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EXPERIMENTAL ANALYSIS OF RESIDUAL STRESSES AT PRODUCTS FOR THE RAILWAY TRAFFIC

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Abstract – The contribution is devoted to the problems of residual stress measurement and reduction at the products for the railway traffic. The measurements were performed by means of cutting, ultrasonic and hole-drilling strain gage methods. Two variants of hole-drilling method were used – method with the full and incrementally drilled depth of hole. The different methods of measurement show often the different results, therefore the standards of the measurement methods for the products were worked out. At the railway traffic the standards of the measurement methods and of the allowed values of residual stresses were elaborated for railway rails, axles and wheels.

Keywords: residual stress, hole-drilling method, railway traffic.

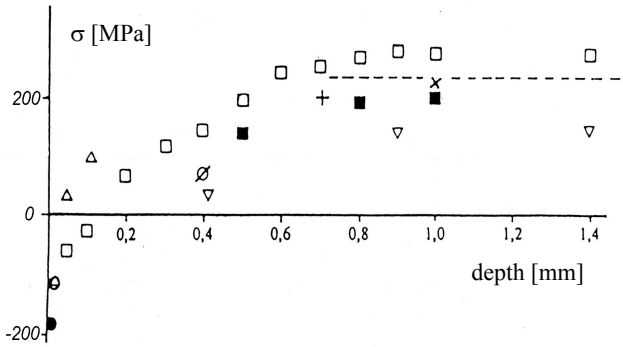
1. INTRODUCTION

The loading and stress of rails and train machine elements increase with the ascending speed at the railway traffic. The level of residual stresses has to note at the stress analysis. The residual stresses arise after the technological processes of production. The manufacturers of these products have to measure and verify the level of residual stress, alternatively they have to reduce its level. The paper introduces some experience and results of residual stress measurement at products for the railway traffic.

2. METHODS FOR RESIDUAL STRESS ANALYSIS

We can use the computational or experimental methods for residual stress analysis. The computational residual stress analysis at rails is published for example in works [1] and [2], at railway wheels in [3]. A lot of problems is connected with the computational solution of residual stresses, especially with the correct setting of boundary conditions. The calculation results are therefore considerably different then the results of measurements.

The results of residual stress measurements are again different by the use of different measurement methods. Reference [4] determines for example the results of residual stress measurements and comparison on the rail head UIC 60. The measurements were performed by means of seven experimental methods, Fig. 1. With a view to comparability of the residual stress level at products of different producers, the European standards dictate both the measurement procedures and the allowable values of residual stresses for some products. The experimental methods are irrecoverable for the present in the sphere of standardized methods for the residual stress detection. We used the cutting, hole-drilling strain gauge and ultrasonic methods for the residual stress analysis at the product for railway traffic.



X-Ray Diffraction ☛ Neutron Diffraction Cutting Method Ring Core Method Ultrasonic Method Hole Drilling Method ▽ Groove Method

Fig. 1: The comparison of residual stress measurement results according to different methods

2.1. Cutting method

Fig. 2. shows the measurement principle and procedure by means of this method. It is the standardized method for

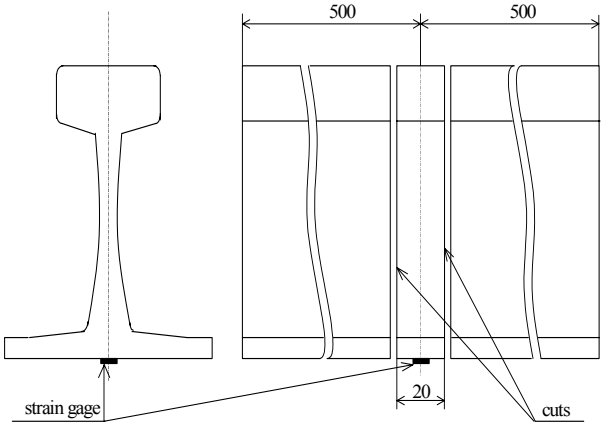


Fig. 2: The residual stress measurement by means of cutting method of rails

the rail producers [5]. The evaluated stress from the difference of measured strains before and after specimen cutting determines the residual stress value by this standardized method. But it isn't the residual stress at the place of strain gauge sticking. It is average value of released stresses consequent on cutting of specimen with the strain gauge from the rail with the non-uniform distributed residual stresses. It is a destructive method, the evaluation is lengthy and arduous.

2.2. Hole-drilling strain gauge method

The principle of this experimental method consist in measurements of released strains in the neighbourhood of small drilled hole. The through or blind holes are drilled according to the thickness of measured product. There are two versions of this method:

a) the hole is drilled at once in the whole depth
b) the hole drilling is made incrementally in some longitudinal steps.

