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Experimental Stress Analysis

Experimental Analysis of Residual Stresses in Backup Roll and FE solution

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Abstract: Due to several technological operations during bandage cylinders manufacturing there are residual stresses on the bandage cylinders surface. This article shows results of a few residual stress measurements realized by means of a hole drilling method on the surface of a bandage backup roll. There was also carried out a numerical stress analysis of the backup roll of rolling mill considering residual stress occurrence after heat treatment process with usage of Ansys software. There was achieved a good match with the experimental solution.

Keywords: Residual stresses, Hole-drilling method, FEM, Initial stresses

1. Introduction

For the rolling mills cylinders there are put high demands. They have to show high strength and also toughness thanks to dynamic loading. Their surface has to be at once very hard, wear and fretting fatigue resistant. Those conflicting demands meet the bandage cylinders build of inner cylinder made of tough material and pressed bandage made of abrasion resistant material with proper heat treatment. During production of such cylinders there are rising considerable residual stresses due to their heat treatment and pressing. The stress occurrence out of the pressing can be easily calculated, but calculation of residual stresses occurrence from heat treatment is complicated and that is why the measurement results are so valuable. There are also interesting and valuable measurement results after cylinders pressing and after their normal functioning in the rolling mill.

2. Experimental study

The measurements were produced during technological manufacturing process of the bandage cylinder as well as during service of the rolling mill. First of all the residual stresses were measured after heat treatment of bandage and after its pressing on the cylinder. After the bandage pressing came to superposition of the residual stresses and stress out of pressing. Stresses out of pressing were also analyzed by means of calculation. Manufactured cylinders were continuously build into the rolling mill and after a certain operational time the residual stresses on the cylinder surfaces were measured. For a comparison residual stresses on a forge cylinder was measured. There were also measured residual stresses on a cracked eliminated bandage of a cylinder.

2.1. Description of measurements

There was used a semi destructive hole-drilling method for the residual stress measurement (Fig. 1). Its principle is based on the measurement of deformation relaxations around the

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drilled hole in the examined place of a measured component. Relaxed deformations were measured by means of strain gauges more accurately by special rectangular rosette type RY 61 – 1.5/120 S manufactured by Hottinger company. The drilled hole in the middle of the rosettes were of 1.6 mm diameter and drilled deep of the hole also 1,6 mm. The drilling was realized by means of equipment RS 200 produced by VISHAY company. Relaxed deformations were measured by static device P 3500 and measure places switcher SB 10 from the same company. Residual stress evaluation is based on correlations for stress distribution around a loaded round hole, derived by Kirsch [1]. Detailed results of some measurements are published in work [2].

Fig. 1. A photo from realised measurement

2.2. Results of measurements

The residual stress measurement on the bandage surface after heat treatment were carried out on a standing bandage in four places, their placement is obvious from Fig. 2. After bandaging the bandage cylinder was placed horizontally and residual stress measurement was carried out in the very neighbourhood of the already measured places before bandaging. The results of both measurements are well summarised in Table 1.

Table 1. The measured values of axial and hoop stresses σ_a, σ_t before and after pressing

Place	R1		R2		R3		R4	
Stress	σ_a[MPa]	σ_t[MPa]	σ_a[MPa]	σ_t[MPa]	σ_a[MPa]	σ_t[MPa]	σ_a[MPa]	σ_t[MPa]
Before	-147	-154	-197	-286	-177	-166	-245	-280
After	-144	-71	-225	-202	-128	-25	-218	-142
Difference	3	83	-28	84	49	141	27	138

Despite the fact, that bandage is rotational symmetric part, the residual stresses after heat treatment are not distributed evenly as can be seen from Table 1. In the vertical cross-section by places R1 - R3 are the hoop residual stresses σ_t about 160 MPa, whereas in the cross-section by places R2 – R4 the residual stresses reach values about 280 MPa. The residual stresses are compressive in both cases.

According to analytical calculations [2] there should be hoop stress on the bandage outer girth thanks to pressing 97.5 MPa. The real measured stresses differences in girth and also axial direction are shown in Table 1. The change of hoop stress near the bandage edge is over 80 MPa, whereas in the central bandage part is about 140 MPa. Cause of the difference is non-cylindrical shape of the shaft. The reason of its special shape is to achieve the minimal stress change after pressing in axial direction and as Table 1 shows the change is really small.

