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Laser Ultrasonics as an Innovative Sensor for Microstructure Control

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What is Laser Ultrasonics?

Laser ultrasonics for metallurgy (LUMet) is an emerging technology dedicated to in-situ monitoring of microstructure evolution during thermomechanical processing. In this non-destructive and non-contact technique, lasers are used for the generation and detection of ultrasound pulse in the material. Ultrasonic velocity and attenuation are measured and related to microstructure parameters. The LUMet system is designed as an attachment to a Gleeble thermo-mechanical simulator to routinely monitor microstructure evolution during laboratory simulated industrial processing cycles (see Figure 1).

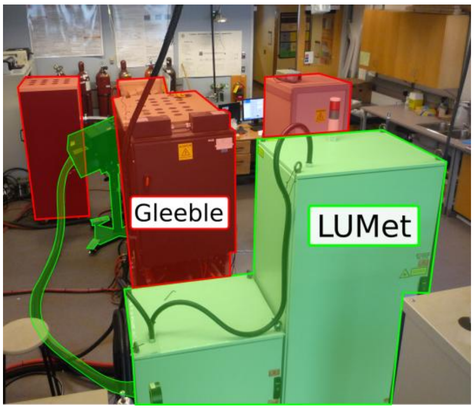

Fig.1: Gleeble3500 at UBC with LUMet system consisting of optical cabinet (in front) and the sensor attached to the Gleeble

Experimental Methodology

Figure 2 provides a schematic of the laser ultrasonic measurement setup. A broadband ultrasonic pressure pulse is generated with a Nd:YAG laser (wavelength of 532 nm) by ablating a thin layer at the sample surface (~10nm).

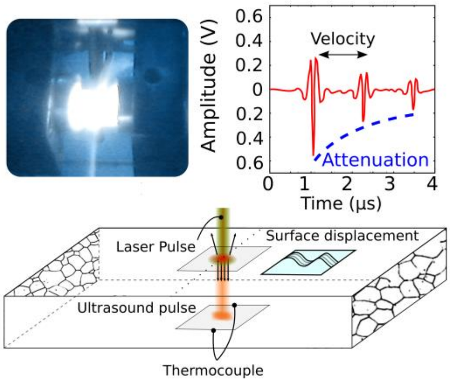

Fig.2: Sample during LUMet test (top left), schematic of LUMet measurement (bottom) and ultrasonic signals (top right)

The ultrasonic pulse propagates back and forth through the thickness of the sample and is detected with a second Nd:YAG laser which illuminates the surface with an infrared radiation. The ultrasound properties measured in this technique are representative of the volumetric properties of the material. Ultrasonic velocity depends on the elastic constants and density, i.e. crystal structure and texture, whereas ultrasonic attenuation is primarily related to the average grain size. In steels, methods were previously developed to correlate laser ultrasonic measurements with the austenite grain size, the recrystallization of ferrite and austenite, as well as the austenite decomposition. These studies provide proof of concept but further exploration of the LUMet technique is critical to develop it into a reliable tool for process design and control in industry.

Austenite Grain Growth

An important achievement of laser ultrasonics has been the measurement of the austenite grain size in low-carbon steels based on analyzing the attenuation. We were able to establish our LUMet system as a tool for regular austenite grain size measurements in linepipe and other microalloyed low-carbon steels. An example of these measurements is shown in Figure 3 comparing the austenite grain growth kinetics during heating at 100 °C/s for low-carbon steels with and without Nb microalloying. The symbols represent metallographic data and the lines give the austenite grain size continuously measured with LUMet illustrating the excellent agreement between both methods.

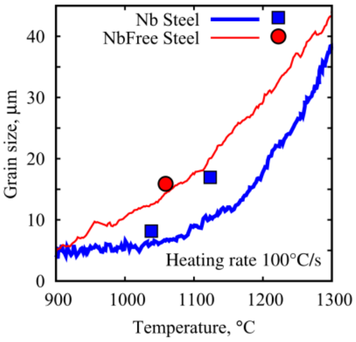

Fig.3: Austenite grain growth during heating at 100 °C/s

Recrystallization

Ferrite recrystallization during annealing of cold-rolled steels can be recorded using ultrasonic velocity as illustrated in Figure 4 for a DP600 steel. Further, static recrystallization of low-carbon steels hot-deformed in austenite have been measured with LUMet using ultrasonic attenuation. The static recrystallization measurements may be considered a prerequisite for what we consider the first major breakthrough that we have achieved with the LUMet system, i.e. the measurement of dynamic recrystallization in a low-carbon steel (0.19%C-1.5%Mn-1.6%Si-0.2%Mo). Here, we were able for the first time to measure in-situ with laser ultrasonics a dynamic microstructure event taking place during (as opposed to after) hot deformation. This type of measurement is enabled by the set-up of our system whereby the laser spot can move with the sample during deformation for up to moderately high deformation rates of 0.1/s.

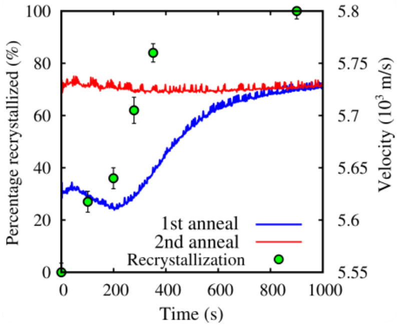

Fig.4: Ultrasound velocity and recrystallization during annealing of a DP600 steel at 625 ºC

Figure 4 shows the attenuation and velocity measured at a frequency of 6MHz together with the flow stress curves obtained during deformation of the investigated steel at 1050 °C. The flow stress curves display a maximum that is characteristic for dynamic recrystallization and coincides with a minimim in both the attenuation and velocity curves indicating that a reliable in-situ monitoring of dynamic recrystallization can be obtained using the non-contact LUMet technique.

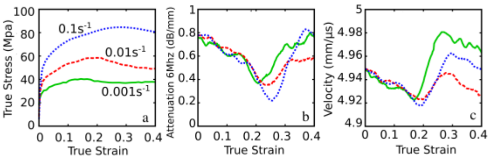

Fig.5: Flow stress curves (left), attenuation (center) and velocity (right) measured by LUMet at 6MHz during deformation of a 0.19%C-1.5%Mn-1.6%Si-0.2%Mo steel at 1050 °C.

Conclusions

The major advantage of LUMet is that it is a fast and remote technique that probes the bulk of the material. Thus, the use of the LUMet system enables to study microstructure evolution much more rapidly for many different processing paths than would be possible with conventional techniques. As a result, LUMet can significantly accelerate the development and evaluation of thermo-mechanical processing routes for advanced steels. In addition to these exciting opportunities for steel and process development in the laboratory LUMet shows also promise to be used as a microstructure process control system in the plant.

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