EFFECT OF DEFORMATION AND TEMPERATURE ON ANISOTROPHY AND RESIDUAL STRESS OF IF STEEL

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VPLYV DEFORMÁCIE A TEPLOTY NA ANIZOTRÓPIU A ZVYŠKOVÉ NAPÄTIA IF OCELE

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Abstrakt

Príspevok sa zaoberá vplyvom stupňa deformácie a teploty na anizotrópiu a zvyškové napätia IF oceli. Z dôvodu spresnenia mikroštruktúrnych parametrov boli použité dva modely: izotropný a anizotropný. Hodnoty parametrov vplývajúcich na anizotrópiu a zvyškových napätí boli namerané na röntgenovom difrakčnom prístroji a následne spracované v programe MAUD (*Materials Analysis Using Diffraction*), ktorý umožňuje výpočet mikrodeformácie z profilu difrakčných čiar Rietveldovou metódou. Z profilu difrakčných čiar v programe MAUD boli vypočítané mriežkové parametre a_0 [nm], veľkosti kryštalitov D_L [nm] a distorzie mriežky ε_z [-]. Mriežkový parameter a_0 [nm] pri oboch modeloch má s rastúcou deformáciou narastať z hodnoty 0.286643 nm do 0.286736 nm . Hodnoty veľkosti kryštalitov D_L [nm] pre oba modely klesajú v rozmedzí od 220 nm do 53 nm. Distorzia mriežky ε_z [-] sa s rastúcou deformáciou výrazne nemení. Zvyškové napätia po hrúbke vzorky z IF ocelí s 90% deformáciou boli merané na röntgenovom difrakčnom prístroji metódou $\sin^2\psi$ ako vzorový príklad. Meranie bolo realizované na oboch stranách vzorky po obojstrannom odleptávaní , ktoré bolo nevyhnutné k zmapovaniu zvyškových napätí po hrúbke vzorky v smere valcovania, smere priečnom a smere 45°. Z nameraných výsledkov vyplýva symetrické rozloženie zvyškových napätí v priečnom smere a nesymetrické rozloženie zvyškových napätí v smere valcovania, kde maximálna hodnota sa nenachádza v strede hrúbky skúmanej vzorky. Koeficient normálovej anizotrópie pre vybrané vzorky z IF ocelí bol vypočítaný softvérom popLA modelom „pencil“ , ktorý je pre daný typ textúry najvhodnejší a v praxi sa používa na stanovenie koeficientu normálovej anizotrópie tenkých plechov, ktorý sa dá len obtiažne určiť mechanickým spôsobom. So stupňom deformácie narastá absolútna hodnota r až na cca 1.6 ale súčasne sa zväčšuje rozdiel v smere valcovania.

Abstract

The article deals with the effect of deformation and temperature on anisotrophy and residual stress of IF steel. Two models of microstructural parameters were used: isotropic and anisotropic. Values of anisotrophy and residual stresses were measured using by X-ray diffraction apparatus and then processed in the MAUD software. The MAUD software allows microdeformation calculation from a diffraction lines profile by Rietvield method, thereby allowing an accurate determination of the structure. The values of lattice parameter a_0 [nm], crystallite size D_L [nm] and lattice distorsion ε_z [-] were measured as the diffraction lines profile in the MAUD software. The lattice parameter a_0 [nm] increased from 0.2866 nm to 0.2867 nm as well the crystallite size D_L [nm] decrease from 220 nm to 53 nm, with increase in deformation value for both models. The change of lattice distorsion ε_z [-] in dependence on deformation is not significant. The residual stresses across sample thickness with 90% deformation of IF steel were measured using $\sin^2\psi$ method by X-ray diffraction apparatus. The measurement was realized on both sides of sample after double-size etching in rolling direction, in cross direction and in 45° direction. Results show that residual stresse distribution was symmetric in cross direction and unsymmetric in rolling direction. The coefficient of normal anisotrophy for IF steel was calculated using by model „pencil“ in popLA software. The popLA software for texture analysis and modeling software provides a comprehensive treatment of material texture analysis by reducing texture data and using these data to predict the normal anisotrophy coefficient. The absolute value of r increases to about 1.6 and with deformation increasing.

