Effect of Heating of Steel Tubes by Induction at High Frequency

M. T. Hannachi, B. Dahache*, E. Guelloudje*

Abstract – **Electromagnetic induction is characteristic of generating heat directly within the material being heated. This feature has many advantages over conventional methods of heating more standard, including reduced heating times and high yields, or the ability to heat very locally. The high power densities in play can achieve speeds of very rapid heating temperatures and heating time, the magnetic flux and frequency are the parameters that govern this process. Variations of these parameters involved in this phenomenon of heating are identified by accompanying explanatory curves by the program QuickField.**

Keywords – **Induction, Parameters, Heating, Frequency.**

I. INTRODUCTION

Electromagnetic induction is a technique for heating conductive materials (metals), commonly used for many thermal processes such as fusion or hot metal. The induction is characteristic of generating heat directly within the material being heated. This feature has many advantages over conventional methods of heating more standard, including reduced heating times and high yields, or the ability to heat very locally. The high power densities [1] in play can achieve heating rates very fast. Induction heating is a method of rapid and uniform heating for applications requiring production of paste or change the properties of metals or other conductive materials. This method relies on electric currents induced in a material to produce heat. Although the basic principles of induction are well known, recent advances in technology semiconductor transformed induction heating method in a remarkably simple and profitable applications for bonding, processing, heating or test materials. The electromagnetic induction heating is based on two physical phenomena, electromagnetic induction and the Joule effect. Advantages of this method are numerous: a zone controlled heating, a heating rate that can be extremely fast, low inertia, direct heating of the room, a high performance, very good reproducibility [2]. The high frequency induction welding (HFIW) is a deformation welding process belonging to the electrical resistance welding segment, which uses the material interface generated heat, caused by electrical current flux resistance (Joule effect) and pressure application [3]. This process is widely applied in industrial longitudinal tube welding. Ferritic stainless steels have been used to manufacture weld tubes through such process, particularly for automobile exhaustion systems [4]. HFIW equipments have a high degree of automation and are compact, in general, and also demand a great initial investment [5]. Thus, welding studies as well as pocess operational parameters optimization tend to have high cost and material consumption (see Fig. 1)

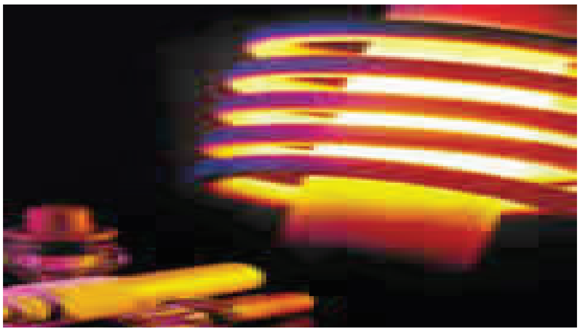

Fig. 1. The induction heating

II. MATERIALS AND METHODS

The material used for welding pipes is steel construction S235JR, in European norm EN 10025, whose chemical composition is given in Table 1.

The grade is indicated by the letter S followed by a number corresponding to the minimum yield tensile strength. If one looks at the issue metallurgy, wecan say that the steel metal construction are steel quality (some are of special steels) are generally not allies (sometimes low alloy) delivered ready that is to say they already have the mechanical characteristics expected and therefore it is not necessary for them to undergo a heat treatment excluding the treatment of stress relieving (to reduce residual stresses) after welding, and sometimes treatment of restoration or normalization. These steels whose carbon content varies with the desired properties, contain (for different reasons) some elements other than carbon, namely Mn (Manganese), Si (Silicon), P (Phosphorus), Al (Aluminum), S (Sulfur) and other elements in small quantities (Nitrogen, sometimes niobium and vanadium or titanium and zirconium) [6].

