COMSOL CONFERENCE
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Electric Welding Process in the Tube Manufacturing: Comparison between a Numerical Model and a Set of Plant Trials

Tenaris

Research & Development – Tenaris – Argentina
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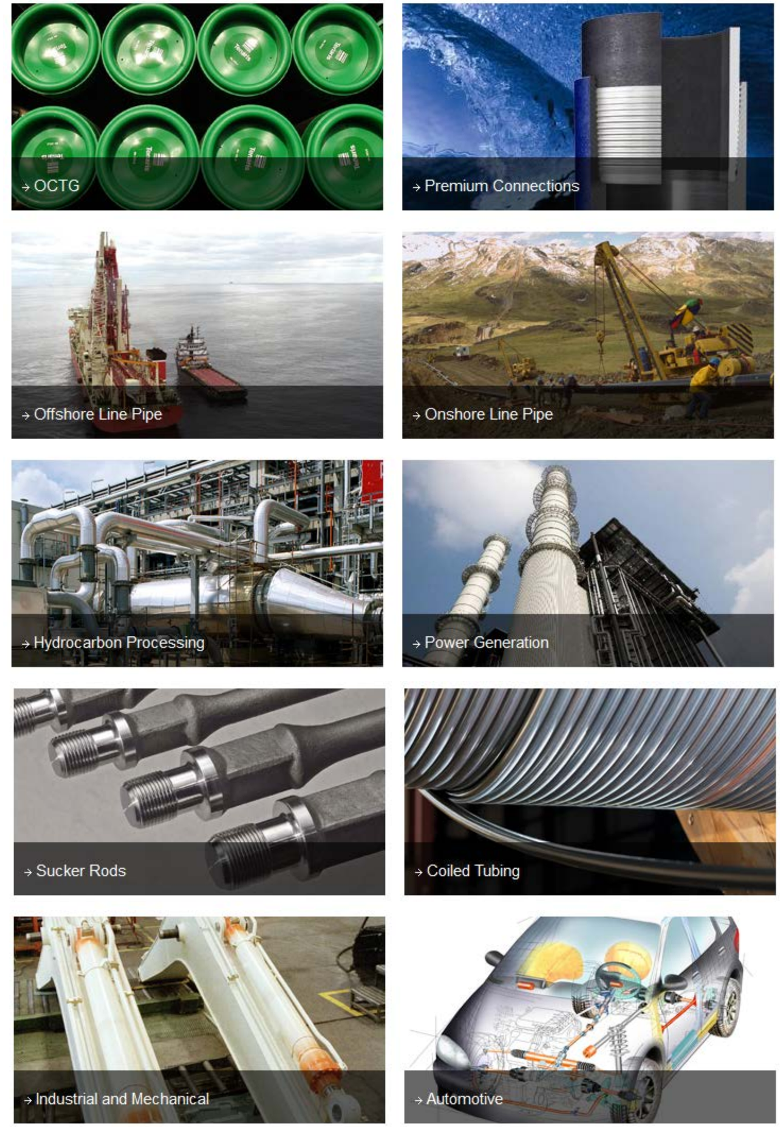
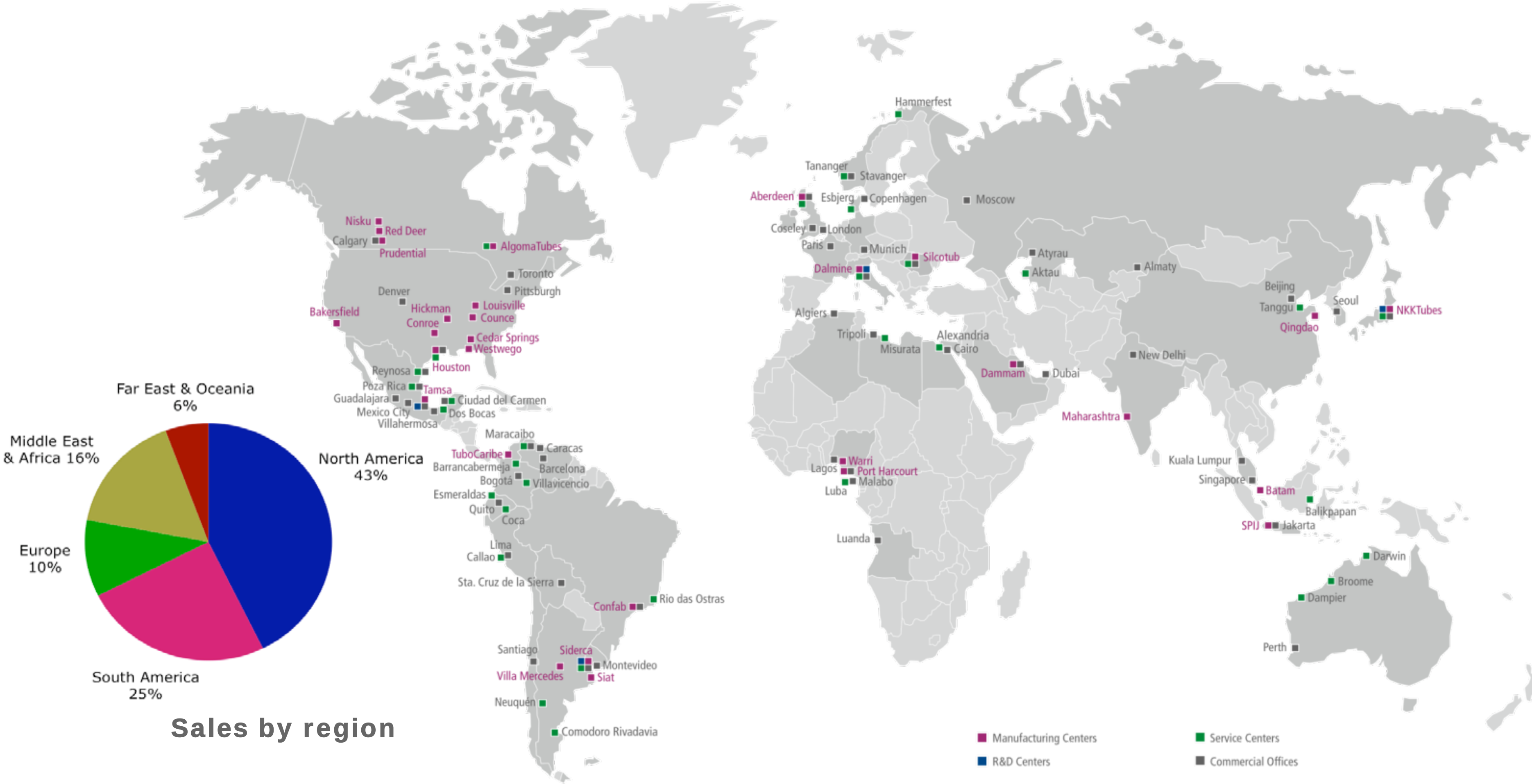
Tenaris. Products



