Spatio-temporal imaging of the thermally hardened surface layer in steel parts

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Background – Surface hardening is a widely applied method to improve surface properties of steel parts like train wheels and rails or automotive parts like crank shafts, gears or bearings. Different methods of surface hardening exist. Here we focus on thermally hardened and quenched parts which exhibit a change in the surface near microstructure. The extend of this layer into the depth of the part is the hardening penetration depth (HPD). Two parameters are crucial for industrial applications: the absolute hardness and the HPD of the surface layer. Standardized approaches to characterize these quantities include indentation tests on sample cross sections and optical imaging techniques. Since destructive methods require an extensive effort in the production process, non-destructive methods which can be incorporated into in-line production are highly sought after. This has stimulated research in different directions based on Barkhausen noise, Eddy current testing and ultrasound based methods, each with their own respective advantages and disadvantages. Here, we will discuss an improved methodology based on laser ultrasound and supervised machine learning to provide a calibration-free determination of the HPD in non-destructive and contact free manner.

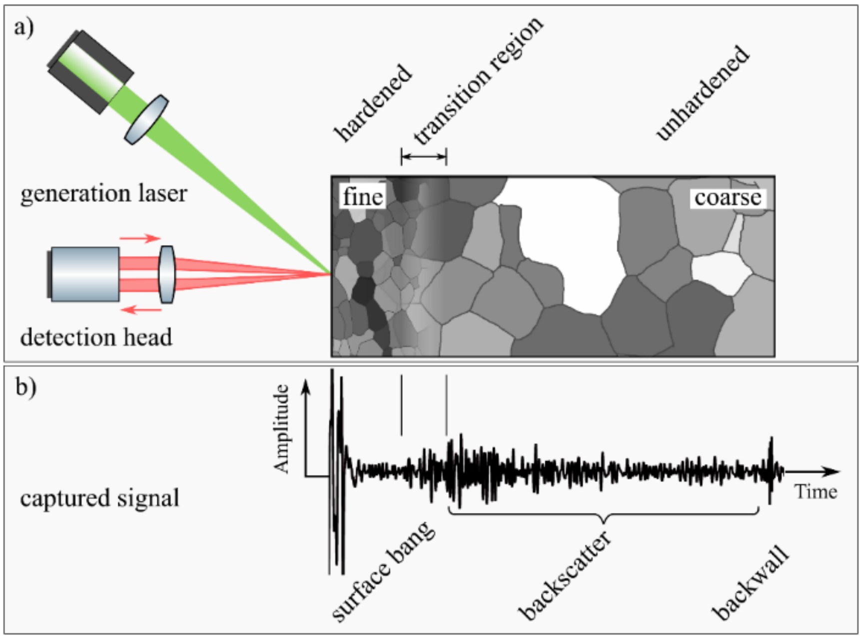

Fig. 1. a) Sketch of measurement geometry and sample microstructure **b)** Exemplary time domain signal

Methods – The working principle of the laser ultrasound approach is depicted in Fig. 1. Ultrasound pulses are excited at the surface of steel parts by a pulsed laser source. These propagate into the sample and are preferentially backscattered at the interface between hardened layer and core due to the difference in grain size. The backscattered waves are subsequently detected at the sample surface by a second laser and a two-wave mixing interferometer that is capable of measuring on rough surfaces. The backscattered acoustic waves carry the information of the extend of the hardened layer similar to pulse-echo schemes.

Results – We demonstrate the method on three industrial grade samples with different microstructural peculiarities accounting for typical difficulties arising in the industrial production process. Due to the inherent fast data acquisition in our laser ultrasonics setup we are able to perform lateral scans along the sample and use the additional spatial information to apply a supervised machine learning approach (1) that provides us with the sub-surface lateral and axial contour of the hardened layer. In general the method performs excellent if no additional scatterers, e.g. segregations are present in the hardened layer. In particular, we require no additional calibration step for the data evaluation which is in stark contrast to the usual time-domain evaluation methods and a major improvement regarding industrial needs. Currently the method is limited to layer thicknesses exceeding the time extent of the initial blind zone, termed surface bang in our data. This contribution stems from optical and acoustic noise caused by the excitation pulse.

Conclusions – A spatio-temporal measurement method based on laser ultrasound is applied to industrial samples with hardened surface layers. The subsurface spatial profile of the hardness penetration depth can be determined by a supervised machine learning approach without additional calibration step. Our current findings also show the need for more sophisticated measurement schemes in the presence of additional scatterers in the hardened layer and a more fundamental understanding of the spatio-temporal scattering in heterogeneous microstructures for quantitative evaluation would be beneficial for further improvements of this technique. Furthermore, the method needs to extended to thinner layers that are currently masked by the initial opto-acoustic noise of the laser excitation mechanism.

References

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