TABLE 1
CHEMICAL COMPOSITION OF STEEL S235JR

%C	%Mn	%Si	%P	%S	%Al
0,10	0,40	0,02	0,003	0,007	0,042

The optimal use of ferromagnetic metals for the electrical design is always a compromise between these magnetic properties, thermal and mechanical [7].

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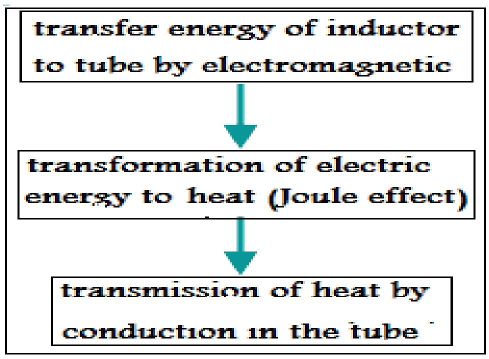

Fig. 2. Transfer of electrical energy and heating

The description of the method transfer of electrical energy and his transformation to energy heating is registered in Fig. 2.

The exact distribution of current in the cross section is described by a set of physical laws known as Maxwell's equations in Eq. 1 and equations of Biot - Fourrier in Eq. (2). The consequences for the first equation are the current density, and the second equation is the heat capacity with thermal conductivity plays an important role in heating.

$$\nabla^2 i_s - j\left(2\pi . f \mu\sigma \cdot i_s\right) = 0 \qquad (1)$$

$$K\nabla^2 T - \gamma C_p \frac{dT}{dt} + Q = 0 \qquad (2)$$

With, i_s the density of electrical current through the tube, f, frequency electric welding, μ the magnetic permeability of the tube, σ the electrical conductivity of the tube, imaginary number j (j^2 = -1), T temperature distribution K, thermal conductivity of the tube, the tube density, Cp, heat capacity of the tube, Q, heat the tube.

More supply frequency f increases, the induced currents are concentrated at the surface. According to Lenz law, the meaning of Eddy Current (Form. 3) is always opposite to that of the current inductor. As the inductor current, the eddy creates ran the alternating magnetic field. The two fields, with their opposite directions, cancel each other partially interior metal. Only near the edges it is a resultant field: one speaks of effet skin (Form. 4). The exact distribution of current density in part depends on the characteristic physical heated material, shape, form and position of conductor, level and frequency of current in the inductor.

$$i_s = e^{-1/d} \qquad (3)$$

When the loop is short-circuiting induced voltage E will result in the emergence of a current short-circuit current flowing in the opposite direction to the phenomenon that generates it. It is the law of Faraday Lenz. If a driver (eg a cylinder) is subjected to a variation of magnetic flux (or placed in an alternating magnetic field), are emerging, as in the case of the closed loop, the induced currents. These currents are called eddy currents and circulating a non-homogeneous in the cylinder. The eddy currents through the electrical resistance of the cylinder, just heat the driver in accordance with Joules law.

$$d = \sqrt{\frac{\rho}{\pi\mu\mu_0 f}} \qquad (4)$$

d: Depth of penetration [m]; ρ electrical resistivity; μ_0, Permeability genetic empty (H /m); μ_r the relative magnetic permeability and f, excitation frequency [Hz].

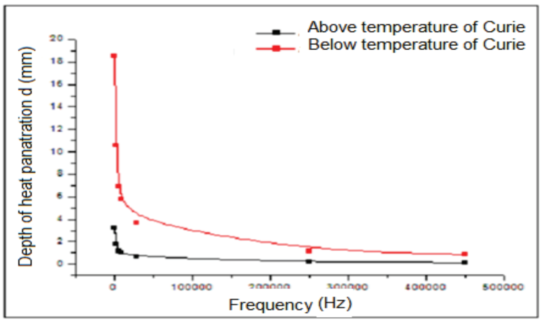

Fig. 3. Effect of skin (penetration) according to the current frequency

The depth of penetration (Heat skin) increases with increasing temperature and this increase is particularly sharp at the temperature above the Curie point (768 °C) by following the passage of the steel of the ferromagnetic state to paramagnetic state even time (Fig. 3).

