TECHNICAL TRANSACTIONS | CZASOPISMO TECHNICZNE
MECHANICS | MECHANIKA
3-M/2015

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FRETTING WEAR IN THE WHEEL–AXLE JOINT OF A WHEEL SET WITH AN AUTOMATIC GAUGE CHANGE SYSTEM

ZUŻYCIE FRETTINGOWE W POŁĄCZENIU KOŁO–OŚ ZESTAWU KOŁOWEGO Z AUTOMATYCZNĄ ZMIANĄ ROZSTAWU KÓŁ

A b s t r a c t

An essential problem in the usage and maintenance of a wheel set with an automatic gauge change system is posed by the wear on the surface of wheel-axle rotary joint. Operational tests have shown that the problem includes fretting wear. This article presents an attempt at explaining this type of wear in a wheel-axle rotary set. The tests were performed on a joint model in which the similarity with the real object in the aspect of dimensions was maintained as well as the character and value of loading. In the description of the fretting wear mechanism in a rotary joint an analogy with wear in a wheel-axle press-fitted joint of a conventional wheel set was shown.

Keywords: railway vehicle, wheelset, railway technology, fretting wear

S t r e s z c z e n i e

W artykule przedstawiono problem eksploatacji i utrzymania zestawu kołowego z samoczynną zmianą rozstawu kół powodowany przez zużycie powierzchni połączenia obrotowego koło–oś. Określono typ zużycia, które występuje w połączeniu obrotowym koło–oś. Badania przeprowadzono na modelu połączenia z zachowania podobieństwa wymiarowego do obiektu rzeczywistego. Przedstawiono analogię mechanizmu zużycia frettingowego w połączeniu obrotowym do zużycia frettingowego w połączeniu wciskowym.

Słowa kluczowe: pojazd szynowy, zestaw kołowy, zużycie frettingowe

DOI: 10.4467/2353737XCT.15.174.4379

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1. Introduction

The Polish railways, operating in places of two different track gauges, with eight transfer stations on the eastern border, could derive great economic benefits from improving cargo transport between Europe and Asia. The stations at the border of countries that use different track gauges occupy large areas, their track layout is complex, they are equipped with numerous facilities and instruments, and they are staffed by many people. During reloading there is a high risk of ecological contamination of the area. Hazardous cargo transport by rail is impossible because their reloading is prohibited.

What could significantly improve railway transport would be the introduction of rail cars furnished with wheel sets of adjustable gauge of wheels moving from the standard gauge directly to the wide-gauge track and back through a gauge changing facility, built at the contact point of the two tracks. This would eliminate all the difficulties mentioned above.

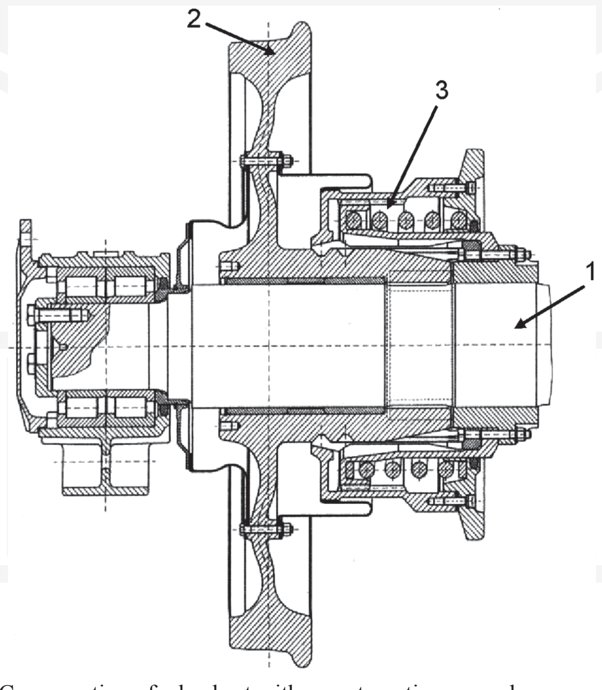

Fig. 1. Cross-section of wheel set with an automatic gauge change system [1]

In an attempt to solve the problem, in the late 1990s an original wheel set was designed and manufactured at the Central Design Bureau of Polish Railways in Poznań. The new wheel set would enable unmanned, automatic transfer from a track of a certain gauge to a track of a different gauge (1435/1520mm), via the gauge changing facility. Part of the cross section of the wheel set discussed has been shown in Fig. 1. Its basic elements include:

– axle (1),
– two wheels moving along the set axle (2),
– locking mechanism (3).