Keywords: IF steels, RTG, MAUD, diffraction, residual stress

1. Introduction

Steel is a very important material in the automotive industry. Steel represents high strength material and also material with excellent plastic properties. High-strength material with excellent elongation was developed based on the IF steel. The rolling is one of the technology for producing the IF steel. For example, increase of finishing rolling temperature increases the plastic properties of the IF steel, represent by the value of the coefficient r_m [1-4].

Many publications and scientific articles are interested in the anisotropy of materials. The term means non-uniformity of properties in different directions. In regard of material anisotropy it is considered to be homogeneous, characterized by three orthogonal axes of anisotropy, for orthogonally anisotropic or orthottropic material. X-axis agrees with the direction of rolling, which is known as the direction 0. In regard of the plate anisotropy, planar anisotropy (in the plane of the plate) and normal (in the direction of sheet thickness) is distinguished [5].

Diffraction methods provide much information on the real state of the structures of polycrystalline materials. Using X-ray or electron radiation may be very accurately for the lattice parameter set, calculation of the change in the lattice parameter, the size of coherent diffraction fields, residual stresses, crystallite orientation etc. This information is obtained by analyzing diffraction record of the location, shape and intensity of diffraction lines [6].

Residual stresses, which are one of many types of internal tensions, arising from non-homogenous deformation. Generally occur in all cases where the plastic deformation of some product parts occurred during the production. Residual stresses can be divided according to various criteria. According to the cause, there are:

Thermal (Heat) - formed during cooling influenced by deformation in different areas of the body, dependent on temperature differences, or several thermal expansion differences.

Deformation - originated in irreversible non-homogenous deformation due to internal forces.

Transformation - arise from spatially non-homogeneous transformation of structure attended by volume effects (length change), for example ($\gamma \rightarrow \alpha$) transformation of Fe [7].

In order to determine the materials properties, the residual stresses of the investigated materials plays important role. For example, the reason for fatigue strength improvement by shot peening can be attributed to the formation of compressive residual stresses in the surface layer of the material. The compressive residual stress usually decreases the tensile stress in the component by external forces and therefore increases the fatigue life of the material [8,9].

2. Experimental methods and material

Experimental material was IF steel. The chemical composition is listed in Tab. 1. Samples were taken from sheet of thickness at 4.82 mm. Finishing rolling temperature of 920 °C and coiling temperature of 597 °C were carried out. The amount of cold deformation is given in Table 2.

Table 1 Local chemical analysis of IF steel [mass %]

C	Mn	Si	P	S	Al	TI	N
0,002	0,15	0,006	0,00499	0,007	0,04	0,067	0,004

Table 2 Amount of deformation of IF steel

Sample	1	2	3	4	5	6	7	8
ε [%]	10	20	30	50	60	70	80	90

3. Results and discussion

3.1 Calculation of microdeformation from diffraction lines profile

To calculate the crystallite size (coherent diffraction areas) D_L and lattice distorsion ε_z MAUD software was used , whereby the diffraction records of IF steel samples with different amount of deformation (10-90%) were measured precisely. Diffraction records were used for profile analysis (Rietvield method) in the MAUD software, are shown in Fig. 1, where anisotropy diffraction profiles depending on the amount of deformation can be observed. A sharp change particularly at the maximum intensity of the planes (110) and (200) was found. For microstructure parameters clarification 2 models were used: isotropic and anisotropic. Based on the measured diffraction profiles lattice parameters a0 were calculated in the MAUD software for different amount of deformation, the dependences are shown in Fig. 2. The graphical dependence in Fig. 2 shows excellent agreement between the isotropic and anisotropic model except for 30% deformation, where the mismatch is likely due to the "reality" of the data measured by x-ray equipment. A linear increase in the lattice parameter wasn´t reached probably from a lack of preparation of samples for measurement. Samples were etched from the surface to a thickness of approximately 0.1 mm, and it showed that it would be preferable to measure the thickness profiles from the center of the sample after previous grinding and etching. Although linearly increasing dependence was not achieved, increase of the grid parameter deformation can be observed.

