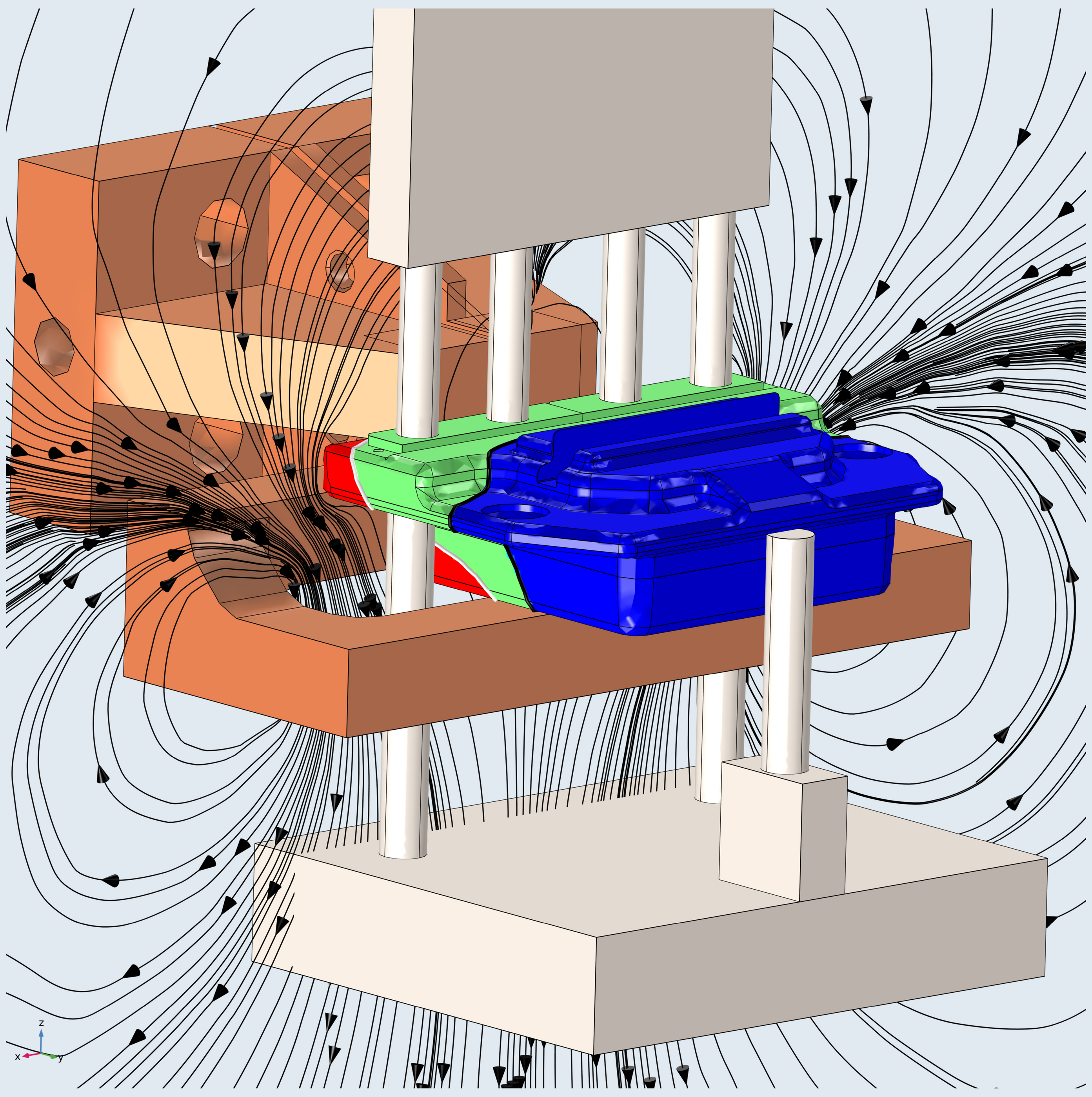

Numerical Modeling of Induction Brazing

Optimize efficiency & reliability of the brazing induction process by performing sensitivity studies on positioning, geometry and power of the inductor.

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Introduction & Goals

Induction brazing is a widely utilized joining process offering efficient and localized heating for the assembly of diverse components. At SCHNEIDER ELECTRIC®, this process is used to assemble a silver tip on a copper part. This work focuses on the advancements and insights gained through the development of a 3D thermal and electromagnetic model with COMSOL Multiphysics®.

Indeed, even if the induction heating process is well understood, the use of numerical model is crucial to optimize precisely the inductor geometry and its positioning [REF 1]. The related operating conditions such as, current frequency, electric power or generator characteristics can also be more easily designed thanks to numerical computations.

