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RESIDUAL STRESS EVALUATION IN NEW RIM-SPRAYED WHEELS

Summary. The ultrasonic method of determination of the residual stresses in the wheel is the most effective method for evaluation of wheel batches with homogeneous orientation of residual stress. The effect of chemical composition of the R7T and R8T grade wheel steels is covered by the effect of heat treatment parameters (spraying regime, tempering). Reduction in the level of residual stresses due to tempering varies with the yield limit level referred to wheel rim material.

OCENA NAPRĘŻEŃ WEWNĘTRZNYCH W NOWYCH KOŁACH Z HARTOWANYM WIEŃCEM

Streszczenie. Ultradźwiękowa metoda badania naprężeń wewnętrznych wieńca koła jest najefektywniejszą metodą oceny serii produkowanych kół z homogenną orientacją naprężeń we wieńcu koła. Wpływ składu chemicznego kół produkowanych z materiałów R7T i R8T jest mniejszy niż wpływ różnic parametrów obróbki cieplnej (parametry opryskiwania, odpuszczania).Obniżenie poziomu naprężeń wewnętrznych pod wpływem parametów odpuszczania zależy od wysokości granicy plastyczności.

1. INTRODUCTION

The residual stresses in the railway solid wheels are significant parameter of their service life. Initiation and growth of flaws in the solid wheels varies with distribution of residual stresses across the section and over the periphery of wheel in the state of failure. The level of the residual stresses, initiated in the wheels in the course of manufacture is considerably changing in relation with the conditions of the railway traffic. Nevertheless, the level of residual stresses in new wheels has substantial effect on redistribution of residual stresses due to service loading and during service life of wheel up to initiation of failure and/or up to its total fracture.

The parameters of heat treatment are most important tooling of the manufacturer how to affect the level of residual stresses in new wheels. In the case of surface-treated wheels, the most important role is played by the chemical composition of steel, by the time and intensity of wheel rim spraying and by the parameters of tempering. The ŽDB, the Czech wheelset manufacturer provided until fairly recently the investigation of the effect of heat treatment parameters on distribution of residual stresses in the machined wheels on the as-delivery state. On the basis of an analysis through the world-wide accumulated experience /e.g. 1,2/, the residual stresses were evaluated in our work by ultrasonic method with the help of the DEBRO device, by the hole-drilling method using the strain-gauge rosettes and by bulk cutting method with the aid of classical strain gauges.

The subject of this paper is :

a) mutual comparison of the above-mentioned measuring methods at determination of residual stresses in the wheel rims,
b) evaluation of the effect of steel chemical composition on the residual stresses in the wheel rim (the R7T and R8T grades according to UIC 812-3, effect of microalloying in the range of the UIC 812-3 conditions),
c) evaluation of the heat treatment parameters on residual stresses in the wheel rims.

2. COMPARISON OF RESIDUAL STRESS MEASURING METHODS IN WHEELS

1. Results of application of various residual stress measuring methods in wheel rims

A wide scope of measuring methods is available for measurement of residual stress in the structural parts. In the field of determination of residual stress in railway wheels some methods have been applied whose principles are ranged following way :

a) the non-destructive methods (for mass inspection of new wheels at the acceptance procedure and of the wheels in service the ultrasonic principle is utilised)
b) the semi-destructive methods (the hole-drilling method by means of strain gauge rosettes)
c) the destructive methods (earlier the semi-quantitative method using the residual stress relieving principle by radial cutting the wheel section according to UIC 812-3 conditions, today the quantitative methods of the residual stress relieving by radial and tangential cuttings of the wheel section according to proposed CEN/TC256/SC2/WG11 Standard, Document MR 80D or AISI S626 Standard conditions).

From the non-destructive methods the ultrasonic method seems to be the most convenient one. This method is based upon the so called acoustoelastic effect /3/ where the rate of propagation of the acoustic waves in a solid body is influenced by the mechanical state of stress. It is going out from direct dependence of the relative change in the propagation rate of the ultrasonic waves in isotropic environment on the mechanical stress

$$(v_{ijk} - v_{0ijk}) / v_{0ijk} = \beta \sigma_k \tag{1}$$

v_{ijk} is the propagation rate of a wave in the solid body with mechanical stress
v_{0ijk} is the propagation rate of a wave in the solid body without mechanical stress, $\sigma_k = 0$
i,j,k = 1,2,3 are directions of wave propagation, wave polarisation and of the affecting stress
$\beta_{i,j,k}$ is the acoustoelastic constant, MPa^{-1} for a given configuration of the indices i,j,k

The draft of the above-cited CEN Standard (Document No. 80D) provides recommendation for application of the ultrasonic method and determines in advance the limits of residual stresses measured by the method over thickness of wheel rim.

The ŽDB as manufacturer of the railway wheels has purchased from Poland a portable device named DEBRO-30 for measurement of the bulk and residual stresses in the wheel rims. The principles of determination of the two kinds of stress are shown in Figs. 1 and 2.

Figures 1 ands 2 illustrate schematically the path of an ultrasonic wave at measurement the time of flight of wave through the wheel rim by means of the surface and bulk method. The bulk method (Fig. 1) provides the average difference of the tangential and radial stress in the bulk of rim given by its width and contact surface of probe with the face of rim. It makes use of the transversal waves polarised in the direction of the evaluated components of stress and propagating perpendicularly to them. The surface method (Fig. 2) determines the average tangential stress in the surface layer down to a depth of approx. 2 mm in the field of probe contact with the measured surface. It makes use of the longitudinal and transversal waves propagating in parallel with the measured stress.

The results of the measurements of residual stresses by the two ultrasonic methods in the wheel rims of R7T grade manufactured at the ŽDB are shown in Figs. 5 a 6. The measuring probes were placed at the outer face of machined rim profiles. The results indicated refer to measurements made on wheels in as-quenched and in as-quenched and tempered state. The dark areas refer to the limits of bulk residual stresses measured over the thickness of the wheel rim as proposed by the CEN Standard. The results show distinct differences in the residual stresses following from both the differences in the principles of methods and the probable heterogeneity in distribution of the residual stresses over the cross section of the wheel rim as will be shown later. In the case of surface stresses the results reveal substantially greater difference between the quenched state and the quenched and tempered one. This result is obviously the outcome of the microstructural gradient in the subsurface layers of the cross section of wheel rim especially at the outer face of rim and below the tread.

