Identification of Residual Stress and Structure Properties in Surface and Subsurface Layers of Austenitic Steel Designed for Nuclear Energetics

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Abstract: The article deals with non-destructive measuring and evaluation of residual stresses and chemical properties of stainless steel sample and its possibility to affect functional properties of the material. This measuring method also determines orientation of residual stress, so it is possible to identify absolute values of shear and normal stress with high accuracy. Monitoring of residual stresses in components can be useful in predicting damage incidences caused by workload over lifetime of components.

Keywords: X-Ray Diffractometry; Nuclear Reactor Austenitic Steel; Residual Stress; Retained Austenite.

1 Introduction

Residual stresses are an integral part of manufactured workpieces, whether they are introduced deliberately, as a part of the design, as a by-product of a process carried out during the manufacturing process, or are present as the product of the component's service history [1–3]. For full classification, it should be noted that residual stresses are called sometimes as technological stresses, because they arise from the action of technological processes during the producing of parts. Direction of residual stress (tension or compression) depends on the kind of deformation [4, 5].

2 Principles of Measurement of Residual Stress by X-Ray Diffraction

From the theory of elasticity the relationship between residual stress (σ) and strain (ε) on the sample surface under plane stress is given by the Bragg equation, $\lambda = 2d \sin\theta$, relating incident X-ray wavelength (λ), lattice inter-planar spacing (d) and diffraction angle (θ) (Fig. 1).The direction of maximum residual stress, that can be tensile or compressive, is assumed to occur in the cutting or grinding direction during most machining operations [6, 7].

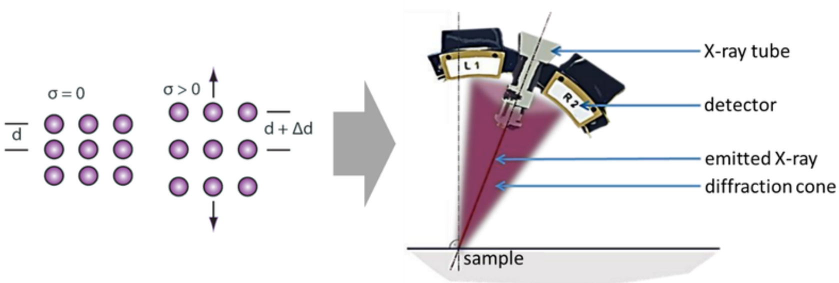

Fig. 1: Principle of measuring of residual stress by X-ray diffractometry based on Brag's Law.

Tab. 1: Surface layers stress and austenite percentage values.

No.	Normal Stress [MPa]	Shear stress [MPa]	Austenite [%]
1	+109.1 ±47.3	68.11 ±25.16	95.45
2	+128 ±18.79	26.86 ±12.6	95.12
3	+93.6 ±13.8	45.56 ±24.99	96.49

3 Experiment Conditions

Experiment was performed on stainless steel 08CH18N10T. This steel is a typical 18Cr-10Ni austenitic stainless steel, equivalent to AISI 321 and X6CrNiTi18-10.

Sample for the experiment was machined by turning technology on CNC turning centre. By the recommendation of manufacturer of cutting tools, cutting speed v_c was set to 150 mm.min^{-1} for both roughing and finishing, depth of cut a_p = 3 mm for roughing and 1.2 mm for finishing, feed rate f = 0.35 for roughing and 0.17 for finishing. The measuring of residual normal and shear stress and measuring of austenite percentage was performed with Proto XRD diffractometer, using WINXRD 2.0 software, on three points around the machined diameter of the sample surface.

The residual stress field at a point, assuming a condition of plane stress, can be described by the minimum and maximum normal principal residual stresses, the maximum shear stress, and the orientation of the maximum stress relative to some reference direction. The minimum stress is always perpendicular to the maximum. The maximum and minimum normal residual stresses and their orientation relative to a reference direction can be calculated along with the maximum shear stress using Mohr's circle for stress if the stress σ_φ is determined for three different values of φ [8–10].

