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THE NEW TECHNOLOGIES FOR INCREASE FATIGUE STRENGTH OF RAILWAYS WHEELSETS AND METHODS FOR VERIFICATION A QUALITY PROCEEDINGS

Key words

Railway wheel, axle, wheelset, protective coating, fatigue strength, surface strength, shot peening, hardness, Almen test, residual stresses, roller burnishing, non destructive method.

Summary

In this paper, we will describe new methods and technology in production of railway wheels and axles. The aim of these new methods and technology is to increase fatigue strength of railway wheels and axles, and, by this, to also increase their reliability in railway service. In this paper, we will again describe new methods for the evaluation and certification of production quality during serial manufacture, including a description of verification tests and a reliability of these new methods within the scope of qualification tests.

Introduction

Considerable financial means have been recently invested worldwide into the construction and modernisation of railway corridors and into the purchase of new modernised railway units, including high-speed units, that can run at speeds exceeding 200 kph. Wheels for newly manufactured railway wheelsets in

Europe are mostly manufactured from carbon steel with the resulting pearlitic structure with small ferrite content – steel grades ER7T, ER8T, ER9T to EN 13262; for American markets, they are made from pearlitic steel grades Class B, Class C, to the standard AAR M107. Regarding axles made to the standard EN 13261, prevailing grades are carbon ferritic-pearlitic, such as steel grade EA1N or medium-alloyed heat-treated grades EA4T. These wheels and axles show sufficiently high fatigue strength. Taking into consideration high operational demands, however, we need to continuously search for new ways for further improvement of fatigue properties of wheels and axles.

1. Increasing fatigue strength of railway wheels

Fatigue damage occurs in railway wheels in the area of fixing the wheel web into the wheel hub that is pressed onto axle with interference. For railway wheels, especially at the American markets, a request is raised for increasing their fatigue strength through their blasting, which is called "shot peening" to the standard AAR M-107/M208 art. 7.0.

Main advantages of shot-peened wheels:

1. Increasing of wheel web fatigue strength by approx. 30% compared with the requirement of the standard EN 13262 that defines that the wheel must sustain, in the critical area, loading amplitude of ±240 MPa during 10 million cycles without crack initiation in this critical area. Fatigue strength is verified on electro-hydraulic testing equipment dedicated to wheel fatigue tests – see Fig. 3.
2. Introducing pressure stresses into the wheel web and more uniform residual stresses on blasted surface.
3. Surface strengthening – increasing hardness.

The required effect is reached by a stream of blast medium that is thrown at a rotating railway wheel by two blasting units. The speed of blast medium stream and its volume can be continuously controlled by a change of revolutions of the engines of the blasting units and by the amount of blasting shots. Railway solid wheels prepared for shot-peening are either completely finish machined or with wheel web finish machined and wheel rim – tread and rim faces – in a rough machined state. Surfaces that should not be blasted and that are already finish machined must be protected against effects of blast medium by means of masking equipment (Fig. 1). Only after shot-peening rough machined surfaces are finish machined.

In order to meet the requirements of standards and to secure stable and reproducible results in all wheels after shot-peening the following parameters have to be regularly checked:

1) blast medium size,

2) blasting intensity, and
3) the degree of blasted surface cover by the blast medium.

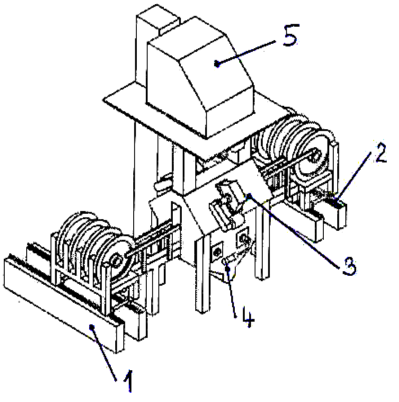


Fig. 1. Scheme of shot-peening equipment for railway wheels [1]: 1, 2 – containers for wheels before and after shot-peening, 3 – blasting unit, 4 – separation equipment, 5 – dust filters

Sub 1) Check of blast medium (blast shots) size is neatly linked with impact energy of blast shots and, therefore, also by blasting intensity. The size of blast shots used for shot peening must be at least to SAE 550; since, the shot sorting unit is equipped with a sieve of mesh size 1.4 mm, it is most advantageous to use size to SAE 660, grade to SEA J 827. Checking the shot size must be performed at least once a shift, together with the replenishment of the container with new shots.