Tenaris is a leading supplier of tubes and related services for the world's energy industry and certain other industrial applications.

Tenaris. Global organization

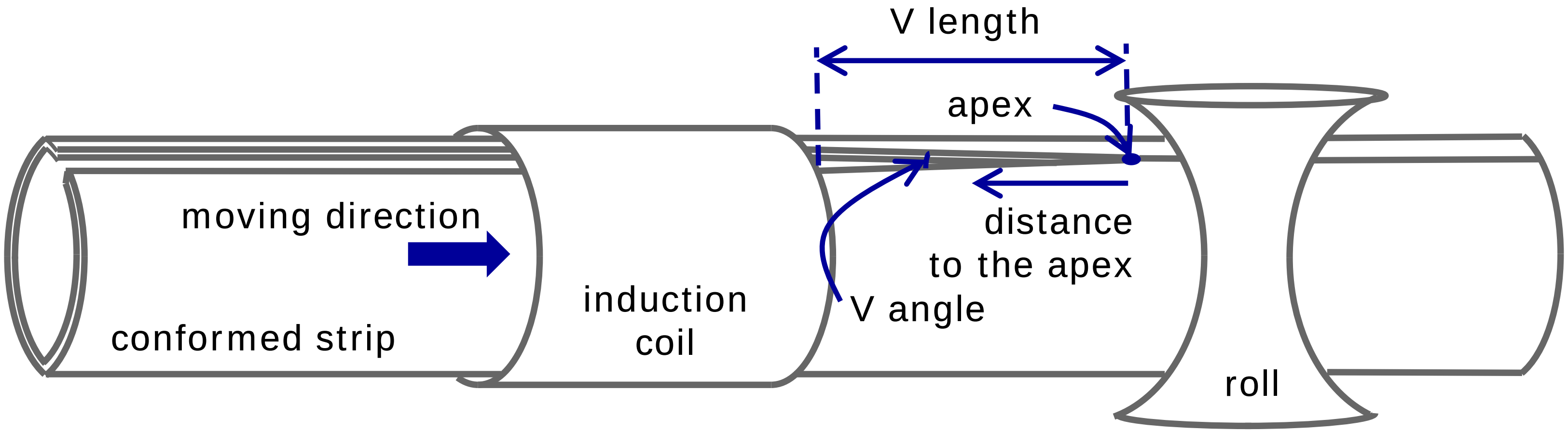


Sales by region

Manufacturing facilities in 16 countries (pink); R&D centers in 4 countries (blue); service yards (green) and commercial offices (grey) in 25 countries ; 27000 employees.

EW process

In welded tube manufacturing, the electric welding (EW) process begins with a coiled plate of steel with appropriate thickness and width to conform the produced tube. The strip is pulled through a series of rollers that gradually cold conform it into a tubular shape. The edges of the cylindrical plate come together forming a V. The strip edges are heated with a high frequency power source, both using contact electrodes or magnetic induction coils. The edges weld properly when they come into contact at a temperature slightly higher than the melting point.



Motivation for the trials

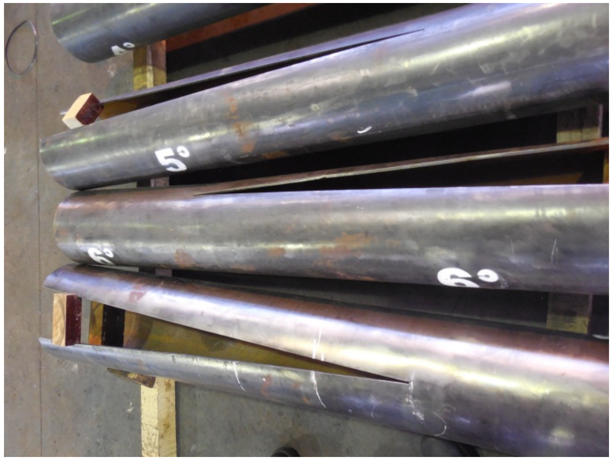
It is desirable to have a model that simulates the complex phenomena that occur during the EW process. But due to the many geometric variables involved it is very difficult to characterize this process. It was then decided to perform some trials to understand the influence of the different parameters in the process, to contribute to their optimization, and to have controlled measurements to compare with the model.

Main idea of these trials is to perform a **static heating** in which all the involved variables be under strict control. The heating was chosen to be static just because is much easier to monitor all the variables in that case. During the heating, the temperature was registered using two thermographic cameras.

For each set of trials the variables were modified to span reasonable ranges, so it is possible the ulterior study of the efficiency of the heating as function of the selected variables.