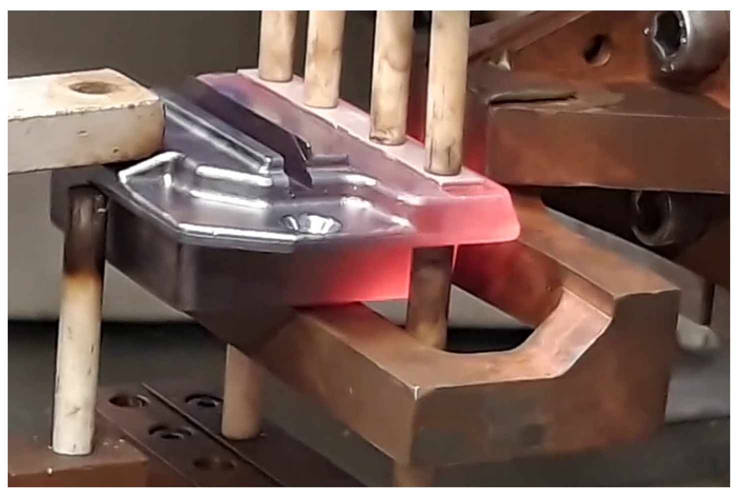


FIGURE 1: Experimental Process

Heat Transfer

$$\rho C_p \frac{\partial T}{\partial t} + \nabla \cdot [-k\nabla T] = 0$$

$$-\boldsymbol{n} \cdot (-k\nabla T) = \frac{1}{2} Re\{\boldsymbol{J} \cdot \boldsymbol{E}^*\}$$

Electromagnetism

$$\nabla \cdot \boldsymbol{J} = 0$$

$$\frac{1}{\mu_0 \mu_R} \nabla \times (\nabla \times \mathbf{A}) = \mathbf{J}$$

$$\boldsymbol{E} = -\nabla V - j\omega \boldsymbol{A}$$

$$\boldsymbol{J} = \sigma \boldsymbol{E} + j\omega \varepsilon_0 \varepsilon_R \boldsymbol{E}$$