What is the essential element of the design is the wheel-axle joint? Unlike the traditional wheel set, in which the wheels are joined with the axle permanently due to pressing, it is a free assembly joint. This solution makes it possible for the wheels to move along the axle when the wheel gauge is being changed, and to be next locked against the axle during travel.

During the initial operation of the set it was found that serious problems in wheel gauge change occurred even after a short distance covered (1.5 thousand km) [1]. There was a considerable increase in the force necessary for the wheel movement along the axle, which even resulted in damage to the gauge changer. The observation of the wheel seat surface after disassembly of the wheel set showed that there appeared to be fretting wear in the area of contact with the wheel hub. Moreover, considerable grease ageing processes were noticed, which resulted in wheel locking on the axle during the wheel gauge change.

The process of fretting wear in the traditional wheel-axle joint has been described in detail [2], but this only dealt with the press-fitted joint, and the analysis was performed on the basis of results of model studies. In the case of the wheel set with automatic wheel gauge change, however, we are looking at a free assembly joint. This is why the different state of the outer layer of the joined surfaces is observed already at the joining process phase, and this difference may initiate the fretting wear.

This article presents the results of studies on a model of a wheel set with automatic wheel gauge change, simulating real operation conditions and verifying the possibility of the development of fretting wear.

2. Investigation of wear in the wheel-axle with an automatic gauge change system

To explain the mechanism of fretting wear propagation in a wheel-axle joint of a railway axle assembly with an automatic gauge change system, experiments were performed on models simulating the real wheel-axle joint. The dimensions of the specimen (shaft, sleeve) and the material were selected so as to ensure similarity with a prototype pair of the real axle assembly (Fig. 2). The shaft outer diameter and the sleeve inner diameter were selected so as to ensure the running fit in the joint. In the fatigue tests the sleeve was locked against the shaft (as in a real assembly) to prevent its displacement along the perimeter and transverse displacement in respect of the shaft, while maintaining the radial displacement.

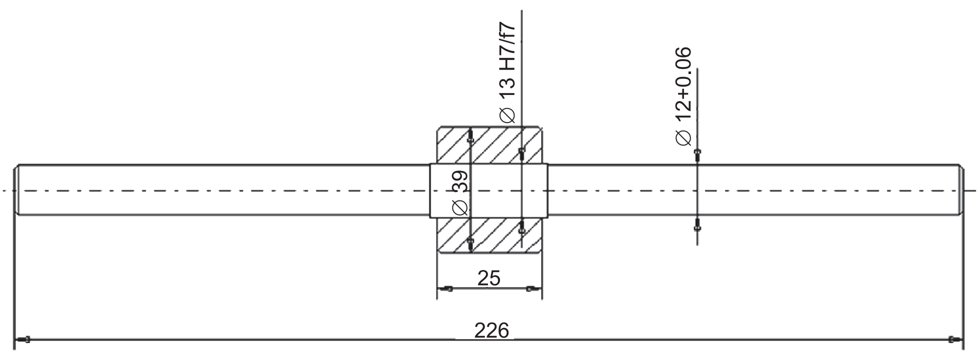

Fig. 2. Dimensions of the sample for modelling tests

The wear tests were performed on a fatigue tester which ensured a load nature in the conditions of rotary bending similar to those in a real wheel set. In the diagram shown in figure 3 the force Q is the base-load of the sample during rotary bending and the force P produces a surface pressure between shaft and sleeve. Forces P + Q simulate the actual static load of the wheelset.