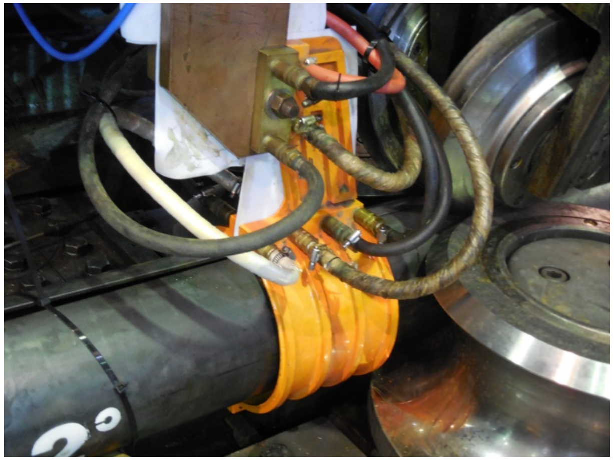
The trials

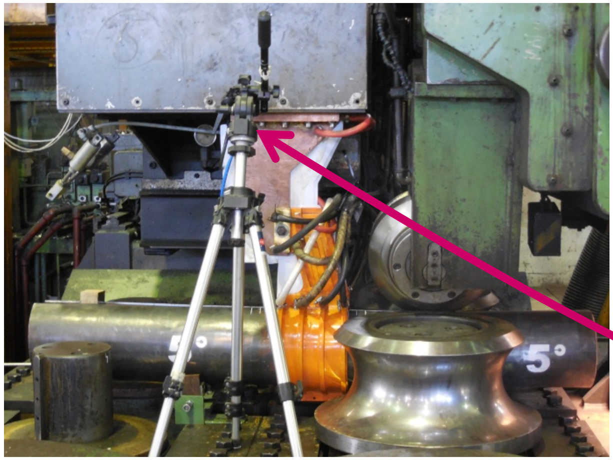
The set of trials was designed to study the static heating of a tube -in which the V is simulated- using induction coil.



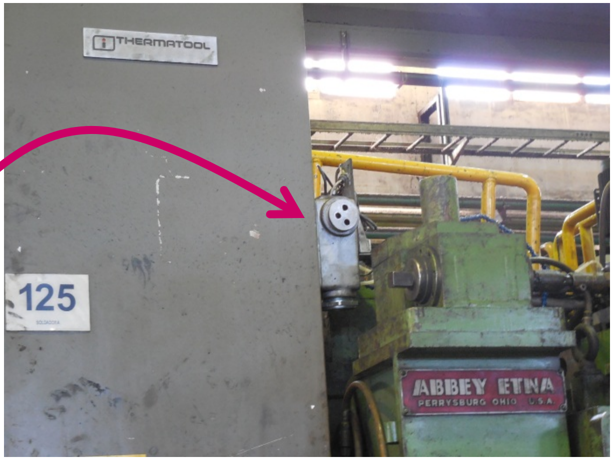
The tube samples were cut to simulate welding sheets at different angles.

The induction coil was used to heat the tube samples.



