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INFLUENCE OF TECHNOLOGICAL METHODS INCREASING SURFACE LAYER DURABILITY ON AXLES FRETTING WEAR IN RAILWAY WHEEL SETS

WPŁYW TECHNOLOGICZNYCH METOD PODWYŻSZENIA TRWAŁOŚCI WARSTWY WIERZCHNIEJ NA ZUŻYCIE FRETTINGOWE OSI KOLEJOWYCH ZESTAWÓW KOŁOWYCH*

The article presents studies whose aim is to use such technologies of improving surface layer of a wheel seat that would eliminate fretting wear. The studies were carried out on a simplified physical model of an actual connection between the wheel and the axle of a wheel set with a self-acting wheel track change. The results of carried out wear studies show that fretting wear development can be successfully limited when metallic coating in the form of molybdenizing is used. Carried out studies indicate that such a solution can be fully used in actual exploitation.

Keywords: *wheel set, surface layer, fretting wear.*

W niniejszym artykule przedstawiono badania mające na celu zastosowanie takich technologii ulepszania warstwy wierzchniej podpiaścia zestawu kołowego, które eliminowałoby zużycie frettingowe. Badania zostały przeprowadzone na uproszczonym modelu fizycznym rzeczywistego połączenia koła i osi zestawu kołowego z samoczynną zmianą rozstawu kół. Wyniki przeprowadzonych badań zużyciowych wskazują, że obróbką skutecznie ograniczająca rozwój zużycia frettingowego może być zastosowanie powłoki metalicznej w postaci molibdenowania. Przeprowadzone badania wskazują na pełną możliwość zastosowania tego rozwiązania w rzeczywistej eksploatacji.

Słowa kluczowe: *zestaw kołowy, warstwa wierzchnia, zużycie frettingowe.*

1. Introduction

A wheel set is one of the most important subassemblies of a rail vehicle, whose durability and reliability decides about the safety of railway traffic. Its proper functional quality decides both about the safety of railway traffic and about the costs connected with the exploitation of a rail vehicle.

A wheel set of rail vehicles, due to the specific work conditions, is especially exposed to fatigue wear development. Because of the role it plays in driving the vehicle on the track, its failures are inadmissible. Results of exploitation studies of the wheel sets show that occurring wears have a significant influence on lowering the fatigue strength or may be a focal point of fatigue cracks, mainly of a set axle which is its basic element. Observations of a wheel seat surface after the wheel set has been disassembled many times revealed, among others, fretting failures in the area of axle wheel seat contact with a wheel hub.

The results achieved by the authors of this article show that fretting wear may significantly influence development of fatigue wear, especially in a forced- in connection of wheel – axle of a wheel set [2]. A similar problem appears in the case of a wheel set with a self-acting wheel track change in which, because of construction reasons, dimensions of the wheel -axle connection surface fulfill the running fit conditions.

Complex physical-chemical phenomena taking place on the contact surface of the associated surfaces and the influence of many factors cause that the mechanism of fretting wear development is difficult to be described and in literature there is no unique definition. What is common for different scholarly publications is only a statement that fretting wear development is conditioned by the occurrence of surface thrusts in the association and oscillatory slides of very low amplitude not exceeding 150 μm [2, 17, 18, 19]. Fretting wear image can be illustrated by corrosion traces on the surface of elements, increase in the surface roughness, micro-cracks in the surface layer, pits. Fretting is a phenomenon of a very complex wear mechanism, in which overlap or follow in succession: adhesive wear, surface fatigue, exfoliation, oxidation, abrasion of surface irregularities by tops and loose wear products. Fretting wear studies were first of all carried out for associations of concentrated or flat contact and also referred to the proposed wear models [7, 10, 16].

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

It follows from the review of fretting wear study results that wear development is closely connected with actual contact of associated surface elements and with presence in the contact area of the so called third body, while the form of this wear depends mainly on the conditions of slide oscillation and amplitude [9, 10, 11]. Straight majority of authors, enumerating examples of elements or connections in which fretting wear occurs, most often indicate forced- in connections [9, 10, 11, 12, 16]. However, studies on such connections were occasionally carried out [16, 17].