For evaluation of the heterogeneity in distribution of residual stresses over the cross section of the wheel rim, the outer surface of wheel rim has been machined by that manner that the width of rim profile would be diminished first by 25 mm and then, by 50 mm. The results of measurements of the bulk residual stresses after reducing the rim width are summarized in the Table 1.

Table 1

The bulk residual stresses in the R7T wheel wim with reduced rim width, MPa

Measured point	State 1	State 2
1	-12, -18, -20	0,-26, -4
2	-12, -29, -28	-29, -21, -32

Comments to the Table 1.
Measured point 1 - approx. 15 mm below the tread
Measured point 2- approx. 45 mm below the tread
State 1 - after reducing the rim width by 25 mm
State 2 - after reducing the rim width by 50 mm

Comparison of the results of Table 1 and of Fig. 5 for a carbon steel without microalloying provides confirmation of the hypothesis on heterogeneity in distribution of residual stresses over the cross section of the sprayed wheel rim.

The surface residual stress has been measured by the hole-drilling method by means of strain-gauge rosettes at the same wheels of R7T grade, as shown schematically in Fig. 4. The principle of this method is the residual stress relieving at drilling a defined hole into a small depth, up to 2 mm. Before the measurement, the evaluated surface is provided with attached strain-gauge rosette with three strain gauges whose lattices gradually form the angles of 0°. 45° and 90° with defined direction of stress (here the tangential stress). The measurement and evaluation of the surface residual stresses have been carried out in accordance with the ASTM E 837 Standard. In the practice the elastic strains $\varepsilon_1,\varepsilon_2,\varepsilon_3$ are measure in the course of hole drilling and these strains with the calibration constants determined per ASTM E 837 show the main stresses σ_1,σ_2 and the angle α between the stress and the lattice 1. In the case of proper orientation of the rosette $\alpha = 0$ and main stresses are identical with the tangential and radial components of stress. Table 2 presents the results of surface residual stresses measured at the outer face of the R7T wheel rim.

Table 2

The surface residual stresses at the outer face of the R7T wheel rim determined by the hole-drilling method

Stress	Measured point	
	1	2
Radial	-150	-162
Tangential	-216	-170

Comments to Table 2.
Measured point 1 - approx. 15 mm below the tread
Measured point 2 - approx. 45 mm below the tread

Comparison of the measured tangential components of the surface stresses measured by the hole-drilling and ultrasonic methods (Fig. 6) for as-quenched and tempered wheel shows a good conformity of the results stated by the two different methods.

Concludingly, to evaluate the R7T wheel grade in as-quenched and as-quenched and tempered state, the bulk residual stresses were deter mined by the cutting method as proposed by the CEN Standard cited above. This Standard provides evaluation of the residual stresses as step-by-step relieving of residual stresses by means of radial and tangential cuts. The principle of method is shown in Fig. 3. The results are the stress at the tread in point 1 and the stress in point B of the last tangential section (see Fig. 3d), corresponding with the rim web edge defined as follows

$$\sigma_{1,3} = E\,(\varepsilon_t + \varepsilon_{ar}) / (1 - \mu^2) \tag{2}$$

$\sigma_{1,2}$ are stresses in the points 1 and B as shown in Fig. 3, cut sections d), MPa
E - The Young´s modulus of elasticity in tension, MPa
ε_t - strain measured by the strain-gauge cross in tangential direction (for both points)
ε_{ar} - strain measured by the strain-gauge cross in axial direction (point 1) or in radial direction (point B)
μ - the Poisson constant

The results of the measurements by the method in question of the R7Twheels in as-quenched and in as-quenched and tempered state are illustrated in Fig. 7. The dark areas refer to the limits of stress over the cross section of wheel rim as proposed by the CEN Standard. It is obvious that the measured data are somewhat higher than the limits proposed by the CEN Standard. The course in variation of stress with the rim thickness is in conformity with the draft of the Standard.

2.2. Reliability of ultrasonic measuring method and wheel heat treatment effect

From the comparison of results of residual stresses measured by the above-cited methods is obvious that the ultrasonic method applied by DEBRO instrument presents a reliable tooling for evaluation of residual stresses in wheels in as-delivered state. The reliability of this method varies with correct calibrating the instrument i.e. correct determination of the acoustoelastic and time constants for the applied kinds of ultrasonic waves and in the case of bulk method even determination of the constant of anisotrophy of the forged wheel rim material.

The acoustoelastic constant will be determined separately for longitudinal waves (probe for surface stresses) and for perpendicular waves (probe for bulk stresses). The measurement is made with the help of a testing bar taken-off below the wheel rim tread surface having longitudinal axis in tangential orientation owing to the wheel rim. The testing bar is consecutively loaded by tensile stresses and the time intervals of ultrasonic pulses are determined for the relevant elastic tensile stresses.

The acoustoelastic constant, to determine the surface residual stresses, will be calculated as follows

$$\beta = (T_0 - T_k) / T_k \sigma_k \tag{3}$$

T_0 - pulse time for $\sigma = 0$, ns T_k - pulse time for $\sigma = \sigma_k$, ns

For the R7T and R8T wheel grades the β was the same and was equal $-125.\ 10^{-7}$ MPa^{-1}.

The acoustoelastic constant β, to be used for determination of the bulk residual stresses. will be calculated as follows

$$\beta = (\Delta t_1/t_1^k - \Delta t_2/t_2^k) / \sigma_k \tag{4}$$

$$\Delta t_1 = t_1^0 - t_1^k \qquad \Delta t_2 = t_2^0 - t_2^k$$

t_1^0, t_1^k - the pulse time intervals for longitudinally polarised wave, ns
t_2^0, t_2^k - the pulse time intervals for perpendicularly polarised wave, ns

The relevant pulse intervals will be determined experimentally for the individual values of elastic stress at loading the testing bar. For the R7T and R8T wheel grades the β was found to be identical and equal to -79.10^{-7} MPa^{-1}.

