The Use of Component's Edge Region as Inherent Information Carriers and Loading Indicators

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Summary: Problematical requirements, regarding intellectual property protection, fatigue life and gentelligence, in the field of component identification and integrity assessment of highly loaded component demand that modern methods be developed to durably introduce and collect data as well as to record the component's loading history in its life cycle. In the current work, both inherent component tagging by means of locally heat treating the component's edge region as well as a newly developed sensor design are introducd for recording and assessing early elevated component loading and loading drops. These technologies significantly exceed the integration level of conventional identification and monitoring techniques.

The principle of securely tagging highly loaded components is realised using a high-powered fibre-optics laser by means of stepwise defined, locally changed microstructural properties of the parent material as well as via the dispersal of hard-magnetic particles. By means of a firm and inherent connection of the information with the component's microstructure, it is guaranteed that this information remains readable during the component's entire life cycle and that a high degree of forgery protection is obtained. The tagging is read by means of the eddy-current technology using high resolution probes. Both heat treatable and carbon steels in their tempered and hardened states as well as metastable, austenitic chrome-nickel steels and Al alloys were investigated for their suitability regarding a local heat treatment and the potential to inherently store information.

The newly developed concept for realising local loading sensors is based on globally cold-working metastable, austenitic materials and the local heat treatment of the formed martensite. In doing this, yield stress values are specifically set in restricted regions of the material so that an overload can be recognised early and component failure can be avoided as a consequence of overloading.

Keywords: Surface Modification, Heat Treatment, Lifecycle

1. General

Laser technology has for many years been employed in the field of surface engineering as a promising future tool for treating surface layers or for labelling products. There are currently only a few methods for labelling metals. Laser marking systems are mainly only capable of legibly labelling, with high-contrast, entire components by means of a focussed laser beam. The interaction with the respective material produces a change such as, for instance, a discolouration or an engraving. A procedure for multi-dimensionally storing information by means of locally changing the microstructure's features has hitherto not been communicated in the literature.

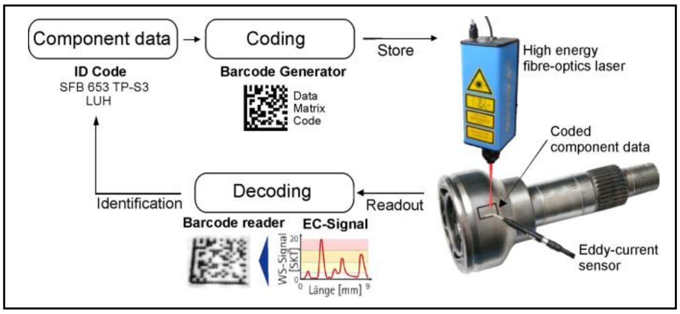

Figure 1. Microstructurally based information storage.

The objective of locally introducing energy using fibre-optic lasers is to individually set a level of microstructural change in heat-treatable steels, carbon steels and chrome-nickel steels by means of the duration and the intensity of the introduced temperature.

Here, to process the surface, the fibre-optics laser is moved by a handling unit using a specified speed such that the tagging and the temperature is available for a definite soaking time. In this way, an individual and learnt process condition is set and employed for coding workpieces Figure 1.

The objective of the sub-project S3 of the collaborative research centre **653 "Gentelligent Components in their Lifecycle"** is to realise GI-components which possess inherent data storage in the component's edge region and to record the loading history with regard to the residual service life using loading sensors integrated into the component. The concept gentelligent was especially coined for this component type and is composed from the concepts "genetic" and "intelligent" [1, 2].

2. Integrity assessment

To record the loading history of components subject to static and dynamic loading, so-called sensor materials are used such as metastable, austenitic manganese steels and chrome-nickel steels, which form deformation-induced martensitic microstructures and which offer the possibility of intgrated applications in metal composites with the component. An assessment of the component integrity requires information about the components loading and type of loading. With respect to this, threshold-value sensors possessing a definite response behaviour and a directionally dependent sensitivity are developed via a global work-hardening and geometrically specific local heat treatment. The introduction of various threshold-value sensors into the sensor material enables assertion to be made regarding the component's enduring loads as well as the principle stress directions and type of loading, Figure 2.

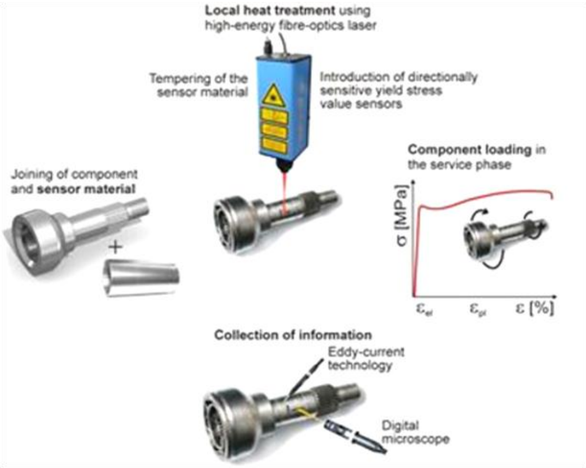

Figure 2. Concept for recording the component loading.

