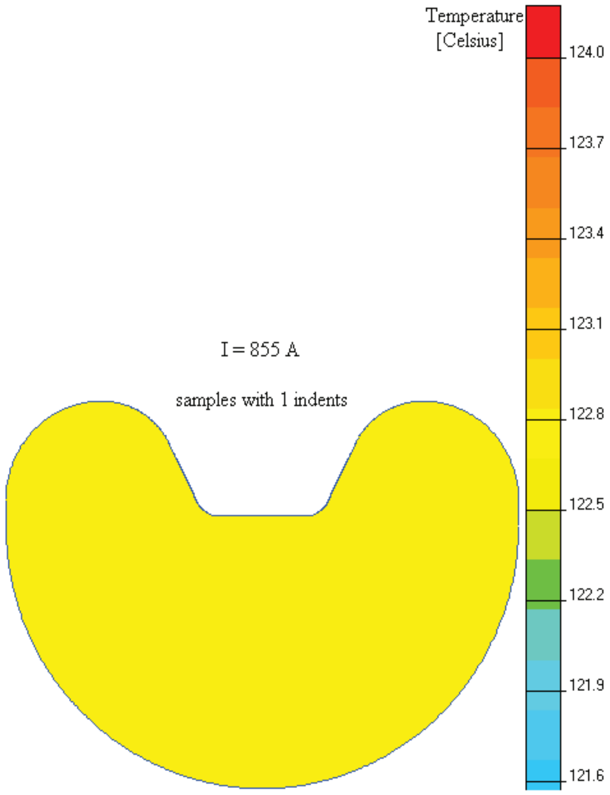


Fig. 12. Temperature for 855 A, sample with 1 indents, θ_a =26 ˚C.

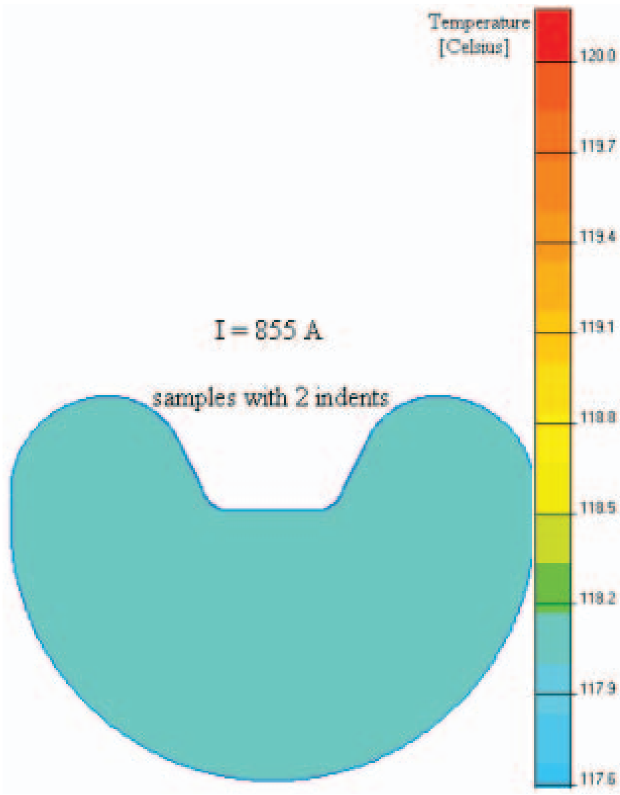


Fig. 14. Temperature for 855 A, sample with 2 indents, θ_a =26 ˚C.