Sub 2) Blasting intensity must at such a level that will allow the deflection of testing tablets ALMEN C by at least 0.2 mm and complete 100% cover of surface. At 100% cover, the whole blasted surface shows overlapping dotting. A wheel will be blasted by a selected automatic cycle, and ALMEN tablets will be measured in the tool with a help of a digital dial gauge. The value of deflection must be at least 0.2 mm and maximally 0.4 mm. A difference in deflection of tablets placed by the wheel rim and by the hub should not exceed 0.07 mm.

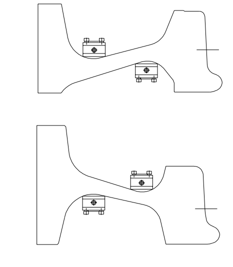


Fig. 2. Method of Almen tests fixing on wheel web

Quality of covering is checked on new and machined and not yet blasted wheels in areas where tablets holders are placed. See the standard SAE J2277 (Fig. 2).

Sub 3) Degree of blasted surface cover is evaluated visually with a pocket microscope with 30x magnification. Blasting time is selected in such way that will allow 100% cover of the surface. Evaluation may also be performed by means of a special fluorescent method or by means of an alcohol marker (Fig. 3).

Fig. 3. A view of a wheel after shot-peening and of the testing equipment built in BONATRANS GROUP a.s. dedicated to railway wheels testing

2. Possibilities for improvement of fatigue properties of railway axles

Contrary to railway wheels, there are many possibilities of how to improve fatigue strength of railway axles (Tab. 1). The following fatigue limits are defined in the standard EN 13261 that a solid railway axle has to sustain during testing in individual section areas (in the area of pressed joint where especially fretting corrosion is in effect, and in the area of the axle body where it is about standard fatigue strength).

Table 1. Shaft / free surface

Steel grade	Fatigue strength on the free surface. (MPa)	Fatigue strength on the seat surface (MPa)
EA1N	200	120
EA4T	240	144

The dependence on a ratio between the pressed joint diameter and the axle body diameter, fatigue strength of a pressed joint and/or of the axle body are especially tested on a resonance testing equipment shown at the Fig. 4.

Fig. 4. Resonance testing equipment dedicated to fatigue testing of railway axles

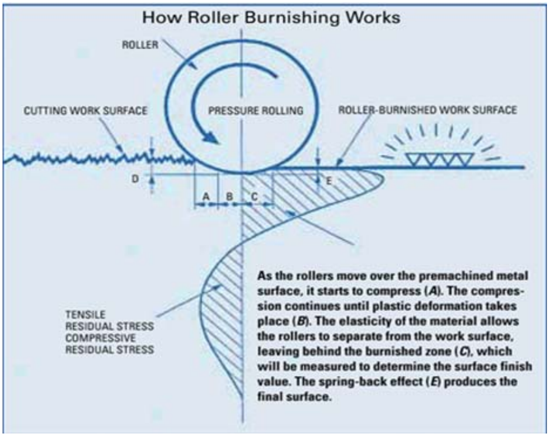
One of possible options for increasing fatigue strength is the roller burnishing of the surfaces of seats and the transitions to the axle body, or the strengthening of surface layer by the application of a metal layer, e.g. Molybdenum layer, ferroalloys, etc., or by special heat treatment, e.g. induction quenching of already heat treated axles that is preferred especially in Japan. We will now describe individual methods in more detail and introduce suggested evaluation of the quality of such modified surfaces.

2.1. Roller burnishing of axles

Two types of technology are used for axle roller burnishing in BONATRANS GROUP a.s.:

a) ECOROL – roller burnishing with surface strengthening to a small depth, and
b) MASTURN – strength roller burnishing with higher sub-surface strengthening.

