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Local Magnetic Characterization of Electromagnetic Pulse Treated Metal: an Inhomogeneous Measurement

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INTRODUCTION

Electromagnetic Peening (EMP) treatment is a novel and unique technique developed by the LaMCoS to enhance and replace classical peening processes (such as ball peening). This still in development technique needs to be evaluated and qualified. This paper will show the usability of needles probe to locally characterize such treated metal. Typical local magnetic characterization is made on materials that have homogeneous properties in depth ; in our case, the material will have strongly varying characteristics on its surface as well as in depth. In a previous paper[1], we showed the usefulness of this needles probe technique to measure properties change of treated material.

PRINCIPLE: Sensors

In order to measure the local magnetic characteristics, we first need to induce a quasi-static flux in the sample, with the excitation coil. Then, using an H-coil and two needles, we can retrieve values reflecting respectively the surface flux (H), and the density of flux going through the surface made by the needles (B).

As discussed in [2], the resulting voltage e between the needles is:

$$e \approx \frac{d}{2} * s * \frac{dB}{dt}$$

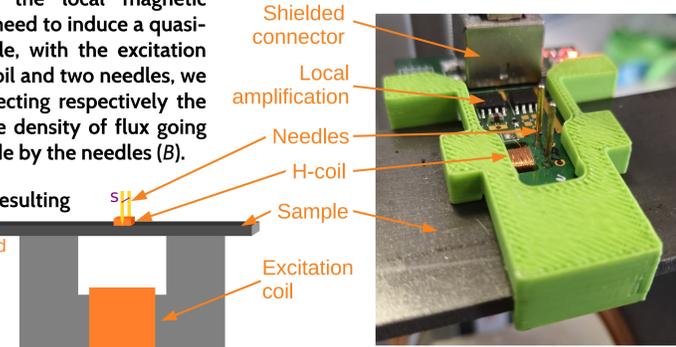


Figure 1: Needle probe sensor.

SETUP: Flexural test

Using a four point flexural setup (fig. 5), we are able to induce an even stress (σ_x) between p_2 and p_3 . If we place a sensor between those two points, we can measure either a tensile (on bottom) or a compressive (on top) stress.

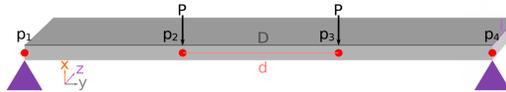


Figure 5: Four points flexural test.

The applied stress is easily deduced from the geometry of the setup. It is linear with the force (imposed by the weights).

By varying the stress and measuring the local magnetic characteristics, we can calibrate the couple [sensors; material] for pure stress response. This will allow us to better understand the sensor response on uneven and mixed stress, for example after an EMP treatment.

$$M_z = P * (p_2 - p_1)$$

$$I_z = l * \frac{e^3}{12}$$

$$\sigma_x = \frac{M_z}{I_z} * \frac{e}{2}$$

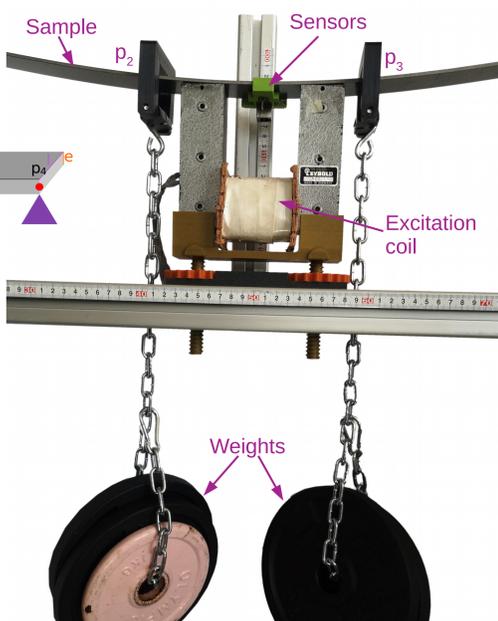


Figure 6: Flexural test experimental setup.

CONCLUSION & FUTURE APPROACHES

- ✓ The integrated sensor solution formed by needles and a coil is validated.
- ✓ The flexural test bench is well made and easy to use.
- ✓ Encouraging first results from the flexural test.
- We are researching a way to provide a better coupling between the excitation coil and the bended sample.
- Other sensing techniques (e.g. Eddy current double coil) are yet to be tested.
- Tensile & compression tests results will be described in a future article.
- EMP treated samples are yet to be characterized

PRINCIPLE: EMP treatment

To achieve the EMP treatment, a high magnetic field, typically around 60 Tesla, must be applied to the test sample. An inductor that is able to create such field has been designed, with the help of finite element modelling. The inductor shall withstand high currents (several tens of kilo-amperes), high voltage (several kilo-volts) and high forces from the coils that repel each other.