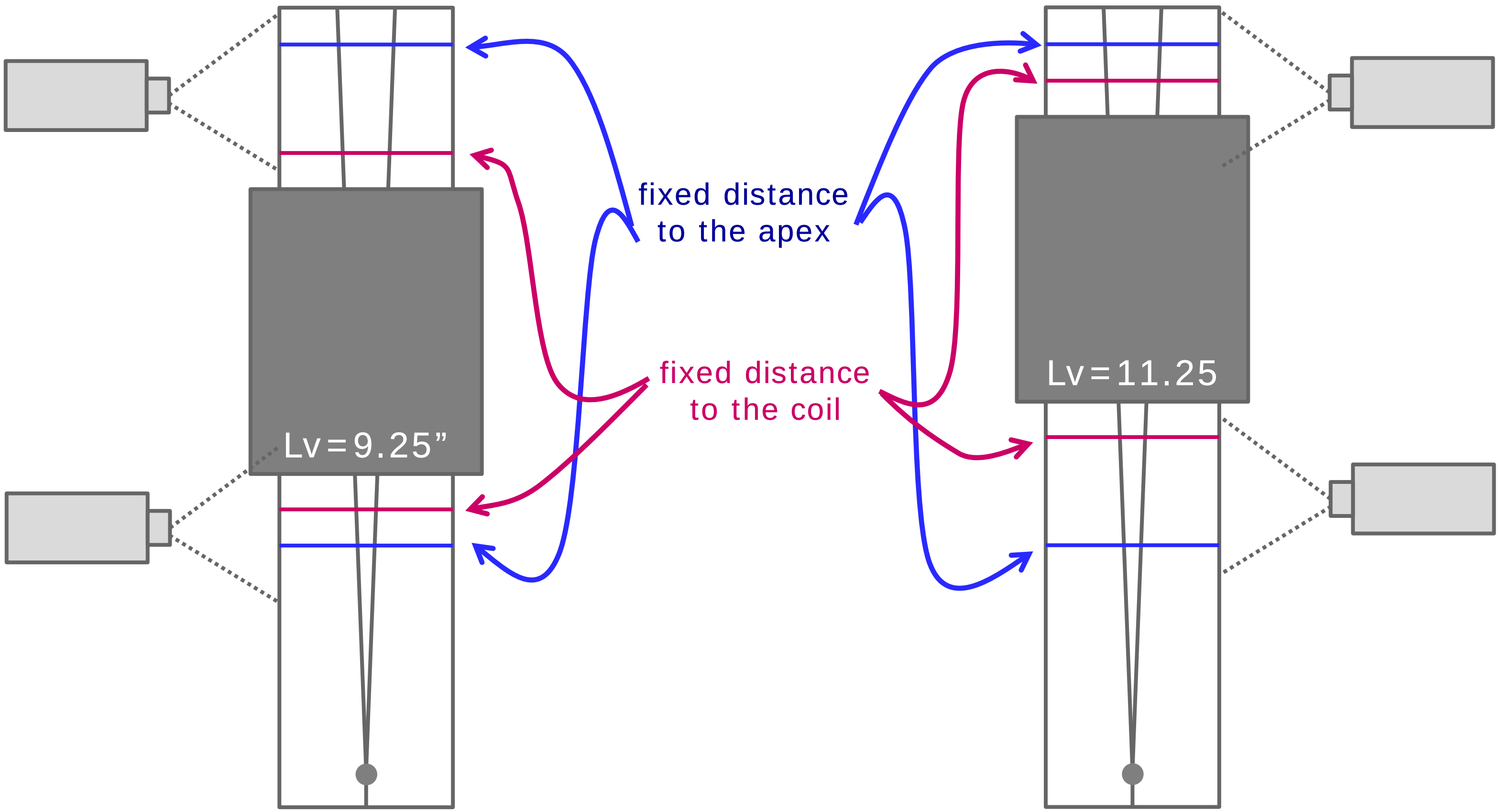


Two thermographic cameras were used to register the heating: one between the coil and the apex, and the other beyond the coil.



Thermographic cameras configuration

Each camera registered the temperature across two lines perpendicular to the axis of the tube as function of time: one at fixed distance to the apex and the other at a fixed distance to the coil. Therefore, the position of this last one depends on the V length.

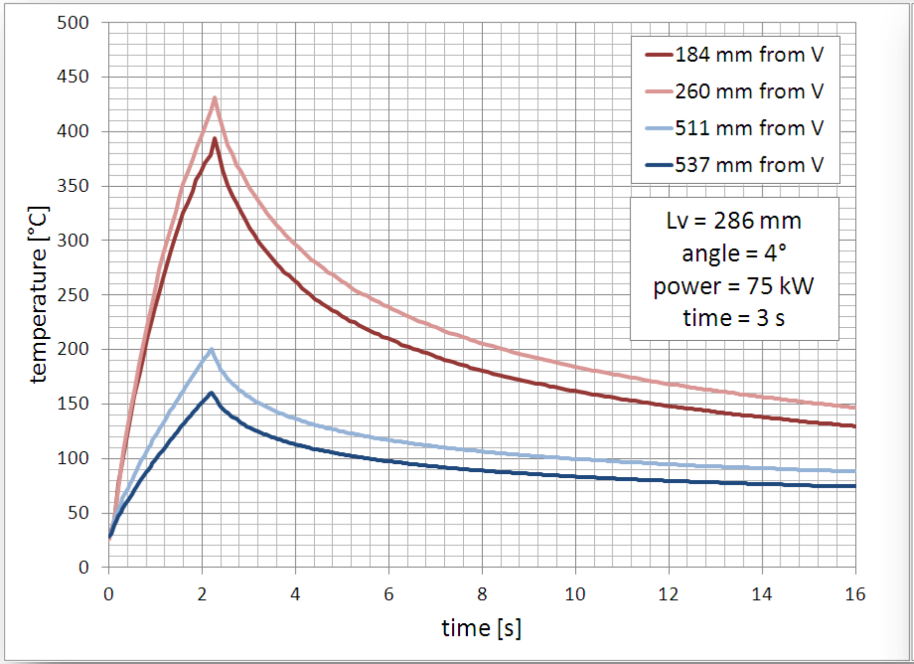


Variables and values explored

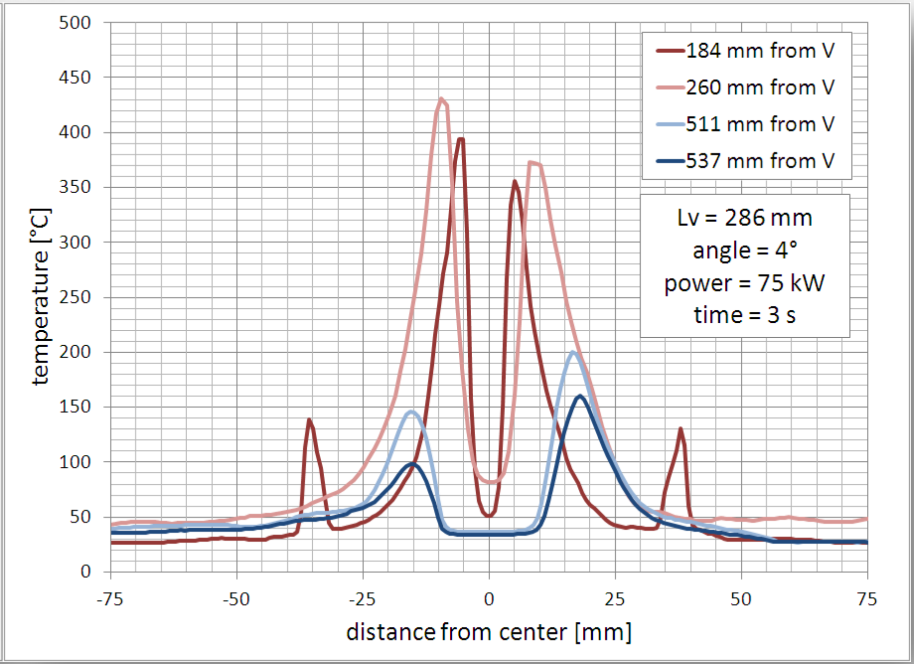
variable	values explored				
tube OD ["]	8 5/8				
tube WT [mm]	5.6				
V length ["]	9.25			11.25	
V angle [º]	3		4		5
impeder	no				
power	given				
induction coil	given				
heating time	given				

Typical temperature curves

For one individual trial, there are measurements of the temperature for four lines, two of them between the coil and the apex and the other two beyond the coil. For each of them, the temperature was registered both as function of the position within the line (i.e., the distance to the V axis) and the time.



maximum temperature in each of the four measured lines as function of time



temperature as function of distance to the axis of the V, for the four lines, at the time in which maximum temperature occurs

Methodology employed

Proxy for the "heating efficiency": we used the average heating rate at 3s. This average is taken between the two edges and the three repetitions performed for each case. The 3 seconds were chosen taken into account the maximum time for which all the trials are ok. The heating rate is defined as:

$$heating\ rate = \frac{peak\ T\ @\ 3\ s\ - initial\ T}{3\ s}$$

To investigate how this proxy depend on the different variables explored, main idea is to fit a least squares model to the data. The more complete model considered is quadratic for the variables of which 3 values were explored (angle α, distance to the apex z), and linear for the variables of which only 2 values were considered (V length L_V).