Sub a) A special device is used for roller burnishing by this method with a rolling ball supplied by ECOROL company (Fig. 5). Roller burnishing by this method is applied on finish machined and ground axles, since roller burnishing by this method does not change the final dimension of the product. During axle roller burnishing, the ball is pressed by a hydraulic device on the axle surface while the ball may freely turn due to a film of pressed grease emulsion fluid.



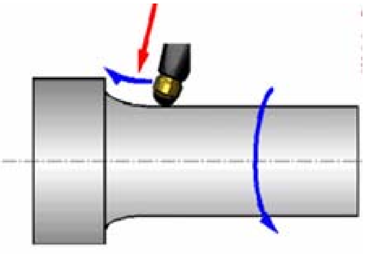


Fig. 5. Schematic illustration of roller burnishing principle through ECOROL technology

Depending on diameter of strengthened surface and the requirement on strengthening, approximately, the following parameters are selected: Feed speed approx. 100 mm/min., speed of rotation of the axle between 140 and 180 revolutions per minute and pressure of emulsion fluid that presses the ball and at the same time allows greasing during rotation and cooling of the ball set between 225 and 250 bar.

Sub b) The equipment MASTURN MT 70C CNC ROLLER is used with the technology of roller burnishing of cylindrical and transitional radial surfaces by means of thrust pulleys shown in the following figure (Fig. 6). Roller burnishing may be performed on cylindrical surfaces as well as on transitional radial surfaces and other profiles, provided that the vector sum of instantaneous radial and axial forces actuates perpendicularly to the burnished surface of the roller. This is secured through the tilting of roller burnishing heads within the range of ± 35° from the mean position perpendicular to the spindle axis. Tilting of heads is carried out as an individual twinned NC axis. Roller burnishing of transition axle body–seat is performed on axles machined with allowances on ground areas only, and other areas are finish machined to final dimensions. Roller burnishing of the transition journal–dust collector is performed on the ground surface.

Fig. 6. Roller burnishing thrust pulleys

The following approximate parameters are selected during roller burnishing: axle rotation approx. 150 min.$^{-1}$, feed approx. 0.1 mm/rev., roller burnishing force that is evoked by a hydraulic unit from 5 to 13 kN selected in the dependence on roller burnished transition.

The following figure (Fig. 7) shows a comparison of the difference between surface strengthening by roller burnishing and by shot-peening.

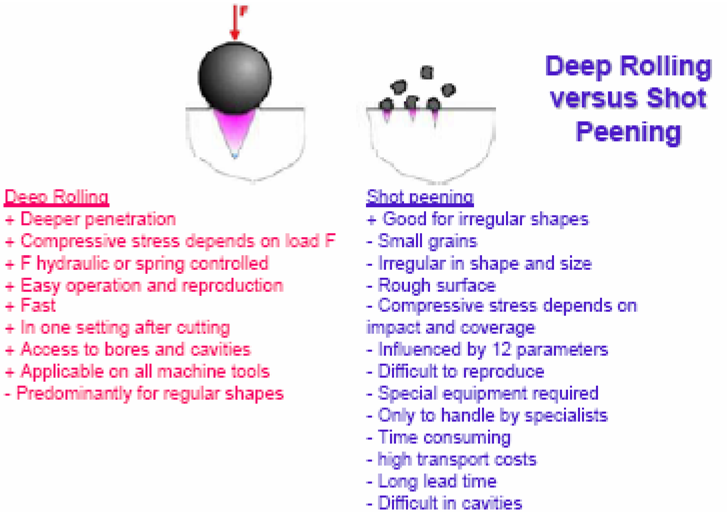


Fig. 7. Comparison of the differences between shot-peening and roller burnishing by the ECOROL technology [2]

Similarly as in surface strengthening by means of shot peening, we can reach, in roller burnished axles, an increase of fatigue strength by up to 25%. We will now describe a method of how to evaluate the quality of the roller burnished surface on delivered axles. Evaluation methods may be divided into

– Destructive methods – in which the axle is destroyed because of execution of a test required by the customer.
– Non-destructive methods – measurement may be carried out on 100% of delivered axles depending on customer requirements.