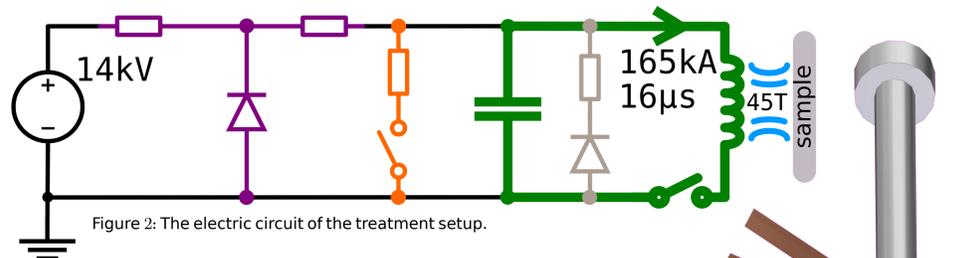


Figure 2: The electric circuit of the treatment setup.

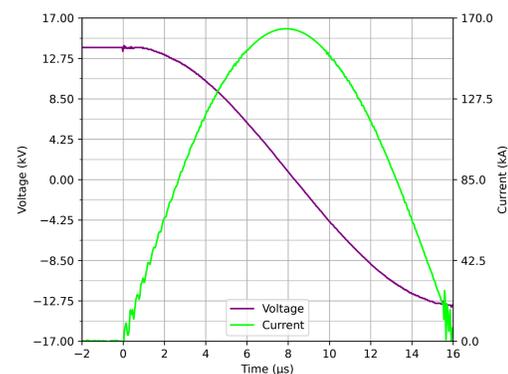


Figure 4: Voltage and current seen by the inductor during the treatment.

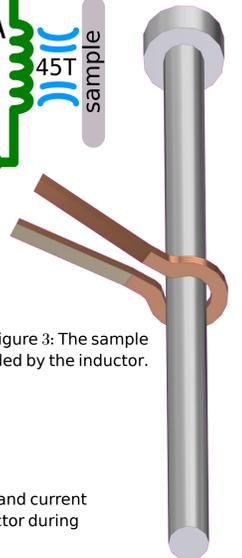


Figure 3: The sample surrounded by the inductor.

RESULTS: Flexural

A first campaign was executed to verify the test bench and the sensors. We were well below the yield limit of the material (structural steel S235). As shown on fig. 7 the permeability is linear with the stress, but with a varying slope between compressive ($\sigma < 0$) and tensile ($\sigma > 0$) stress. This is due to the coupling to the excitation coil.

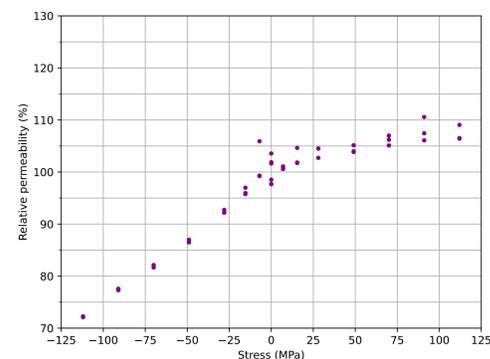


Figure 7: Relative initial permeability of S235 structural steel vs applied stress.

RESULTS: EMP

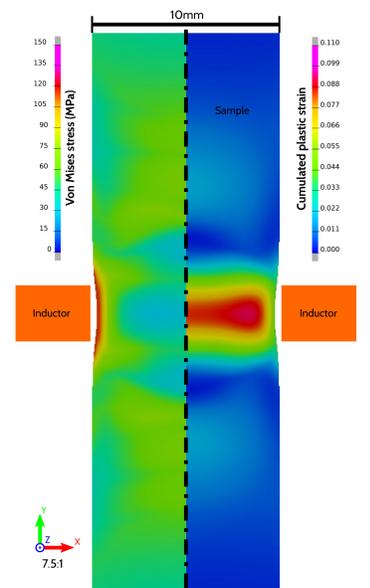


Figure 8: Axisymmetric simulation of the EMP treatment on an AA6061 rod.

The EMP treatment, a still in development process, was successfully tested and validated with simulations and experiments. On fig. 8, we can see that the affected area goes much deeper than classical shot peening[3]. The challenge is now to adapt the sensor for a cylinder, and to characterize an EMP treated sample...

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