3. Characterization of local material properties

High resolution eddy current sensors and optical methods are developed and implemented to record the local material properties. Regarding the improvement of the sensor's resolution, a compromise has to be struck between the sensor's sensitivity and its effective range. The sensing effect for verifying elevated component loading stresses by using the sensor materials is based on the reformed martensite subject to the plastic deformation of metastable austenite in the sensor region. A change in the ferromagnetic material properties is also associated with the phase change. This change in properties can be detected via the eddy current sensors. With the aid of a harmonic analysis of eddy current signals, particularly via an analysis of the higher components of the harmonic signals, it is possible to obtain sensitive assertions about the change in the ferromagnetic material properties. This is the basic prerequisite in order to arrive at a classification of the sensor regions as well as at an unambiguous assessment of the loading stresses exceeding the yield stress values.

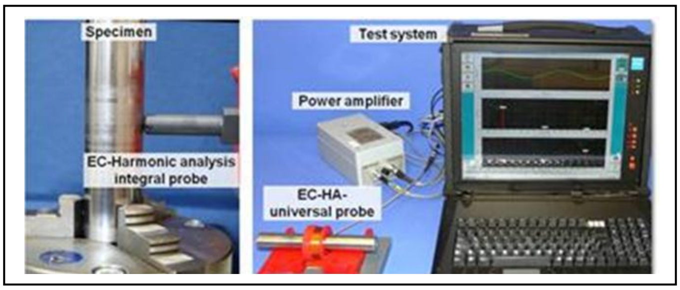

Figure 3. Local and integral low-frequency EC-probes.

4. Component identification

Besides the dispersal of particles possessing specifically desirable properties, an inherent tagging is also performed via a local change in the microstructural characteristics by means of the focussed introduction of heat energy into a hardened heat treatable component surface or one which strengthen by means of cold deformation, Figure 4.

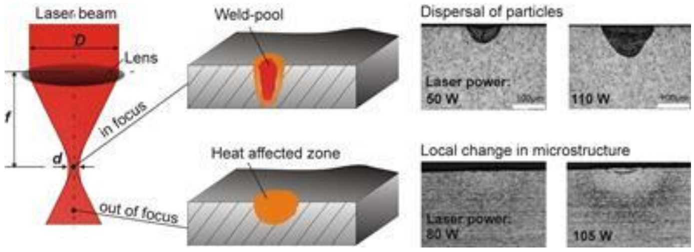

Figure 4. Focussing the laser beam.

This enables a tempered or recrystallised microstructure to be set which possesses locally changed electrical and magnetic material properties. Besides the level of microstructural modification, its penetration is also specifically modified by varying the intensity and duration of the energy introduction (tempering temperature, depth effect). Apart from the processed 2-dimensional component surface for carrying information, this also permits the extent and depth of the microstructural changes to be used as additional informational dimensions. With the aid of the eddy current technology, the deposited information; in the form of a data field, as well as the material microstructure's physical characteristics are readout and is to be correlated. In order to read a label, the components surface is linearly scanned, the level of microstructural changes or the volume of the changed microstructure is determined and compared with the previously specified threshold values so that the individual tags can be assigned to the corresponding steps, Figure 5.

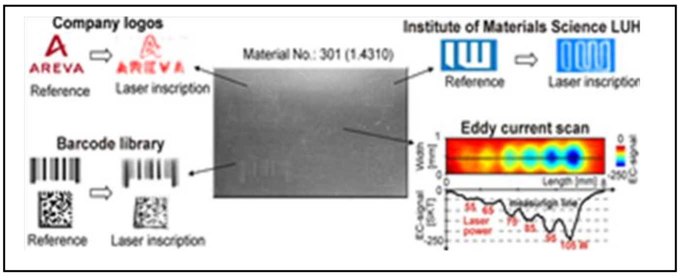

Figure 5. Focusing the laser beam.

A multidimensional tagging code consists of the ciphered information in the form of coloured points or lines and depends on the type of code with a different number of characters. The aim of the coding is to obtain the highest possible information density as well as a high data security. Apart from the hitherto point-code tags, a comprehensive barcode library as well as company logos can also be inherently stored. Both for the standard 2D bar code as well as for the 2D data matrix code, the labels can be optically readout; see State of the Art. This presupposes either a clean and almost undamaged surface or requires the application of an error-correction algorithm. Multi dimensional component tagging, which is not required to be optically readout but is simultaneously resistant to mechanical and thermal influences, do not yet currently exist for metallic components.

5. Assessment of the loading stresses

The current maintenance of complex, highly loaded components using conventional monitoring technologies still have inadequacies. The current description of components' failure behaviour is based on reliability models. However, real data regarding a possible failure in the future are not continuously recorded and can not frequently be unambiguously interpreted. This shortcoming leads to bottlenecks or to under-utilisation of capacity since the times of failure can not be exactly predicted. With regard to this, gentelligent components serve to collect process parameters which are relevant to their maintenance and utilise inherited loading histories for predicting possible damage events.