The resistivity and magnetic permeability are characteristics of body heat; the frequency is a quantity that can be chosen by user. It has a means for controlling the dissipation inside the body to heat and to choose the most suitable heating. The electrical resistivity: the depth of penetration is proportional to the square root of the resistivity of the armature. This, for metals, is generally believed with temperature. To model the evolution of the electrical resistivity, we own both models, developed from measurements (see Fig. 4).

$$\rho = \rho_0\left(1 + \alpha\left(T - T_0\right)\right) \qquad (5)$$

with, ρ electrical resistivity, ρ_0 initial electrical resistivity at 20°C , T temperature (°C) and T_o is the initial temperature (T = 20 °C).

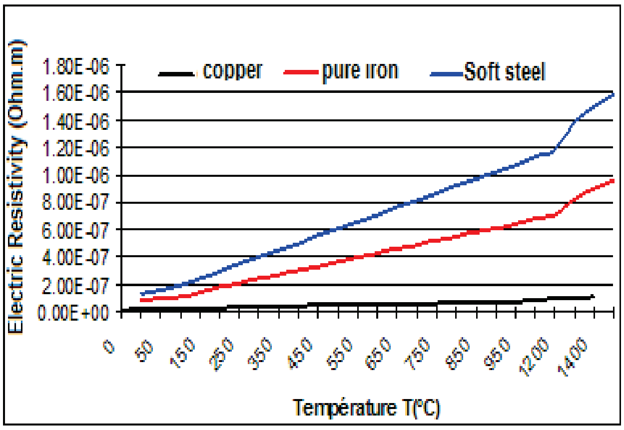

Fig. 4. Variation of electrical resistivity with the temperature of heat

Before welding, the slit width is kept constant by a roller or a blade to maintain geometrical constant during welding. The energy required for welding is supplied to the tube (still open in the longitudinal direction) by a coil (inductor). This is done by induction, without contact with the tube as shown. The inductor is traversed by a high current and must be cooled by water. And HF induces a voltage in the open tube, which gives rise to the movement of a current whose lines will contain the contact point edge (point welding). The net current along the edges cause the heating of the latter on the section between the inductor and the welding point. An additional heating to the point of welding the tube leads spontaneously to the welding temperature (see Fig. 5).

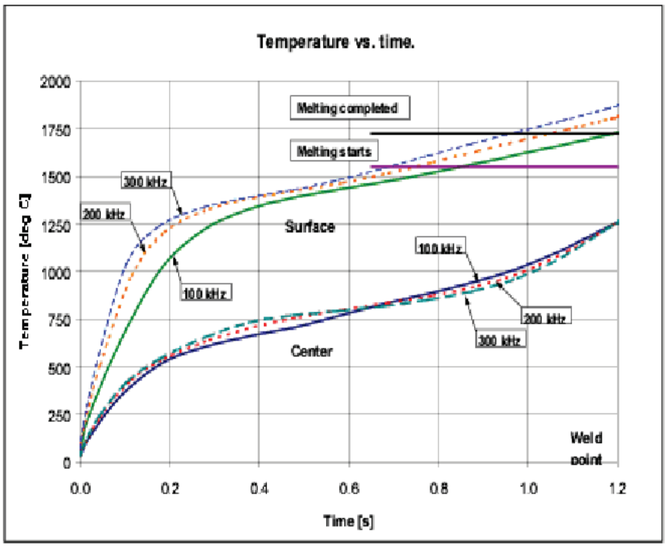

Fig. 5. heat temperature function of time in center edge and surface [9]

This heat is produced, among others, by the output of the magnetic field outside the tube to the welding point and the concentration of power lines to the right point of the weld itself.