Quoted in work [2] statistical data referring to wear failures of the axle in exploitation conditions show that the place of wear cracks development coincides with fretting wear area development. The above is also proved by the results of wear studies carried out by L. Stasiak [12] on actual wheel sets in laboratory conditions. This shows that there is a probable link of wear failures occurrence of the wheel set axle with fretting wear development.

In the light of the above facts an essential element of providing reliability and safety of the exploited rail vehicle is to eliminate or significantly limit fretting wear development in the wheel – wheel set axle connection. The article presents the results of model studies carried out by the authors, the influence of chosen technological methods of increasing durability of the surface layer on fretting wear of railway wheel sets with an automatic wheel track change.

2. Research object

A classic wheel set of rail vehicles consists of an axle and two wheels which are connected with the axle by forcing-in. Such a stable connection ensures correct and safe rolling of the vehicle along the track. Apart from this basic rail set construction in rail vehicles there are also special solutions, allowing, for example, rolling of the wheel on the axle wheel seat.

In the 90s of the previous century in the Central Construction Office of PKP (Polish Railways) in Poznań a wheel set SUW2000 was designed and made, which allowed automatic, self-acting passing from a track of one width to another one of a different width, performed on a track shift stand.

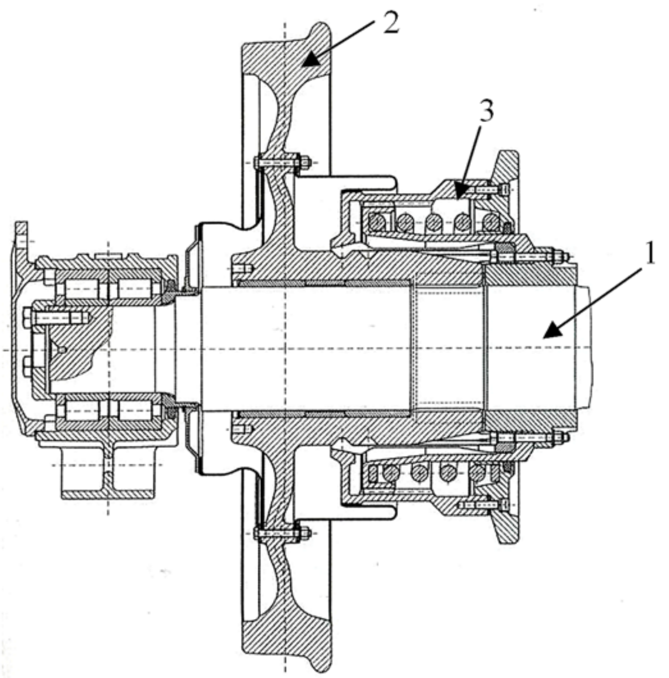

Fig. 1. Cross section of a wheel set with automatic change of wheel track SUW2000 [13];1 – wheel set axle, 2 – wheels rolling on the set axle, 3 – lockup mechanism

A fragment of a cross section of the designed set is presented in Fig. 1. A significant element of the presented construction is the connection of a wheel with an axle. In contrast to the classic wheel set, where the wheels are permanently connected with the axle in result of forcing-in, in this construction the connection is a running fit. Such a solution enables the axial movement of the wheel when changing the gauge at the next lockup of the wheel in relation to the axle when driving. In the prototype set both the wheel and the axle were made from materials in accordance with UIC standards. The wheel from R7E steel and the axle from A1N steel. Chemical composition of those steels is shown in Table 2.

Initial exploitation of the set showed that after not a very long run (about 1.5000 km) there occur big problems during the change of the wheel track [13, 14]. The force necessary to shift the wheels on the axle was increasing significantly, thus leading even to failures in the shift stand. Observations of the axle wheel seat after having disassembled the wheel set showed, among others, fretting failures at the contact area with a wheel hub, as well as significant processes of lubricant ageing. These factors caused lockup of wheels on the axle during its wheel track change. The characteristic feature of fretting wear occurring on the axle of the wheel set with an automatic wheel track change (running fit) is that the place of occurrence and the image of wear is very much like in the case of an axle of a classic wheel set (forced-in connection). Fig. 2 presents a fragment of an axle of both types of a wheel set with fretting wear on their surfaces.

