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RESIDUAL STRESSES DETERMINATION IN MATERIALS WITH PREFERRED ORIENTATION

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ABSTRACT

The aim of this contribution is to present a new approach for residual stress evaluation in materials with preferred orientation. In the beginning, an overview of X-ray diffraction determination of macroscopic residual stresses in textured materials is outlined. Afterwards, experimental results from three already established X-ray diffraction techniques and the new one used for residual stresses determination of single-phase and dual-phase steels after cold-rolling are presented. The discussion of the obtained stress values proves the validity of the new approach for residual stresses determination in textured materials. The works are going on with further verifications necessary for generalization of the proposed methodical approach.

INTRODUCTION

The majority of nowadays-used diffraction measurements methods and algorithms for residual stresses (RS) calculation assume a case of isotropic (non-textured) polycrystalline material. Due to the comparatively frequent occurrence of preferred orientation (texture), it is more than desirable to have a method, procedure and even a computing algorithm for proper and correct RS determination.

Currently, a universal method with the potential to properly evaluate RS in textured materials is still missing and this problem is solved, in the worst scenario, by neglecting the texture (X-ray elastic constants (XEC) are used). The most known this type approach is the $\sin^2\psi$ method which generally leads in the case of textured materials to non-linear $d(\sin^2\psi)$ dependencies. Using *{h00}* or *{hhh}* planes [1], multiple reflections with high Miller's indices [2] or texture independent directions [3], could result in linear $d(\sin^2\psi)$ dependencies, but still uses wrong elastic "isotropic" constants.

More correct attitude is to choose one of the methods using anisotropic elastic constants (X-ray stress factors – XSF) which are dependent on real structure of the material. These constants are not tabulated and it is necessary to be calculated from the texture. The usually proposed methods are e.g. harmonic function [4], crystallite group [5], strain pole figures [6] methods, etc.

A new method was developed and used for determination of RS without neglecting texture. The new method is based on the Dölle model [7]. However, contrary to the Dölle procedure, our method determines the XSF (R_{ij}) as the average between the single-crystal elastic constants (s_{33ij}) and the XEC (r_{ij}), weighted according to the relative intensities I in the measured directions φ, ψ, see Eq. 1.

$$R_{ij}(hkl,\ \varphi,\ \psi) = I(hkl,\ \varphi,\ \psi)\ r_{ij}(hkl) + \\ + (1 - I(hkl,\ \varphi,\ \psi))\ s_{33ij}, \qquad (1)$$

where hkl are the Miller indices of the analysed planes. For texture limits, i.e. $I = 0$ and $I = 1$, the applicability and correctness of the method are evidently proofed. The general method uses function $f(I)$ depending on the texture. To simplify and according to previous experiments [8], the function $f(I)$ could be approximated by a quadratic function rather than a linear function in Eq. 1. Unlike other methods, this approach allows determining RS in materials with a very weak, strong and moderate texture too. The main disadvantage of this method derives from the accuracy of calculated orientation distribution function (ODF), likewise the harmonic function method.

EXPERIMENT

The tested samples of plate shape were made of AISI 420 (ferritic), AISI 304 (austenitic) and AISI 318LN (austenitic-ferritic or duplex) type of stainless steel. The samples were cold-rolled with 0, 10, 20, 30, 40, and 50% reduction in thickness (deformation). After deformation, the austenitic and ferritic with duplex samples were annealed in air laboratory furnace for 4 hours at 840 °C and 7 hours at 650 °C, respectively, in order to reduce RS. The tested samples were marked as F0–F50, A0–A50, and D_F0–D_F50 and D_A0–D_A50 for particular phases of duplex steel. All