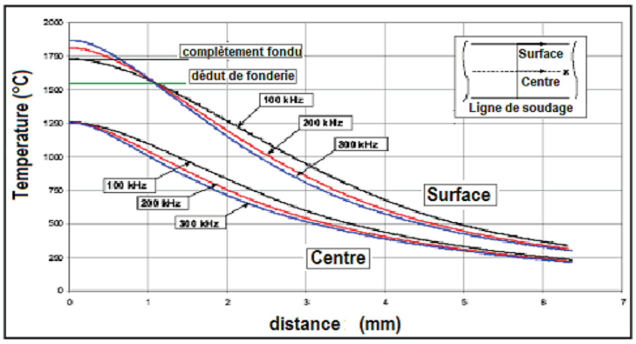

Fig. 6. Temperature depending on the distance

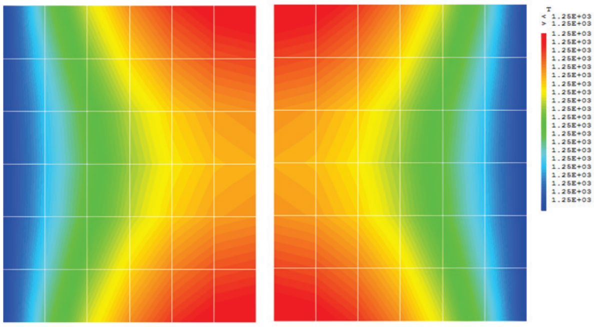

Fig. 7. Simulation of heat in center of the two edge of tube before welding by castem 2016 [10]

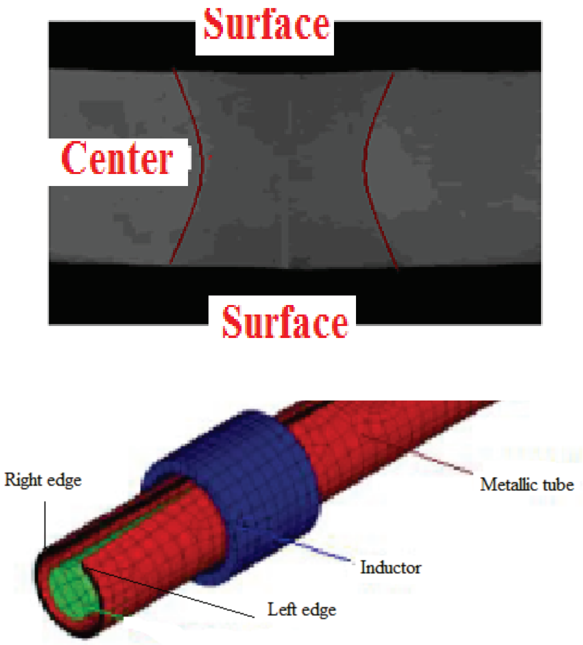

Fig. 8. The shape of the welded joint section of the tube

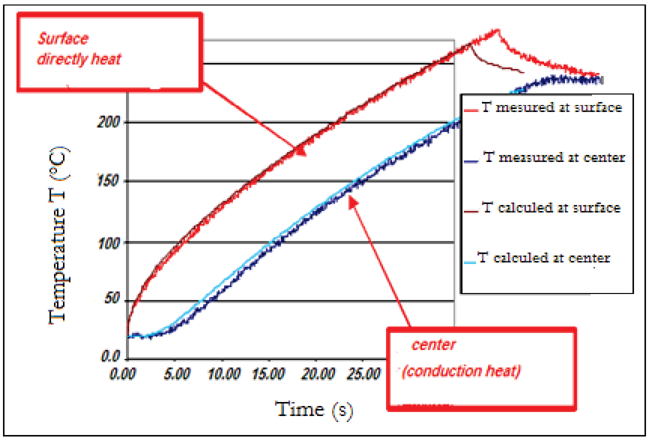

Fig. 9. Heating at surface and center of edge of tube [11]

III. Simulation of Parameters of Heat by QuickField

QuickField is a calculation software very efficient finite element (FEM) for electromagnetic problems, thermal and mechanical stresses. It consists of several modules that use the latest technology with a resolution easy to use preprocessor and a powerful postprocessor. The preprocessor QuickField allows you to define your models quickly, easily and completely. You can import your designs from AutoCAD and other CAD systems. The geometry is defined, the mesh creation is effortless.

