X-RAY GIABD IN APPLICATION TO LASER TREATED STEEL SURFACES

V. Antonov[1], I. Iordanova[2], K. Krezhov[1]

[1]Institute for Nuclear Research and Nuclear Energy, 72 Tzarigradsko Chaussee, BG-1784 Sofia

[2]Department of Solid State Physics and Microelectronics, Faculty of Physics, University of Sofia, blvd. J. Bouchier, BG-1164 Sofia

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Abstract
Among other techniques in use for modification of the surface, the laser beam treatment is remarkable with its potential for tailoring the surface properties. For metals and alloys it was proved that desired properties such as enhanced resistance to wear, corrosion and oxidation can be achieved. In medium and high carbon steels these effects are well pronounced and became a topic of interest in scientific papers. In contrast, despite the broad use of low carbon steels the information on laser treatment of their surface is rather scarce. Also little research has been carried out to reveal the influence of the initial microstructure on the final properties of the laser treated material. These are the objectives of the presented paper. Two different materials were prepared from 08kp mild rolled sheet steel using different metallurgical treatments and subjected to laser treatment. GIABD method suitable for thin films was used to study the changes of the residual stresses via the adapted $\sin^2$ method with applied refraction correction and on the surface. It has been shown that the refraction correction for GIABD evaluation of residual stresses is obligatory for accurate estimation of the diffraction peaks positions. The applied laser treatment increases the residual stress values, which show dependence from the type of material and anisotropy in relation to the rolling direction.

Introduction

Surface laser treatment is being used to achieve enhanced resistance to wear, corrosion and oxidation of metals and alloys. Steels are among the materials most often modified by surface laser treatment and recently are the main topic of scientific investigations in this field.

The present paper demonstrates GIABD X-ray technique in its application to residual stress analysis of surface laser treated low carbon mild sheet steels.

Material and experimental techniques

The investigated material is 08kp (rimming) mild sheet steel (equivalent to 1008 steel), produced by "Kremikovtzi" Ltd, Bulgaria. The chemical composition is: C 0.05 %, Mn 0.34 %, Cu 0.11%, Ni 0.03 %, Al 0.03 %, S 0.018 %, P 0.014 % and Fe balance. Two different materials were prepared from the initial steel namely hot rolled (HR) with thickness 0.46mm and cold rolled (CR) with thickness 2.6mm sheet.

Two sets of rectangular samples sized 3 2.6 cm were cut from each material and then mechanically graded, polished and degreased. First set was used to study the structure of the initial materials. The second set was subjected to laser surface treatment with Nd:glass pulsed laser. The following laser beam parameters have been applied: energy 7J for HR and 6J for CR specimens, pulse duration 7 ms, beam diameter 2 mm. Because CR material is thinner than HR material the energy of laser pulse for CR material was chosen lower in order to maintain the same temperature field for both materials.

GIABD analysis was performed with Cu K radiation by URD6 Seifert&Co diffractometer which allows separate rotation of the sample holder and detector. The goniometer set up was rearranged to perform GIABD experiments by introducing an additional 15 cm long Soller cassette on the diffracted beam path between the sample holder and the secondary plane graphite monochromator placed in front of the scintillation detector (Fig. 1). The 1 mm wide slits in the cassette are placed vertical which allows to avoid the high horizontal broadening and thus to improve significantly the quality of the registered patterns [1].

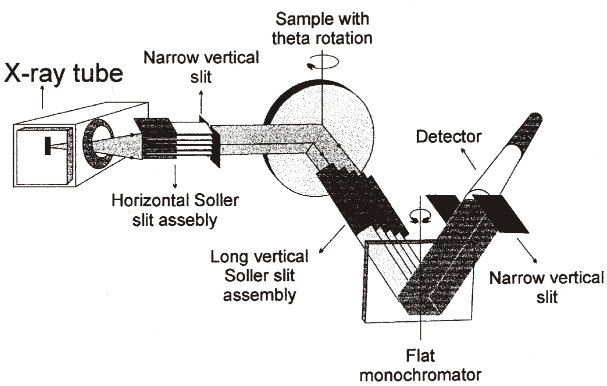


Fig. 1. Setup of URD-6 diffractometer for GIABD analysis.