From the profile of diffraction planes crystallite size D_L and lattice distortion ε_z have been calculated. Graphic dependence in Fig. 3 shows the crystallite size calculated according to isotropic and anisotropic model. Crystallite size decreases with the deformation for isotropic model and for anisotropic model they are the components of tensor D_{L11} and D_{L23}, the other components don´t show a strong dependence.

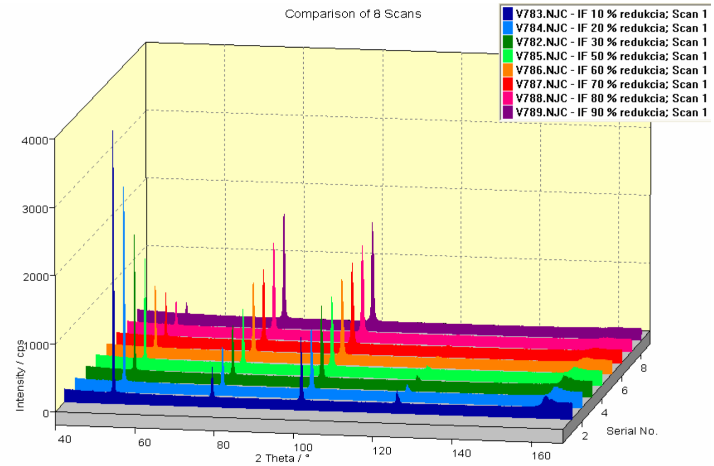

Fig.1 Difraction profile of plains (110), (200), (112), (103) and (222) of IF steel with deformation 10 – 90%

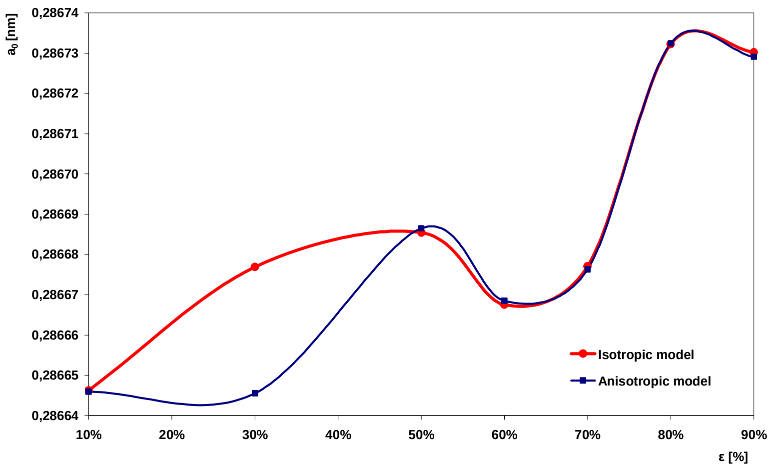

Fig.2 Calculated lattice parameters a_0 of IF samples for isotropic and anisotropic model

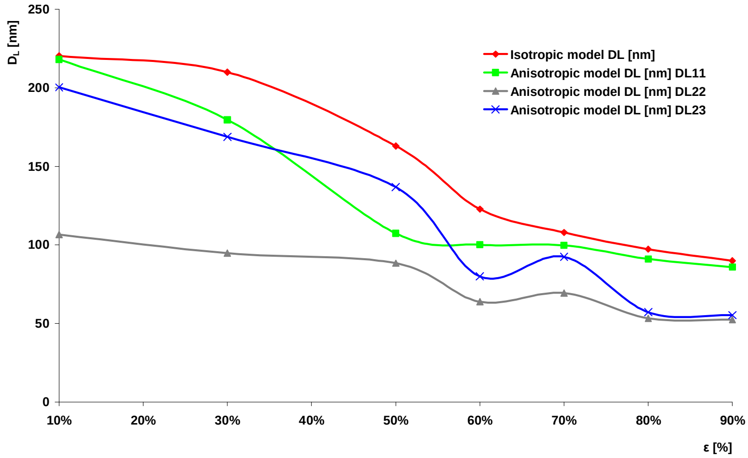

Fig.3 Crystallite size D_L calculation for isotropic and anisotropic model of IF steel

