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Induction Preheating for the Submerged Arc Welded Steel Tube Production

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Abstract
Tenaris is a leading supplier of tubes and related services for the world's energy industry that manufactures a complete range of seamless and welded steel tubular products. The welding facilities are located in North and South America, and perform three types of welding processes, namely Electric Resistance Welding (ERW), Spiral Submerged Arc Welding, and Longitudinal Submerged Arc Welding (LSAW). Regarding the ERW process, in recent years we studied both the welding using Comsol [1,2], and the ulterior seam heat treatment using an in-house developed FEM model [3,4]. During the LSAW process, after the plate is conformed through the UOE forming process, the butt joint of the pipe is welded in three phases, first of which aims at presenting the edges and joining them but without filling in the bevels, the second one is to fill in the seam region at the inside of the pipe and the third one to do this operation on the outside. The welds are made by melting with an electric arc the bare metal electrodes. Pressure is not applied on the pipe during welding. Depending on the final product properties sought, a preheating near the edges with a relatively narrow temperature range is required for these three welding stages. In this article we focus on the inductive preheating for the tack welding stage of a continuous production line; it involves an open tubular geometry whose edges are facing and separated approximately 10 mm. There is no need to reheat the full tube, but only a region of ±75 mm from the edges approximately. Given the geometry and the required localized preheating, usual solution would be bar type inductors as those used typically for seam annealing. Alternatively, cylindrical coils can be used instead of inductive bars. 2D and 3D numerical models of different inductor bars and cylindrical coils are used in order to assess both kinds of preheaters and to understand the advantages and disadvantages of each one.

Key words: induction heating – steel tubes – submerged arc welding

Introduction
The LSAW process that is studied in this work involves four main stages: first, water remaining after cleaning the already-formed steel sheet is evaporated in a combustion dryer, then the edges are joined in the tack welding process, subsequently the ID welder fills in the internal seam, and finally the OD welder does the same with the outer one, as shown in Fig. 1 (see reference [5]).

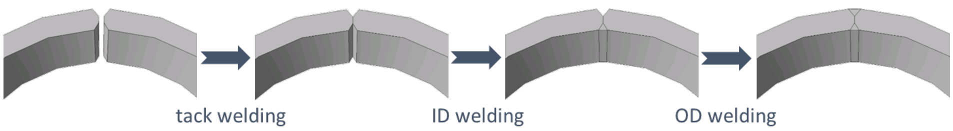

Fig. 1: Main processes in a LSAW line (after forming).

These three welding processes require tight temperature ranges in the zone to be welded. Besides, there is a maximum spot temperature that can be reached to avoid oxide formation. As the region of interest is about ± 75 mm surrounding the edges, for large OD products this represents a small percentage of the tube mass, and therefore heat conduction to the colder tube body cools down fast the preheated zone. On the other hand, if a wider preheated zone is generated, the process efficiency diminishes and the time to cool down such a large mass of steel is high and strongly depends on the mill conditions. Even more, the cooling time can become a bottleneck for the OD welder, given the fact that it is a process with a maximum acceptable temperature not very high.
Therefore, the preheating processes and the transference times from the furnaces to the welders are critical to meet the specifications, and the balance between preheating temperature (and distribution) and time is very delicate.
This study focuses on the tack welding process, defined as "a weld made to hold the parts of a weldment in proper alignment until the final welds are made" [6]. Although preheat is not required in this case according to this standard, there was a need to adapt the whole line for an out of range product that required a significant productivity improvement. The combustion chamber showed not to be sufficient for the previous necessary drying, and therefore the need of an extra preheating stage came up. Due to the reduced space available in the existing line, new induction heating equipment was

considered.
Given the fact that after the tack welding the strip edges are in contact and induced currents are able to close circumferentially, in what follows attention is focused on the tack welding preheater that requires an "open tube" geometry –a non-standard configuration in the industry–.

