The Experimental Study of the Inductive Heating Process by the cleating Method

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***Abstract* - The paper focuses on one method of welding of two coaxial cylinders, made of different materials. The method of welding uses inductive heating technology, and it is based on the different dilatation coefficient of the materials, the inside material has an upper value of the dilatation coefficient. In the paper it was analyzed the induced power density inside the ferromagnetic material, and the distribution of the temperature field inside the structure. The theoretical results were utilized to make an experimental model.**

***Keywords*: cleating, electromagnetic field, inductive heating, heating process bimetallic components**

I. INTRODUCTION

One of the most important problems in mechanics is the problem of the friction between the moving parts of the machines. This problem of the reduction the energetic losses by friction, in mechanics it is solve by using the bearings, which change the sliding friction into rolling friction, or by using materials with low sliding friction coefficient. For that, the present paper is focused on a study of a technology to make the bimetallic pieces used in the building of the sliding frictions axes.[1,2,8]

The theoretical idea of welding these two materials is based on the principle of the heating of them to the soften temperature, and then press them. In this mode in the separation zone of the two materials, because of the thermal agitation of the constitutive particles, and because the mechanic pressing there appears a transitional area in which the particles of the materials are mixed. When the materials are cooling, this zone provides the welding of the materials.

The technology which is proposed, is based on the inductive heating of the materials, and the relative pressing force between these two work pieces it is insured by the different dilatation coefficient. For the study it was selected steel for the external and internal ring. The model of structures that are studied is represented in figure number 1.

From the theoretical study made, the following conclusion was drawn, i.e. that the optimum of the heating process from the point of view of the heating process speed, together with the distribution, takes place at the work frequency of the inductor of 2500 Hz.[3,4]

The experimental part of the study, in the first part consists in heating a cylindrical steel structure with the dimensions $\varphi_{ext.} = 38$mm, $\varphi_{int.} = 29,7$ mm and the length of the spare part l = 60 mm.

Figure 1. The structure to study

In figure number 2 it is shown the steel spare part introduced inside the inductors, made ready to be heated.

Figure 2 . The work piece who will be processed

II. THEORETICAL PROBLEM

The welding process is based on the thermal conduction between two mediums, in contact, by thermal conduction. The study structure is possible to be represented by a model, which is shown in figure number 3.[6]

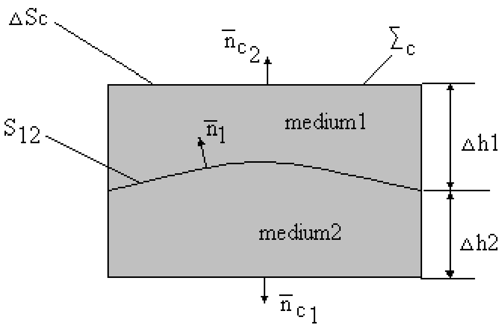

Figure 3. The theoretical structure

The external thermal conduction is given by Newton law, which shows that the thermal density flux is directly proportional with the temperature difference between the medium surface, and the point near them. The proportional constant value is the external conductivity value. Mathematics:

$$\overline{q_0 . n} = q_0 = \alpha(\theta - \theta_0) \qquad (1)$$

The thermal balance to the separation surface, between medium 1 and medium 2, when it is considered that in medium 2 we not have thermal source, is:

$$p\Delta S_c \Delta h_1 = \overline{n}_{c_1} \Delta S_c \overline{q}_1 + \overline{n}_{c_2} \Delta S_c \overline{q}_2 + \rho c \Delta S_c \Delta h_1 \frac{\partial \theta}{\partial t} \qquad (2)$$

Imposing the condition $\Delta h_1 \to 0$, $\Delta h_2 \to 0$, and taking in account that

$$\lim_{\Delta h_1 \to 0} nc_1 = -n_1, \text{ and } \lim_{\Delta h_2 \to 0} nc_2 = n_1,$$

and in concordance with Fourier laws:

$$\overline{q_1} = -\lambda . \text{grad}\theta \qquad (3)$$

Relation (2) becomes:

$$\lambda \frac{\partial \theta}{\partial n_1} + q_0 = 0 \qquad (4)$$

The quasi-stationary electromagnetic field, and the thermal field satisfy the equations system:

$$\text{curl}\overline{H} = \overline{J} \qquad (5)$$

$$\text{curl} \frac{\overline{J}}{\sigma(\theta)} = -\frac{\partial[\mu(H_1\theta)\overline{H}]}{\partial t} = -\frac{\partial \overline{B}}{\partial t} \qquad (6)$$

$$\nabla \lambda \nabla \theta - \lambda \nabla^2 + \rho c \frac{\partial \theta}{\partial t} = \frac{J^2}{\sigma(\theta)} \qquad (7)$$

The border condition is by the type which was represented by relation (4).