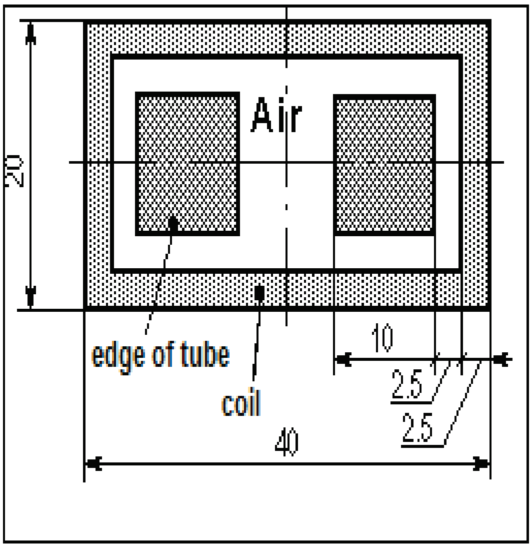

Fig. 10. The two edges of tube (section) into a rectangular coil for heating by induction

We assume that the flow is contained within the coating, so we can put a Dirichlet boundary condition on the outer surface of the coating.

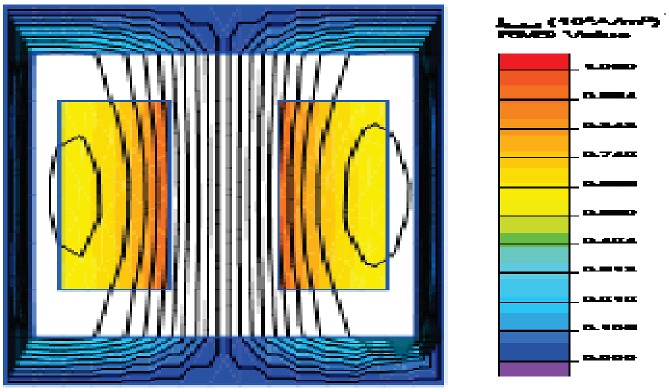
Fig. 11. Simulation of curent density

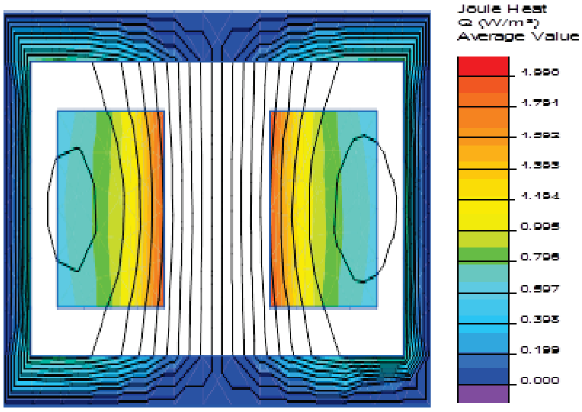

Fig. 12. Joule effect of heating (power density)

The induced current decreases exponentially, then we define a depth of penetration or skin depth d, where the induced current is reduced by 1/exp (approximately 0.37 or 37% is) is where is the value of the current induced on the surface. So there is concentration of the heat effect in this layer represents 87% of the energy dissipated expression of d, depending on the used frequency f is given by equation (3). The skin effect (Fig. 3) is tendency of an alternating electrical current to circulate in a conductor so that the current density near the surface of the conductor is greater than its core. It causes the effective resistance of the conductor increases with frequency current. It is proportional to the square root of the resistivity of the armature. This, for metals, is generally believed with temperature. The high frequency current does not spread in the cables as the DC or low frequency. Instead of using the entire section of the driver they are confined in the layers near the surface of the conductor. The current density decreases exponentially as and as the distance from the surface.