Sub a) It is a method of a measurement of surface hardness by reflexive dynamic ball hammer and a method for the determination of residual stresses introduced to surface layers by the method of gradual drilling,

Measurement of surface strength is carried out by means of a delivered special dynamic ball hammer and a probe dedicated for the measurement of hardness on the ground and fine machined surfaces. The principle of this method is the measurement of the kinetic energy of a ball shot against the surface and the kinetic energy of a ball reflected from the measured surface. Kinetic energy is scanned by means of an electromagnetic induction coil. A drop of energy depends on hardness and the modulus of elasticity of the measured material. The advantage of this method is the fact that, in combination with a selected probe, it does not leave a substantial indentation in the material and, based on customer request, it can be used as a non-destructive method and axles can subsequently be used in operation. A view of a dynamic ball hammer used in BONATRANS GROUP a.s. is shown in Fig. 8.

Fig. 8. Dynamic ball hammer used in BONATRANS GROUP, including a view of a probe used for measurement of hardness by reflection method

A strain gauge method of measurement of stresses through the method of gradual drilling is another method used for the measurement of sub-surface residual stresses (Fig. 9). By drilling of a hole in a surface layer, stress around the hole is relieved. Such stress can be measured in a form of relieved deformations by means of a glued strain gauge rose 0°-45°-90. Such measurement was also carried out on fatigue testing bodies of a scale 1:3 manufactured from EA4T grade. The results of measurements shown in Fig. 10, where a positive influence of roller burnishing of a surface layer by the ECOROL technology (ball), can be seen.

Fig. 9. View of the drilling device used for destructive measurement of residual stresses

While measured and determined mean stresses in a machined fatigue test bar of grade EA4T were around zero up to +100 MPa, a sub-surface high pressure stress near the yield point of the material was determined in a bar that was roller burnished by the ECOROL method. This bears evidence about plastic deformation of the material surface layers during roller burnishing. Discontinuity on the stress curve has been measured on the test rod with EA4T steel grade. This result is due to the measurement of small values and also the high sensitivity of the released deformations measurement integral method [3].

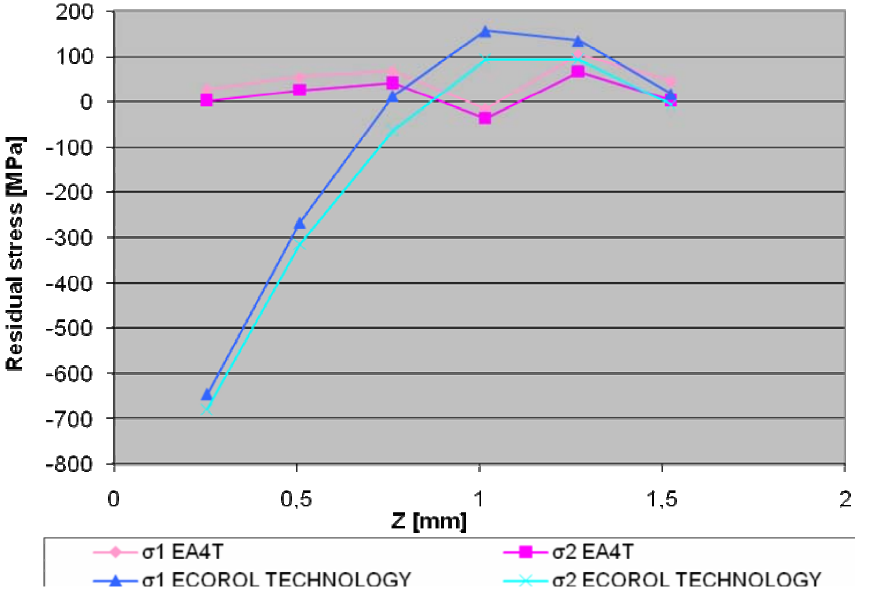


Fig. 10. Graphic relationship of measured sub-surface residual stresses on a test rod grade EA4T and the same rod submitted to roller burnishing by the ECOROL method