Initial proposals for the preheater
Induction bars were the first option that was considered because of the similarity with the standard seam annealing process. Two possibilities were analyzed:

- An annealer-like inductor, i.e., a central conductor with two returning branches symmetrically placed, parallel to the seam direction, as those used for the seam heat treatment in the Electric Resistance Welding (ERW) lines.
- A U-shape inductor, namely, two parallel conductors with opposite currents, or eventually same direction current, and a distant returning conductor. This kind of bar inductors are not very usual, given the fact that at the middle of both bars the magnetic flux density is null (first case) or lower than near one of the conductors (second case). As in the present case exists a separation between both zones to be heated (the edges), this issue could, in principle, be benefic for the considered geometry.

Both cases were simulated using COMSOL Multiphysics® software, in a 2D approach that disregards the heat diffusion in the axial direction and the effects of the finite length of the inductor bars and the formed steel. The model solves first the electromagnetic problem, and then uses the computed power density to feed the thermal problem, with boundary conditions trying to reflect the mill environment. Some results are shown in Fig. 2.

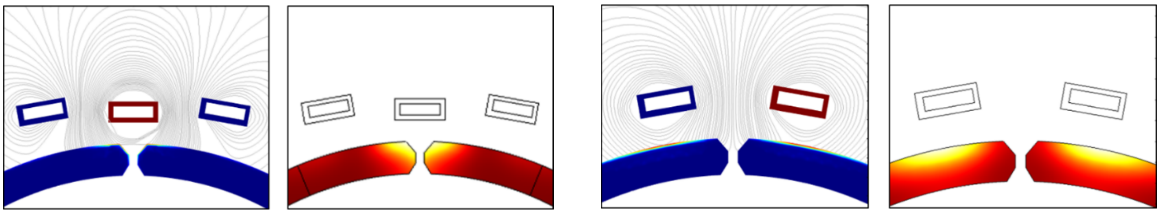

Fig. 2: The two figures on the left, an annealer-like inductor. First, the electromagnetic problem: a central conductor with free current circulating in one direction (red rectangle) and returning by the lateral conductors (blue ones). The color map in the formed steel sheet represents the power density distribution, while the magnetic flux density streamlines are depicted in grey. Second, temperature distribution at the preheater outlet. The travel time up to the tack welder inlet produces the needed homogenization in the region of interest. The two figures on the right, the same graphs but for a U-shape inductor.

The temperature distributions obtained from these simulations reach in some cases the desired conditions, depending on one hand on the conductors' transversal geometry and the gap with the steel, and on the other on the free current amplitude, the bars length, and location relative to the tack welder inlet. However, concerns regarding the tube bending and the consequent effect on the gap between the inductor bars and the steel surface, that highly affects the heating homogeneity, prevented the implementation of these options.

Final proposal for the preheater
In order to get a temperature distribution not so dependent of the gap between the inductor and the steel surface, interest was focused on a full body coil, that generates a more uniform inner magnetic flux density distribution. This kind of inductors have a circumferential free current that induces in a tube a current in the opposite direction and have a typical efficiency of 0.80 for reasonably good-tuned industrial equipment (as the one that was available in the plant for this operation). However, in this case the tube is not yet closed, and there is scarce literature of using a full body coil to heat an "open tube", that prevents the possibility of circumferential induced currents. The calculation of these currents requires to pose a 3D problem, for which the geometry and the mesh of the formed steel sheet plus the coil are shown in Fig. 3.

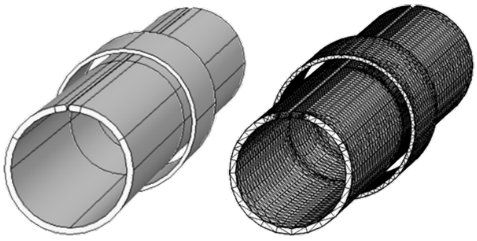

Fig. 3. Geometry and mesh for the formed steel sheet plus the full body coil.

Fig. 4 and Fig. 5 show the results obtained using color maps for the circumferential and the axial induced currents respectively. As schematized in Fig. 6, the current circulates along the outer surface circumferentially, and in the opposite direction respect to the free current of the coil. When it comes to one edge, most of the current surrounds the bevel and close the circuit returning along the inner tube surface. The rest of the current proceeds in a direction parallel to the strip edges, moving away from the coil center, and closing the circumferential path in a distributed way along tube sections that are out of the coil. As the length of steel that is under the coil is much shorter than the tube length, the current density magnitude is much smaller outside the coil, and the heating is therefore concentrated inside the coil, particularly near the bevels. Moreover, as the current surrounds the bevels, the power density in the zone of interest is distributed at the surface, both outer and inner. This fact improved the homogeneity of the heating through the thickness, as shown in Fig. 7, to be compared with Fig. 2 of the bar inductors mentioned before.