Wear, whose characteristic image is shown in Fig. 2, comprises an area from the front of the hub into the depth of the connection of 30mm in width. Wear occurs on the whole perimeter of the wheel

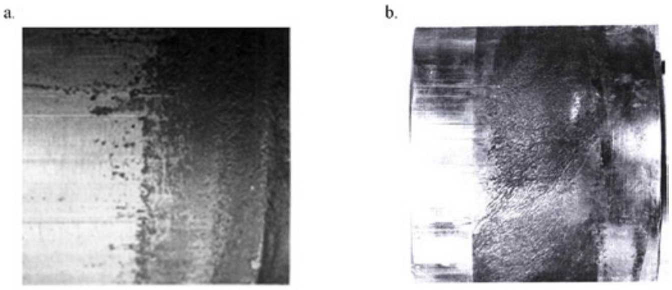

Fig. 2. Fretting wear at the edge of axle wheel seat: a) traditional wheel set [2], b) wheel set with automatic wheel track change [13]

seat surface in the form of a characteristic ring. Failures observed in this surface area are mainly pits and build-ups. The area is also of a characteristic dark brown – black colour, what proves its oxidation. The only difference in wear on both the axles is the place in which it occurs. In the case of traditional connection it occurs mainly in the central part of the axle, while in a running connection it occurs on both sides of the wheel set axle.

2.1. Work conditions of a wheel set

Work conditions of the analysed connection of the running fit a wheel – an axle of the wheel set with an automatic wheel track change may be with a great approximation referred to the forced-in connection a wheel – an axle of a traditional wheel set. The basic difference is only in the initial stress state caused in the top layer of the connected elements. In the forced- in connection, in result of forcing-in the wheel on the axle on the whole contact area there originates an initial state of compressive stresses. It is also accompanied by deformation state in the surface layer of the connected elements. In the case, however, of the running connection a wheel – an axle of a wheel set with an automatic wheel track change, only a non - conformal contact occurs and the stresses result from axial force coming from the set loading.

For studies the scheme of a rail set load presented in Fig. 3 is most often accepted. According to the accepted scheme, a complex system of a wheel set load when the rail vehicle is in motion, is as follows:

- vertical concentrated load P_1 and P_2 acts on the pivots
- lateral force $H_{1,}$ dependent on the wheel position in relation to the rail head, acts on the edge of rolling wheels.

In the wheel set axle there occurs a bending moment which is the result of loads acting on it (Fig. 3). The maximum value of this moment occurs on the axle wheel seat in the plane of R_1 and R_2 reaction (the point of wheel and rail contact), in the area of connection with a wheel hub. The axle, therefore, works in the conditions of rotary bending. The effects of the above, during the set rolling, may be oscillations between an axle and a wheel hub at the edge of connection. The authors of work [1] explain the occurrence of relative micro-displacements in forced-in connection of the axle wheel seat with the wheel hub in the following way: under the influence of external loads (Fig. 3), the axle of the wheel set experiences strains shown in Fig. 4. In the upper axle layers the strains are tensile, while in the lower layers they are compressive ones. This kind of axle strain would not have significant meaning if the wheel hub had similar strains. To have a simultaneous strain of the axle wheel seat and the wheel hub, unitary friction forces p_T at the contact point should be greater or at least equal to the normal strains σ_n in the axle wheel seat. Fretting wear image stated by the authors proves that in this area relative wheel slides occur, what is in agreement with Mindlin's model:

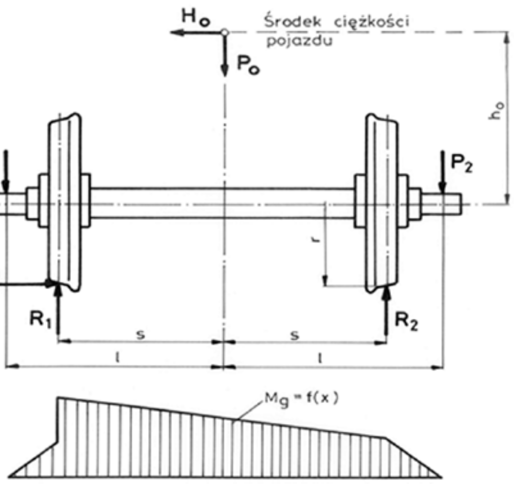

Fig. 3. Load scheme of a wheel set and corresponding to it bending moment distribution when the set is moved to the left [2]

