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Residual stresses of railway Wheels

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Abstract: At the end of the seventies there came to a significant innovation of railway wheels by introducing a quenching of wheel rim surface. By this procedure was achieved increased hardness of the rim tread and circumferential compressive stresses, accompanied by a reduction of wear, which resulted in a significant extension of life of the wheels. Compressive stresses in the wheel rim increase the safety of railway wheels, especially against a sudden failure. Compressive stresses in the wheel rim and the plate were checked in various ways, for instance by X-ray photography method or by release of material by drilling of column or hole with measuring released stresses by strain gauges.
Today, there are standardized and widely used two methods for measurement of residual stresses in the wheel rims. The first method is a non destructive method of ultrasound measurement of residual stresses and the second one is the classic method by cut off parts of material that is especially used for verification of stresses and used procedure. In this papers there are discussed the results and differences in tests according to European and other standards.

Keywords: railway wheels; residual stress; analysis, destructive methods, strain gauges, European standards, ultrasonic waves

1. Introduction

Railway monobloc wheels were formerly produces and delivered in so called normalization state, it means heat treated but without quenched rims. With higher service speeds, were related greater demands on the service life of wheels and there were sought about ways to reduce tread wear and also increase safety. In the seventies of last century there was standard UIC 812-3 [1] was added by requirements for quenching wheels. In this standard the initial condition N was added by hardened state T.

2. Methods of measuring residual stresses

Evaluation of residual stresses in railway monobloc wheels can be divided for destructive and non destructive methods. From historical point of view the oldest method is destructive method in accordance with standard UIC 812-3 [1]. Principle of the method is that on the outside of the rim two lines indicate a distance of 100 mm and then there is made the radial cut from the top of the flange to the bore in the

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distance hub. Than the distance between the lines is measured, and change of the must be greater than or equal to 1 mm. The change of the distance shows on the compressive stresses in the rim of the wheel.

This method of determining compressive residual stresses also took over a new European standard EN13262 in Annex F. 04.03, [2].

This European standard EN 13262 prescribes also in chapter 3.5 an acceptable level of circumferential stresses near the surface of a wheel rim. Level of compressive circumferential stress, measured near the surface of the tread must be in the range from 80 to 150 N/mm2. This stress must be within 35 to 50 mm below the running surface equal zero. Stress distribution line under rolling contact is shown in Figure 1. For verifying the stresses is prescribed either cutting destructive method using strain gauges or non destructive ultrasonic method.

Strain gauges cutting method that is described in annex C of standard EN 13262 includes a number of cutting operations that lead to the progressive release of residual stresses, which are present in a rim of wheel. Change in residual stress that occurs during each cutting operation will be evaluated by measuring the local surface deformations using strain gauges. Changes in the inside of the rim are reached by linear extrapolation of the state evaluated on the surfaces. The evaluation is done only on one radial cross section, because according to experience heat treatment effectively induces a uniform state of residual stress around the perimeter of the wheel.

The measurement procedure is obvious from the diagram in Figure 2. At first on the cross-section of the rim are glued strain gauges in the circumferential and axial directions at five places (positions indicated in Figure 2: 1 - tread, 2I, 2E rim 3I, 3EI-rim-web transition part). Following are three steps of cutting:

a) Cutting the rim with a length of at least twice the width of the rim (step 1 - Figure 2, 2a). After first cutting step there is necessary to measure stress and record values of radial cross-section on one side of the rim section, and glue gauge 4 (2b).

b) Cutting along a plane parallel to the axle at the beginning of the transition part rim – web (step 2 - Fig. 2,2b). After the second cutting step, stress to be measured with strain gauges 1, 4, thickness h1, h2 and glue strain gauge 5.

c) Cutting along a plane that is parallel to the passage of the axle through the ring (step 3 ¬ C Fig.2, 2c). This step is done only when the rim thickness is greater than 30mm.

d) Finally, there are measured stresses on the strain gauges 1, 5 and thickness h1 and h2.

In Annex D of EN 13262 there is described ultrasonic non-destructive method. Measurements of residual stresses across the rim of the new monobloc wheels are made by method of measurements of velocity of ultrasonic waves in the

material. The distribution of residual stress in the volume of new monobloc rim wheels are evaluated using an index of double bending of ultrasonic waves.

Time differences between the two polarised ultrasonic waves along the radial and along the circumferential direction is proportional to the difference of two stresses acting in the direction of vibration of the US waves. Period between output and input of US signal shows two main stresses given by formula:

$$\sigma_{cir} - \sigma_{rad} = k(t_{rad} - t_{cir})/t_{cir} \qquad (1)$$

where: σ_{cir} σ_{rad} = principal stresses in circumferential and radial direction
t_{rad} , t_{cir} = periods of transverse waves spread and direction of vibration
k = acoustic / elastic coefficient

The result of measurements at one point represents the difference of principal stresses acting in the space of a sound field of measured point. For obtaining of "stress profile" as a rule, there are made measurements at 3 points locations spaced radial across the rim. The largest measured stress near the tread must be pressure. Obtained stress profile does differ less than - 100 MPa from the principal stress.

Residual stresses are not only important parameter during inspection of new wheels, but they are very often criterion in assessing the behaviour of wheels in railway service. For example, above mentioned method of ultrasound evaluation of residual stresses is one of the criteria for the evaluation of wheel braking tests in accordance to EN 13979 [3].