General model is therefore:

$$y = a_1 + a_2\, L_V + a_3\, \alpha + a_4\, z + a_5\, L_V \alpha + a_6\, L_V z + a_7\, \alpha z + a_8\, \alpha^2 + a_9\, z^2$$

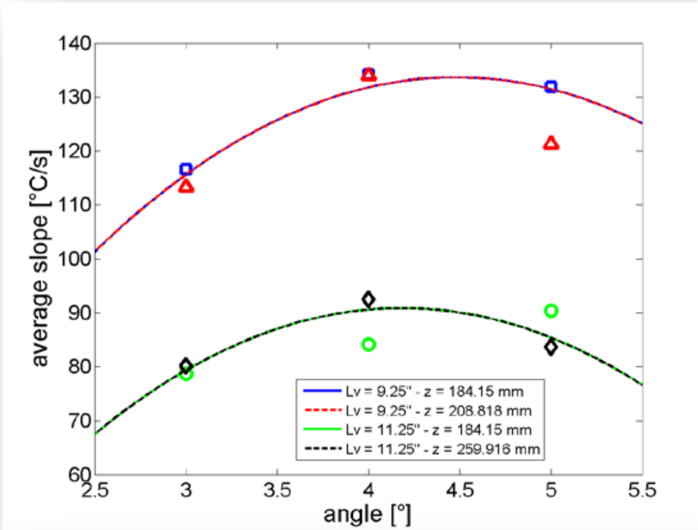
with errors given by:

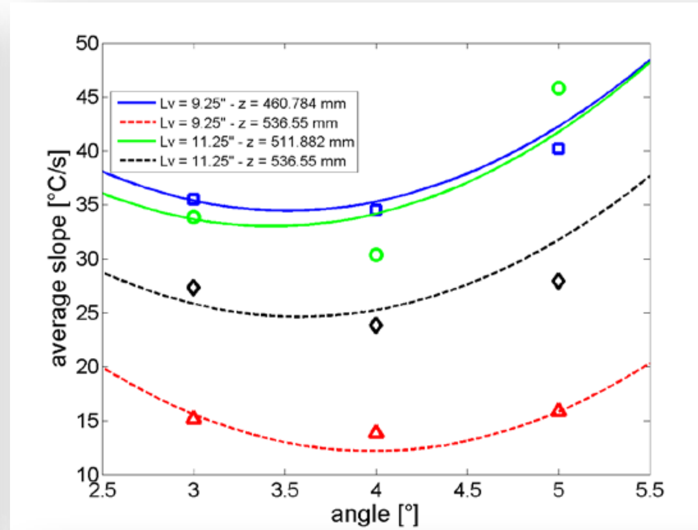
$$\delta y^2 = \sum_{i,j=1}^{9} \frac{\partial y}{\partial a_i} \frac{\partial y}{\partial a_j} \delta a_i \delta a_j$$

Coefficients $a_1 \cdots a_9$ are computed using least squares.

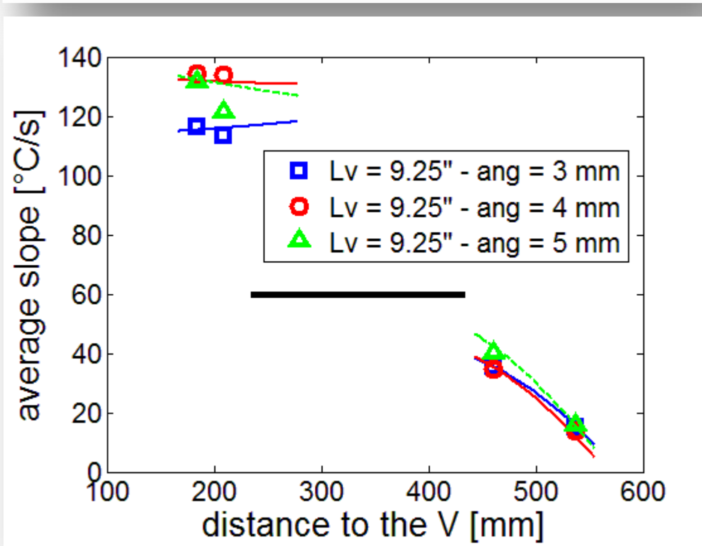
Measurements results

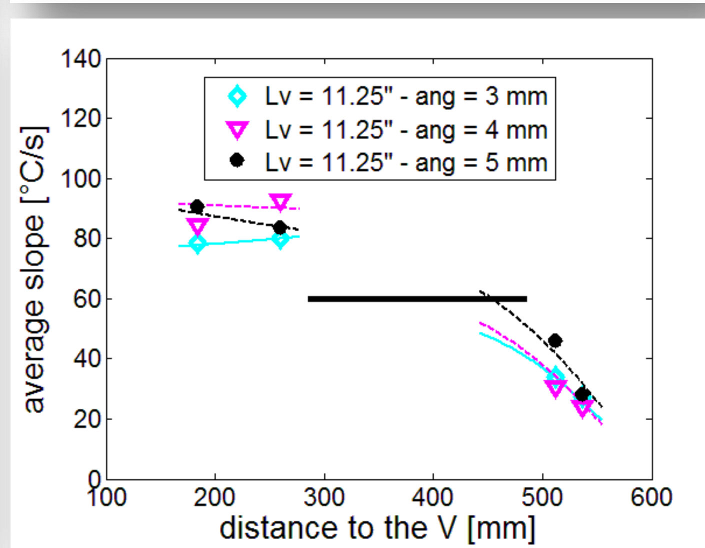
as function of the V angle





as function of the distance to the apex





The model for the electromagnetic heating

We designed a model to simulate the process using COMSOL. It does not include yet the non linear effects of the magnetic properties of the steel. As we do not have any electrical measurement in the welder, the frequency and amplitude of the current circulating by the coil in the model are reasonably chosen.