$$p_T = p_{sr} \cdot \mu \le \sigma_n \tag{1}$$

Such a state of loads and strains distribution can also be referred to a wheel set with an automatic wheel track change. In the wheel set between the sliding sleeve and the axle appears running fit, thus, because there are no surface assembling pressures, there is a considerably greater probability of oscillation occurrence between the associated surfaces of the elements, what together with an unfavourable influence of the external forces can lead to wear and failure of the axle, especially in the place of a wheel and an axle connection.

It is difficult to measure the actual sliding amplitude between the contact surface of the sleeve and the shaft in rotary-flexural wear studies. As the results achieved by different authors show, fretting wear development is closely connected with oscillation occurrence. Therefore, it is essential whether in the studied connection oscillations may occur, whose visible effect should be an image of failures on the connection surface. In the work a very simple, approximate evaluation of the sliding amplitude value was proposed, which will be the result of shaft deflection under the influence of acting force Q and P. Fig. 5 presents a scheme of slide occurrence between connected elements of running fit. Fig. 5a shows associated elements without bending moment load but with force P only. Due to this the sleeve is pressed to the upper surface of the shaft, while in the lower surface maximum clearance appears, what is the result of running fit. Points A_1-A_2 are connected with the shaft surface and determine the contact place of the shaft surface and the sleeve head. In result of shaft deflection under the action of the bending moment (Fig. 5b) also the plane coming through points A_1-A_2 will rotate. It will take the position determined by points $A_1'-A_2'$ covering the radius of the shaft deflection curvature. Concave surface of the shaft (compressed) will shorten and the convex (tensioned) one will elongate. In result of this, point A_1 will relocate on the compressed surface under the sleeve, taking position A_1', and on the tensioned surface point A_2 will move outside the sleeve head, taking position A_2'. Displacement quantity of point A_1 in relation to the sleeve head was marked α'.

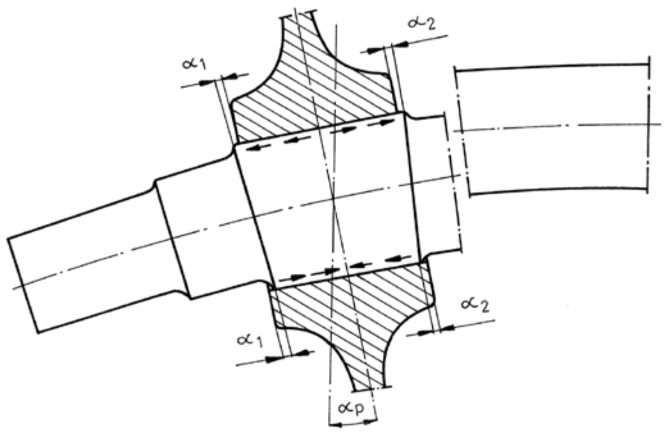

Fig. 4. Wheel set deformation under the influence of external load [1]

Point A_2 on the tensioned surface due to the clearance caused by running fit will not have contact with the shaft surface. A direct

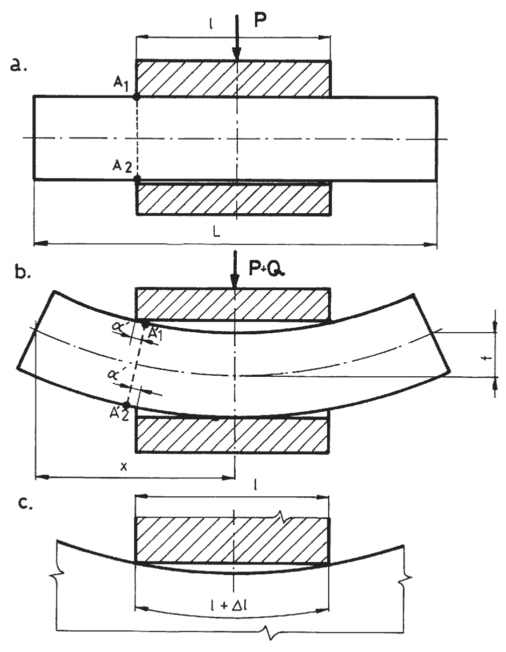

Fig. 5. A scheme of determining slide amplitude between the sleeve head and the surface of the shaft seat: a) a sample in a free state loaded only by force P, b) a sample loaded by bending moment, c) a scheme of sleeve association with the shaft to determine oscillation amplitude

