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High temperature resistant eddy current sensor for "in situ" monitoring the material microstructure development of steel alloys during heat treatment – bainite sensor

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Abstract

Production of tools and component for automotive and energy production includes in most application the adjustment in hardness, toughness, fatigue and wear properties. This is done by heat treatment [4]. Depending on material and target course different treatment processes are applied like martensitic hardening, bainitic hardening [3], nitriding, nitrocarburizing, carburizing and annealing. Up to now these heat treatment processes are done by recipe. Temperature and time of treatment are measured. No information about the change in material microstructure is available during treatment. So scattering results are the consequence and high security time factors have to be included to get the necessary process capability. To overcome this difficulty, eddy current sensors, measuring and analysis systems have been developed and are implemented in the hot furnace to measure in-situ the progress of the developing material microstructure during heat treatment of the components.

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Keywords: eddy current; bainite sensor, material microstructure

1. Sensor principle

Many heat treatment processes for adjusting hardness, mechanical and tribological properties of the material also change the magnetic and electric properties. So eddy current measurement is a possibility to have a closer into material during treatment [1]. Furthermore, eddy current sensors work contact free and have no impact on the microstructure development. Like illustrated in figure 1 an exciting alternating electromagnetic field produces eddy currents in the material. The retroactive effect depends on electromagnetic material properties and can be measured by a second coil. To extract as much as possible

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information from the retroactive eddy current signal, harmonic analysis is done as illustrated in figure 2. By this way, different microstructures can be assigned.

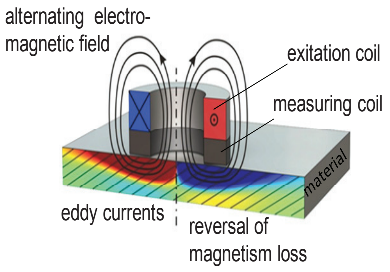

Fig. 1 Measuring conditions

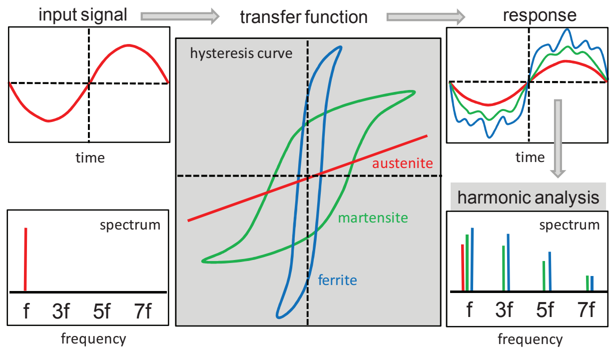

Fig. 2 Harmonic analysis

2. Measurement

The coils for the eddy current sensor are isolated by ceramics and are temperature approved up to 500°C. The housing is made of thin austenitic steel plate and is vacuum sealed. This very robust constructed sensor (figure 3) can be implemented into the heat treatment furnace to measure contact and distortion free. This sensor is applied in the furnace to the surface of components to be heat treated. One example of sensor signal and material microstructure development during bainite hardening [2] is illustrated in figure 4.

According to the development of the material microstructure the real part of the first harmonic of the eddy current sensor correlates to the portion of bainite transformation as it is illustrated by the metallographic pictures.

Further information about effects developing microscopically can be extracted frequency dependent from the higher harmonics. The first harmonic is interpreted as the part of material which changed from paramagnetic to ferromagnetic. The higher harmonics as the third give a closer look to microscopic details of the microstructure, as it is determined by carbon diffusion and cementite precipitation. Examples of measurements plotted in the complex plane are shown in figure 5 and 6.