The stress solution in the neighbourhood of the hole was obtained by G. Kirsh in 1898 [6]. The procedure of measurement and evaluation of residual stresses are detailed in [7] and [8]. This method is a ground of American standard for the residual stress measurement [9]. The evaluated value determines the actual residual stress at the measured place unlike the cutting method by [5]. We can take the residual stress distribution and gradient under surface by means of the incrementally hole-drilling strain gage method, Fig. 3. It is a semi-destructive method.

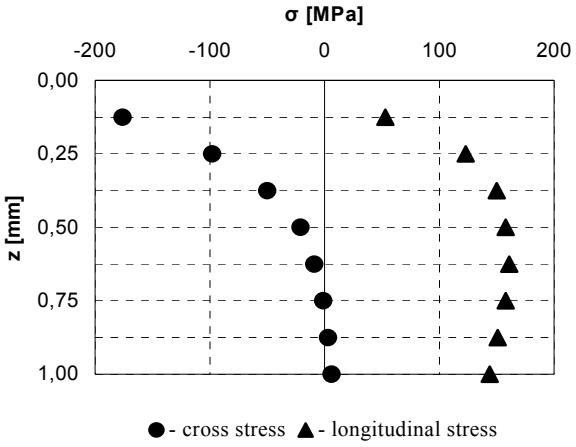


Fig. 3 : Residual stresses distribution under the rail foot surface

2.3. Ultrasonic method

The principle of the method is ground on speed measurement of ultrasonic waves at measured material. This speed depends on the stress state at measured place analogous to light waves by photoelasticity. The calibration measurements are needed for each material. We made the measurements by means of DEBRO device from Polen [10]. It is a non-destructive method and the evaluation of residual stresses is very fast.

3. RESIDUAL STRESSES AT PRODUCTS FOR THE RAILWAY TRAFFIC

The residual stress measurements according to the European standards, but by means of the other methods, were performed for rails, axles and wheels.

3.1. Residual stresses at rails

The residual stresses at rails arise both as a result of the disproportional colling after the rolling and as a result of the process of the straightening on the disc straightening machine. The residual stress at rails after rolling and before straightening is relatively small, the straightening process increases its level substantially (Fig.4). The hole-drilling and

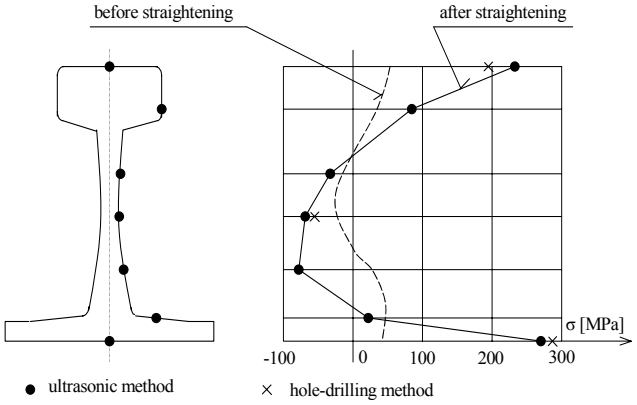


Fig. 4: The residual stresses at rail before and after of straightening

ultrasonic methods were used for the finding of residual stress distribution according to Fig. 4. The cutting method doesn't enable such research, but it is compulsory for the rail producers [5], Fig. 2. The residual stresses at the rail foot have to be smaller then +250MPa, the cutting method has to be used for the measurement. The acceptable level +250MPa is relatively high, there is a compromise between the customers and suppliers of rails. The cutting method is destructive method and the evaluation of measurement is relatively lengthy and labour consuming, these are the disadvantages of this method.

The hole drilling method is possible for the residual stress measurements at the chosen point of rail. This method enables the measurement of residual stresses along the depth of drilled hole. Fig. 3 shows the course of residual stresses in the axis of surface of the rail foot. The pressure residual stresses are on the rail foot surface, the tensile residual stresses are till at the some depth and their value approach the value, measured by means of the cutting method.

The ultrasonic method was used for industrial measurements and for monitoring of changes of production technology influencing residual stresses. This is a non-destructive method that made it possible to measure the stresses in course of production technology, i.e. in rails at the cooling bed after cooling and before straightening, at interrupted process of straightening as well as in a bent rail between straightening machine's discs and obviously mainly the achieved level of residual stresses after the straightening

process which considerably increases this level. In order to optimise the straightening process in such a way that the level of residual stresses was as low as possible after achievement of the required platness we have carried out many experiments concerning straightening with various settings of discs in horizontal and vertical stage of straightening machine. The use of the non-destructive ultrasonic method made it possible to measure the level of residual stresses immediately after straightening and to optimise immediately the straightening process on the basis of measurement results during these experiments.

3.2. Residual stresses at axles

The European standard was performed for the residual stress measurement at axles too [11]. The places of measurement according to EN 13261 standard we can see on Fig. 5.

