Experimental report

16/09/2019

Proposal: 1-02-261 **Council:** 10/2018

Title: Validation of Stress and Hardness Determination by a New NDT Method

Research area: Engineering

This proposal is a resubmission of 1-02-248

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Samples: surveillance specimen
formed part of automotive industry
weldment

Instrument	Requested days	Allocated days	From	To
SALSA	3	1	20/06/2019	21/06/2019

Abstract:

Using the reference techniques of neutron diffraction, mechanical hardness test and magnetic hysteresis measurement the new non-destructive testing (NDT) approach for residual stress, hardness and coercive field determination by Barkhausen noise amplitude as a function of the strength of magnetizing field will be validated. For that purpose, it is planned to consider different industrial components: steel plate with a welding seam, formed automotive component and reactor pressure vessel surveillance specimens reconstituted by Beam Welding methods. A positive validation for that examples would have a big impact for further applications of the described Barkhausen noise method since the reliability of the obtained NDT data will significantly increase.

Validation of Stress and Hardness Determination by a New NDT Method

Scientific background: To guaranty quality and safety of weldments, formed automotive components and other industrial components it requires the control of residual stress as well as the hardness because of accumulated plastic deformation. The determination of residual stress in various regions with inhomogeneous microstructure due to plastic deformation is a rather complex task. In the framework of conventional micro-magnetic methods [1], it would require solving the calibration of the used micromagnetic parameters with a huge number of samples with different definite stress states for all relevant deformation structures. From the practical point of view this task seems to be unsolvable since such calibration samples will not be available in practise and sometimes reference samples are absent at all. Therefore, a new approach was developed by the author [2,3] based on the amplitude of the measured Barkhausen noise signals (BHA) and the behaviour of that amplitude on the strength of magnetising field H, i.e. the rump-up curves BHA(H). Considering the results of all measuring points with different stress as well as plastic deformation a scaling transformation of the Barkhausen noise amplitude was suggested, i.e. BHA(H) → X*BHA(Y*H), to get a set of rump-up curves with only one unified crossing point at the magnetising field H^*. Below that field ($H < H^*$) the scaled amplitude increases proportional to the mechanical stress, but for $H > H^*$ the amplitudes have an inverse behaviour. Applying this procedure to any steel sample with different residual stress and microstructure it is suggested that the scaling parameter X will be a measure for the hardness, the Y-parameter should be correlated with the coercive field of the tested material. At least the scaled Barkhausen amplitude X*BHA(Y*HWF) at the working field HWF < H^*can be used for the determination of the stress value. For that purpose, the resulting set of corresponding scaled amplitudes for a larger number of measuring points can be treated within an autocalibration procedure [4]. Similar auto-calibration is proposed for the hardness. Considering physical reasonable calibration functions the parameters of those functions are determined by the least square fit procedure for the failure of the fit functions with respect to the experimental determined data. The obtained results for different cases (bending sample, welded sample, crankshaft, formed automotive component) seems to be reasonable, however, a comparison of that with correct reference data is missing so far.

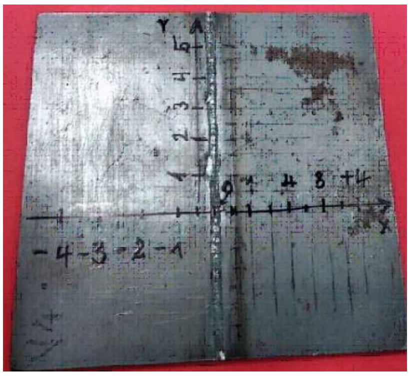

Figure 1: Butt-welded joint of plates, welded by means of YAG-laser beam welding without filler material. Steel plate is of low-alloyed steel C45. Specimens has dimensions of 100 × 100 × 2.5 mm. At the marked points Barkhausen noise measurements were performed.

Aim of the measurements: Using the reference techniques of neutron diffraction and mechanical hardness test the described new non-destructive testing (NDT) approach should be validated. For that purpose, a steel plate with a welding seam was investigated. For this specimen neutron diffraction measurements were already performed at the neutron source IBR 2 in Dubna [5]. However, the spatial resolution of 2x2x10 mm³ was not good enough for the comparison with the magnetic method, where the detecting probe has a size of 1x1 mm² and the penetration depth of Barkhausen noise signals is significantly less than the plate thickness, which is of about 2.3 mm. It is worth to mention that FEM simulations are available for the welded specimen – see [5]. To compare neutron data with the Barkhausen noise results it was first important to determine the stress variation in different depth of the welded plate at the welding seam, for the heat affected zone (HAZ) and for the basic material. In dependence of these results the following measuring strategy has to be specified for measuring points along the HAZ and along a line perpendicular to the welding seam.

Results: Before coming to ILL the Barkhausen noise measurements were performed at the marked positions of the welded plate (see Fig. 1) and the obtained experimental data were analysed by the new approach. Additionally, mechanical hardness tests at selected positions were performed after the neutron experiments. The measurement of residual stresses for the welded plate were carried out using the SALSA instrument on 20th – 21st June 2019. Relatively long time we need for the beam and sample alignment to perform depth scan with a gauge volume of 0.6x0.6x2 mm. The strain change was obtained by the 211-reflex. During the allocated beam time it was possible to realize the scans for the normal (z-), transfer (x-), and longitudinal (y-) directions for the position at the welding seam (x = 0 mm, y = 0 mm), the HAZ (x = -5 mm, y = 0 mm) and the basic material (x = 10 mm, y = 0 mm – here only the longitudinal component), only – see Fig. 2.