4 Experimental Results

Measuring procedure of identifying austenite percentage using X-ray diffraction was based on average peak method. This method uses four individual peaks to determine austenite amount. For each peak is calculated R-value and intensity

Graphic output and values of measured stress and austenite percentage are shown in Fig. 2 - 3 and Tab. 1.

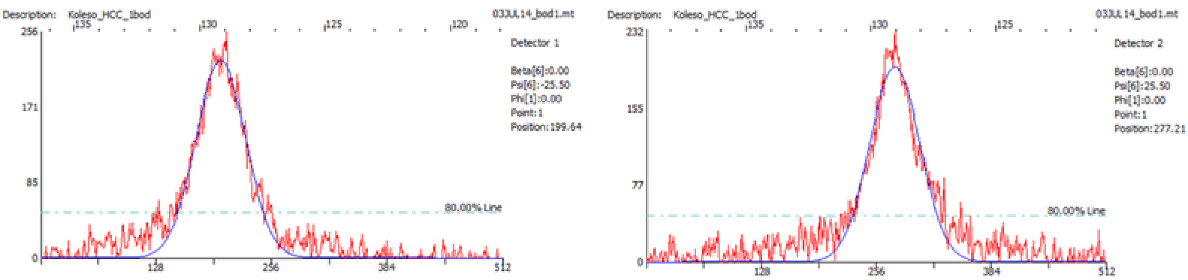

Fig. 2: Graphic output of experimental stress measuring No.1.

5 Discussion and Conclusion

Due that machining brings stress to machined material, both normal stress and shear stress, it is necessary to be able to measure its value and orientation. X-ray diffractometry offers the opportunity to determine these properties of machined or differently technologically treated material to predict deterioration of components. This measuring technology is non-destructive, so it can be used in wide area of applications [11, 12].

Measurement on sample of machined austenitic steel determined normal stress values from +93.6 MPa to +128 MPa (Fig. 4). That means the surface of the sample is under tensile stress and there is high probability of

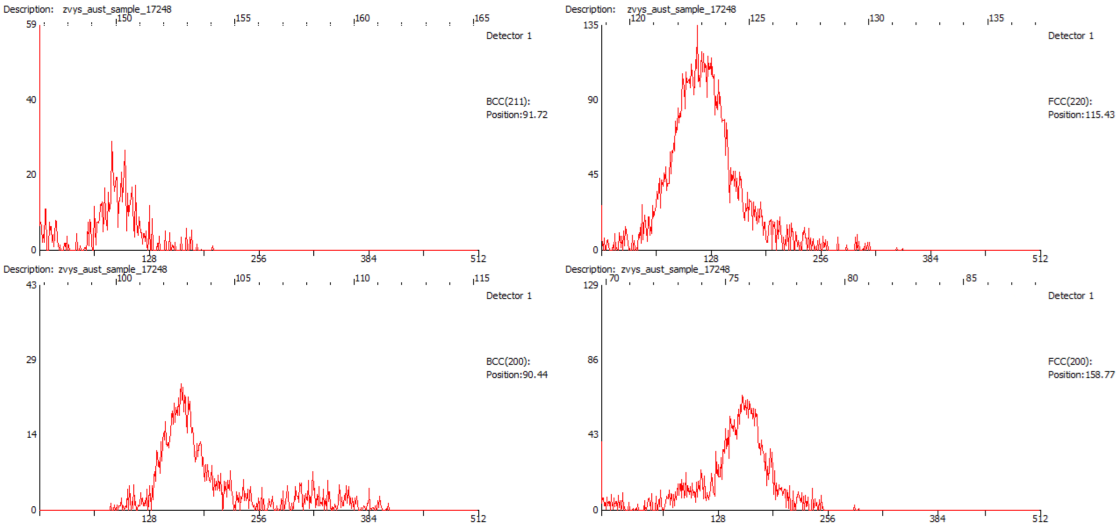

Fig. 3: Graphic output of experimental austenite percentage measuring No. 1.

emerging primary micro-cracks in surface layers. Metallographic evaluation of the material samples confirmed existence of micro-cracks in surface layers (Fig. 5).