The Russian standard OST 32-167-2000 [4] sets out the process for saw test of railway and tramway wheels. This standard distinguishes procedures for cutting of wheels for type tests and acceptance procedure or for analysis of causes of wheel damage during service. For evaluation the influence of technological operations on stresses is performed circumferential cut of rim from the web and then part of rim is radials cut for pieces with strain gauges (see fig.3).

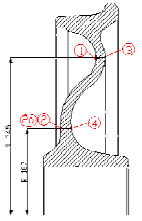
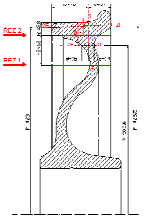
3. Some of the results and discussion

From every batch of heat treated rough wheels, there are in BONATRANS GROUP a.s. carried out sampling for mechanical tests and metallographic analyses, and strain gauge cutting test in according to UIC 812-3, too. On customer request on the finished wheels there are performed ultrasound measurements of residual stress according to EN 13262 with Debbie device. Measurements are carried out in accordance with the requirements of this standard and are performed in three cross sections rotated by 120 °. Measurements are usually performed between 15 and 35 mm below the running surface.

In cooperation with the Department of material strength at Faculty of Mechanical Engineering Technical University in Ostrava there was for certification of new products introduced hole drilling strain gauge method. Evaluation of residual stresses in accordance with a TN-503-4 [5] is carried out using sets of data logger HBM SPIDER 8-30 and hole drilling sets VISHAY RS-200.

Rather complicated procedure for strain gauge cutting method led us to attempt to compare the values of residual stresses in the railway wheel measured by methods according to EN 13262 and the values of residual stresses measured by hole drilling method according to TN-503-4. Results of measurements are given in Table 1.

Tab. 1: Measured values of residual stresses in the rail wheel [6]

Method of measurement	Measured point	Depth [mm]	Radial stress MPa]	Circumferential stress [MPa]
TN-503-4 	1	0,076 2,604	-136 -298	-50 -177
	2 / 2a	0,076 2,604	-47 / -23 29 / 30	-58 / -31 -25 / -28
	3	0,076 2,604	-8 191	-60 -5
	4	0,076 2,604	-6 -19	-4 -77
EN 13262 	1	0	-	-325,7
	2E	0	-	-230,1
	2I	0	-	-193,8
	3E	0	-	-327,9
	3I	0	-	-229,6
	4	½ s	-	-55,8
	A	½ s	-	-152,5

Circumferential stresses in both measurement methods showed in all measured points values of compressive residual stresses. Only in one comparable place on the wheel web by hole drilling method was close to the surface on the outer side measured value of residual stress -50 MPa and -60 on the inner side, which corresponds exactly with the value of -55.8 MPa measured in point 4 by cutting method. But when using the results from drilling at a depth of 2,604 mm, values measured by both methods are different.

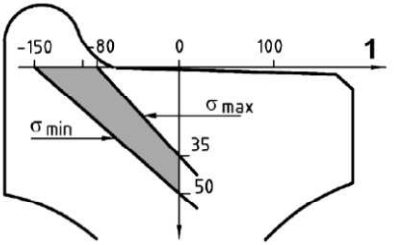
4. Conclusions

State of stresses in railway wheel is very important from security point of view. In new wheels state of stresses in accordance with demands of standards shows that high safety against fracture and high mileage of wheel are secured. Knowledge of state of stresses in the old wheels allows in time reject wheels that could lead to fracture as a result of tensile stresses in the rim.

For ensuring inspection of stresses in the new wheels was introduced measurement of residual stresses. According to the purpose, type and extent of control is used several methods to allow comparisons between them.

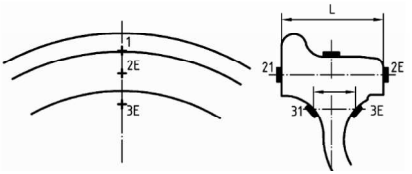
In particular, it is a non-destructive ultrasonic inspection of residual stresses. This method is prescribed by EN 13262 for the control of the newly manufactured

wheels. For verifying of the results another methods have been used such as strain gauge cutting method, hole drilling strain gauge method, X-ray method or ring core method.

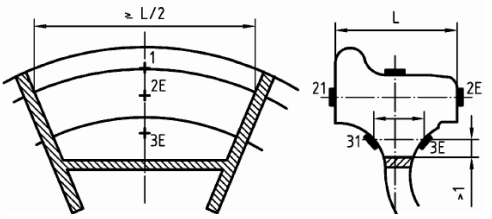


1 = Circumferential stress in MPa.

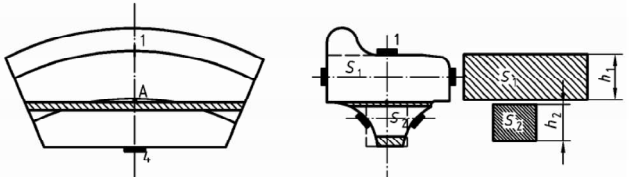
Fig.1: Range variation of circumferential stress values



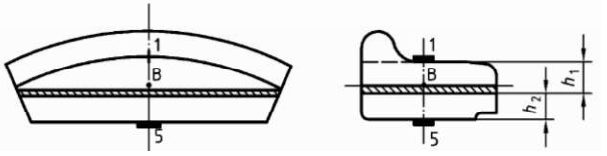
Initial state



First cuts



Second cut



Third cut

Fig.2: Strain gauge cutting method procedure.

Reference

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