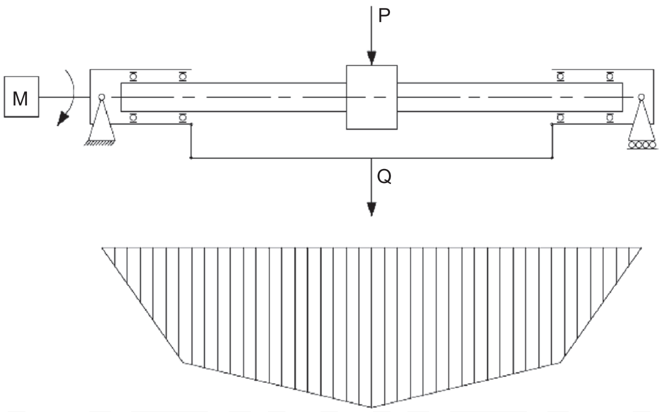

Fig. 3. Specimen loading and bending moment distribution

The tests were performed on a model in which both shaft and sleeve were made from steel (as in the prototype). No lubricants were used in the joint. This variant of specimen preparation was selected in order to obtain the image of the potential wear non-contaminated by other agents. The damage at the coupled elements contact zone will be affected only by the surface pressure from the normal force load P (Fig. 3) and the relative slip between the coupled interface resulting from the deflection of the rotating specimen. These are also the conditions for fretting wear development.

The parameters of specimen testing on the fatigue tester were: rotations n = 1360 rpm, specimen loading Q = 300 N and P = 50 N, number of cycles $N \approx 6 \times 10^6$.

The fatigue tests showed damage on the shafts surface typical of fretting wear. Fig. 4 illustrates a characteristic image of the damage recorded along the length of the joint with the sleeve. Its characteristic feature, common for this type of coupling and loading conditions, is damage distribution, found mainly on the coupling edges.

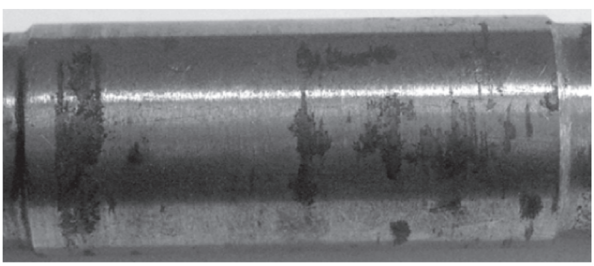

Fig. 4. Shaft surface after fatigue testing – clear marks of fretting wear on shaft edges, with decrease intensity inwards, magnified ca. 3×

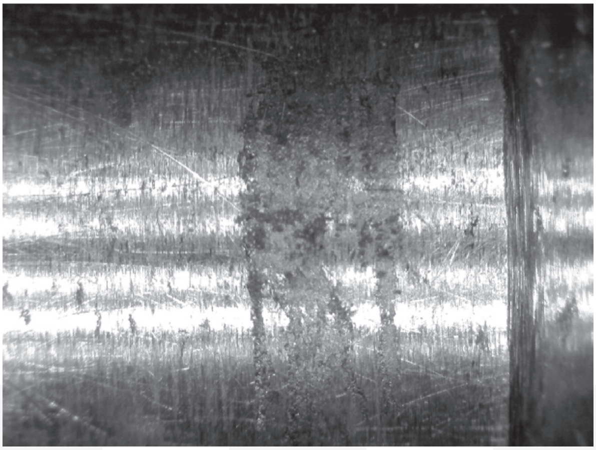

Fig. 5. Macroscopic picture of fretting damage on shaft surface – corrosion marks characteristic of fretting, magn. ca. 15×