Lattice distorsion ε_z is displayed in graphical dependence in Fig. 4 for the isotropic and anisotropic model. It was expected that lattice distortion will increase with the amount of deformation but it was found that the lattice distorsion does not have strong dependence of the isotropic or anisotropic model, which can be seen from Fig. 4. Based on the results obtained it can be argued that the difference is only in absolute values of ε_{22} and ε_{33} components that are close to zero. Component ε_{11} has similar absolute values as the value of the isotropic model ranging from 6 x 10^{-4} to 9 × 10^{-4}.

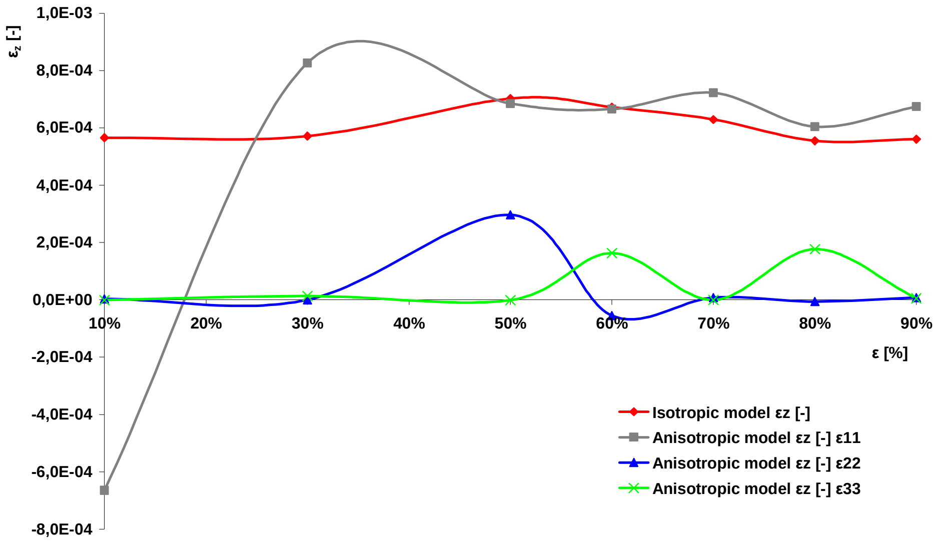

Fig.4 Calculation of size of lattice distorsion ε_z for isotropic and anisotropic model for the IF steel

Scattering of measured values can be attributed to the examined place, which was located at the beginning of the sample characterized by high heterogeneity of the thermal field and plastic deformation.

3.2 Dependence macrostress the thickness of the sample

Dependence of macro-stresses across the sample thickness. As a model example residual stress (macrostress) by sin2 ψ method was measured across the thickness of the sample of IF steel with 90% deformation. Measurements were made on X-ray diffraction apparatus. Residual stress was measured on both sides of the sample by gradually doublesize etching. By this method the residual stress has been obtained across the sample thickness in the rolling direction, transverse direction and the direction of 45°. Measurement results are given in graphical dependence in Fig. 5, which shows that the residual stress across the sample thickness in the transverse direction is symmetrical, unlike the rolling direction, where the stress is unbalanced and the maximum value is in the middle of the sample thickness. This unbalance is caused probably by rolling under laboratory conditions, which could give rise to non-homogeneties of deformation across the width of the sample. This fact is reflected in practice bending sheet metal for cutting thin strips.