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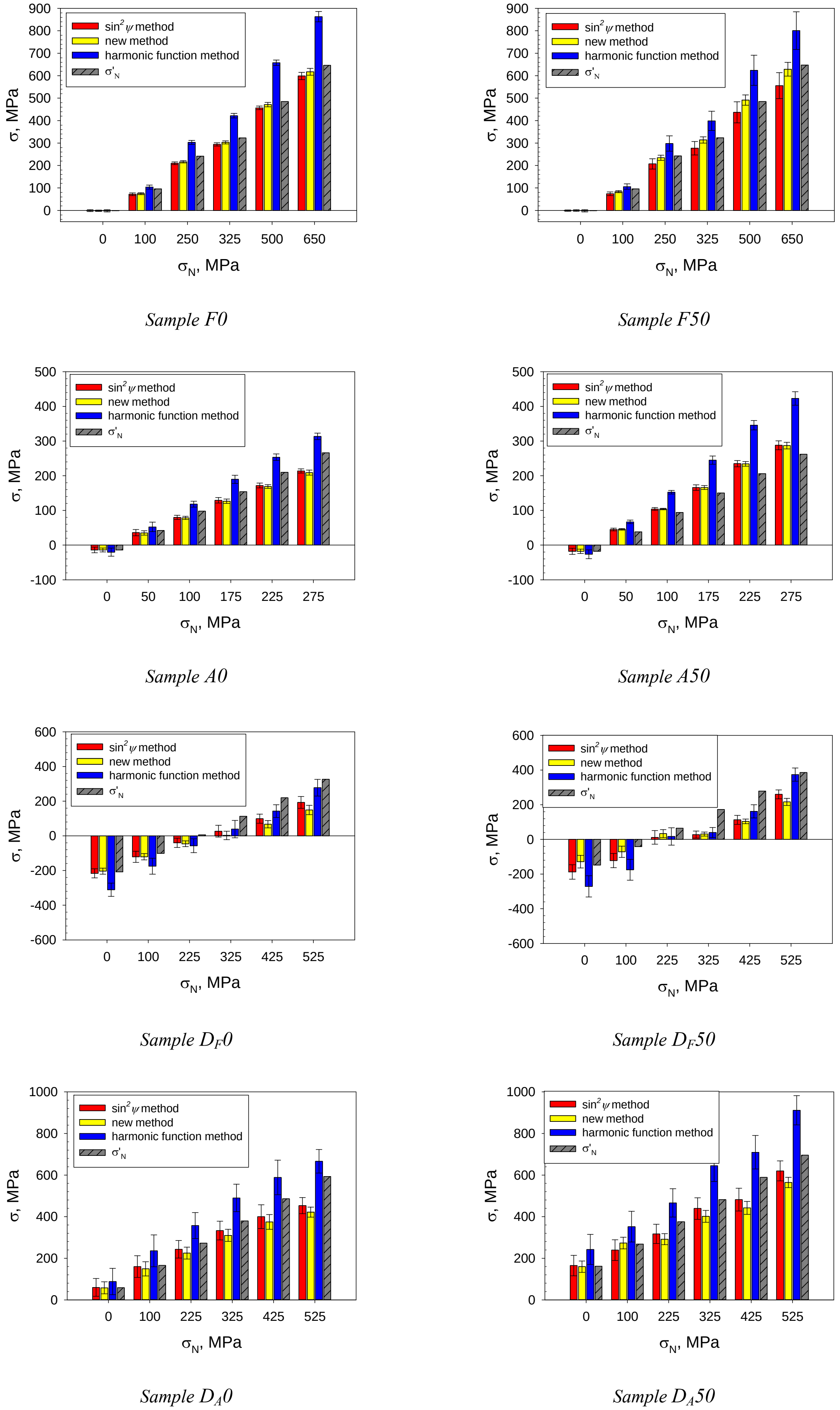
samples were four-point bent until the yield strength of the given material (see Figs. 1).



Sample F0 *Sample F50*

Sample A0 *Sample A50*

Sample D$_F$0 *Sample D$_F$50*

Sample D$_A$0 *Sample D$_A$50*

Fig. 1. Determined stresses σ depending on load σN stress with 0 and 50% deformation

The *X'Pert PRO MPD* diffractometer with cobalt radiation was used for texture and phase analyses. Texture analysis was performed on the basis of the ODF calculated from experimental pole figures (PF), which were obtained from three diffraction lines *{110}, {200}, {211}* of ferrite phase and *{111}, {200}, {220}* of austenite phase using the *MTEX* software [9]. The *ResMat* software was used to determine the harmonic coefficients, which are necessary for XSF calculation using the harmonic function method.

The *X'Pert PRO MPD* diffractometer with the manganese and chromium radiation was used to measure lattice deformations in austenite and ferrite phases, respectively, in the rolling direction. The diffraction angles $2\theta^{hkl}$ were determined from the peaks of the diffraction lines $K\alpha_1$ of planes *{311}* for the austenite and *{211}* for the ferrite phase. The Rachinger's method was used for separation of the diffraction lines $K\alpha_1$ and $K\alpha_2$ and the diffraction lines $K\alpha_1$ were approximated by the Pearson VII function.

RESULTS AND DISCUSSION

The presented stresses σ were determined using three mentioned methods by X-ray diffraction. The stresses σ'_N are the superposition of the external (load) stresses σ_N induced by four-point bending and the RS of surfaces areas of the tested samples after annealing σ_{RS}, i.e. $\sigma'_N = \sigma_N + \sigma_{RS}$. For the external stresses calculation, Young´s moduli of tested materials were determined using the *ultrasonic pulse-echo method* [10]. In the ideal case, the values of σ should be equal to σ'_N.

RS calculated using common $\sin^2\psi$ method differ from σ'_N values due to omitting the presence of texture and using the XEC instead of the XSF. The relatively small errors result in the case of sharp texture and measuring in the texture independent direction.

The stresses determined by the harmonic function method have in most cases higher values and errors in comparison with other methods. The main reasons are the accuracy of ODF (or harmonic coefficients) calculation, the presence of sharp texture, and grain size (related to the Reuss or the Voigt models).

The newly developed method uses relative intensities of pole figures. The main benefit of this method is the absence of the PF or ODF fitting. For this reason, it is suitable for fine-grained materials with very strong and sharp textures too. The necessity of good accuracy of ODF calculation is the main disadvantage of this method. The good validity of the proposed method is for single-phase steel, where the function *f(I)* could be approximated by a quadratic function, see Figs. 1a–d. Due to the multi-phase interaction during deformation of duplex samples, the accuracy of the method was confirmed for stresses up to 50% of yield strength, see Figs. 1e–h. For all cases, the RS values were determined by the proposed method with smaller experimental error than other methods.

CONCLUSION

The applicability of the new method of residual stress determination in textured materials was proofed for single-phase materials and for major phases of multi-phase materials to approx. 50% of yield strength, see Figs. 1. Compared with the standard $\sin^2\psi$ and the harmonic function methods, much more accurate results were achieved. The main reason is the presence of very sharp and strong texture, especially in duplex steel. The further works are going on a generalization of the proposed methodical approach.

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