The model uses Magnetic Fields physics. The geometry represents only half of the problem because of the symmetry, including the tube with the V, the coil and the surrounding air. Due to the high frequencies involved, we replaced the tube by its boundaries and applied an impedance boundary condition.

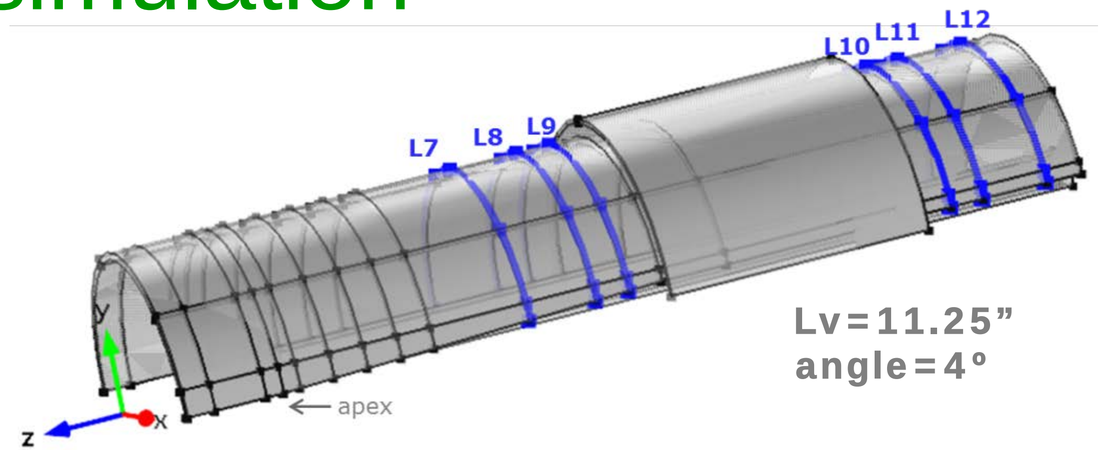
All the geometry is parametric in order to easily change it and simulate the different trial conditions.

So far, only the electromagnetic problem is solved. Therefore, to compare the measurements with the simulations, two different variables are used:

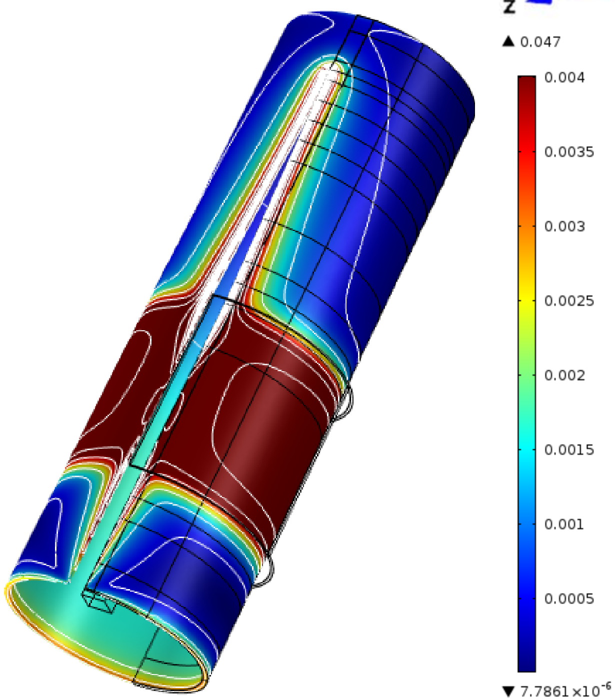
- for the measurements, average peak slope (between both edges) at 3s is used.
- for the simulations, the square of the surface current just at the edge (where maximum occurs) is used instead. This should be proportional to the power delivered to the steel.