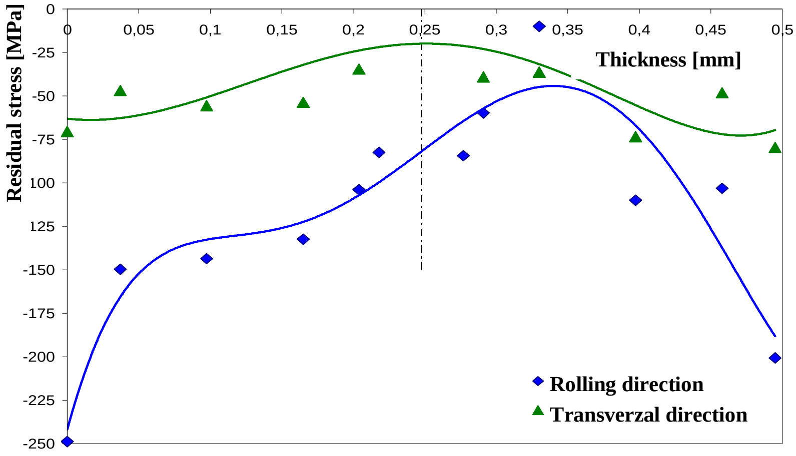

Fig.5 Dependence of macrostress on the thickness of the sample

3.3 The coefficient of normal anisotropy

In practice, the coefficient of normal anisotropy is provided by measurement of tensile test in uniform deformation area. Texture analysis allows calculation of the coefficient of normal anisotropy by suitable model. For selected samples of the IF steel coefficient of normal anisotropy was calculated by software popLA and the model "pencil" which is the best suited for the type of texture, Fig. 6. This model is in practice used in determining the coefficient of normal anisotropy of thin plates (Covering areas of thickness 0.15 mm), where by mechanical means it is difficult to determine the value of Δr. With increasing amount of deformation the absolute value of r increases up to about 1.6, but also the value gap is widening in the rolling direction, transverse direction and the direction of 45°. This difference of plane anisotropy Δr is reduced during recrystallisation process to a minimum about 0.1.

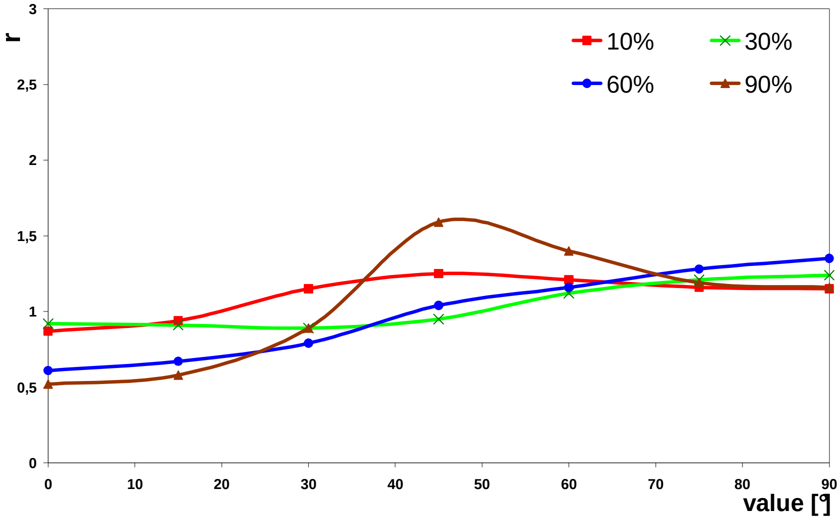

Fig.6 The coefficient of normal anisotropy of IF steel samples

4. Conclusion

The results can be summarized into following:

Crystallite size decreases with amount of deformation of isotropic model and for anisotropic model they are the components of tensor D_{L11} and D_{L23}, the other components don´t show a strong dependence.

For isotropic and anisotropic model no significant lattice distorsion was found. Based on the results, it can be argued that the difference is only in absolute values of ε_{22} and ε_{33} components. Component ε_{11} achieved similar values in comparison with the absolute value of isotropic model, i.e. ranging from 6 x 10^{-4} to 9 x 10^{-4} [-].

Absolute values of residual stress in the longitudinal direction across the thickness of the sample are higher than in the transverse direction. In transverse direction of studied IF steel the residual stress is symmetrical across the thickness of sample, unlike in the rolling direction.

Results show that optimal values of normal anisotropy were obtained. This difference of normal anisotropy Δr is reduced during recrystallisation process.

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