The medium power which is developed in the volume unit is:

$$p = \int_{V_c} \frac{J^2}{\sigma(\theta)} dv = \int_{V_c} \frac{(\text{curl}\overline{H})^2}{\sigma(\theta)} \cdot dv \qquad (8)$$

The solving of the electromagnetic field coupled with the thermal field equation is possible to make by iterative numerical method.

The modeling in this paper was made with the professional FLUX 2D software, which is using the finite elements method (FEM).

For numerical modeling and simulation we study a structure which approximates the real situation. In figure 4 it is shown the structure which will be heated, and in figure 5 it is shown the inductor with the steel-steel structure inside.

The external cylinder is made of iron, and has the dilatation coefficient $\alpha_i = 11{,}5^oC^{-1}$ and the internal cylinder made by brass has the dilatation coefficient $\alpha_b = 11{,}5^oC^{-1}$.

The heating process has lasted 30 seconds, and the heating simulation was made to the maximum value of the temperature to 803°C.

Figure 4. The steel piece inside of the inductor

Figure 5. Final temperature of the inductive heating process

As a practical application of the studies of inductive heating, there was used a steel spare part of a cylinder form. This spare part was heated in view of achieving a process of combining two materials (steel and steel), based on the process of dilatation of the heated spare part, followed by its contraction during the chilling process.

That is why, in the moment of reaching the final temperature, the spare part is taken out of the inductor, and within 6 seconds inside of it there shall be introduced another spare part from the same type of steel. This spare part of steel having the dimensions $\varphi_{ext.}$ = 29,8mm, $\varphi_{int.}$= 20 mm and the length of the spare part l = 60 mm.

Figure 6. The real structure

For simulation of the heating process it was imposed a 16 A/mm^2 value of the inductor supply tension, and the work frequency was imposed at 2500 Hz.

The results of the theoretical modeling and simulation, were compared with the experimental results which were obtained in the real heating process. In the experimental heating it was looked for the time variation of one point on the external surface of the steel cylinder, and the results approximated the theoretical results with 14% error. The temperature was measured with an infrared system [2,3,8].

The obtained ensemble after cooling the 2 structures is shown in figure 6.

Figure 6. The steel-steel structures in all heat transfer processes

In order to outline the phenomenon of combining the two materials, at the level of the contact surface among these, there was determined the force at which the relative movement of the two structures appears.

In this sense there are made two auxiliary spare parts, which should enable the application of force, only on the interior cylinder, while the exterior cylinder is mechanically blocked, on a support.

This procedure was performed on a hydraulic press which enables the measurement of the force applied progressively, as well as the value of the force at which there appears the relative movement of the component spare parts of the structure taken into study.

The pressing force on the ensemble studied was progressively applied and the value at which the relative, movement of the two cylinder appeared, in the case of the steel-steel structure was of 6400 Kgf.

As a conclusion, of the practical study carried out, there can be seen that on the contact surfaces between the two structures joined together by the *cleating* procedure, there appeared a considerable (emphasized by the indications of the press), further to the dilatation of the exterior spare part during the process of inductive heating followed by its contraction during the process of cooling.

IV. CONCLUSIONS

This study approaches a problem of practical application in what concerns the possibility of using the inductive heating methods of cylindrical structures in view of performing a procedure of combining them by *cleating*. This procedure of combining two cylindrical metallic structures is based on the phenomenon of dilatation, during heating.

We can also appreciate the fact that the inductive heating method in the procedure of combining by cleating is viable, allowing, as compared to the classical methods (heating in rezistive ovens, heating with flame, etc.), the shortening of the duration of the procedure, as well as its automatization.

By the methods of numeric modelling and simulation there was obtained the distributiuon in time of the thermic field and there was analysed with the help of a program achieved for various work frequencies the dilatation process, there being traced the variation curves of the interior diameter of the spare part in time.

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