Experimental Report

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Proposal: **1-02-132** **Council:** 10/2012

Title: Improvement of high speed quenching by characterization of residual stress profiles in massive steel samples

This proposal is a new proposal

Researh Area: Engineering

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Samples: Fe, C

Instrument	Req. Days	All. Days	From	To
SALSA	7	7	01/08/2013	07/08/2013

Abstract:

Experiment 1-02-132: Improvement of high speed quenching by characterization of residual stress profiles in massive steel samples

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Introduction

Increasing the fatigue limit of components is a persistent research topic, in particular within the actual context of CO2 emission reduction. Intensive quenching of steel components is a possibility for increasing this limit [1, 2, 3]. By choosing the right parameters for a high speed (HS) quenching process, it is possible, to create compressive residual stresses at the surface instead of tensile stresses (RS) or to increase existing compressive RS. The current problem concerning this process is that the parameters used are based on experience for specific parts and it is therefore not possible to generalize the known results. The connection between the different quenching process controls, the heat transfer coefficient (HTC) and the component properties are not fully understood. In previous investigations, it has already been showed that the Biot number is an important dimensionless number for the through hardened case [4]. For low alloyed steels (C35 and C56E2) HS quenching has been applied in such manner, that the near surface regions will undergo a martensitic transformation while the deeper areas transformed to bainite and/or to ferrite and pearlite. In that case during the first stage of the cooling process plastic deformations in the austenite phase occurs. Later on during the process martensite with a lower density transforms from austenite. Both processes should lead finally to compressive stresses at the surface. In order to identify and understand the mechanisms that are responsible for the creation of compressive residual stresses at the surface of the treated components, FEM simulations are performed. Several materials and components geometry as well as different process parameters were tested. The largest number of samples was investigated by X-ray diffraction. For verification and validation, non-destructive neutron diffraction measurements of residual stresses in massive steel samples were performed.

Materials, shape and size of specimens

In this experiment, 4 different samples (cylinders) were investigated in terms of residual stress distributions from the surface to the core. The investigated cylinders had a different geometry and were made from two different steels. The samples were quenched with different heat transfer coefficients. The data about the samples are as follows: Ø 43.4 mm (C56E2) 35 000 W/m².K ; 40 mm (C35) 40 000 W/m².K ; 30 mm (C56E2) 27 000 W/m².K ; 25 mm (C35) 20 000 W/m².K.

The depth of the created compressive residual stress layers was expected to be around 3 mm. Therefore, the residual stress measurements were performed from the surface to the center of the cylinders with a spatial resolution of 0.3 to 0.4 mm in depth near the surface and larger steps of 1 mm towards the core. In order to reach the required spatial resolution, the measurement of small volume elements was needed. For these investigations the characterization of layers close to the surface was also important. Depending on the measured stress component, collimators of 0.6 or 2.0 mm were used. In order to reduce measurement times and increase the intensity, the beam was opened to maximum in the cylinder longitudinal direction.

For the determination of d_0 evolution from the sample to the core of each sample, combs were prepared from similarly treated samples by electro-discharge machining and measured.

Results

The combs were first measured as well as all samples in radial and tangential directions in order to use the same experimental set-up. These measurements could be performed without problems by using gauge volumes of 0.6 × 0.6 × 20 mm. However, for axial measurements, large beam opening in longitudinal direction of the sample was not possible anymore due to geometrical condition and therefore the set-up had to be changed to 0.6 × 0.6 × 2 mm. Due to this, for the samples with a diameter larger than 30 mm very low signal were obtained leading to very long measuring time. Due to a non-planed reactor shutdown, only the sample with diameter 25 mm could be completely measured in the 3 direction, while the other three samples could only be measured in radial and tangential directions.

The evolution of Full Width at Half Maximum (FWHM) measured for all samples is given in Figure 1. Below a more or less constant surface region, a strong decrease can be observed from the surface to the core for all samples. The decrease is related to the varying cooling rate from the surface to the core leading to the formation of martensite at the surface, a mix a martensite and bainite in the intermediate level, and ferrite/pearlite in the core. This is also accompanied by a strong hardness gradient from the surface (high hardness) to the core (low hardness). The samples made of C56E2 present much higher FWHM at the surface and decrease in deeper layers than for the samples made of C35. This is due to the increasing hardenability as a consequence of the higher carbon content. There is no significant effect of the sample diameter on the FWHM distribution.

