# DIFFRACTION STUDY OF RESIDUAL STRESS DEPTH DISTRIBUTION IN SURFACE LAYERS OF SHOT-BLASTED DECARBURISED STEELS

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**Keywords:** steels, shot peening, residual stresses, X-ray diffraction, decarburization

## Abstract

Surface decarburization of construction steels occurs during their forging, drawing and casting. As a softening process, decarburization leads to a considerable fatigue limit decrease. This detrimental effect can be reduced by strengthening the decarburized layer using plastic deformation induced by shot peening. As a result compressive residual stresses are created in the surface layer.

The aim of the contribution is to present the results of X-ray diffraction analysis of residual stress depth profiles in surface layers of sand-blasted and shot-blasted steels. Depth distributions of macroscopic (first-order) residual stresses were determined up to approx. 500 μm beneath the blasted surface.

## 1. Introduction

Decarburization, the kinetic process in which carbon diffuses from the surface of a metal (typically steel), weakens the surface layer of the specimen since the hardness, i.e. strength, of a steel is dependent mainly on the carbon content and phases present [1]. Common high temperature technological processes of steel and cast iron semi-products like casting, working (forging, rolling, etc.) and any other heat treatment without protective atmosphere are susceptible to decarburization [2]. It has been known for a long time that the process of decarburization leads to harmful effects if not dealt with through a secondary process by strengthening the decarburised layer using plastic deformation induced by, e. g. shot peening. As a result compressive residual stresses are created in the surface layer. There is no analytical technique which allows us to evaluate such non-uniform stress fields as efficiently as X-ray diffraction.

## 2. Samples investigated and experimental techniques

Five squared samples 50 × 50 × 3 mm$^3$ from the steel of Czech grade 12 020.1 subjected to various blasting conditions were investigated. The effect of sandblasting was caused by using SiO$_2$ sand with grain size of 0.5 - 0.7 mm in diameter. Granulated steel of particles 0.6 - 0.8 mm in diameter (hardness 40 - 55 HRC) was blasted onto samples with three different pressure levels and total amounts of particles – see Table 1.

**Table 1.** Working conditions for investigated surfaces.

| sample | cutting operation | total mass of particles, kg | pressure, MPa |
|---|---|---|---|
| AR | as received | --- | --- |
| 0.5-0.5 | sand-blasted | 0.5 | 0.5 |
| 4-8 | shot-blasted | 4 | 0.8 |
| 8-8 | shot-blasted | 8 | 0.8 |
| 8-12 | shot-blasted | 8 | 1.2 |

The residual stress measurements were performed with a - X'Pert PRO diffractometer in -arrangement with CrK radiation. The line {211} of -Fe phase was measured. Nine different tilts angles ( ) from 0° to 63° were used. The sin$^2$ method was applied for determination of macroscopic residual stress [3]. The X-ray elastic constants (1/2) $s_2 = 5.95 \cdot 10^{-6}$ MPa$^{-1}$, $-s_1 = 1.325 \cdot 10^{-6}$ MPa$^{-1}$ were used in stress calculations [4]. The single line Voigt function method [5] was applied for corrections of instrumental broadening and determination of crystallite size $D$. In order to analyse the stress gradients beneath the samples surface the layers of material were gradually removed by electrolytic polishing.

The surface roughness was measured by laboratory tester *MITUTOYO SURFTEST 2000*. The arithmetical

