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Qualification of Barkhausen Noise and Eddy Current Based Sensors for Online Monitoring of Strain-Induced α'-Martensite Phase Transformation During Flow Forming

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Summary:
This study illustrates the sensitivity of Barkhausen noise and eddy current based sensors to monitor the evolution of micromagnetic properties during phase transformation due to plastic deformation of metastable austenitic steel AISI 304L. The phase transformation was carried out on flow formed tubes, under specific thermomechanical conditions to produce local graded areas. The results show a very good potential of both types of sensors to monitor the evolution of magnetic properties during the production process in order to use those signals in closed-loop property-control systems.

Keywords: micromagnetic testing, magnetic Barkhausen noise, eddy currents, flow forming, phase transformation.

Background Motivation and Objective

The production of components by flow forming has gained recently importance mainly in transportation industries [1]. The use of austenitic steel in combination with advanced manufacturing techniques enables the production of high-quality components. During forming of metastable austenitic steel, plastic deformation changes the geometry and microstructure of the workpieces. In particular, phase transformation from metastable austenite to α'-martensite occurs, which modifies the magnetic and mechanical properties [2]. The production of graded components with specific mechanical properties requires the development of closed-loop controlled processes. This entails the use of suitable sensors to monitor the evolution of properties during plastic deformation.

Non-destructive techniques, like micromagnetic testing have been widely used for the detection of the amount of ferromagnetic α'-martensite phase. In different studies, the magnetic Barkhausen noise (MBN) and eddy current analyses have shown a remarkable sensitivity to the changes of the ferromagnetic properties and permeability, respectively. This gives them great potential to be used within closed-loop control systems [3].

The objective of this work is to show the suitability of MBN and eddy currents to perform local measurements of α'-martensite.

Description of Methods and Systems

The specimens for the qualification of the sensors were produced in a PLB 400 spinning machine from Leifeld Metal Spinning GmbH (Ahlen, Germany) by means of flow forming (Fig. 1a). The specimens were manufactured using stainless steel AISI 304L (X2CrNi18-9, 1.4307) seamless tubes, 80 mm outer diameter. The specimens were manufactured cooling to a temperature of about -195°C during the deformation process, on the area marked in red (Fig. 1b). This favors the transformation of metastable austenite into α'-martensite during plastic deformation, according to literature [2].

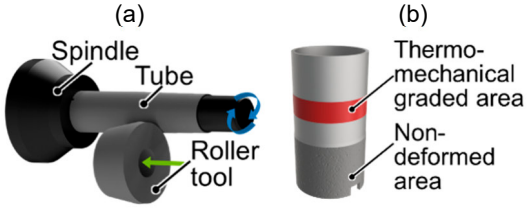

Fig. 1. Specimen manufacture: (a) flow forming process; (b) specimen specifications. The area marked in red contains a higher amount of strain-induced α'-martensite.

On the locally cooled areas, where plastic deformation occurs, a higher α'-martensite fraction is expected. On the area where plastic deformation occurs without cooling (light grey area in Fig. 1b), a less amount of α'-martensite is expected and on the non-deformed areas only austenite is present.

The characterization was carried out by means of a Feritscope FMP30 (Helmut Fischer GmbH, Sindelfingen, Germany), whose measurements are not possible to be transferred and used within a closed-loop control system. However, the measurements are an important tool to establish reference values. MBN and eddy current analysis deliver measurements over the time, that are usable as control signals and can be well correlated and calibrated with the phase transformation phenomena. In this study, the 3MA-II system (Fraunhofer IZFP, Saarbruecken, Germany) and Elotest PL600 (Rohmann GmbH, Frankenthal, Germany) were used to qualify the MBN and eddy currents methodologies, respectively, to monitor the phase transformation.

Results

The measurements were carried on three different lines along the axial position at different angular positions (Fig.2).

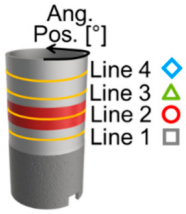

Fig. 2. Detail of measurement points on specimens.

Fig. 3 shows measurements of α'-martensite fraction determined by Feritscope FMP30. These measurements are not online transferable to a controller and are used only as comparison data.

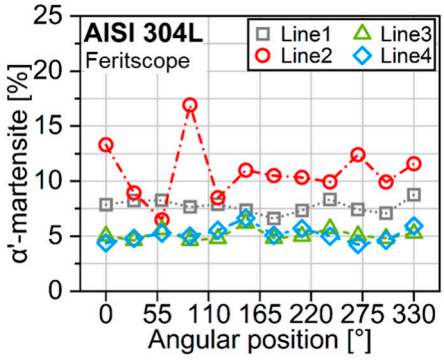

Fig. 3. Graph of strain-induced α'-martensite percentage at different measurement points.

The results show higher amounts of α'-martensite along the line 2. This area was cooled during the forming process, which favors the phase transformation during flow forming. A maximal peak is reached at an angular position of 0° and 80°. The line 1 has the second higher amount of α'-martensite due to the heat transfer direction caused by the movement of the forming tool between line 4 and 3. The deformation process without cooling warms these areas, which hinders the formation of α'-martensite.

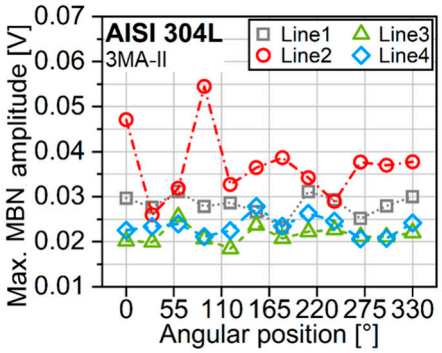

Fig. 4. Graph of maximum amplitude of MBN, measured by 3MA-II system at different points.

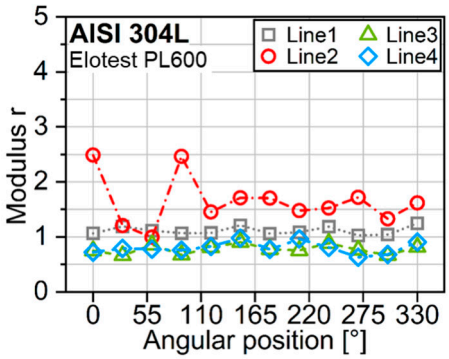

Fig. 5. Graph of the modulus r of the eddy currents method, measured by Elotest PL600 at different points.

The measurements carried out using MBN and eddy current based sensors show a promising sensitivity for applications where the phase transformation must be monitored in time. The sensors detected the phase amount peaks at 0° and around 80°. Both devices allow the transfer of the measured signals to be used in closed-loop control systems.

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