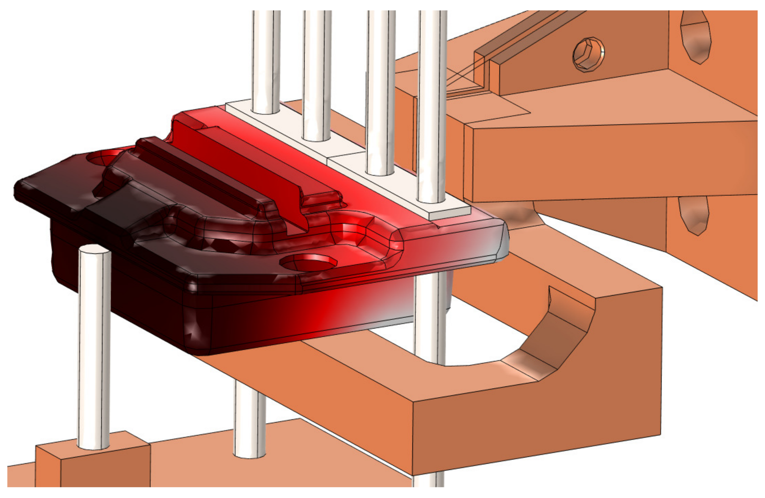


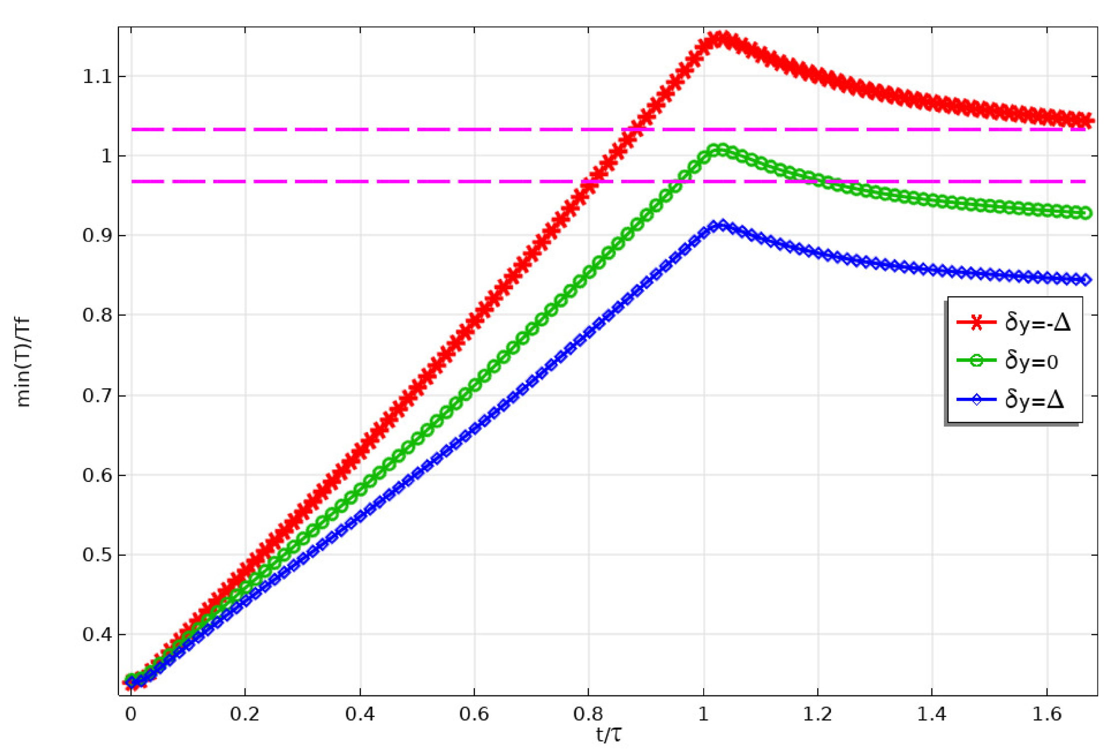
FIGURE 2: Digital Twin

Methodology

Due to the high current flowing through the metal pieces, thermal energy is generated. Transient heat equation is solved to describe temperature evolution through space and time. Given the high frequency used in the process (for surface heating the solder), a surface impedance assumption is used to describe the electromagnetic field in the metal parts. To control the electric power, a global ODE is added to the problem. Moreover, a strong coupling between electromagnetics and thermal equations is considered because of the strong variations of electrical conductivity with temperature. Finally, energy balance is numerically verified to validate the mesh and timestep parameters.

Results

After qualitative validation with experimental data (see Figure 1 and Figure 2), the model is used to simulate the influence of the inductor position. The major advantage of this simulation lies in its flexibility for studying quickly the influence of different parameters. The evolution of the minimal solder temperature is plotted in Figure 3 for nominal operating conditions ($\delta y = 0$, in green). Magenta lines highlight the acceptable zone of correct melting. Corresponding temperature range is also shown in the right. By moving the inductor away of the piece ($\delta y = \Delta$), the acceptable area (in green) required to correctly melt the solder, is not reached. By approaching the inductor ($\delta y = -\Delta$), too high temperature is reached in the solder leading to poor brazing quality. Thanks to this digital twin, precise operating tolerances have been determined to optimize the process.



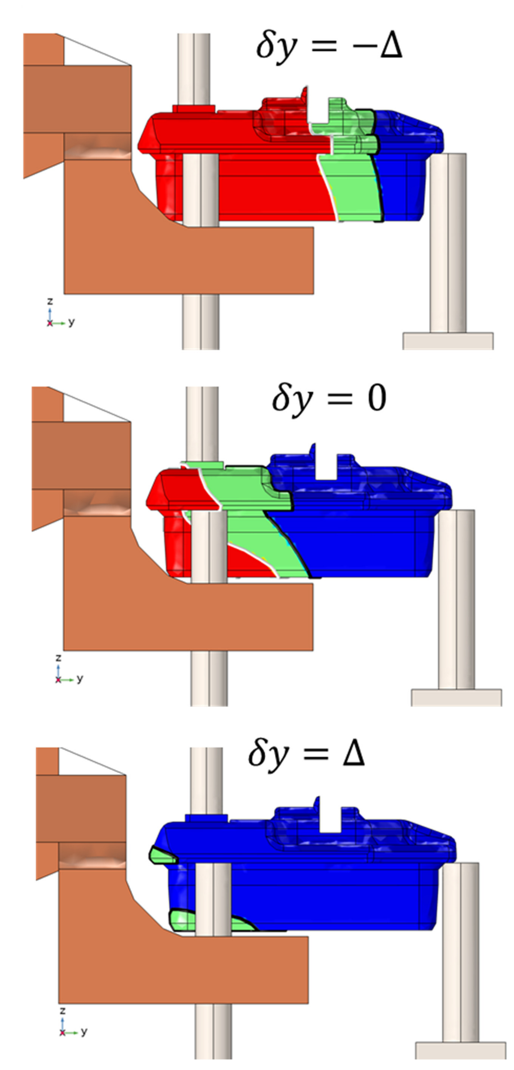


FIGURE 3: Minimum temperature evolution as a function of time for three y-positions of the inductor (on the left)

Resulting temperature range for each position (on the right), with acceptable area in green

REFERENCES

1. J. Jin, The finite element method in electromagnetics, Wiley New York, 2002, pp. 22-23.