The components are to internally carry information about their loading during their service phase and make this available for later use and for passing on to the next component generation. In the component's edge region, local yield stress value sensors are set to the expected loading by means of a local heat treatment. An overload will lead to a microstructural transformation which possesses changed physical and optical properties of the sensor material. In addition to this, the overload will be monitored using magneto-inductive testing methods of the harmonic-analysis from the eddy current signals together with a digital-microscope, Figure 2. With respect to the expressed aim, the behaviour of material No.: 1.4310 was investigated subject to various loading profiles. The adaptation of the sensor strength to the component's loading stresses and the relationship between the mechanical material properties is depicted in Figure 6 for the material No.: 1.4310. A local heat treatment by inroducing the energy in steps leads to the stepped tempering of the martensite in the austenitic microstructural matrix and to reducing the strength and yields stress values. It should be noted that the 1100 MPa yield stress values R_{p0} of the matrix microstructure is a maximum. The minimum yield stress is in the third region (R_{p3}). During the loading, a part of the austenite in the sensor material is transformed into martensite owing to the yield stress being exceeded. The mechanism influences the surface state as well as the electrical and magnetic material properties.

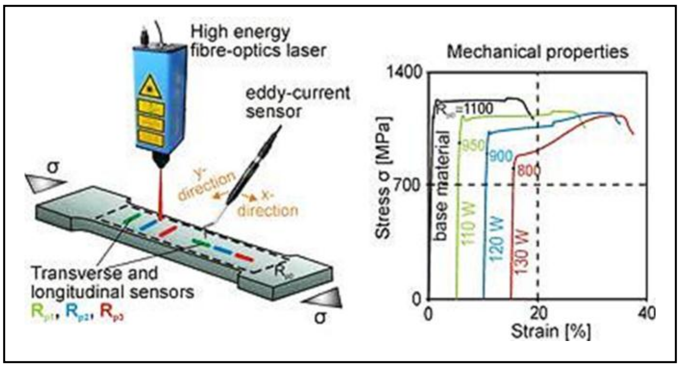

Figure 6. Adaptation of the sensor strength to the component's loading stresses.

Subject to plastic deformation, the linear patterns in the specimen's longitudinal alignment are hardly influenced. In contrast to this, the linear patterns in the transverse alignment reform the martensite and this increasingly so the stronger the tempering state and the lower the local yield stress values are in the sensor region. For a linear layout, the loading sensors show different sensitivities regarding the plastic deformation and the martensite formation for pronounced normal stresses in the longitudinal and transverse directions. Subject to loading in the longitudinal direction, the linear sensors in parallel alignment lie in the force path and the load is essentially transmitted by the adjacent higher strength sensor material. On loading the linear sensors in the transverse direction, the force flows across the width of the loading sensor and, for loading stresses above the yield stress, plastic deformation occurs and martensite is newly formed in the linear region, Figure 7.

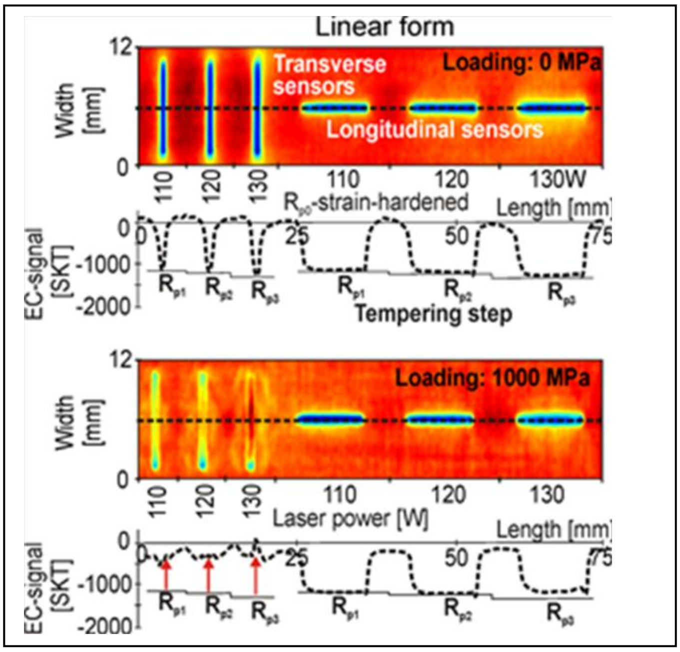

Figure 7. Detecting the component's loading using directionally sensitive yield stress sensors.

In this way, local yield stress value sensors in various geometrical alignments and forms as cascaded, directionally sensitive threshold value sensors offer new possibilities for collecting loading histories with regard to the occurring loading stresses and the drop in loading via the reformation of martensite in the corresponding yield stress value sensor region. The local reformation of martensite is, according to the local yield stress value, a measure of the component's enduring loading and can be verified by means of a suitable, high resolving eddy-current sensor technology based on a harmonic analysis.

Acknowledgements

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