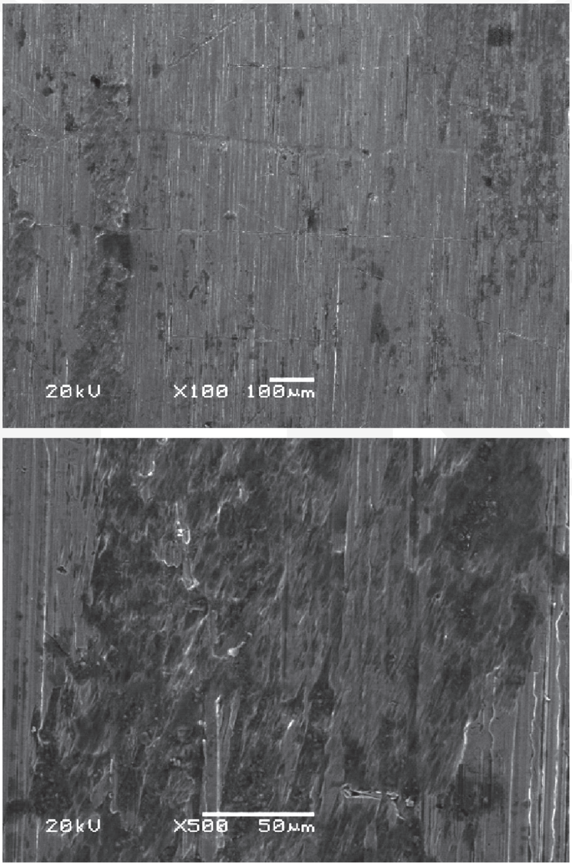

Fig. 6. Scanning picture of fretting damage on shaft seat – pits and material ridges in damage area and its oxidation, magn. 100× and 500×

Fig. 5 shows a macroscopic picture of the surface damage due to fretting wear for selected parts of the shaft seat, Fig. 6 – an image of the damage recorded with a scanning microscope.

For comparison in what follows, the results of tests on a specimen modelling the wheel-axle joint of a conventional axle assembly are discussed. As mentioned before, this is a press-fitted joint. The dimensions of the specimen (shaft, sleeve) and the material were also selected so as ensure the similarity with the real wheel-axle set.

The wear tests were also performed on the MUJ fatigue tester providing specimen variable loading in rotary bending conditions. The parameters of specimen testing were as follows: rotations n = 1360 rpm, load of specimen Q = 400 N, number of cycles $N \approx 6 \times 10^6$. In the tests the specimen loading with force P was disregarded. For models with press-fitted joint this force is of no consequence for wear development. What is essential is surface pressure resulting from press-fitting the sleeve onto the shaft together with the bending moment which determines the relative slips between the coupled surfaces. Moreover, the tests covered various specimen manufacture manners including different roughnesses of assembly surfaces and different values for the press-fitting. The aim was to test and describe the mechanism of fretting wear development in the wheel-axle joint of a rail vehicle axle set.

The figures below present the characteristic images of wear recorded in tests. Fig. 7 shows a macroscopic picture of the damage on the shaft seat surface for various values of press-fitting, while Fig. 8 gives a scanning picture in the area of the fretting damage.

a) b)

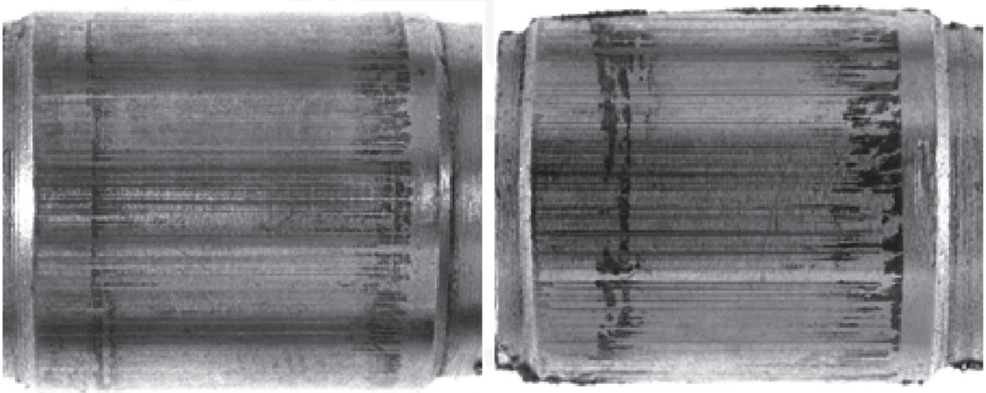

Fig. 7. Photographs of shaft seat after wear tests, press-fitted joint, magn. 4×, press-fitting:
a) – 0,02 mm, b) – 0,04 mm.