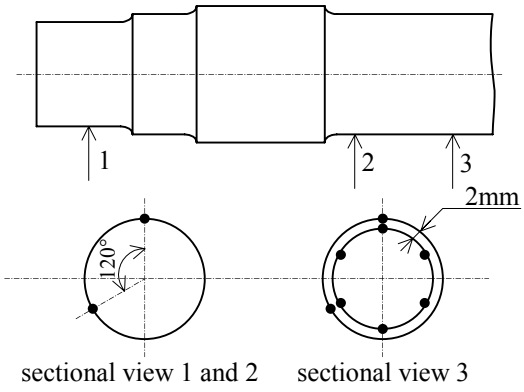


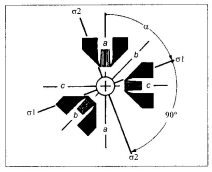
Fig. 5: The places of residual stress measurement at axles according to EN 13261 standard

Measurement shall be made either with strain gauges or by X-ray diffraction [12]. The method shall be agreed between customer and supplier. The measurements must be carried out at 6 places of axle boundary, and at 6 places in the depth 2 mm under the boundary. The residual stresses at the axle boundary have to be smaller then + 100 MPa, the stress difference at the depth 2 mm has to be smaller then 40 MPa. The hole drilling method with incrementally drilled depth was used for the residual stress measurements, the cutter diameter and hole depth was min 4 mm. The residual stresses at the boundary have to extrapolate. The research of the production and machining influence on the residual stresses at axles were performed by means of this method.

The results of residual stress measurements are processed in the form of test report, Fig. 6. The test report includes heading, table and graph. The heading determines the basic data about the measurement and measured material. The measured values of relaxated strains and evaluated residual stresses are given at the table. The distributions of main residual stresses commensurate with the drilled depth are described at the graph. The test reports are the basic documents of legislative reports for customers [13].

The test report from residual stress measurement

Place : 3 - Náprava
Hole diameter : 5,1 mm
Rosette : RY21-3/120
Material : A1N
E : 2,10E+05
μ : 0,28



Z	Z/D	εa	εb	εc	σ1	σ2	α	σ r	σ t	σ red
mm	-	μS	μS	μS	MPa	MPa	°	MPa	MPa	MPa
0,318	0,024	3	4	2	-11,6	-30,4	125,8	-24,0	-18,0	26,6
0,635	0,049	13	9	6	-25,4	-43,8	85,9	-43,7	-25,5	38,1
1,27	0,098	27	26	14	-24,9	-44,5	110,1	-42,1	-27,2	38,6
1,905	0,147	38	39	22	-26,3	-44,6	114,2	-41,6	-29,4	38,9
2,54	0,195	53	46	25	-29,1	-48,1	103,3	-47,1	-30,1	42,0
3,175	0,244	52	45	21	-23,9	-42,8	104,4	-41,6	-25,1	37,1
3,81	0,293	64	50	25	-29,2	-49,2	97,9	-48,8	-29,6	42,8
4,445	0,342	60	48	22	-25,8	-44,6	100,1	-44,0	-26,4	38,8
5,08	0,391	66	50	23	-27,2	-46,9	97,2	-46,6	-27,5	40,8
5,461	0,420	65	49	21	-25,5	-45,2	97,6	-44,9	-25,8	39,2

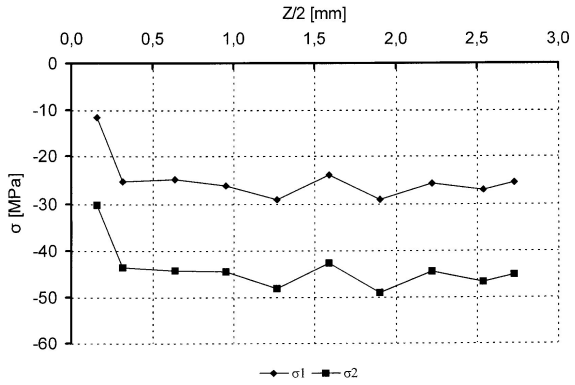


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Fig. 6: The test report from residual stress measurement by means of incrementally hole-drilling strain gage method

3.3. Residual stresses at wheels

The cutting method is imposed by European standard for the residual stress measurements at wheels [14]. However this method is very labour consuming and lengthy. Therefore the hole drilling and ultrasonic method were used for the research and optimisation of wheel production.

3.4. Residual stresses at brake discs

There isn't European standard for residual stress measurement at this element. Nevertheless we performed a lot of measurements by means of incrementally hole drilling method. The brake discs are made both from the gray and modular cast iron. The measurements were performed both before and after the intensive braking.

4. CONCLUSIONS

The paper briefly summarizes our research and experimental works, which were performed at the area of residual stress measurements at products for the railway traffic. Besides the standardized residual stress measurements for rails, axles and wheels the relatively

extensive research was performed in order to minimize the residual stresses at product after the production. The research reports include the detailed results of residual stress measurements.

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