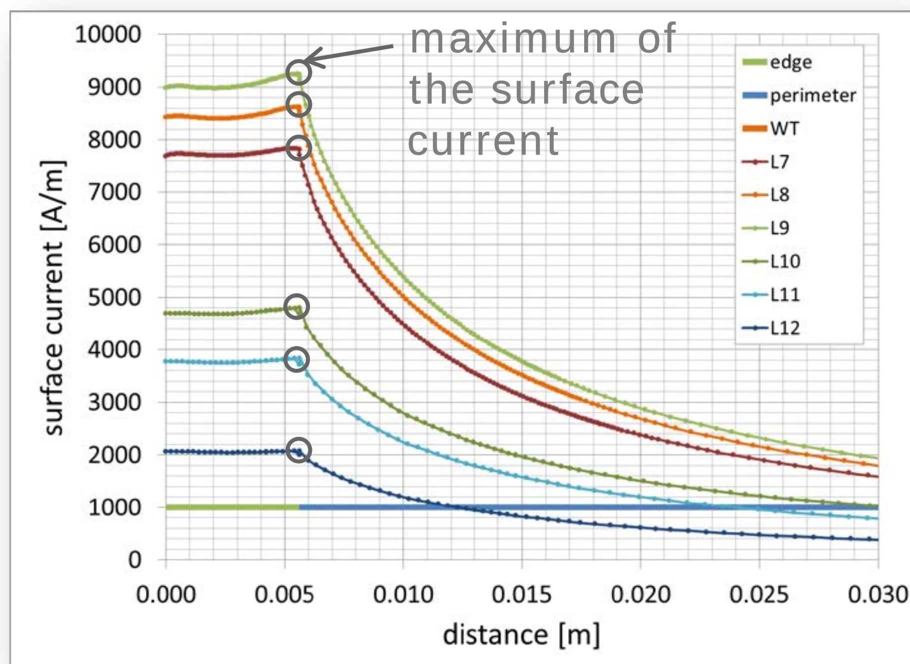
Example of simulation

color map: magnetic flux density norm
contour: surface current density norm



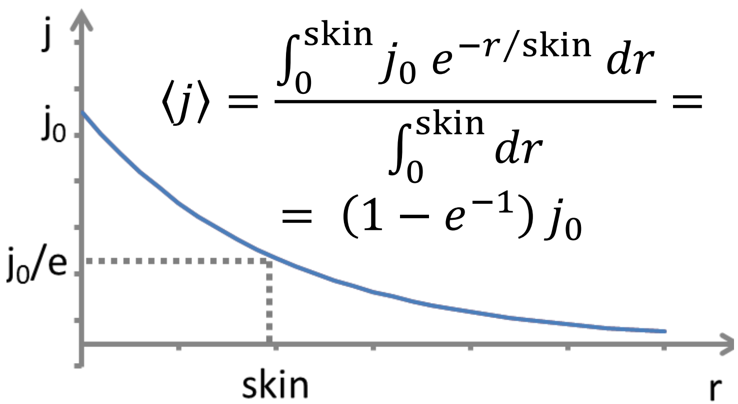
Lv=11.25”
angle=4°





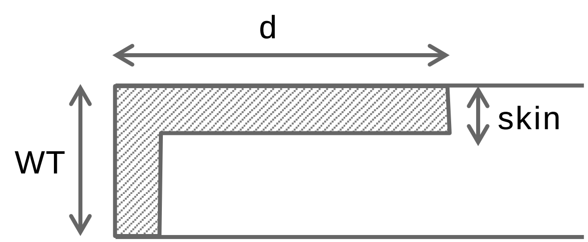
How to compare heating rate with surface current

$$\rho c_p \frac{dT}{dt} = p + \vec{\nabla}\left(k\vec{\nabla}T\right) = \frac{j^2}{\sigma} \Rightarrow \left.\frac{dT}{dt}\right|_{\text{sup}} = \frac{\langle j\rangle^2}{\sigma\rho c_p}$$



$$\langle j\rangle = \frac{\int_0^{\text{skin}} j_0\, e^{-r/\text{skin}}\, dr}{\int_0^{\text{skin}} dr} = $$

$$= \left(1 - e^{-1}\right) j_0$$

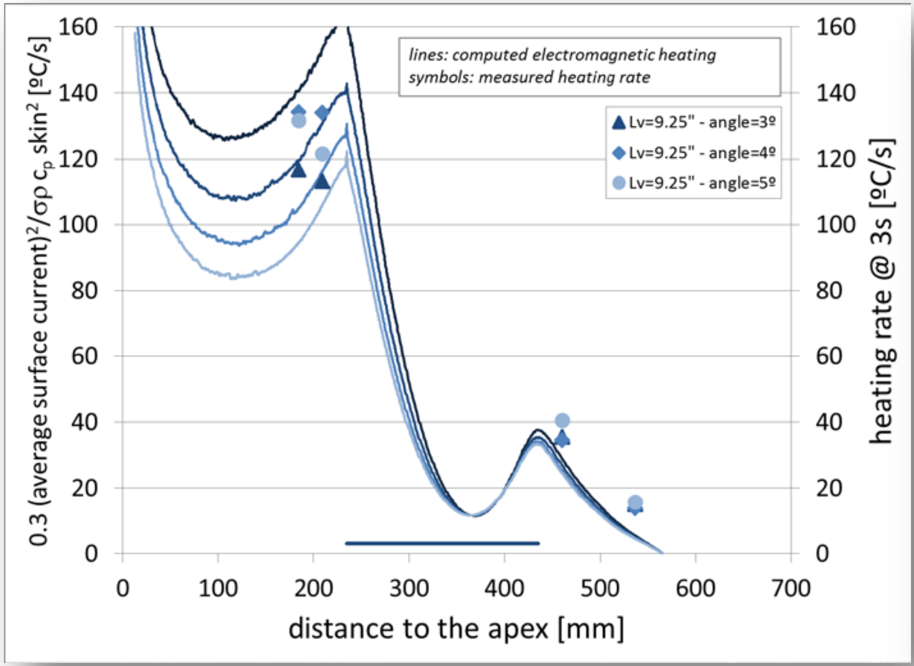


$$j_0 \text{ area} = g_0 \text{ perimeter} \Rightarrow j_0 \approx \frac{g_0}{\text{skin}}$$

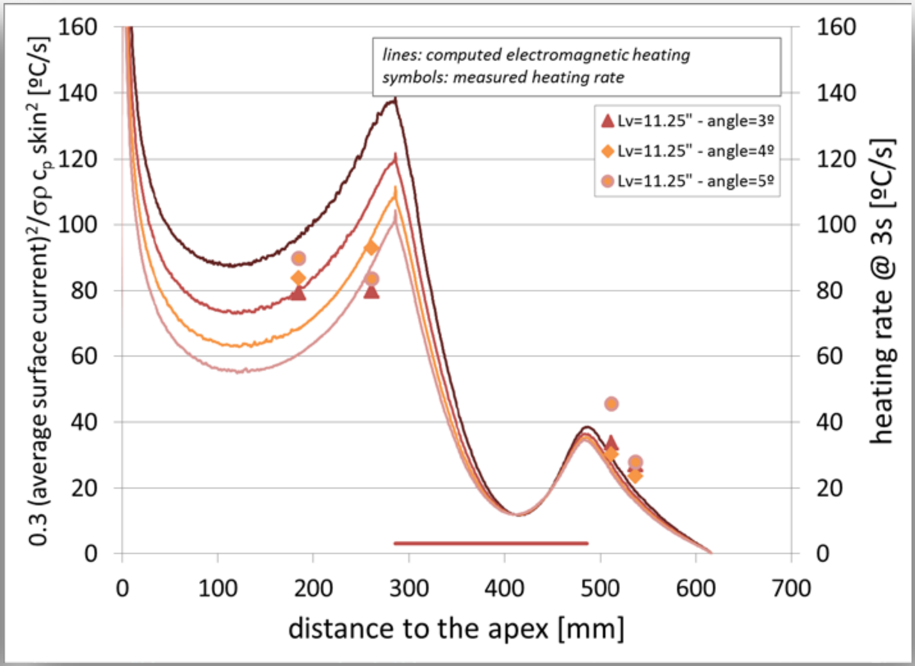
$$\Rightarrow \left.\frac{dT}{dt}\right|_{\text{sup}} \approx \left(1 - e^{-1}\right)^2 \frac{g_0^2}{\text{skin}^2 \sigma\rho c_p} \approx 0.4\, \frac{g_0^2}{\text{skin}^2 \sigma\rho c_p}$$