slide between the associated surfaces will take place only on the compressed surface of the shaft. Maximum oscillation amplitude will occur at the sleeve edge and will be equal to α′, while in the symmetry connection axis it reaches zero value.

To determine estimated slide amplitude in the studied connection a model presented in Fig. 5c was used. Loading of the sample by bending moment will cause deflection of the shaft and its result will be elongation of its surface on the length of contact with the sleeve by Δl. value. If we assume that the shaft deflection is a small one and strains are elastic, then to determine Δl elongation Hooke's law can be used, according to which relative linear elongation ε may be determined by formulas:

$$\varepsilon = \frac{\sigma_n}{E} \quad \text{and} \quad \varepsilon = \frac{\Delta l}{l} \,,$$

hence:

$$\Delta l = \frac{\sigma_n \cdot l}{E} \qquad (2)$$

Total relative displacement (slide amplitude) of the shaft surface in relation to the sleeve head will therefore be equal to $\alpha = \Delta l/2$. Table 1 presents calculated acc. to formula (2), estimated slide amplitude value between the sleeve head and the shaft surface for accepted model study parameters (column 2)

Table 1. Estimated a slide amplitude value and the vector value of deflection f_0, f_{rz} of the sample

1	2	3	4
(P + Q) [N]	α [mm]	f_o [mm]	f_{rz} [mm]
350	0,0046	0,51	0,75

According to formula (2) oscillation amplitude depends on normal stresses, and hence on the value of applied bending moment, which in turn will decide about the bending value of the sample. Therefore there will be a close connection between the shaft deflection and the oscillation amplitude. The above was made use of to verify the calculated estimated oscillation amplitude value in comparison to the actual amplitude. The vector value of shaft deflection f_o was analytically calculated and compared with the actual measured value of sample deflection f_{rz}. To calculate shaft deflection value a scheme of sample loading as in Fig. 7 was used. The analytically calculated deflection vector f_o was placed in Table 1 in column 3. The actual value of deflection vector f_{rz} determined during static measurements of the sample deflection was placed in table 1 in column 4. Comparison of those two values shows that actual deflection is greater than the analytically calculated value. Hence it may be judged that actual slide amplitude may also be greater than the analytically calculated one. It is necessary here to underline that in analytical calculations of the slide amplitude simplifications were accepted. First of all friction forces on the contact of connected surfaces were not taken into consideration.

3. Research methodology

Because of the wheel sets dimensions the studies on an actual object are expensive and time consuming, as it is necessary to use a specialist test stand and also adequately long study time. Due to this, wear tests were carried out on samples modelling the connection sleeve – axle making use of a fatigue machine of the MUJ type. Fatigue tests of the sample in rotary bending conditions ensure simulation of actual loads of the wheel set in exploitation conditions.

Experimental tests referred to:

- determination of the actual surface layer state in the area of sleeve connection with the shaft after wear tests for singled out technological processes
- determination of the influence of chosen technological processes on fretting wear development

What was important when choosing a sample modelling slide sleeve – axle of the wheel set was dimensional similarity behaviour in the connection area. For this, proportions of connection length and axle diameter as well as fitting were kept

The sleeve was fixed in relation to the shaft by means of a headless screw with a socket, what prevented axle and perimeter shifts and ensured the sleeve movement in relation to the shaft in the radial direction during rotation.