Because of the dimensions of a railway wheel rim and the forging technology, the wheel material shows anisotrophy. Owing to the coincidence in orientation of the axes of the forging texture with the directions of the principle residual stresses in the wheel rim, the complex stress parameter can be determined for the bulk method as algebraic sum of the factors influencing the residual stress and material anisotrophy. Therefore, the coefficient of anisotrophy is determined on the wheel segment after stress-relieve annealing. The coefficient of anisotrophy was also determined for the R7T and R8T wheel grades and was found to be identical and equal to -15 MPa.

The effect of heat treatment parameters on the bulk residual stresses data, as determined by means of DEBRO-30, has been examined for the R7T and R8T wheel grades. The measurements were always carried out in 4 points of wheel rim periphery displaced by 90° and at each point in 2 localities of rim thickness (15 mm below the tread and 15 mm from the rim-web edge).

In the case of R7T grade, the set of 20 wheels has been evaluated when subjected to heat treatment in one batch. The frequency histogram of the bulk residual stress values is illustrated in Fig. 9. The average value of set for a distance of 15 mm from the tread equals -112 MPa, while the maximum compressive stress equals -167 MPa and the minimum one is -84 MPa. The average value of the set for a distance 15 mm from the rim-web edge equals -43 MPa, the maximum compressive stress is -67 MPa and the minimum one is -1 MPa. Simultaneously, the distribution of the rim bulk residual stresses over the wheel periphery has been statistically evaluated. The average values for individual points vary within -122 and -110 MPa (15 mm below the tread) and -41 to -46 MPa (15 mm from the rim-web edge).

The set of the R7T grade wheels was evaluated after the heat treatment in one batch. The frequency histogram of the bulk residual stresses is shown in Fig. 8. The average value of the set for a distance 15 mm from the tread equals -131 MPa, the maximum compressive residual stress equals -196 MPa, the minimum value is -102 MPa. The average value of the set for a distance 15 mm from the rim-web edge equals -65 MPa, the maximum compressive residual stress value equals -113 MPa and the minimum one is -10 MPa. The average value of the rim bulk residual stresses in the individually measured localities over the wheel periphery vary within -132 and -123 MPa (15 mm below the tread) and between -59 and -73 MPa (15 mm from the rim-web edge).

3. INFLUENCE OF CHEMICAL COMPOSITION ON WHEEL RIM RESIDUAL STRESSES

As mentioned earlier, the residual stress in the wheel rim is influenced, apart from the anisotrophy due to forging texture of wheel rim material, by the microstructural gradient and by the mechanical properties over the rim cross section. The gradient is originating in the course of the heat treatment by rim water spraying and is influenced by the chemical composition the wheel is made of.

Carbon and manganese together with microalloying elements, improving the steel hardenability (Cr, Ni, Mo, V) are the elements producing the most significant effect on distribution of the microstructure over the wheel rim cross section in accordance with UIC 812-3 rules. The ŽDB, as manufacturer of railway wheels, produces machined wheels with ferritic-pearlitic microstructure over entire rim cross section, free of quenching phases in the wheel rim steel. The above-cited elements in steel together with the technology of heat treatment, however, influence the gradients of the ferritic-pearlitic microstructure and mechanical properties parameters over the rim cross section and in the same time the integral values of the rim bulk residual stresses. The result of such gradients is a heterogeneous distribution of the residual stresses over the wheel rim cross section, when measured in tangential direction as indicated in Chapter 2.

From the comparison of the results of the R7T and R8T grade residual stresses measurement (carbon quality, see Figs. 5 and 6) with identical regime of heat treatment (spraying and tempering parameters) and with same level of alloying, the higher carbon content of R8T wheel grade enhances the compressive residual stresses in the wheel rim, especially in the subsurface layers below the tread. The extent of residual stress growing is controlled by the heat treatment parameters. As follows from the basic statistical data for the sets of R7T and R8T wheel grades, the effect of carbon content is less expressive than that of the heat treatment regime.

The residual stresses in the wheel rim are also influenced by the microalloying elements (Figs. 5 and 6, microalloyed variant of the R7T grade). For the microalloyed variant the spraying intensity was reduced so that no quenched microstructural phases would occur below the rim tread and simultaneously, the gradient of microstructure and mechanical properties parameters in that locality should be reduced too. The figures show obviously that the distribution of bulk and surface residual stresses over the rim thickness reveals identical features. This confirmed the simultaneous effect of the chemical composition and of the heat treatment on distribution of residual stresses in the wheel rim.

4. INFLUENCE OF RIM SPRAYING PARAMETERS ON RIM RESIDUAL STRESSES

In accordance with the UIC 812-3 conditions, the solid wheels are heat treated after austenitization heating by spraying the rim periphery by means of pressure water jets (T-grade) or by volume quenching in water (E-grade). The majority of solid wheels in the European Continent is heat treated by spraying. The selective rim cooling by spraying has to carry the fundamental mechanical properties and the microstructure as specified in the UIC 812-3 technical conditions. The fundamental parameters influencing the wheel rim properties are the spraying intensity governed by the volume and pressure of spraying water and by the spraying time.

Evaluation of the effect of these two spraying parameters on the bulk residual stresses over the wheel rim periphery has been made with five R7T grade wheels. There are the wheels from the same batch which are statistically evaluated relating to residual stresses as described in Chapter 3. Selected wheels have been heated to the austenitization temperature and then sprayed in various regimes as indicated in table 3.