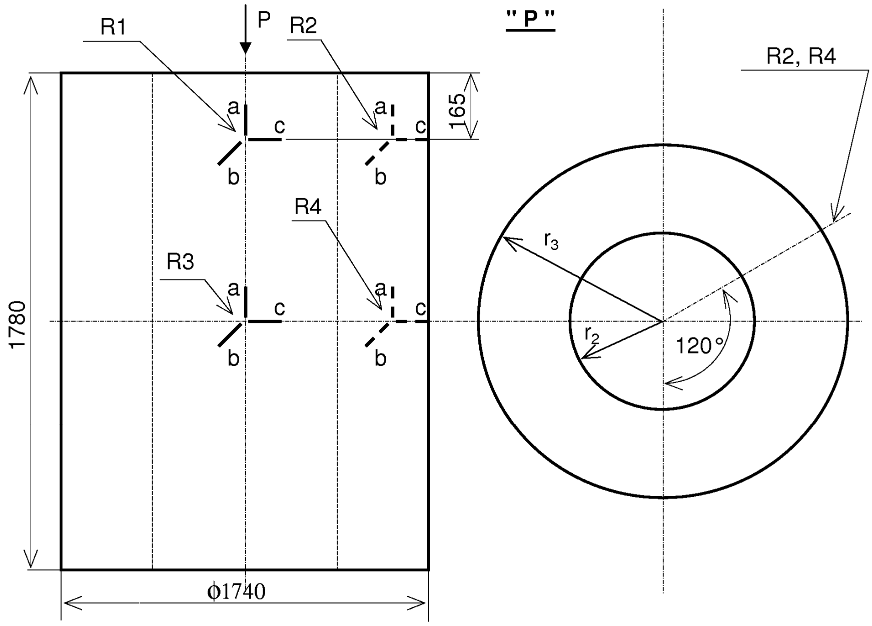

Fig. 2. The strain gauge russets placement and orientation of strain gauge patterns on the bandage

Even after bandaging the main stresses remain on the bandage surface compressive. Measurement results are valuable contribution for researchers, constructors and bandage cylinders manufacturers and they give access to comparison with a numerical solution.

3. Numerical study

In the previous numerical study there was shown a contribution of numerical solution for shape optimisation of a support cylinder [3]. The goal of this article is a demonstration of FEM usage for stress analysis of the bandage after pressing with consideration of the residual stresses which were measured after heat treatment.

3.1. Description of FEA

Analysis was carried out by means of a finite element method in ANSYS 12.1 software. There was modelled only half of the bandage cylinder considering symmetry of the task. Other simplifications are not possible considering assumption of an uneven stress distribution around the cylinder girth. The SOLID185 element was used in the analysis. The whole model contains 98240 elements. There were considered different elastic constants for the core and bandage. Pressing was simulated by means of contact between outer core area and inner bandage area. The calculation was carried out by the method of Lagrange multipliers without a friction consideration.

First of all there was checked a way of calculation without residual stresses remaining in bandage after heat treatment. Stress caused by pressing was detected analytically from given values based on theory of thick-wall pressing cylinders. Computed results match places where the core is of a cylindrical shape and they are shown in a table below together with FE results.

Table 2. Stresses resulting from pressing

		theory	FEM
outer surface of bandage	σ_t [MPa]	97.5MPa	96.3 MPa
inner surface of bandage	σ_t [MPa]	163.3MPa	168.5 MPa
Contact pressure between shaft and bandage	p [MPa]	65.8MPa	65.5 MPa

The measured residual stresses were used in the analysis as initial stresses using special macro, which calculate the values of axial and hoop stress for each element of bandage. The initial stresses were applied consistently with the values of residual stresses measured on the surface. Distribution of axial and hoop stress through the thickness of bandage was considered parabolic, but in the axial direction they were applied as constant using values of stresses for place R3.

3.2. Results of FEA

In the FE analysis, the variation of hoop stresses on the bandage outer girth, gained experimentally, was neglected. It is difficult to predict correct variation of stresses around cylinder from two measured points. Results from the simulation of pressing are presented in Fig. 3 and 4.

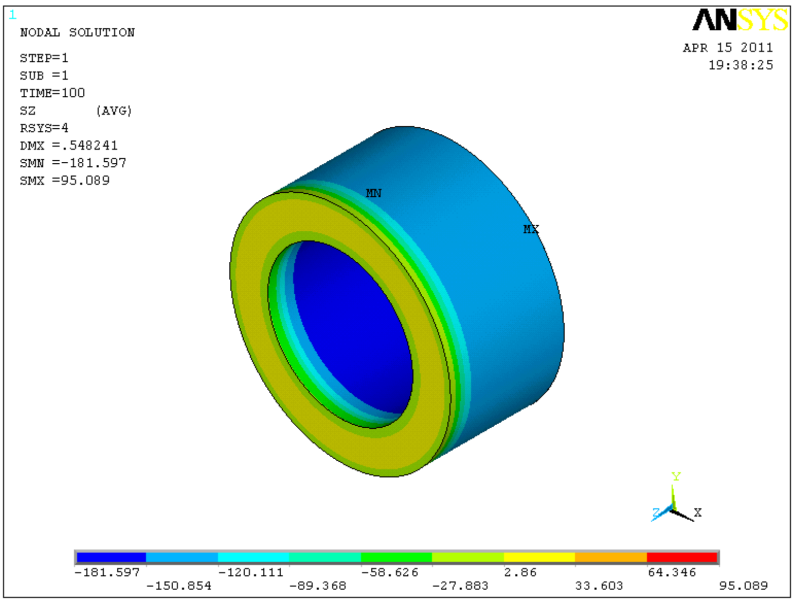

Fig. 3. Contours of axial stress σ_a [MPa].