The diffraction patterns were taken in GIABD geometry, which is schematically shown in Fig. 2. According to it the crystallographic planes in Bragg position satisfying Bragg equation are those making an angle with the surface. The pattern is registered by rotating the detector applying 0.1^0 steps and counting times of 60 s (2 scan) and keeping the incident angle constant. For the quantitative estimation of the parameters of the registered peaks they have been computer simulated applying few different fitting func-

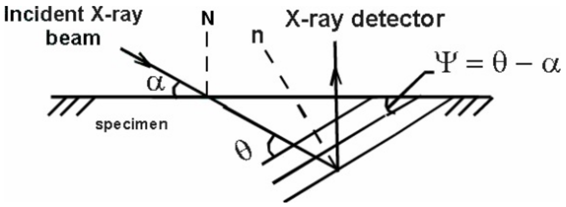


Fig. 2. Schematic of GIABD geometry; N and n – normals to the surface and to crystallographic planes.

tions as suggested in [2]. In all cases fitting with Pseudo - Voight gave the best results.

Experimental results and discussion

Residual macro-stresses have been estimated via $\sin^2$ method realised in GIABD geometry. Due to the well-pronounced crystallographic texture the method was applied to more elastically isotropic crystallographic direction d for which the dependence $d_{\{200\}}$ versus $\sin^2$ showed a good linearity. The registered {200} -Fe diffraction peaks have been computer fitted for estimate the centre of the peak $2\ {}^{fit}_{200}$. Then $2\ {}^{fit}_{200}$ values have been corrected to eliminate the refraction influence, the last being more pronounced when the incident X-ray beam falls at relatively low angles onto the surface. The refraction correction has been realised by the following equation published in [3]:

$$2\ {}^{true}_{hkl} \quad 2\ {}^{fit}_{hkl} \quad \frac{2}{\sin 2\ {}^{true}_{hkl}} \quad - \tag{1}$$

where $\frac{e^2}{mc^2}\frac{N_{Av}\ \ Z}{M}; \frac{e^2}{mc^2}$ - classical electron radius; N_{av} - Avogadro's number; - the X-ray wavelength; - physical density; Z - atomic number; M - atomic mass.

The estimated in this investigation -value for -Fe is equal to 2.36×10^{-5}.

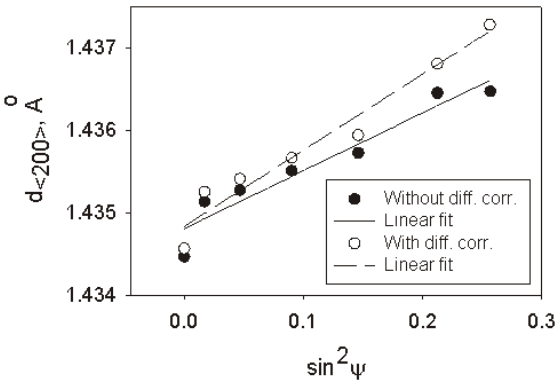
After numerical solving of equation (2) the obtained $2\ {}^{fit}_{200}$ values were substituted in Bragg equation and thus the true $d_{<200>}$ values were estimated and used for the linear plots $d_{<200>}$ versus $\sin^2$. The main equation for the estimation of residual stresses ( ) is taken from [4]:

$$\frac{E}{1} \quad \frac{1}{d_0} \quad \frac{d}{\sin^2} \tag{2}$$

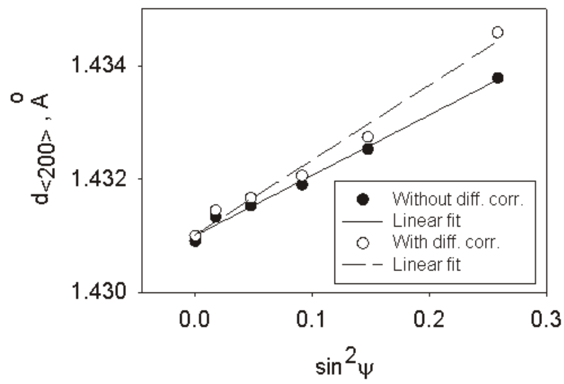
where E, are X-ray elastic constants namely Young's modulus $E_{<200>}=1.35\times10^5$ MPa and Poisson's ratio $_{<220>}=$ 0.37, calculated for the investigated <200> direction as it is described in Ref.[5]; d_0, $d\ /\ \sin^2$ - the intercept on the d-axis and the gradient in the linear plot d-spacing versus $\sin^2$ respectively.