The electrical conductivity is a phenomenon that is explained by the existence of free electrons, moving with great speed in a metal material subjected to electric voltage. Electrons during their journey through the metal collide with ions or atoms of the grid. The electrical resistivity (Fig. 4), being dependent on the temperature of the material is more important than for the mean free path given the number of collisions is high. The evolution of the overall electrical resistivity of the material is to model the temperature fields on all surfaces of the material. The time of heating up the melting temperature is extremely short (only 0.1 *s* for an average speed of 30 m/min and a thickness of 3 mm), the temperature gradient must be extremely high with increasing power.

The material to be heated plays a role in reducing the power for different frequencies, this is due to the increase of heating time and hence the crossing of significant thickness, this to a starting temperature of heating. Heating the material regulates the temperature increase versus time is legible. The specific heat is an example of this, the Curie temperature; the material goes through a phase transformation by using energy as the molten steel requires much energy. In reality, this happens in a short interval of temperature. We have matched this with another distribution almost linear (see Fig. 5 and Fig. 6). Therefore, the temperature continues to rise in this interval, continuing to be more or less constant until enough energy is absorbed to melt steel. Therefore, induction heating has the appearance of a process very short in heater. Note that the Heat Affected Zone (HAZ) is shaped like an hourglass (see Fig. 7 and Fig. 8). This is because the heat generated by the HF current enters the strip edge from the top and the side of the edge. The HAZ is usually darker than the parent metal because carbon in the steel diffuses toward the hot edges during the welding process and becomes trapped on the edge when the weld cools (see Fig. 9). The bond plane is usually light colored because it is very low in carbon. The carbon on the very edges oxidizes to CO and CO_2, leaving the iron without carbon to darken it. The effect of frequency on the magnetic flux of impeder is interpreted by two methods, the first concerns the evolution of the frequency with the reduction of flows necessary to transfer the same amount of power, the second reason is when frequency welding is reduced, the transition process of thermal mode to mode of electric power's demands more power for welding the same geometric data of the tube and the same welding speed. Increased power transfer requires more flux in the magnetic core, the power increases with time, which gives the property of heating at high frequency short duration and thus facilitate the transition to direct temperature melting process the temperature above the melting temperature have practical significance metal in this case fall. You do not need to define the characteristics of the mesh as the sophisticated technology editor can generate a mesh suitable for your geometry. You can set your loads and boundary conditions, and this completely independently of your mesh, and change them at any time. The interactive postprocessor QuickField [12] you will analyze your results in many graphical visualizations: tensor, vectors, field lines, colors, curves along arbitrary contours. In addition it is equipped with a powerful calculator that allows you to easily get the various parameters of your design and also to calculate various surface integrals and volume in arbitrary regions. The numerical simulation by quickfield of the parameters [13] for the heating of the edges Fig. 10 of the tube is succinctly illustrated in Fig. 11 and Fig. 12.

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I dedicate this modest work to all members of the Laboratory of materials and environment at the university of Tebessa and all the researchers in the world.

IV. CONCLUSION

Induction heating is a technique well adapted to heat treatments in metallurgy. However it is necessary to properly size the inductors to have an optimal process. Given the number of parameters calculated and taken into account in this study, it seems that this phenomenon is heating a little clearer, the need is adequately supplemented by use of digital technology. The example of solder in pipes at high frequency is one method of induction heating high frequency used for the production of pipes soet pipe mills, and most profitable in terms of cost. Since profit margins are narrow in the industrial tubes and pipes, even a small performance improvement can be a big difference compared to the results, it will not only direct economic costs of energy, but an improvement quality and productivity as well. Recent advances in technology of semiconductors have transformed the induction heating method in a remarkably simple and profitable applications for bonding, processing, heating or test materials.

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