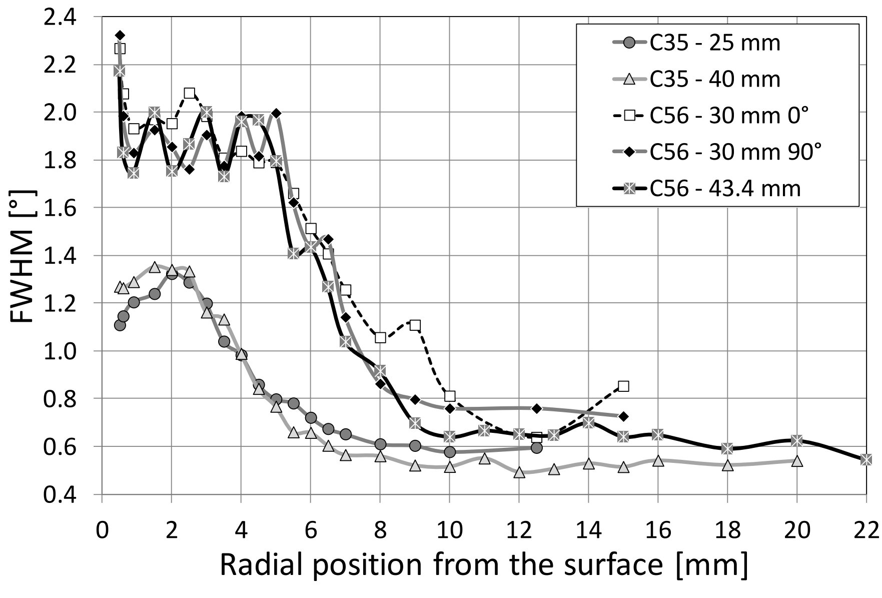

Figure1: Evolution of FWHM from the surface to the core of all samples

The evolution of the three residual stress components measured in the sample with Ø 25 mm (C35) is presented in Figure 2. Here, very large compressive residual stresses were determined close to the surface, in particular in tangential direction (-800 MPa). In axial direction values of about -500 MPa are reached while in radial direction, residual stresses close to zero are present, as expected. In axial and in tangential direction, the residual stresses present a monotonic and continuous increase towards the core, while crossing the 0 MPa line at 3 mm (axial) and 6 mm (tangential) to continue to grow in tensile region. In the center, maximum tensile residual stresses are present in axial direction with about 550 MPa. As expected, the levels of tangential and radial residual stresses reach similar values close to 300 MPa in the centre.

The results of FEM simulation are also presented in figure 2 together with the experimental results. The simulations were performed with the software Sysweld © by using a 2D axis-symmetric model taking into account an isotropic work hardening model. The agreement between measurements and simulation results is excellent in all three directions. The monotonic increase from high compression at the surface to tensile in the core is confirmed by both methods. Moreover, the residual stress distribution measured with neutron scattering and also the results of the FEM simulations could be also confirmed by X-ray diffraction measurements at the surface, showing a value of -750 MPa, which is very close to the simulation result.

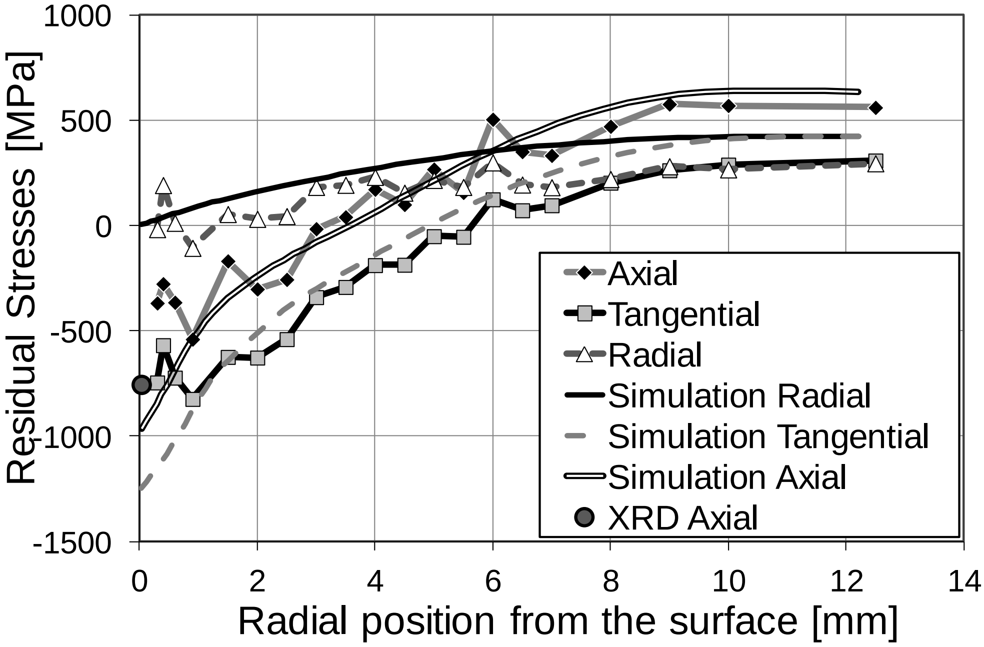

Figure 2: Distribution of triaxial residual stresses from the surface to the center of a cylinder made of C35 with Ø 25 mm measured by neutron diffraction and calculated by FEM simulation

In further investigations, the strains resulting from the measurement of the 3 other samples in radial and tangential directions will also be compared to the simulations results. A dependence of the residual stress distribution on the quenching strategy will then be developed.

References

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