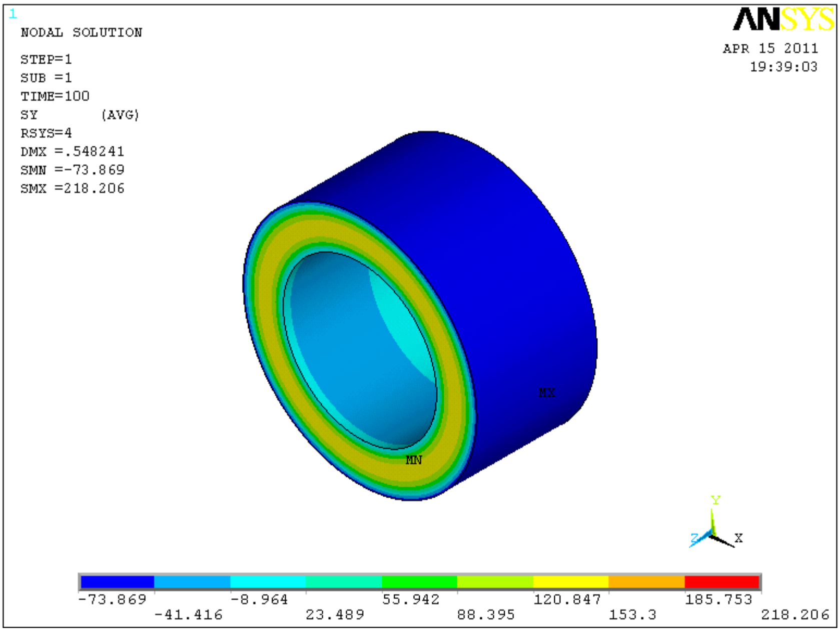

Fig. 4. Contours of hoop stress σ_t [MPa]

The contact pressure distribution between the bandage and the shaft is also uniform in the hoop direction because of neglecting stress variation around cylinder as can be seen at Fig. 5. Consistently, there are compared results only for places R1 and R3 in Table 3.

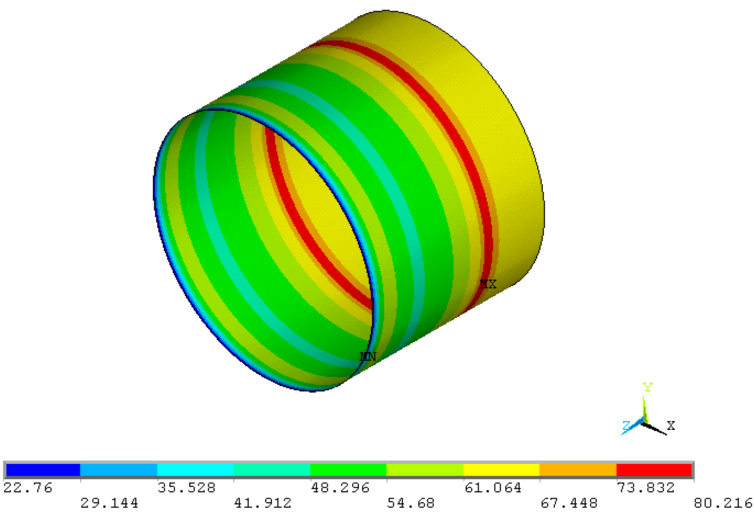

Fig. 5. Contact pressure distribution

Table 3. Comparison of numerical and experimental results (σ_a – axial stress, σ_t -hoop stress)

Place	R1		R3	
Stress	σ_a[MPa]	σ_t[MPa]	σ_a[MPa]	σ_t[MPa]
FEA	-105	-68	-146	-57
Experiment	-144	-71	-128	-25
Difference	39	3	-18	-32

4. Conclusion

Results from FE analysis show good agreement with the experimental one. Main result of this study is confirmation of the proposed methodology for considering of residual stresses in FE analysis. Indeed, there is necessary to emphasize, that in the cases when residual stresses are caused by plastic deformation and applied loading leads to change of plastic strains, there is significant influence of loading history and therefore, method described here is not applicable. In our case, results of experiments and simulation agree with the superposition principle.

It is clear from this study, that a proper combination of an experimental and numerical approach can reduce the number of measurements. Numerical analysis can be useful also for shape optimisation of the shaft to improve its wear and fatigue resistance.

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