The new non-destructive method of measurement of sub-surface stresses and/or of hardness is prepared in relation to previous customer requirements on the quality inspection of roller burnished axles that underwent the roller burnishing ECOROL technology or the technology of roller burnishing and strengthening of hardness to larger depth MASTURN 70/300 CNC ROLLER. After several discussions with foreign companies, a device developed by the Instytut Mechaniki Precyznej (IMP) Warsaw was selected. The device works on a principle of the measurement of the decrement of eddy currents. It is therefore a non-destructive method. Eddy currents are considerably influenced by electric conductivity and the magnetic permeability of materials. Since these properties depend on the degree of heat treatment and the degree of material transformation, they can also be used for the measurement of hardness and stresses.

The WIROTEST device (Fig. 11) consists of the device itself and of a measurement probe. The device itself contains a high-frequency generator with a measurement frequency up to 9.5 kHz and a measurement part with memory. At the front face, it is equipped with a digital display for immediate reading of measured values. Different measurement probes are used for the measurement of stresses and hardness. The design of a measurement probe also depends on the shape of a measured area. Transfer of measured values and their computer processing is performed through a MS Excel program Wiroterminal.xls.

Measurement of surface stresses and hardness is a comparative measurement. In order to evaluate measurement results quantitatively, it is necessary to perform calibration on the calibration blocks. For the measurement of hardness, calibration blocks are available that were calibrated by means of the etching RTG method (X-ray diffraction). The depth of penetration of an eddy current changes with a change of frequency, which enables the measurement of stresses in four steps as a function of distance from the surface to the depth of approximately 2.5 mm.

The non-destructive nature of measurement destines provides the WIROTEST device 100% inspection on seats and transitions of seats after roller burnishing.

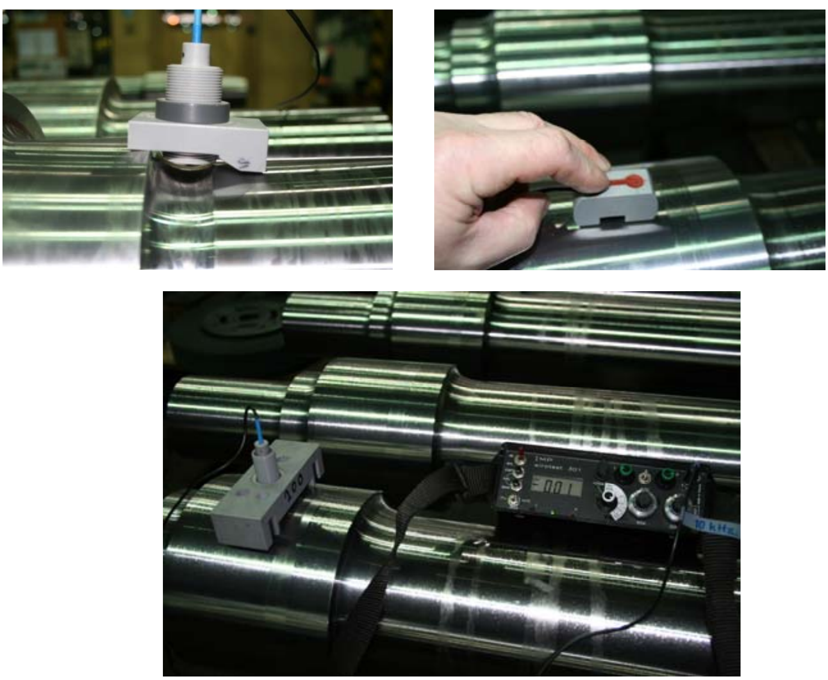


Fig. 11. View of WIROTEST device including measurement probes

2.2. Application of protective coating in the area of axle seats

Another way that can increase fatigue strength of railway axles in a pressed joint is the application of protective coating, e.g. Molybdenum layer or ferroalloys, etc. Application of Molybdenum coating is used especially for German customers.