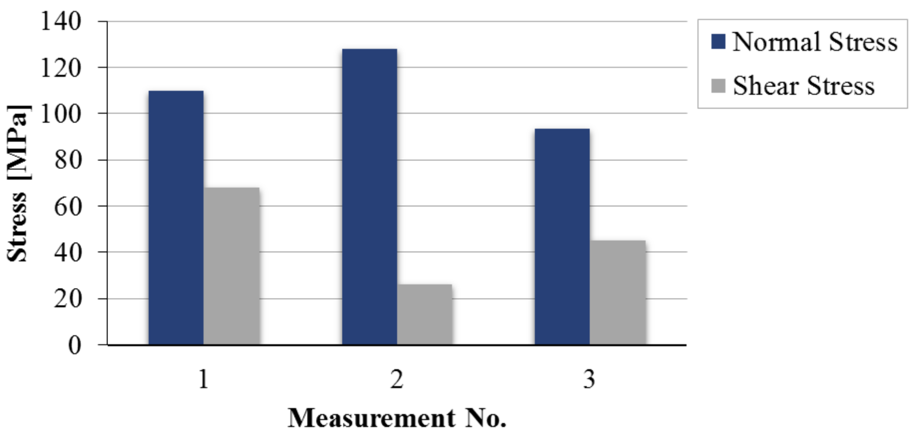

Fig. 4: Measured normal and shear stress values.

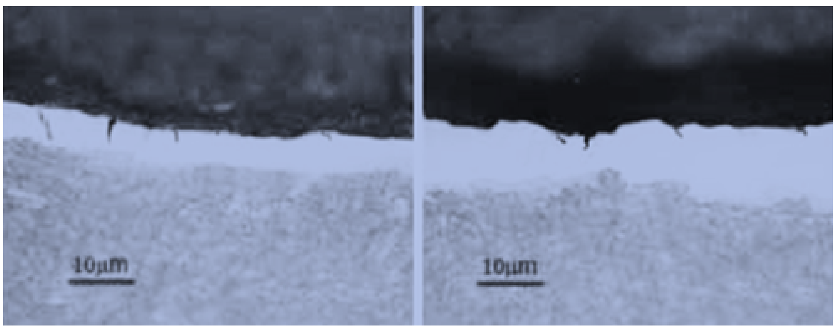

Fig. 5: Formation of micro-cracks in surface layers – light metallography.

In this case, high values of shear stress supports the crack spread and can lead to secondary trans-crystal crack into subsurface layers of the material (Fig. 6). Spread of micro-cracks is accelerated also by presence of working load of component and chemical influence of work environment (pitting corrosion).

Measured values of austenite percentage in surface layer ranged from 95.12 % to 96.49 % what means that the surface layers of material consist small amount of another phases in addition to austenite.

The experiment proved that X-ray diffraction can be essential non-destructive method for identifying properties of used material treatment and predicting potential component deterioration. Results of the experiment

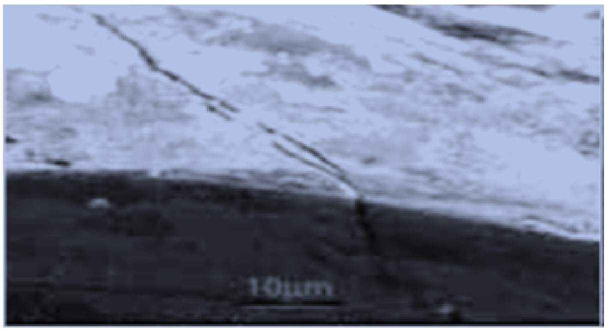

Fig. 6: Surface detection and microstructure of the crack spread across base material – SEM microscopy.

identified that chosen cutting parameters are unsuitable for machining stainless steel 08CH18N10T and is necessary to continue in technological research to bring comprehensive stress into the material and to lower the shear stress.

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