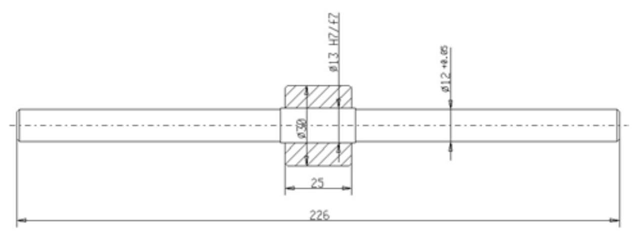

Fig. 6. Sample dimensions for model tests [6]

For initial tests the shaft was made from steel 45 and the sleeve from steel 36HNM, through machining with no additional strengthening of the surface layer. The choice of materials provided close properties to the materials from which the actual object was made in the prototype version (Table 2). Such a model was to be a reference point for different variants of the sleeve – axle association, which should limit or eliminate wear, at the same time providing the least shift force in the axial direction.

On the basis of literature analysis, referring to the mechanism of fretting wear development in forced-in connections of the wheel and axle such technological processes were proposed that should limit fretting wear initiation on the shaft surface and would allow to obtain a suitable state of a wheel seat which would ensure minimum, stable force necessary to move the sleeve along a wheel seat before and after the wear tests. Table 3 presents chosen variants of a sleeve slide axle friction pair model.

For wear tests a fatigue machine of the MUJ type was used, which allowed to achieve parameters simulating actual exploitation condi-

Table 2. Chemical composition of steels used to produce axle and wheel of the wheel set with an automatic wheel track change and of the sleeve and shaft modelling the studied connection

Material symbol	Chemical composition [%]					Mechanical properties [MPa]	
	C	Mn	Si	P max	S max	R_e	R_m
ER7	0,52	0,80	0,40	0,020	0,015	≥ 520	820-940
A1N	0,40	1,20	0,50	0,020	0,020	≥ 320	550-650
45	0,42- 0,50	0,50- 0,80	0,10- 0,40	0,040	0,040	340	600-700
36HNM	0,32-040	0,50- 0,80	0,17-0,37	0,035	0,035	750-800	850-1000

tions of a wheel set. Construction of the machine allows to obtain periodically changing load with a simultaneous bending of the rotating sample. In fretting wear tests it was important to achieve such a distribution of the bending moment on the axle wheel seat that would result in its deflection, what is the condition of oscillatory contact shifts between the surfaces in contact.

Table 3. Chosen association models singled out for wear tests

No.	Sample type	Shaft seat surface	Sleeve material
1	basic	steel	steel
3	modified	molybdenum	steel
8	modified	Hardened steel	steel

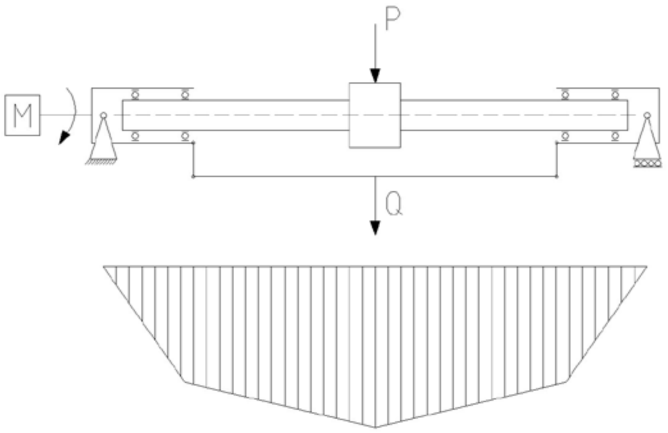

Fig. 7. Scheme of sample loading on a testing machine of MUJ type and corresponding to it bending moment distribution

Fig. 7 presents a scheme of sample loading on a testing machine of MUJ type. The scheme corresponds to the wheel set loading in which it was assumed that the wheel set rolls along straight rail without running onto the rail head.

Sample parameters tested on a testing machine were as follows:

- revolutions n=1360 rev/min
- sample loading Q= 300 N
- sample loading P= 50 N
- number of cycles $r > 6x10^6$

Assumed rotational speed of the sample corresponds to the speed of 75km/h of a railway car.

In wear tests of the sample modelling the connection slide sleeve – wheel set axle the value of loads was assumed for which the stress value on the shaft seat surface was higher than the stresses in an actual axle. The stresses in the sample were calculated by finite elements method in ANSYS programme. The values of forces Q=300 N and P=50 N were assumed.