The residual-stress analysis has been performed in two perpendicular surface directions, i.e. along the rolling (RD) and transverse (TD) direction. In Fig. 3 the dependence d versus $\sin^2$ of the initial and laser treated samples along RD is represented.

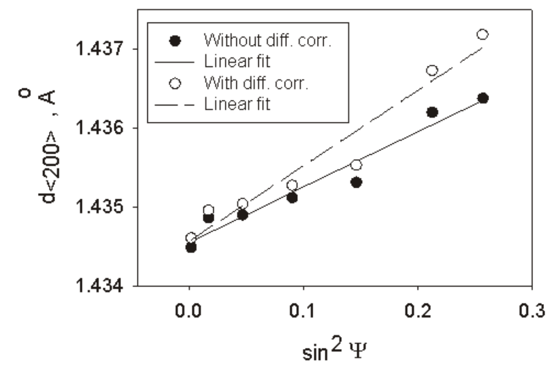
From the plots in Fig. 3 it is obvious that after the refraction correction the data points differ significantly from those without correction, which shows that this correction



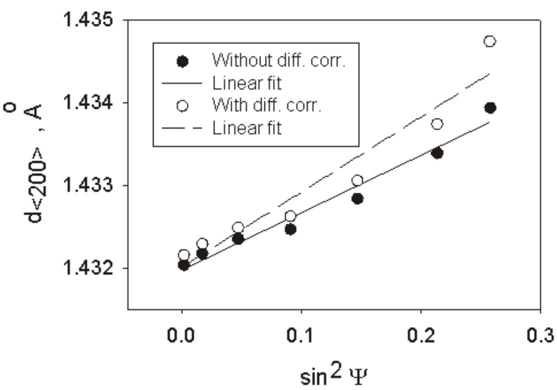
a) HR initial



b) HR laser treated



c) CR initial



d) CR laser treated

Fig. 3. Interplanar d-spacing versus $\sin^2$ plots for the materials before and after the laser treatment.

Table 1. Residual macro-stresses , MPa.

Material	Initial	Laser treated		
	RD	TD	RD	TD
HR	862	472	895	687
CR	618	343	623	904

is obligatory. The positive slope of the linear fits determines the existence of tensile residual macro-stresses. Qualitatively similar are the plots for TD (not shown in the figure). The estimated values in both analysed surface directions are given in Table 1. It is obvious that due to different nature of the processes during cold- and hot-rolling the residual macro-stress values in the initial materials are different being higher in HR sheet. This is probably due to the fact that during hot rolling in addition to plastic deformation the material undergoes through polymorphous transformations and precipitation from oversaturated solid solutions [6]. From the table it follows that in both initial materials the residual stresses are about twice higher in RD than in TD. As can be seen the applied laser treatment introduces additional tensile residual stresses but their values are dependent both on the material and the direction. Thus, the differences in parameters and anisotropy of the initial microstructure causes different and anisotropic behaviour during the laser treatment as discussed in [6] and leads to the observed different and anisotropic values of the introduced with the laser treatment residual macro-stresses in each particular material.

Summary

GIABD method has been developed and applied for the investigation of residual macro-stresses and their evolution during surface laser treatment of HR and CR mild sheet steels. It has been shown that the refraction correction for GIABD evaluation of residual stresses is obligatory as it should be for all quantitative GIABD analyses based on the accurate estimation of the diffraction peaks positions. The rolling process leads to the formation of anisotropic residual stresses in both analysed surface directions namely rolling (RD) and transverse (TD) direction. The stresses are higher in HR than in CR initial sheet. This is probably due to the polymorphous phase transformations and precipitation from oversaturated solid solutions occurring during hot rolling and possibly contributing to the residual stress formation. The applied laser treatment slightly increases the residual stress values in RD and significantly along TD of both investigated mild sheet steels.

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