Table 3

The regimes of spraying of the trial R7T grade wheels

Wheel No.	Spraying regime
1	reference regime to achieve the quality requirements of the UIC 812-3 conditions
2	spraying intensity saved, the total spraying time longer by 60 sec owing to 1
3	spraying intensity saved, the total spraying time shorter by 40 sec owing to 1
4	the total spraying time like to 1, spraying intensity elevated by 30% owing to 1
5	the total spraying time like to 1, spraying intensity reduced by 30% owing to 1

At the end of spraying all the wheels were subjected to tempering at 520°C with a dwell period of 2 hours. The bulk residual stresses were measured by ultrasonic method with the help of the DEBRO-30 device at the outer face of wheel rims in four points on the wheel rim periphery ; the measuring points are displaced by 90° one to another. In each point of the rim periphery, the bulk residual stress was determined in two localities of the rim thickness i.e. 15 mm below the tread and 15 mm from the rim-web edge. The measured residual stresses are listed in the table 4.

Table 4

The bulk residual stresses in the wheel rim after various spraying regimes

Wheel No.	1		2		3		4		5	
Point in the rim	T	LW	T	LW	T	LW	T	LW	T	LW
Point on periphery	-189	-72	-205	-123	-129	-34	-143	-70	-127	-41
	-121	-66	-189	-152	-130	-48	-147	-67	-131	-69
	-174	-76	-163	-136	-110	-38	-140	-65	-116	-52
	-182	-91	-175	-118	-133	-56	-145	-66	-129	-56

The wheel numbers refer to the codes of heat treatment regimes as shown in the table 3. The letter T refers to the point of measurement 15 mm below the tread and the letters LW denote the point of measurement 15 mm from the rim-web edge. Table 4 shows remarkable dependence of the bulk residual stresses in the two measuring points over the rim thickness on the total spraying time (wheels numbered 1, 2 and 3). The variation in the spraying intensity at the beginning of rim spraying has brought a drop in the bulk residual stresses especially below the tread (wheels numbered 1, 4 and 5). No expressive qualitative displacement occurred in the residual stresses due to influence of spraying intensity between the wheels 4 and 5.

6. CONCLUSIONS

1. The ultrasonic method seems to be the most effective approach to the mass evaluation of the residual stresses in the rims of railway solid wheels. This method can be used for evaluation of the average state of stress over the cross section of rim and in the subsurface layers with the homogeneous orientation of the direction of residual stresses (tensile or compressive). The hole-drilling method by means of strain-gauge rosettes is a suitable completion of this method to determine the surface residual stresses especially for evaluation of the residual stresses in the wheel plate and in the wheel hub.
2. The scatter of results of residual stresses determined in the wheel rim is influenced by correct calibration of the measuring instrument (determination of the acoustoelastic and time constants for the bulk and surface methods and the constant of anisotrophy for the bulk method) and the heat the wheel batches. The measured coincidence of the acoustoelastic constants for the R7T and R8T wheel grades are associated probably with small differences in the technology of heat treatment of the above-mentioned wheel grades. The neglecting value of the anisotrophy coefficient of two described wheel grades is associated with a high degree of the rim forging and consequently with low anisotrophy of rim wheel rim properties. The present-day technology of R7T and R8T wheel grades applied by ŽDB shows much lower level of compressive residual stresses relating to the CEN Draft Standard limit than the French manufacturer /1/ and the highest stresses below the tread surpass only slightly the above-mentioned limit -150 MPa.
3. The heat treatment and partially even the chemical composition are the technological parameters of solid wheels manufacture that affect substantially the level of residual stresses in the wheel rim. Reasonable selection of the spraying parameters for the R7T and R8T wheel grades, to meet the material properties as required by the customer, could cover the effect of chemical composition (it refers to carbon, manganese and microalloying elements in the range of UIC 812-3 conditions).

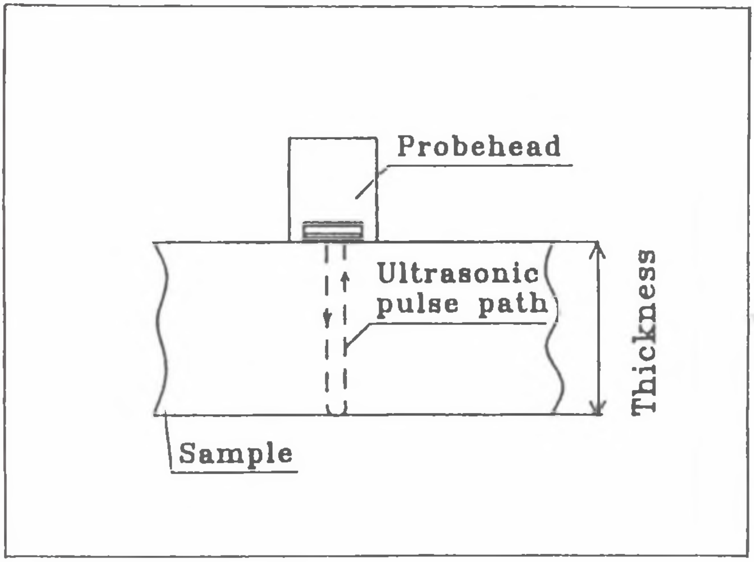


Fig.1. Scheme of determination of bulk residual stresses by ultrasonic method
Rys.1. Schemat pomiaru naprężeń własnych pionowych metodą ultradźwiękową

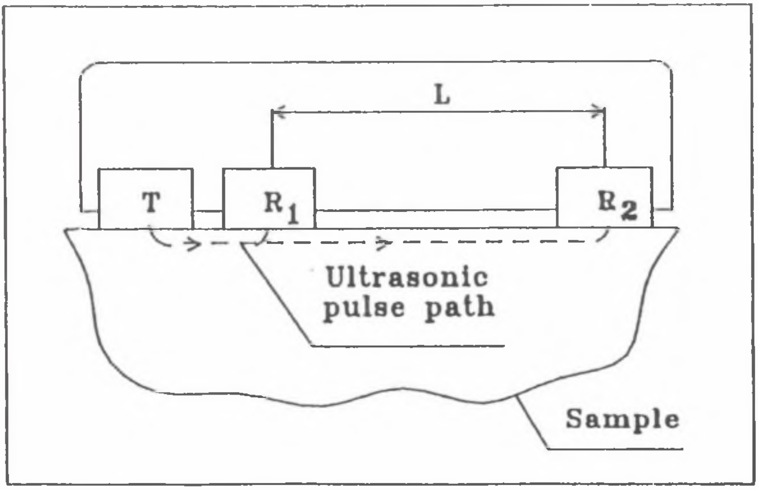


Fig.2. Scheme of determination of surface residual stresses by ultrasonic method
Rys.2. Schemat pomiaru naprężeń własnych poziomych metodą ultradźwiękową