The results of tests on a wheel-axle press-fitted joint model show that it is the state of the outer surface of the coupled elements that is the decisive factor in fretting wear development. The state of the surface, in turn, depends on the assembly surface roughness and the value of fitting pressure [2]. The characteristic image of the contact interface for press-fitted joint has been shown in Fig. 8. The effect of the tested factors on the real contact interface is very complex. The decisive aspect is the manner of joint manufacture (press-fitted or thermocompression joint). The other two factors, initial roughness of the surfaces and fitting pressure value are of minor importance, increasing or decreasing the intensity of the changes on the interface.

a) b)

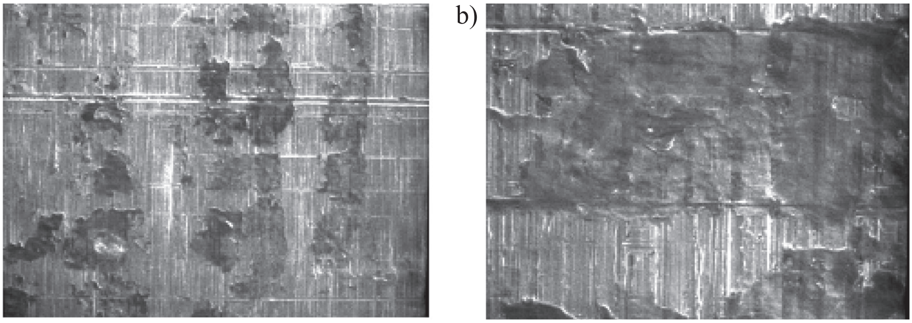

Fig. 8. Scanning picture of fretting wear on shaft seat surface, press-fitted joint,
a) magn. 200× – wear areas scattered on the surface in the form of oxidised ridges,
b) magn. 1000× – material ridges, plastic deformations, pits

a)

b)

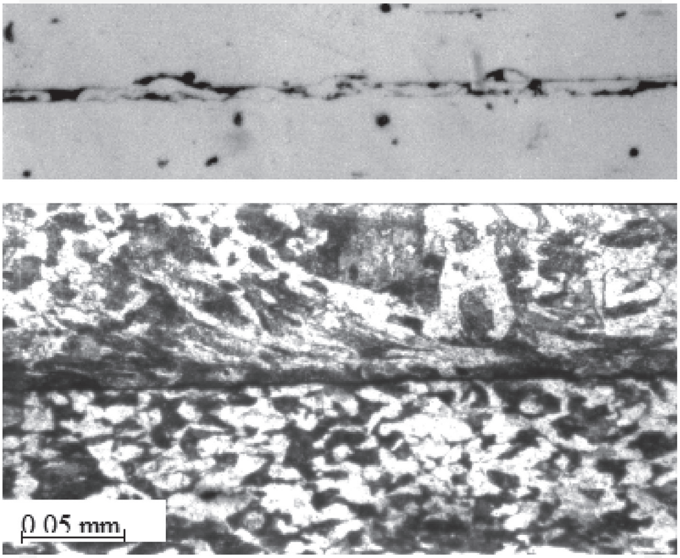

Fig. 9. Shaft-sleeve interface, press-fitted joint, magn. 320×, a) non-etched, b) etched

The press-fitting process results in the surface of the contact region along the length of the joint being uneven. The actual contact of primary (first) bodies takes place mainly in the middle part of the joint. Practically, it does not occur on the edge. The other regions of the joint, in turn, are a place where a third body accumulates as a product of surface micro-irregularities truncation during press-fitting. With the increase of roughness of the joined surfaces the length of the contact region containing the third body increases, while the area of the real contact of the primary (first) bodies decreases. An increased fitting pressure value increases the region of the actual contact of the primary bodies.

In fretting wear development in a press-fitted joint the wear is mainly initiated by adhesion, formation and disruption of adhesion tacking. Other types of wear, also at work, such as plastic deformation, oxidation, micro-machining are of minor significance, they intensify the damage formed earlier due to adhesion tacking disruption. It should be noticed that the majority of researchers [3–8] treat fretting as a phenomenon of very complex wear mechanism, in which adhesive wear, surface fatigue, delamination, oxidation, truncation of irregularities and wear loose by-products overlap or follow each other. The disagreements among particular scientists are derived mainly from the adoption of one of these processes as the initiator of the fretting wear development.