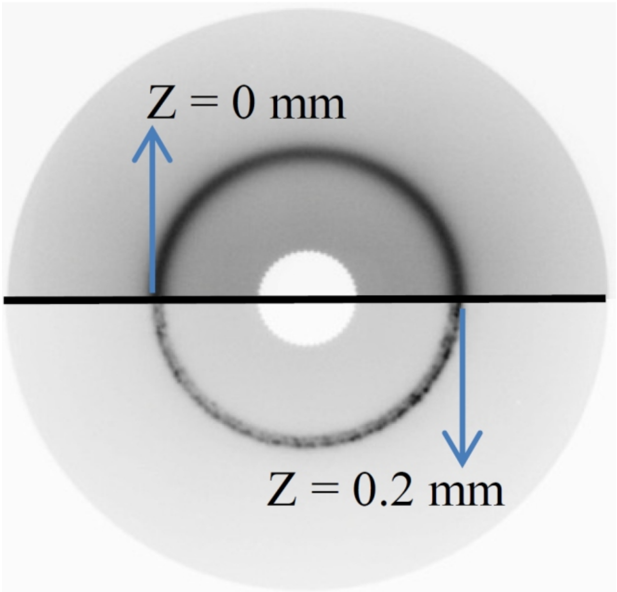

**Figure 1.** Back-reflection X-ray diffraction patterns from the surface ($z$ = 0 mm) and after removing a layer of the thickness 0.2 mm of the sample 0.5 0.5.

**Table 2.** Values of surface macroscopic residual stresses $_L$, $_T$ and *FWHM* of {211} -Fe diffraction line, crystallite sizes *D* and roughness parameter *Ra* determined on all the investigated surfaces.

| sample | $_L$, MPa | $_T$, MPa | <*W*>, deg | *D*, nm | *Ra*, µm |
|---|---|---|---|---|---|
| AR | -31 ± 3 | -37 ± 3 | 1.413 | 248 ± 16 | 3.82 ± 0.72 |
| 0.5-5 | -370 ± 6 | --- | 2.648 | 35 ± 2 | 3.20 ± 0.98 |
| 4-8 | -338 ± 5 | -347 ± 9 | 2.507 | 48 ± 2 | 2.65 ± 0.79 |
| 8-8 | -270 ± 6 | -286 ± 8 | 2.635 | 43 ± 6 | 3.84 ± 1.06 |
| 8-12 | -175 ± 5 | -186 ± 10 | 2.780 | 36 ± 2 | 4.33 ± 0.92 |

mean surface roughness of measured profile *Ra* was evaluated.

## 3. Results and their discussion

The back-reflection X-ray diffraction patterns, taken before performing residual stress measurements, correspond to diffraction of the spectral doublet CrK on crystallographic planes {211} -Fe (see Fig. 1) While the surface shows isotropic fine-grained polycrystalline structure with plastic deformation (the diffraction line is broad, continuous, and has homogeneous intensity around its perimeter), in the case of the removed 0.2 mm layer, the diffraction line becomes narrow with a slight indication of discrete diffraction spots located uniformly around perimeter, i.e. without any sign of texture. Therefore, the samples can be used for determination of the surface residual stress by means of X-ray tensometry.

Table 2 contains results of surface residual stress measurements ( $_L$, $_T$) performed in two mutually perpendicular directions, the parameter *FWHM* of {211} -Fe diffraction line, and the arithmetical mean surface roughness of the measured profile *Ra*. The inaccuracy or experimental error of *FWHM* is approx. 0.05 °2 .

It is evident that surface values of residual stresses (see Table 2) are not able to represent the essence of the process of interaction of blasting particles with the worked material. For this reason, depth profiles of monitored values *s* and *FWHM* were determined (Fig. 2, Fig. 3). The crystallite size *D* depth profiles (Fig. 4) calculated from the {211} -Fe diffraction lines according to [4] give additional information about the influence of blasting on the real structure of the samples under investigation.