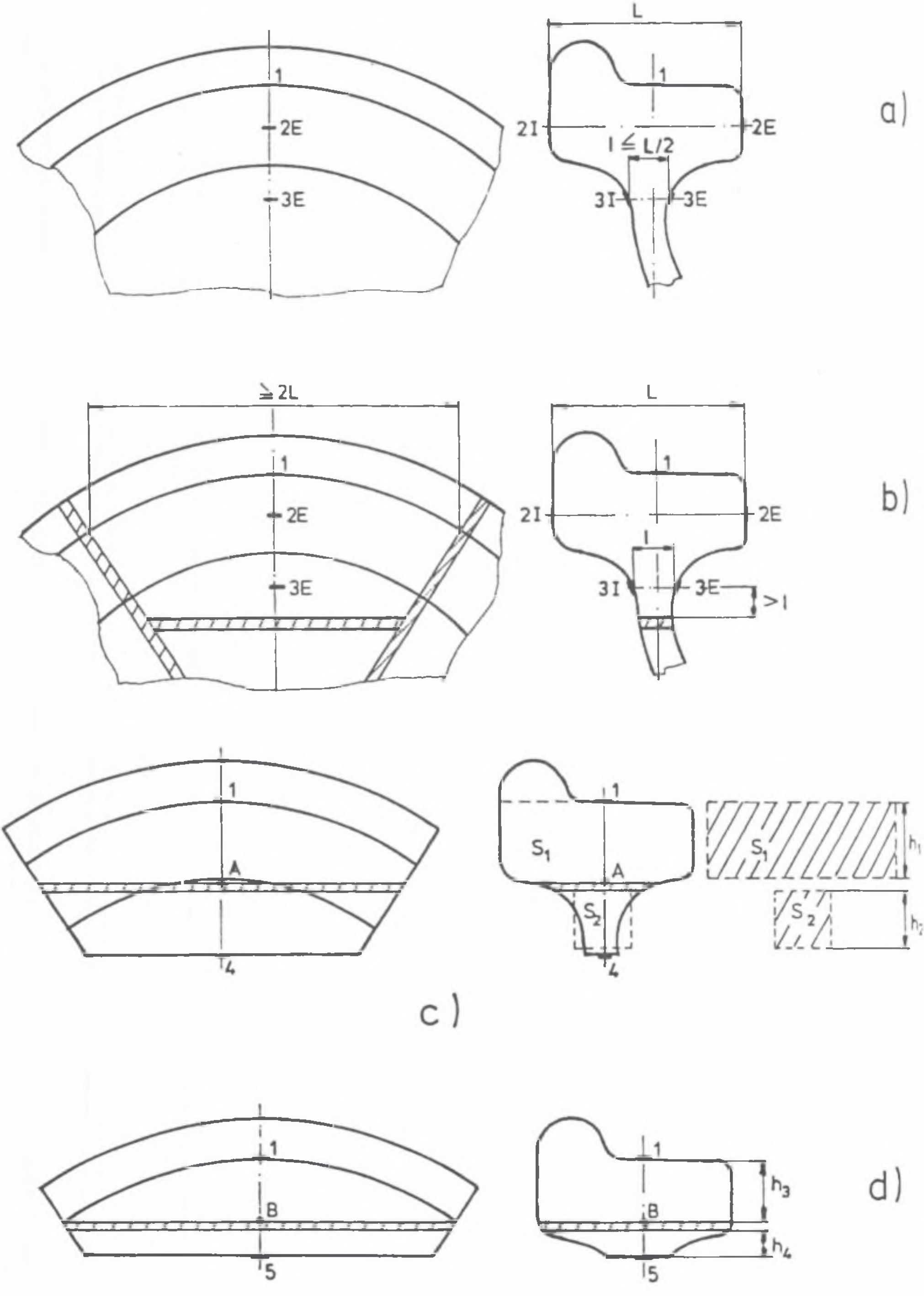


Fig.3. Scheme of determination of bulk residual stresses by CEN cutting method
Rys.3. Schemat pomiaru naprężeń własnych metodą trepanacyjną CEN

