REPORT ABOUT THE POSSIBILITIES OF FEM APPLIED IN THE VERIFICATION OF X-RAY MEASUREMENT OF RESIDUAL STRESSES

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Residual stress diffraction measurements in a thin surface layer are completely nondestructive. For subsurface stress profiling, the destructive X-ray analysis can be performed by sequentially removing surface layers by using electrolytic or chemical polishing. When stressed layers are removed, the measured stress values in depths beneath the surface are in general affected by the relaxation created due to the layer removal. Therefore a correction should be involved in the depth profiling procedure. Accepted procedures used till now presume the removal of the whole surface of the investigated laboratory samples. The aim of the contribution is to present the possibilities of FEM for evaluation of the credibility of X-ray stress-strain states measurements. An estimation of changes of depth distribution due to the stress relaxation created by the removed layers was simulated by FEM in the case of a small electrolytically polished area 12 mm in diameter in the middle of cylindrical samples of the height of 7 mm.

Keywords
Residual stress, X-ray diffraction, Layers´ removal, Stress redistribution, FEM

1. Introduction

The measurement of macroscopic residual stresses is a topic of interest in materials research and industrial production as a tool for quality control and service life evaluation. If the residual stresses are known, it will be possible to predict the operational reliability of mechanical parts.

For complete characterization of the state of residual stress produced by machining, grinding, shot peening, and other surface treatments, it is generally necessary to determine the distribution of residual stress with depth beneath the surface.

The main reason for necessity of depth profiling is that in general the surface values are not representative to characterize stress distribution. Very often comparable surface residual stresses are observed for a wide range of various manufacturing techniques. However, residual stress distributions in depth could be qualitatively different (see Fig. 1). X-ray diffraction method based on the measurement of the strain in the crystal lattice and their converting into stresses using elasticity theory is a well developed technique for residual stress determination (see [Hauk 1997] and [Kraus 2000]).

Taking into account the penetration depth of X-rays used in diffraction experiments into most technical metals being from a few to several tens of micrometers, depending on the material´s absorption, X-ray wavelength and diffraction geometry, it is clear that diffraction measurements in a thin surface layer are completely nondestructive. If the subsurface stress profile is required, the destructive X-ray analysis can be performed by sequentially removing surface layers and thus by X-ray diffraction measurement of the subsurface material at each step of removing. Electrolytic and chemical polishing are usualy appied as stress-free methods for material removing. In electropolishing, the electrolyte and operating parameters applied depend on the material under investigation. When stressed layers are removed, the measured stress values at depths beneath the surface are in general affected by the relaxation created due to the layer removal. Therefore a correction should be involved in the depth profiling procedure, i.e. all values except the surface one must be corrected to obtain the true stress distribution that existed when the specimen was intact. The basic considerations dated from 1958 refer to several geometric sample shapes and did not evolve till 2007 (see [Ricardo 2007]) when the standard technique for measuring was revised to take into account X-ray absorption effects. All these procedures prerequisite the removal of the whole surface layer of the investigated laboratory samples.

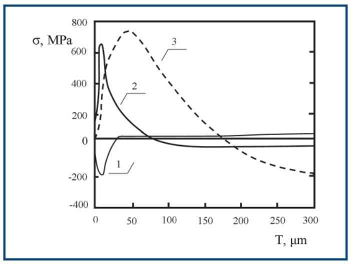

***Figure 1.** Residual stress distribution after gentle (1), normal (2), and abusive (3) grinding of hardened steel (stress measured in direction of grinding) measured by a mechanical layer removal method.*

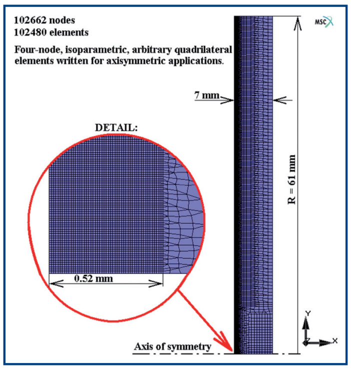

***Figure 2.** Finite element model and its dimensions.*

When large samples (machine parts) of complicated shape are investigated the measurement is realized only on a small area. Thus the volume of the removed layer is a very small fraction of the whole volume of the object under investigation. In the case of such service measurements it is often supposed that the change of original state of stress is negligible (see [Kraus 2000]).

The aim of the contribution is to present the possibilities of FEM for evaluation of the credibility of X-ray stress-strain states measurements. An estimation of changes of depth distribution due to the stress relaxation created by the removed layers was simulated by FEM in the case of a small electrolytically polished area 12 mm in diameter in the middle of cylindrical samples of the height of 7 mm, see Fig. 2.

Science/technical development supplies new ways for the solution of the presented problem, Hence, the Finite Element Method (FEM, MSC.MARC/MENTAT 2005r3 software, see Fig. 2) was used for the solution of this problem.