Application of a protective coating on the surface of pressed joint has generally the following functions:

- Increases fatigue limit in the pressed joint,
- Helps easier assembly and subsequent disassembly of wheels,
- Prevents the origination of corrosion (especially fretting corrosion) in the pressed joint, and
- Extends initiation stage till the time of the creation of micro-cracks and subsequent fatigue cracks in the base material compared with surface without the application of protective coating.

We can meet friction corrosion (fretting corrosion) in railway applications, especially in the pressed joints between the railway wheel and the axle seat in operation, where there are repeated relative movements with small amplitude of mutual movement (0.025 mm). Small oxide particles start to occur at the surface of the railway axle in the pressed joint that are sometimes accompanied by localised pitting visible at the contact surface of the axle. At certain operational conditions, fretting corrosion may lead to nucleation of fatigue cracks and to fatigue fracture of the axle. Axle fatigue strength in the pressed joint reaches only approximately half the value, compared with the axle fatigue limit at the bare surface.

By application of protective coating by Molybdenum or by ferroalloys, conditions for the initiation and propagation of a fatigue crack in the pressed joint change. Namely, the origination of corrosion products and pitting at the axle seat surface and their subsequent propagation in the form of fatigue crack initiation are slowed down, which has an effect in the positive increase of fatigue limit by up to 30%. [4].

Evaluation of adhesion of a thermally applied coating to the base material (surface of the testing sample) is an inseparable part of quality inspection. Evaluation is performed by means of shear tests with the defined surface of the coating (1695 mm^2). A layer of coating of a thickness of at least 800 μm is applied on surface of the testing sample, and the sample is subsequently extruded through a smaller shear hole. Application of coating is performed in the same way, with the same surface preparation (blasting by cast iron grit) and preheating, as it is applied, e.g. during the application of a coating onto the axle seat. During extrusion, we monitor and record the maximal force necessary for shearing off a certain ring from the coating with a defined area of the applied coating. Results are then recorded in $N.mm^2$. The average value from three shear tests of Molybdenum coating should not be smaller than 40 $N.mm^2$, and the minimal value must not be below 30 $N.mm^2$.

Measurement of adhesion of Molybdenum and other coatings by peel test is a newly developed method for the evaluation of the quality of applied protective coatings. The peel testing device enables automatic performance of adhesion test by means of a target with diameter 20 mm glued to the axle with applied Molybdenum or other protective coating. This evaluation has a decisive influence on the evaluation of the reliability of the applied layer, particularly on achieving the stated values of fatigue strength (Fig. 12).

Fig. 12. View of a peel-testing device used for the measurement of adhesion of applied layers

3. Conclusion

There are recently many methods that we have partly described and that enable the increasing of fatigue limits of railway wheels and axles. Together with putting these methods into practice, it is also necessary to develop new methods for the evaluation of the quality of such applied methods on the final products, so that required values of higher fatigue strength of these parts may be reached in real loading in service. As regard to the testing of products, non-destructive testing methods are preferred that may be applied on 100% of products with sufficient measurement accuracy and rate of such evaluation. Some of the described methods and equipment still need to be finalised with their producers in terms of concrete technology and manufacturing conditions. The authors have sought to show possible directions for the development of these technologies and also for methods of their quality evaluation.

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Recenzent:
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Nowe technologie zwiększające wytrzymałość zmęczeniową zestawów kołowych oraz metody weryfikacji procedur jakości

Słowa kluczowe

Koło kolejowe, oś, zestaw kołowy, powłoki ochronne, naprężenia zmęczeniowe, naprężenia powierzchniowe, twardość, test Almena, rolkowanie, metody nieniszczące.

Streszczenie

W artykule opisano nowoczesne metody i technologie w produkcji kół i osi kolejowych zestawów kołowych. Celem prezentowanych metod i technologii jest zwiększenie wytrzymałości zmęczeniowej zestawów kołowych oraz ich niezawodności. W referacie opisano nowoczesne metody oceny i certyfikacji jakości produkcji w seryjnym wytwarzaniu wyrobów.