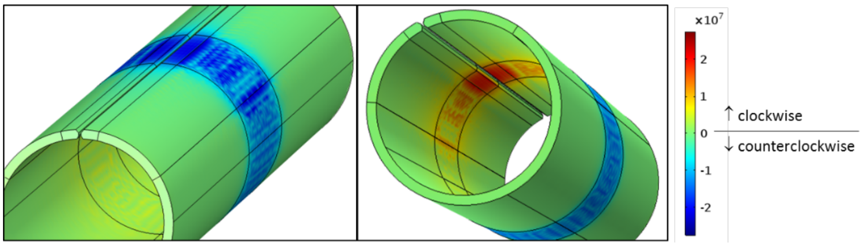

Fig. 4. Color map of the circumferential induced current density.

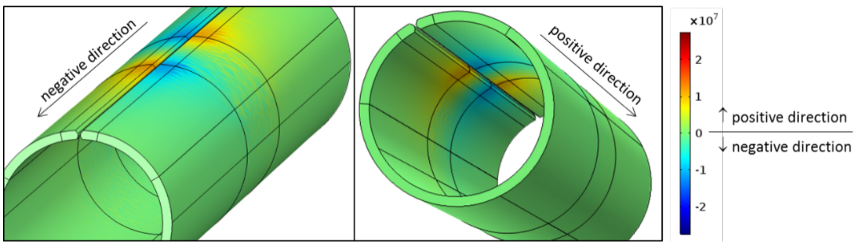

Fig. 5. Color map of the axial induced current density. Same color scale than in Fig. 4 is used

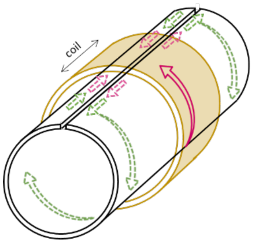

Fig. 6. Schema of the current circulation in the steel piece. The arrows in magenta represent the currents circulating on the outer surface, while the arrows in green account for those on the inner surface.

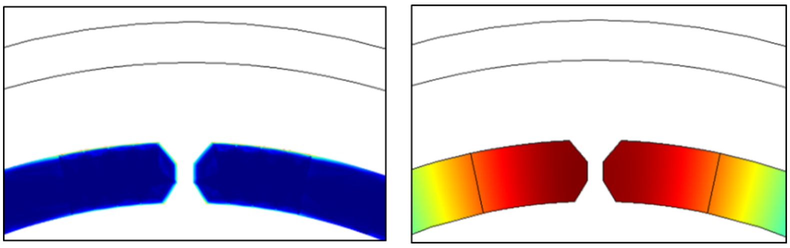

Fig. 7. Same as Fig. 2, but for a full-body coil. Power density at the middle of the coil length, on the left, and temperature distribution when the desired value is reached (at this plane), on the right.

Closing comments

Using numerical simulations it was verified that the preheating with a typical full body coil of a formed tubular steel sheet, not yet closed by the LSAW process, is feasible for the line conditions.

Moreover, this type of coil has two main advantages as compared with bar-type inductors. In first place, as the magnetic flux density is more uniform in the center of the coil, the distance of the bevels to the inductor is not as important as for a bar inductor, in which the field falls dawn quickly with the bar-tube gap. This issue becomes very important given that the localized heating could produce a considerable bending. In second place, the induced power is distributed both in the inner and outer surfaces of the zone of interest, not only at the outer side as in the bar case. The temperature distribution is therefore more homogeneous and improves the process.

Lastly, even though not shown here for lack of space, a static trial was performed that allowed to estimate the efficiency of the process in 0.30. Although obviously lower than the efficiency of heating a tube with a full-body coil, it has to be compared with the annealer-like inductor, for which the efficiency is estimated in 0.55 (below Curie temperature) in the case of a seam heat treatment.

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