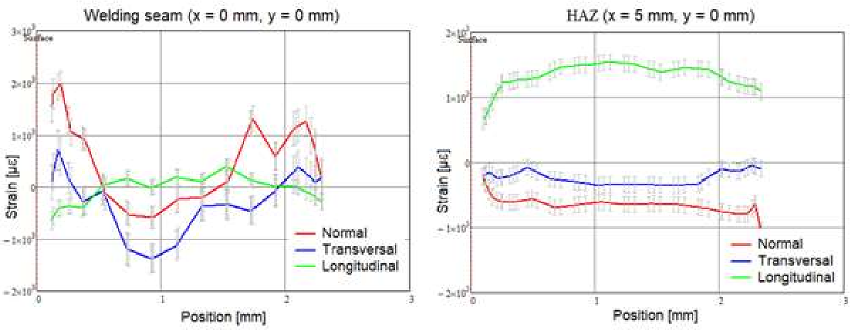

Figure 2: Strain change for the three stress directions at the welding seam and at the HAZ. The absolute values of the strain are under question, since the correct stress-free scattering angle could not be determined correctly, so far. The error bars are attapted.

As far as the correct stress-free lattice spacings are unknown for the welding seam and HAZ material, trial values for the corresponding stress-free scattering angle was chosen to fit the calculated stress values to that one derived by the Barkhausen noise technique. For that purpose, the depth dependent neutron diffraction stress data were averaged over the depth with an exponential weighting factor $\exp(-z/d_o)$ to simulate the situation of the Barkhausen noise measurements. The Barkhausen noise signals were detected with a frequency band from f_s = 20 – 200 kHz. At f_s = 20 kHz the penetration depth of the noise signals was found to be of about 1 mm [7], then the penetration depth for the performed Barkhausen noise measurements with the detection frequency f_s is $d(f_s)$= 1mm $(20\text{kHz}/f_s)^{1/2}$. Averaging over frequencies f_s = 20 – 200 kHz one obtains the relevant penetration depth for our calculations: d_o = 0.481 mm. The results are collected in Fig. 3.

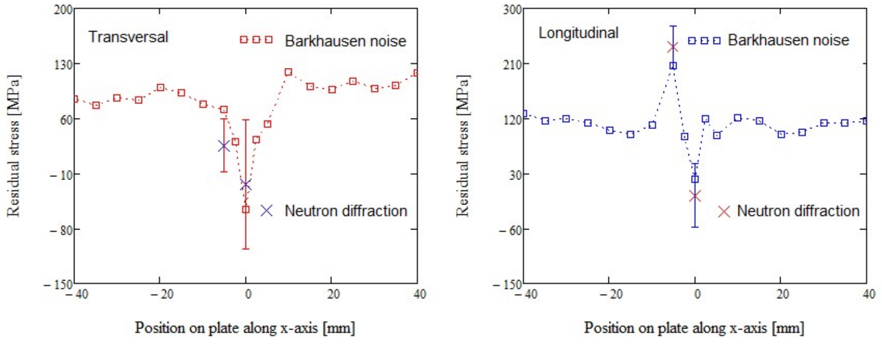

Figure 3: Residual stress for the transversal and longitudinal directions determined by the scaling approach for Barkhausen noise measurements compared with the results of the neutron diffraction, where only the stress-free scattering angle θ_o was chosen different for the welding seam (θ_o = 93.3215°) and for the HAZ (θ_o = 93.433 °). Error bars of the diffraction method are shown.

Despite the uncertainties with the stress-free scattering angle the found results demonstrates that the autocalibration of the scaled Barkhausen noise amplitudes yield quite reasonable absolute stress values. In forthcoming experiments, the θ_o-values must be determined by additional measurements with small sample parts of the welding seam, the HAZ and the basic material area, where the complete samples are inside the neutron beam.

To complete the analysis in Fig. 4 the results are shown for the hardness values obtained by the new Barkhausen noise approach in comparison with values of the mechanical hardness tests at selected points.

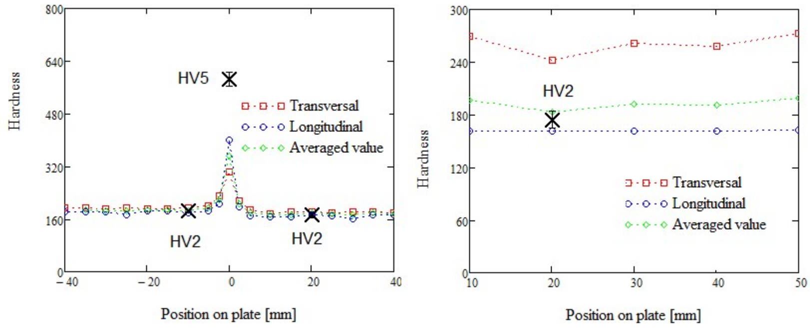

Figure 4: Hardness values determined by the scaling approach for Barkhausen noise measurements compared with the results of mechanical hardness tests, where the Vickers hardness was obtained for indentation force of 2 kp and 15 s holding time, but for the welding seam the force 5 kp was applied. In the Barkhausen noise method the hardness is anisotropy, hence for comparison with the mechanical tests the average of the longitudinal and transvers values were calculated.

Conclusions: The present results of the neutron diffraction, especially the depth scan explain the difficulties of the stress calibration for Barkhausen noise measurements using neutron diffraction reference data. The determination of 2D surface stress requires analysis of the stress gradient, otherwise calibration fails. However, the performed experiments point at the way how to do it accurately. Of course, it takes much time, however, for the validation of new testing methods it is worth practicing. Consequently, a continuation of the present proposal seems to be necessary in order to get a validation of the new approach with the scaled Barkhausen noise amplitude. A positive answer attempt would have a big impact for further applications of the described Barkhausen noise method since the reliability of the obtained NDT data will significantly increase.

Literature:

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