Model: Comparison with simulations as function of the distance to the apex

Lv=9.25”



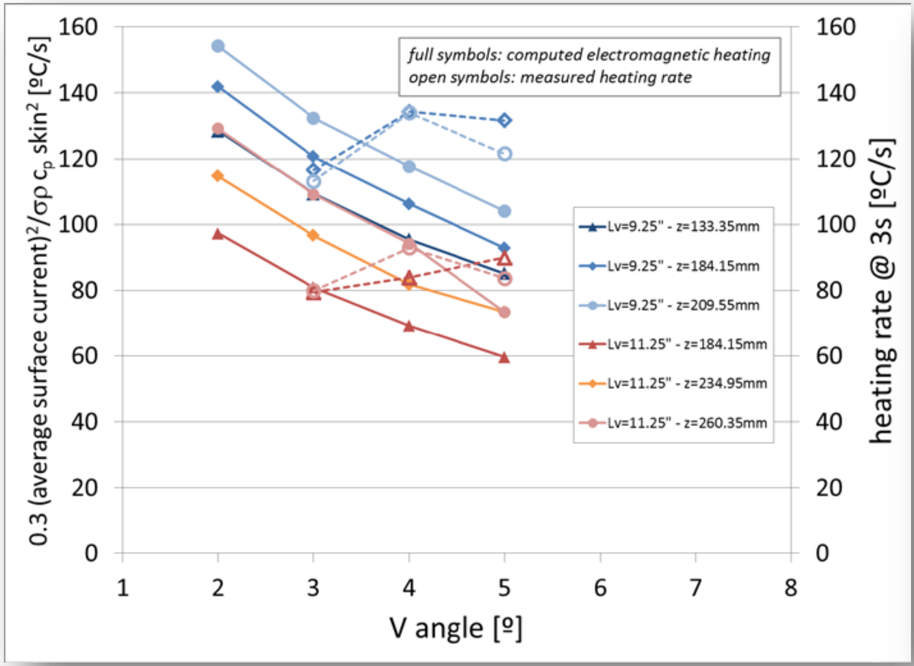
Lv=11.25”

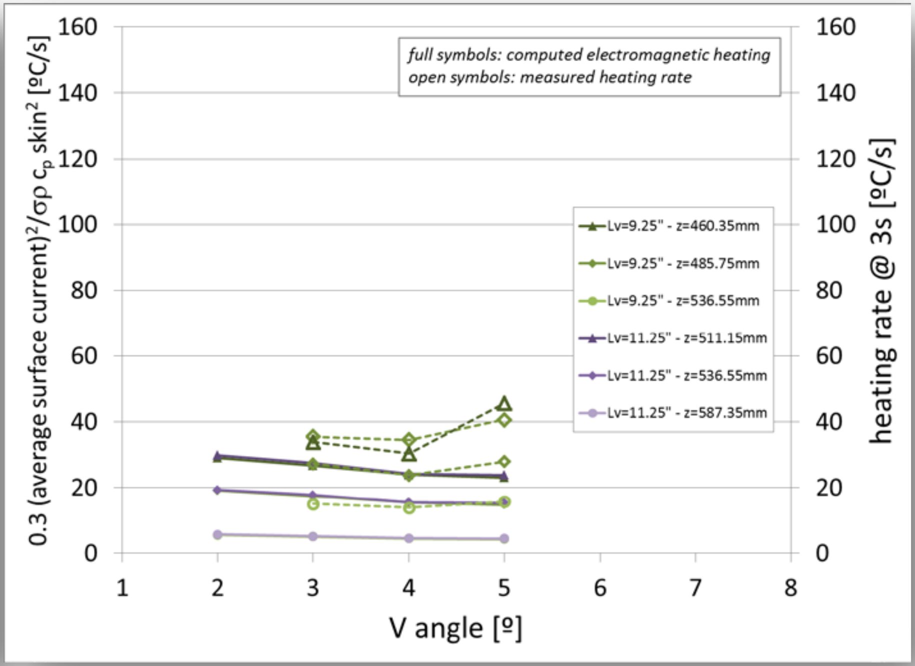


Model: Comparison with simulations as function of the V angle

between the apex
and the coil

beyond the coil





Comparison between model and measurements

Between the coil and the apex, the electromagnetic heating has a local minimum. The measurements on the other hand are not so populated as to appreciate this tendency.

Beyond the coil, the electromagnetic heating decreases with the distance to the coil. This is equivalent to the decrease in peak slope observed in the measurements.

As function of the angle, we see an optimal angle for the heating close to 4.5º. This tendency is not well reproduced by the simulations, which –between the apex and the coil- tend to increase for smaller angles with no restriction.

Beyond the coil, both measurements and simulations are quite constant. Simulations do not show differences when varying V length.

Anyway, given the simplicity of the present model, for all the cases the match between measurements and simulations is remarkably good.

Thank you!