In [2] the fretting wear development mechanism in a wheel-axle assembly was proposed as a process of several stages the most important elements of which are:
- formation of primary (first) bodies actual contact regions during press-fitting,
- generation of relative displacements of very low amplitude at elements surfaces contact due to rotary bending,
- formation of adhesive tacking in regions of actual contact, at joint edges in particular (highest amplitude of relative slips), which next are disrupted to form gaps and ridges on the contact surfaces,
- oxidation of formerly damaged area,
- micro-machining with the oxidised ridge tops of the opposite surface,
- formation of wear by-products as a result of micro-machining – formation of the third body and wear process stabilisation.

3. Conclusions

The comparison of macroscopic and scanning pictures of damage on shafts surfaces in both a press-fitted joint of a conventional wheel set and a rotary one modelling an wheel set with an automatic gauge change system show the similar character of fretting wear development in both joints. The essential conditions for fretting wear development have been met: surface pressures between the coupled surfaces relative slips resulting from specimen deflection in rotary bending conditions. It can then be safely stated, too, that in the wheel-axle joint of an wheel set with an automatic gauge change system the conditions for fretting wear development are satisfied and they will be initiated by the adhesion processes.

Adhesive tacking formation is affected by the following factors:
- physical and chemical properties of the coupled metal surfaces,
- the value of pressure in the contact between the coupled surfaces,
- no oxidised layers on the contact surface,
- the amplitude of the coupled elements oscillations.

The fretting wear development is restricted by, first of all, prevention of adhesion. Oscillations, due to the coupling working conditions, cannot practically be restricted.

One of the ways to eliminate or restrict adhesion, and consequently fretting wear, is to manufacture the elements contact surfaces from materials with a high toughness gradient or to use appropriate lubricants in the joint.

Fig. 10 presents a picture of molybdenum shaft seat surface coupled with a steel sleeve in a rotary joint after fatigue tests using the same parameters as in the rotary joint model. The molybdenum surface hardness was 460 HV that of steel shaft 210 HV. Complete elimination of fretting wear is evident.

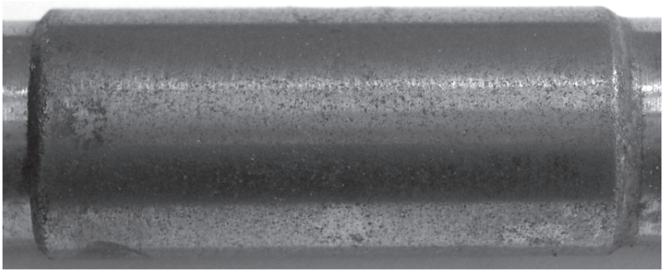

Fig. 10. Surface of molybdenum shaft after fatigue tests – no fretting wear, magn. ca. 3×

A similar effect was obtained when Glacier grease was used in the coupling. The shaft and sleeve were made from steel, similar to the rotary joint model. The image of the shaft surface after fatigue tests is shown in Fig. 11.

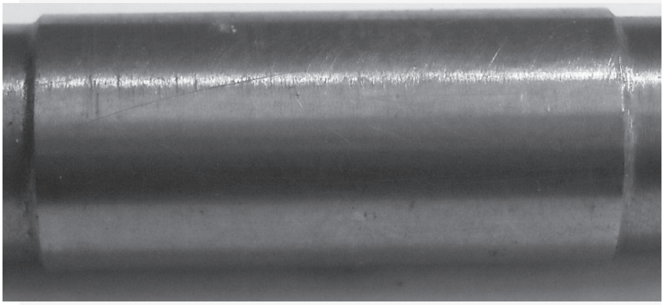

Fig. 11. Surface of steel shaft lubricated with Glacier grease after fatigue tests – no fretting wear, magn. ca. 3×

The examples of shaft surfaces after fatigue testing in manufacture variants other than the prototype model to restrict adhesion confirm the very favourable effect leading to fretting wear elimination. In this way the thesis is also confirmed that the fretting wear process is initiated by adhesion.

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