2. FEM Solution of Elastic State

The finite element mesh (axisymmetric ring made of steel) and its dimensions are shown in Fig. 2. This FE model was used for evaluations of the changes of the elastic stress-strain distribution during the sequentially removing surface layers (controled deactivations of the chosen finite elements), see Fig. 3.

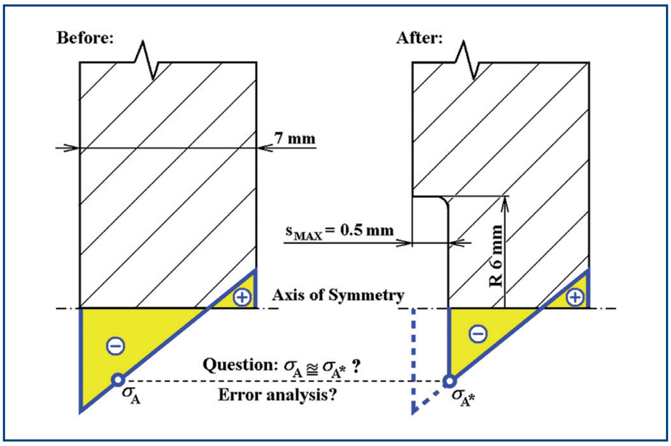

Figure 3. *Removing of surface layers and changes of stresses.*

Some results of elastic state are shown in Fig. 4. For more information see references [Ganev 2007] and [Frydrysek 2007].

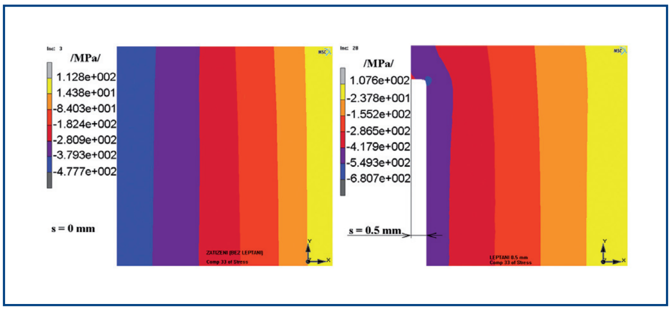

Figure 4. *Residual stresses distribution and their changes acquired by FEM (elastic analysis, linear distribution - axi-symmetric bending).*

3. FEM Solution of Elasto-Plastic State

FE mesh and its dimensions used for elasto-plastic stress-strain distribution are shown in Fig. 2 (similar problem like in the chapter 2 but with elasto-plastic material and elasto-plastic stress distribution). Some results are shown in Fig. 5. For this non-linear material were used isotropic, kinematic and combined hardening rules. For more details see [Frydrysek 2007].

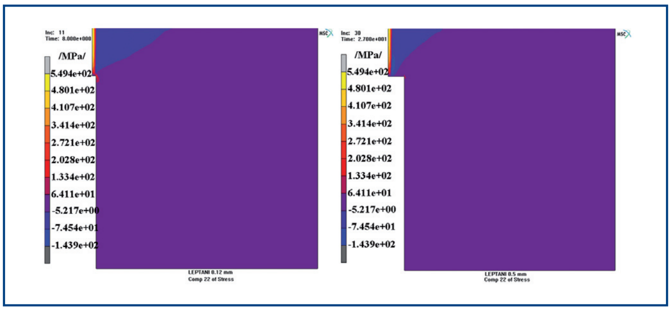

Figure 5. *Residual stresses distribution and their changes acquired by FEM (elasto-plastic analysis, nonlinear axi-symmetric distribution).*

4. Error Analysis

From the Fig. 6 is evident, that the relative errors of elastic analysis calculated over the depth s (chapter 2) are acceptable. However, the relative errors of elasto-plastic analysis calculated over the depth s (chapter 3) cannot be acceptable in some situations, see Fig. 7. For more information see reference [Frydrysek 2007].

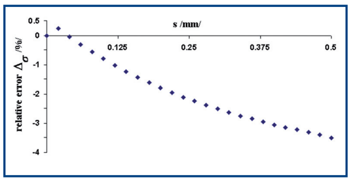

Figure 6. *Comparing of acquired values of σ_φ (elastic analysis, measurements and FEM evaluation).*

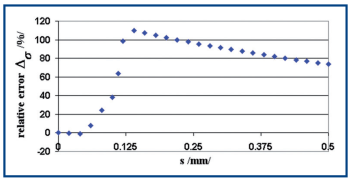

Figure 7. *Comparing of acquired values of σ_φ (elasto-plastic analysis, measurements and FEM evaluation).*

5. Conclusions

From the results of the presented solution is evident that X-ray measurement of residual stresses gives small errors in general only for small depth s. Presented results can be used for the development of a new method of correction. For more information see references [Ganev 2007] and [Frydrysek 2007]. Other example is solved in reference [Halama 2008].

Acknowledgements

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