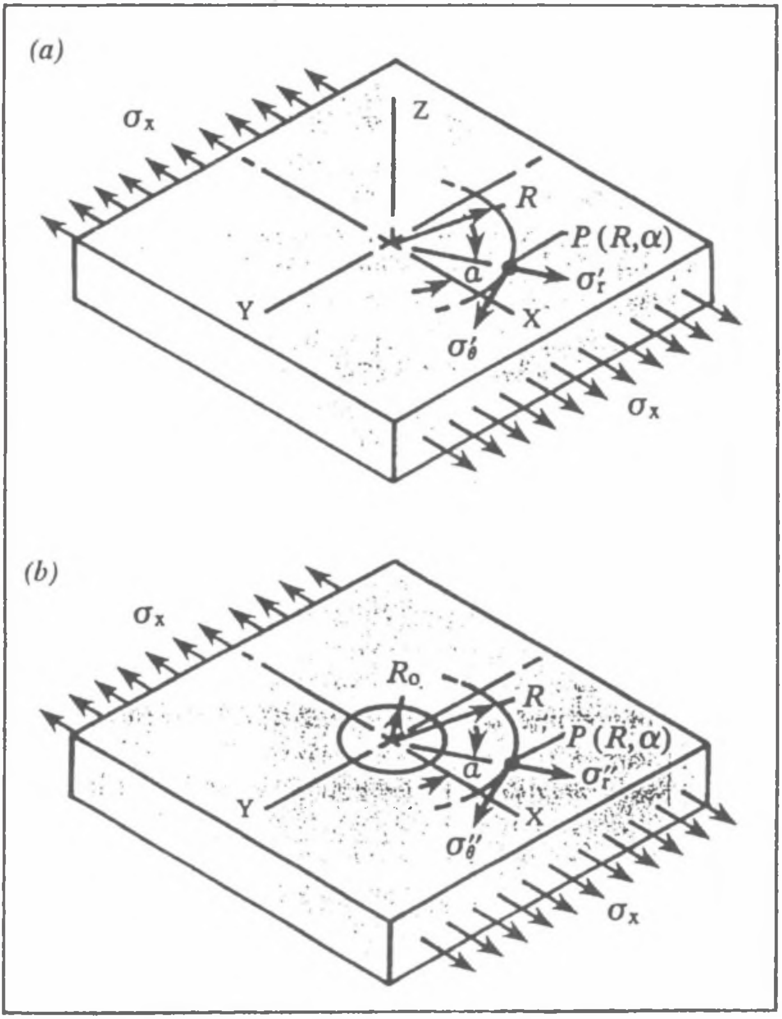


Fig.4. Scheme of determination of surface residual stresses by hole-drilling method according to ASTM 837 Standard

Rys.4. Schemat pomiaru naprężeń własnych powierzchniowych metodą wiercenia otworu wg standardu ASTM E 837

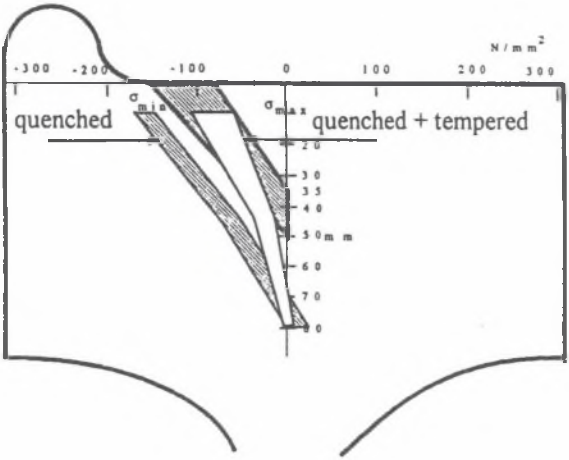


Fig.5a. Determination of bulk residual stresses in the carbon steel R7T wheel rims by CEN ultrasonic method (DEBRO-30)

Rys.5a. Określenie naprężeń własnych w kole ze stali węglowej R7T metodą ultradźwiękową CEN (DEBRO-30)

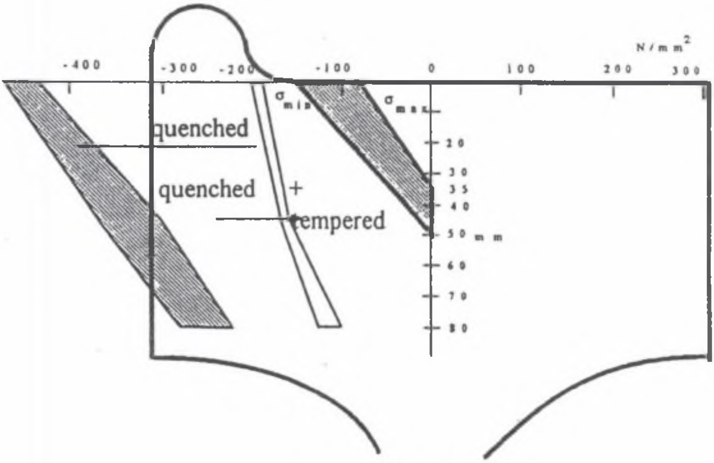


Fig.5b. Determination of bulk residual stresses in microalloyed steel R7T wheel rims by ultrasonic method (DEBRO-30)

Rys.5b. Określenie naprężeń własnych w kole ze stali niskostopowej metodą ultradźwiękową CEN (DEBRO-30)

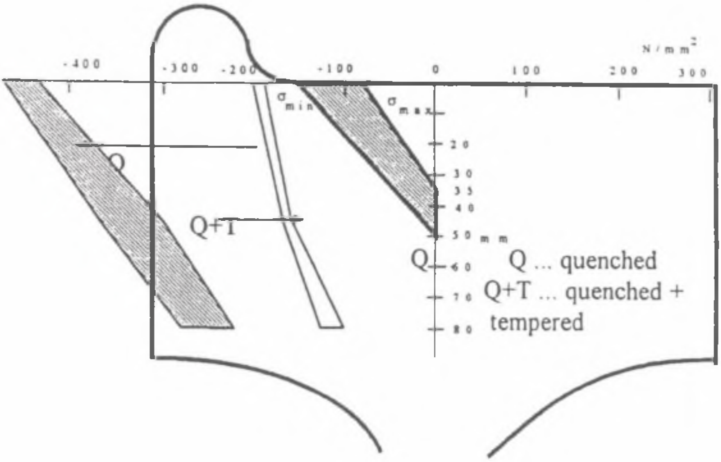


Fig.6a. Determination of surface residual stresses in carbon steel R7T wheel rims by ultrasonic method (DEBRO-30)

Rys.6a. Określenie naprężeń własnych powierzchniowych w kole ze stali węglowej R7T metodą ultradźwiękową CEN (DEBRO-30)

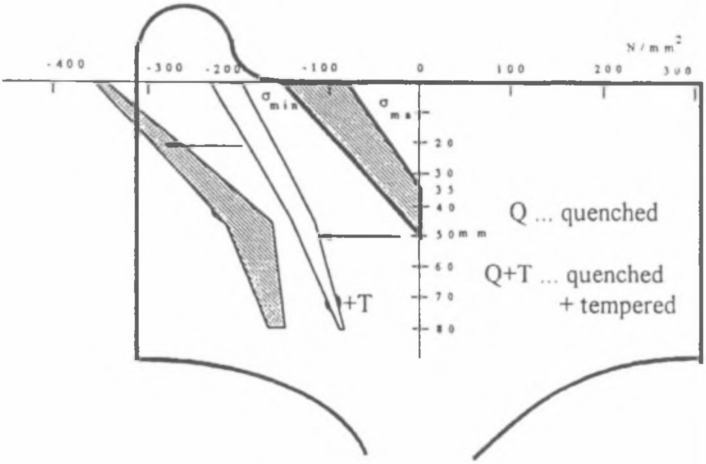


Fig.6b. Determination of surface residual stresses in microalloyed steel R7T wheel rims by ultrasonic method (DEBRO-30)