## 4. Main conclusions

The essential conclusions that can be derived from the performed analyses are listed below:

- On the surface of all the investigated samples was identified the so called centrally symmetric biaxial state of favourable compressive residual stresses, i. e. $_L$ $_T$. The highest value (–370 MPa) was found on the sand-blasted surface.
- The lowest values of residual stresses and diffraction line width are in the case of the as-received sample.
- The increase of air pressure leads to a decrease (relaxation) of the surface compressive stresses, and in the same time diffraction line width *FWHM* increases, which indicates the higher degree of plastic deformation.
- The roughness parameter *Ra* (see Table 2) at the beginning declines with the total blasting intensity – the original surface becomes smoother – up to the sample *8-8*, and then again increases since the high velocity (energy) particles brings about new pits in the surface.
- The depth profiles of residual stresses reflect the different intensity of blasting particles. The stress influenced

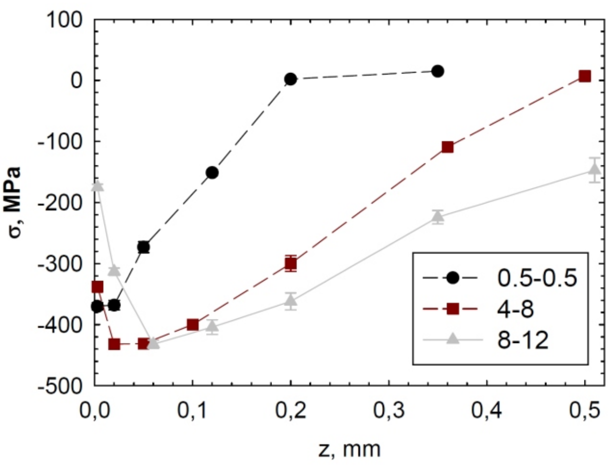

**Figure 2.** The depth profiles of macroscopic stresses in surface layers of investigated samples.

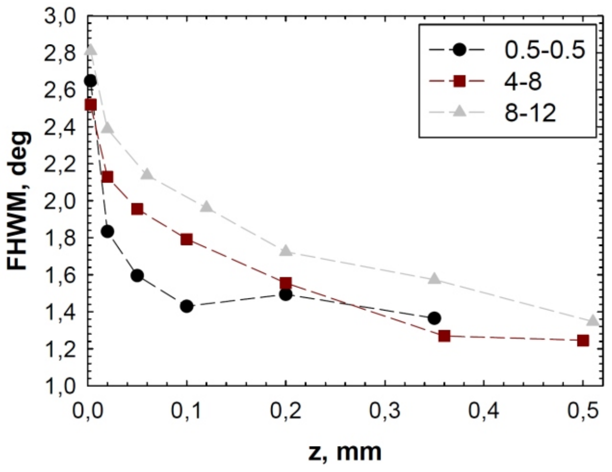

**Figure 3.** The distributions of width of {211} -Fe diffraction line beneath the blasted surfaces.

depth of the sandblasted sample 0.5 0.5 is only 0.2 mm (see Fig. 3), whereas for the other samples, the compressively pre-stressed layer is deeper than 0.5 mm. Profiles of crystallite sizes *D* (Fig. 4) correlate with the stress distributions.

## References

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## Acknowledgements

*This research was supported by the project TA02011367 of the Technology Agency of the Czech Republic.*

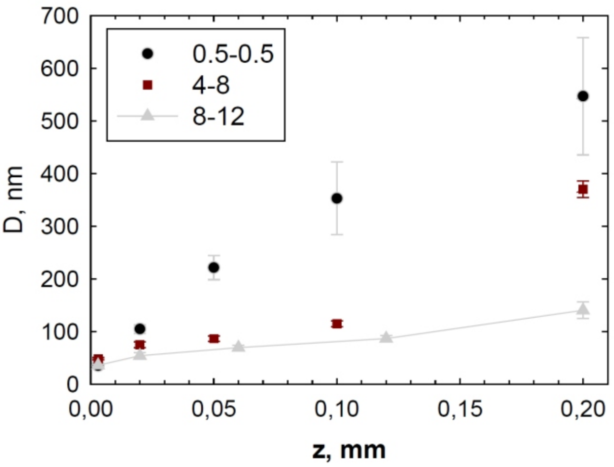

**Figure 4.** The depth profiles´ courses of crystallite size *D* determined from the -Fe {211} line profiles.