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Study of Barkhausen emission from the surface martensite layer on induction-hardened carbon steel

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Abstract

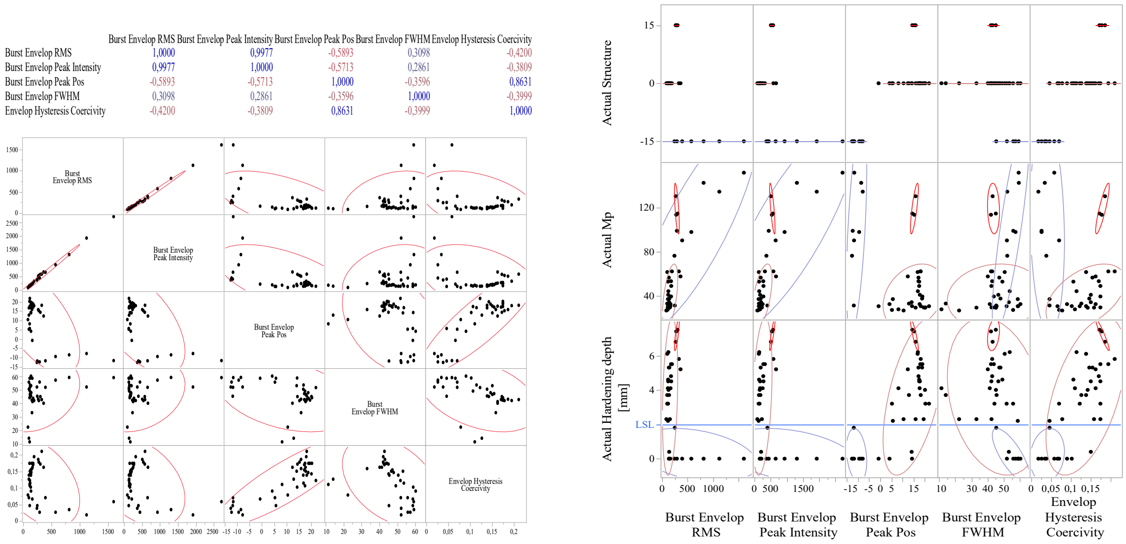
Induction hardening is one of the finishing processes to improve hardness and wear resistance on steel products by developing a hard martensite-rich surface layer. Non-destructive Barkhausen noise (BN) evaluation is used for quality assurance. While the routine production is set to develop a desirable hardening depth of this specific structure, the variations of microstructure and grain size overlay the outbound results in the assessment and make the interpretation ambiguous. This work correlates the different parameters in a BN-signal with the deviations from the targeted martensite by predictive and numerical modelling means.

Keywords: Barkhausen noise (BN); Martensite; Grain size; Predictive modelling; Numerical modelling; Induction hardening

Problem Statement

Non-destructive Barkhausen noise (BN) technique is one suited method for ferromagnetic martensite layer evaluation. Still, data interpretation regarding the martensite assessment is uneasy. Collection of magnetic parameter (Mp) readings, an indicator for product quality control, from a series of induction hardened surfaces under different processing conditions, shows that the qualified martensitic surfaces can be distinguished from the others. But, Mp alone has failed to tell if martensite has formed into undesirable sizes, or if non-martensite has formed.

Authors extend the parameter study by analysing the BN signal more thoroughly. Parameters include peak intensity, RMS value, FWHM and peak position in the BN bursts, as well as remanence (B_r), coercivity (H_c), integral area and permeability (μ) in the integral envelope generated from the burst parameters, and also spectrum area in the amplitude spectrum, of the sample series are studied by means of data mining. Observation from the scatterplot matrix (Fig. 1) shows that peak position of the burst and coercivity in the envelope can be the deterministic features for the microstructure categorisation.



	Burst Envelop RMS	Burst Envelop Peak Intensity	Burst Envelop Peak Pos	Burst Envelop FWHM	Envelop Hysteresis Coercivity
Burst Envelop RMS	1,0000	0,9977	-0,5893	0,3098	-0,4200
Burst Envelop Peak Intensity	0,9977	1,0000	-0,5713	0,2861	-0,3809
Burst Envelop Peak Pos	-0,5893	-0,5713	1,0000	-0,3596	0,8631
Burst Envelop FWHM	0,3098	0,2861	-0,3596	1,0000	-0,3999
Envelop Hysteresis Coercivity	-0,4200	-0,3809	0,8631	-0,3999	1,0000

Figure 1 Scatterplot matrix about correlation in the BN measurements (left) that makes predictions by multiple linear regression indecisive and no single predictor can be used to categorise the induction hardened surfaces (right).

Correlation Decomposition by means of Multivariable Analysis

Physically correlated parameters make the analysis difficult. Multivariate approach by means of partial least square (PLS) analysis reduces the complexity of the data by identifying the mathematical orthogonal factors which are linear to the original predictors (1). By applying 2 factors, it is possible to capture around 60 % of the variations in Mp readings, microstructure and hardening depth, respectively. While increasing the number of PLS factors to 4, the explanation power for each response has increased to at least 75 %. Thereby, PLS helps to reduce the data complexity and to design the decision support criteria for this monitoring process.

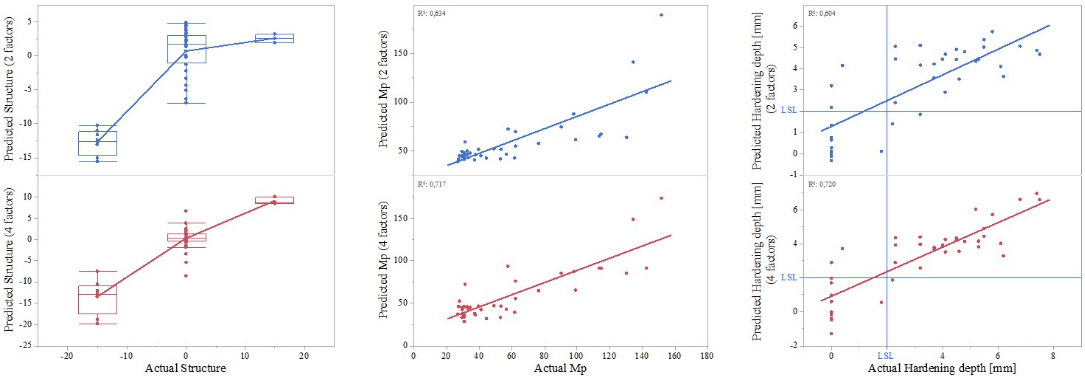


Figure 2 PLS model based on 4 factors separate and predict the microstructure and hardening depth responses with the reliability over 60 % in the present case.

Numerical Modelling

With reference to the statistical study, it is observed that Mp reading, or the peak intensity and RMS values, increases with martensite layer thickness when it is more than 4 mm. Numerical simulation of such was carried out based on certain simulated physical properties of martensite that are defined in our earlier study (2).The linear multi-layered model, with typical material parameters, is presented in (3). The overall response of the Mp reading is predicted by computing the magnetic flux, in agreement with the investigation conducted by White et al. (4). The modelled layer consists of martensite on top of bainite for a plane of 5 mm thick. Magnetic flux predictions on the top surface show that the signal decreases for increasing martensite thickness up to 3 mm. Impeded by the signal penetrating depth, thicker martensite layer do not contribute the signal increment further, which do not agree with the experimental data. This implies a more complex relation between hardening depth and material parameters. The numerical model, at this stage, lacks the possibility to model some material behaviour, such as hysteresis, and this will be a future improvement. In order to make a more accurate prediction, a numerical model for a probe with the same geometry as the experimental one will be needed.

References

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