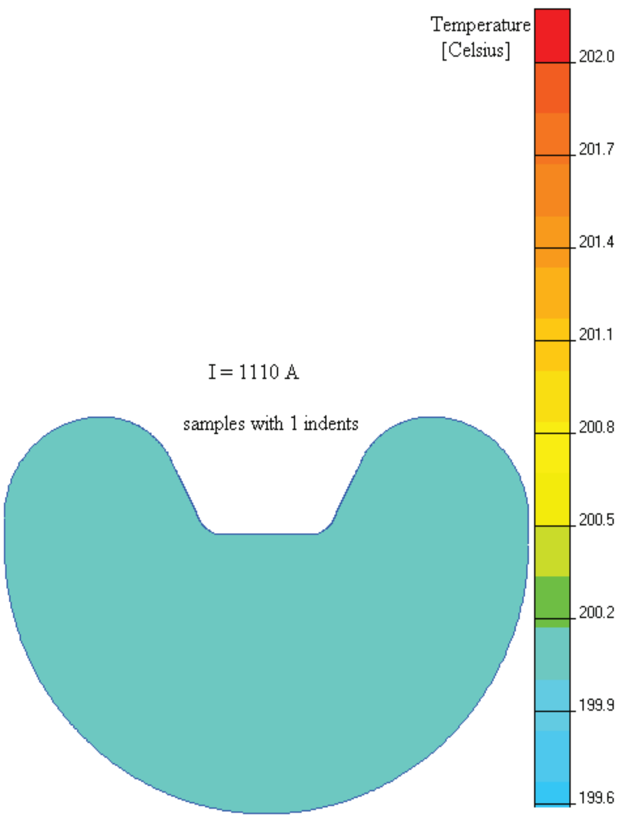
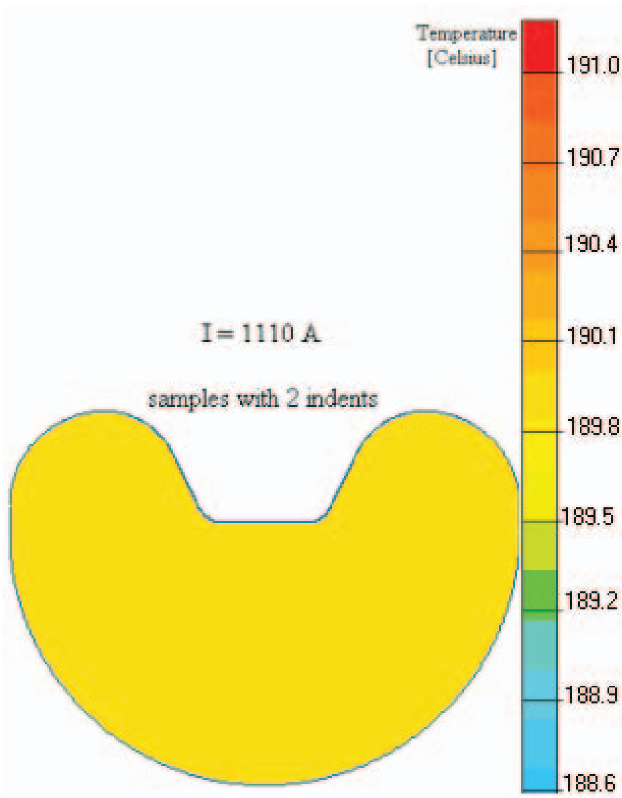


Fig. 13. Temperature for 1110 A, sample with 1 indents, θ_a =27..2 ˚C.



Temperature for 1110 A, sample with 1 indents, θ_a =27..2 ˚C.

III. CONCLUSIONS

An important parameter in numerical simulations is the heat transfer coefficient which depends on overtemperature. Knowing the heat transfer coefficient law and using it in numerical simulation can be obtained the real numerical temperature values.

For obtaining the numerical values of temperature must be solved a coupled problem: AC Magnetic – Steady-State Heat Transfer. First, the AC Magnetics problem was solved to obtain the specific Joule heat. Then, the source term was imported in steady state heat transfer problem to solve it.

The temperature dependence of the global heat transfer coefficient has been taking into account in numerical simulations. For calculating the relative error, the numerical results must be compared with experimental ones.

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