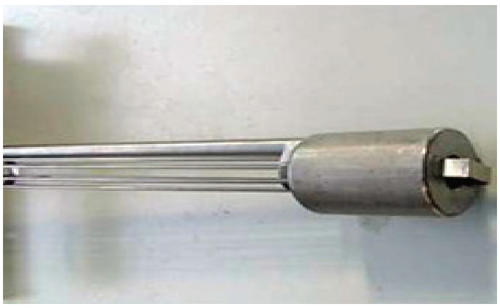

Fig. 3 Sensor prototype – heat resistant up to 500°C

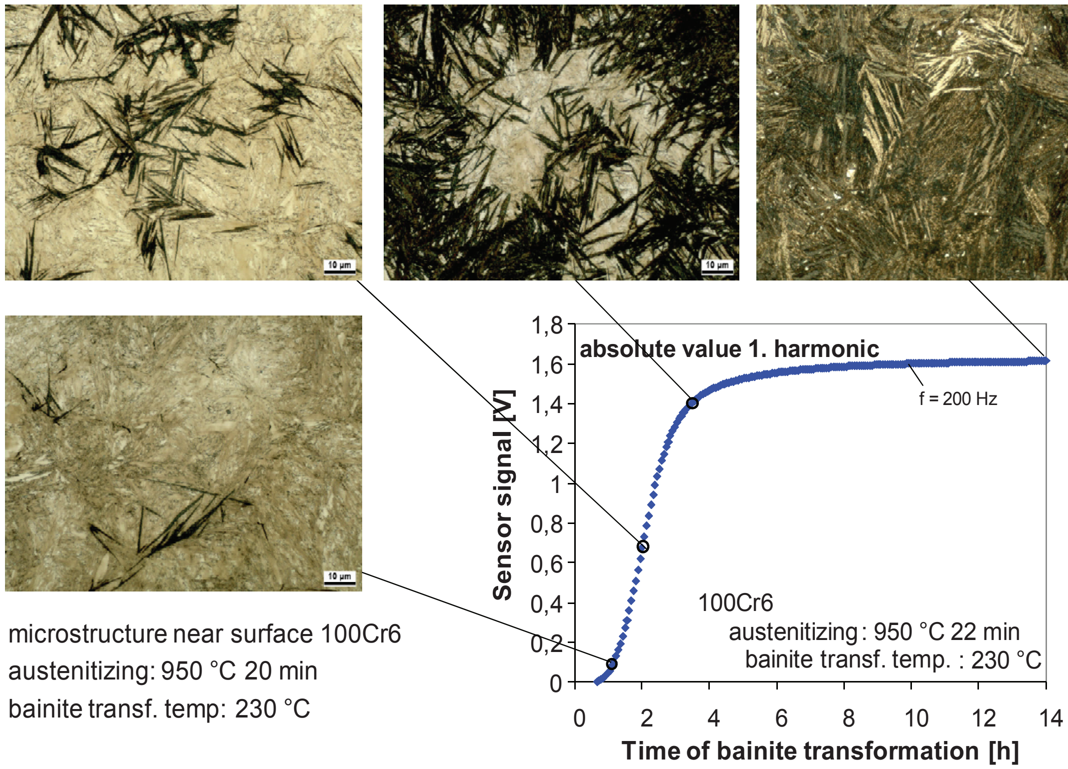

Fig. 4 Development of material microstructure and sensor signal during bainite transformation [2]

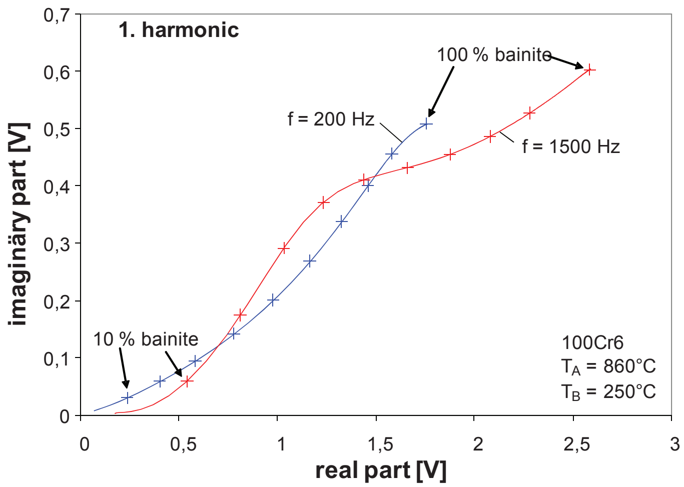

Fig. 5 Frequency dependent sensor information of the first harmonic plotted in the complex plane describing the microscopic bainitic transformation

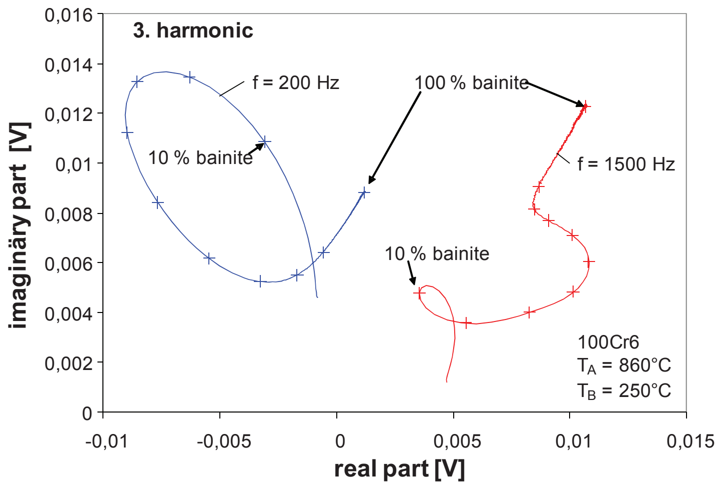

Fig. 6 Frequency dependent sensor information of third harmonic plotted in the complex plane describing the microscopic bainitic transformation

This method opens a new possibility to look to material microstructure. Even effects not to be resolved microscopically can be detected. First qualitative interpretations according different microstructures as martensite, bainite or ferrite can be done. Further analysis will give more detailed understanding in mechanisms of transformation.

Acknowledgements

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