Rys.6b. Okreslenie naprężeń własnych powierzchniowych w kole ze stali niskostopowej metodą ultradźwiękową CEN (DEBRO-30)

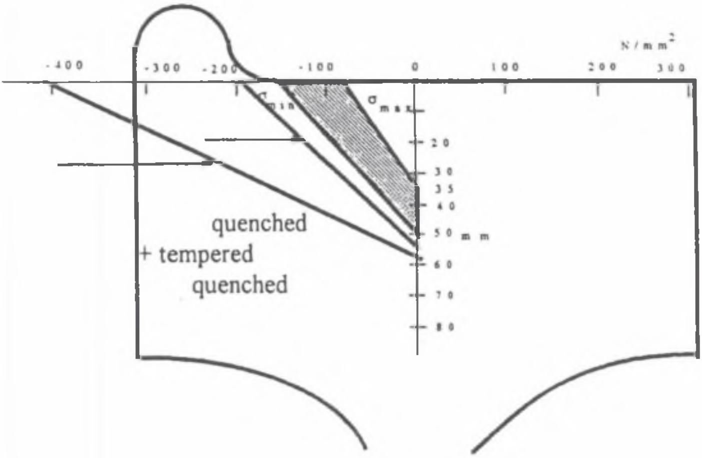


Fig.7a. Determination of bulk residual stresses in carbon steel R7T wheel rims by CEN cutting method
Rys.7a. Określenie naprężeń własnych w kole ze stali węglowej R7T metodą trepanacyjną CEN

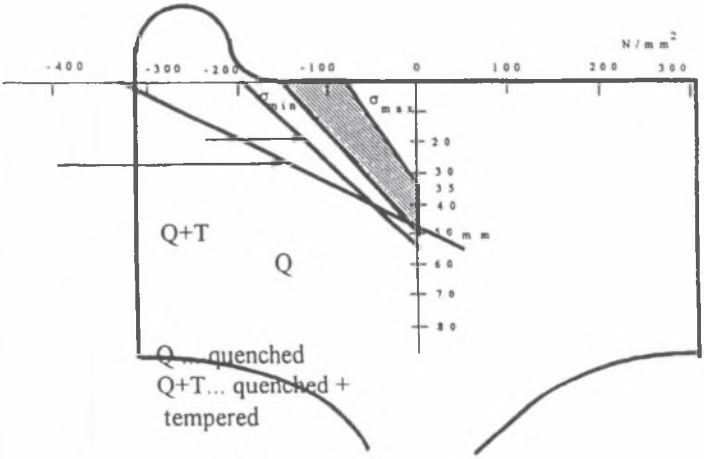


Fig.7b. Determination of bulk residual stresses in microalloyed steel R7T wheel rims by CEN cutting method
Rys.7b. Określenie naprężeń własnych w kole ze stali niskostopowej metodą trepanacyjną CEN

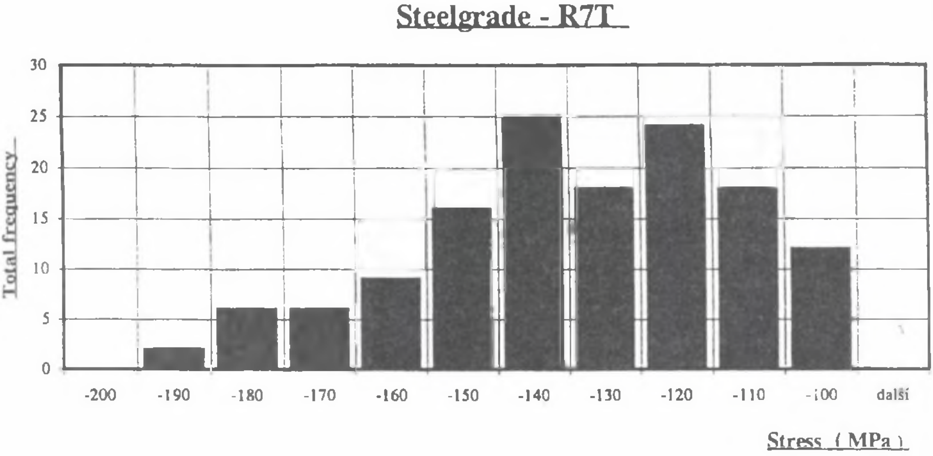


Fig.8a. Frequency histogram of residual stresses measured near the tread
Rys.8a. Histogram częstotliwości występowania naprężeń własnych mierzonych w pobliżu okręgu tocznego

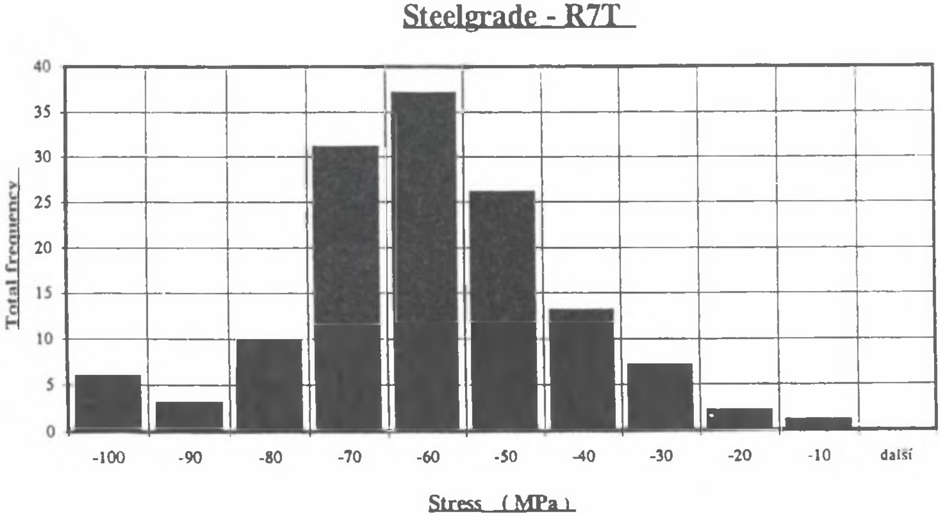


Fig.8b. Frequency histogram of residual stresses measured near the rim – web edge
Rys.8b. Histogram częstotliwości występowania naprężeń własnych mierzonych w pobliżu obrzeża koła

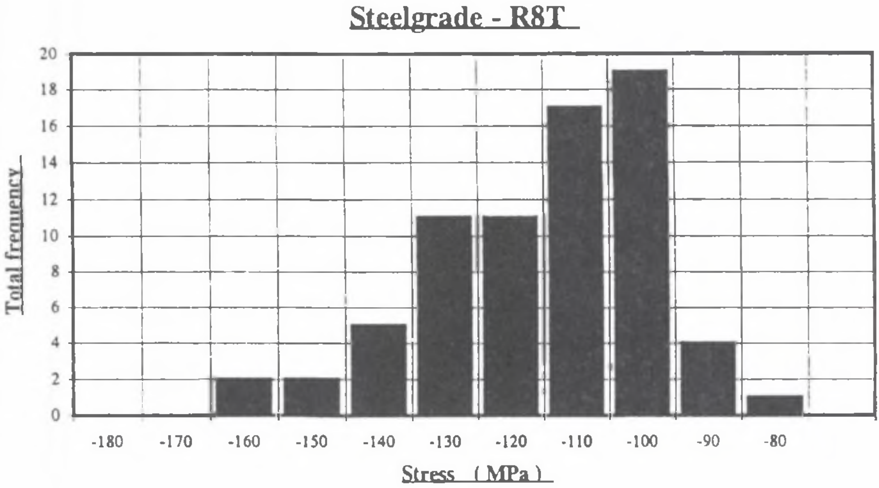


Fig.9a. Frequency histogram of residual stresses measured near the tread
Rys.9a. Histogram częstotliwości występowania naprężeń własnych mierzonych w pobliżu okręgu tocznego

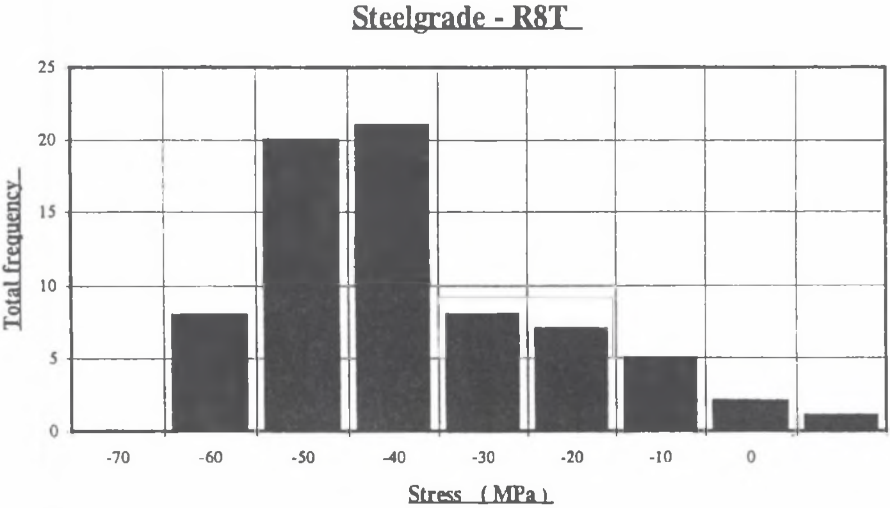
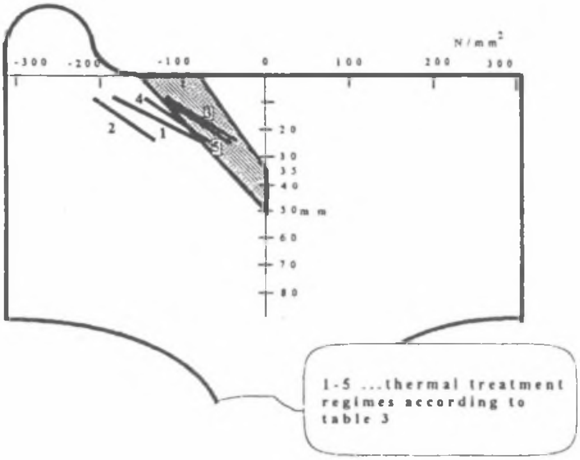


Fig.9b. Frequency histogram of residual stresses measured near the rim – web edge
Rys.9b. Histogram częstotliwości występowania naprężeń własnych mierzonych w pobliżu obrzeża koła



1-5 ...thermal treatment regimes according to table 3

Fig.10. Bulk residual stresses in the R7T wheel rims treated by various regimes of spraying (measured by DEBRO-30)

Rys.10. Naprężenia własne w kołach ze stali R7T po chłodzeniu (pomiar DEBRO-30)

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Streszczenie

W artykule porównano trzy metody pomiaru naprężeń wewnętrznych we wieńcach kół (metodę ultradźwiękową urządzeniem DEBRO-30, metody odwiercaniem z użyciem tensometrów według normy ASTM E 837 i metodę dzielenia profilu wieńca z użyciem klasycznych tensometrów według propozycji normy CEN/TC256/SC2/WG11). Przedstawiono ocenę wpływu składu chemicznego według specyfikacji UIC 812-3 i rozrzutu wielkości objętościowych i powierzchniowych naprężeń wewnętrznych po obwodzie koła namierzonych metodą ultradźwięków, a także ocenę wpływu technologicznych parametrów obróbki cieplnej (parametry opryskiwania, odpuszczania) na zmiany rozłożenia naprężeń wewnętrznych we wieńcu kół z materiału R7T według UIC 812-3.