Distribution of normal stresses on the shaft surface for the set load values did not cause plastic strains (deflection vector 0.27 mm). The maximum strain value for assumed load conditions was 61 MPa. The value exceeds local strain values in an actual axle, which are 40-50 MPa.

4. Experimental tests

4.1. Base sample

The aim of testing a base sample was to verify the model choice by achieving a similar wear image as in an actual object and as a reference to the proposed changes. Macrographic observations of the steel shaft seat surface in a base sample show that surface failures occur on both sides of the shaft seat (Fig. 8) A big contact area of cooperating elements of tribological nodes creates conditions for adhesive tacking formation on the connection edge, which cause surface layer destruction and in consequence formation of distinct fretting wear traces.

In macroscopic photographs of the shaft surface presented in Fig. 9 brown colour was observed in the area of fretting wear occurrence, typical of atmospheric iron corrosion. The most probable reason of this phenomenon is the contact of the damaged area with oxygen because of the fissure being formed between the surfaces of the shaft and the sleeve in result of sample deflection.

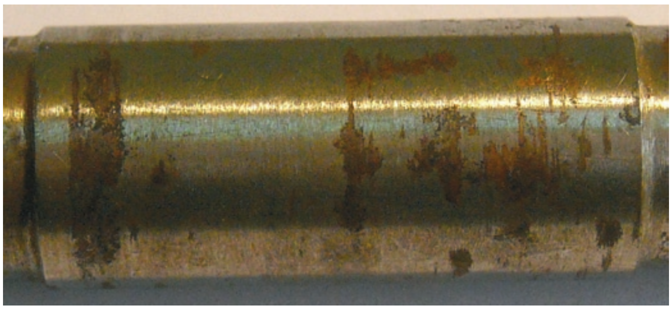

Fig. 8. Base shaft surface after fatigue tests - distinct traces of fretting wear on the shaft edges of lower intensity into the connection centre, magnified. about 3x [6]

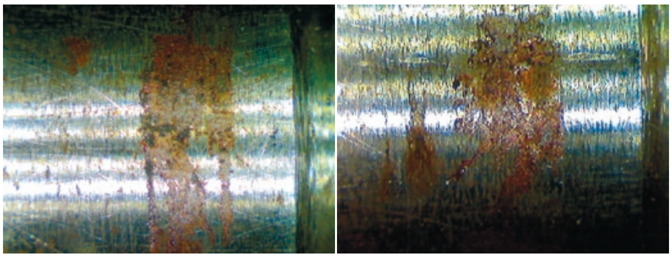

Fig. 9. Base sample after fretting wear, magnified about 15x. Lack of machining strengthening the surfaces. Visible traces of fretting wear [6]

In the images of spatial roughness profile (Fig. 10) and in the scanning images (Fig. 11) of the base shaft seat characteristic material growths may be noticed, which undergo plastic deformation and oxidation. Observations of the surface showed local abrasions and micro-pits. Surface failures in the form of micro-growths and micro-

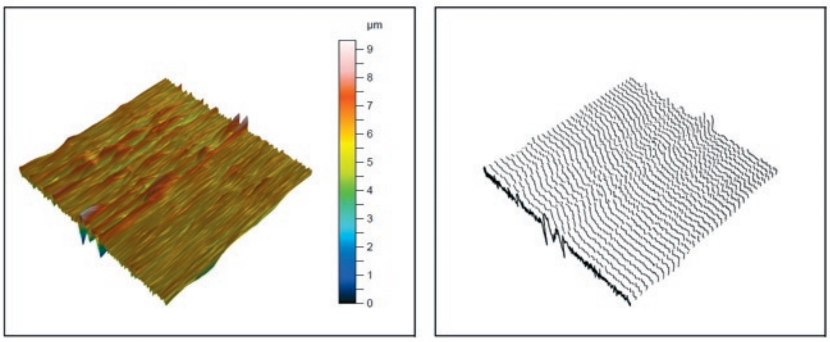

Fig. 10. Spatial image of shaft surface roughness profile in the area of fretting wear

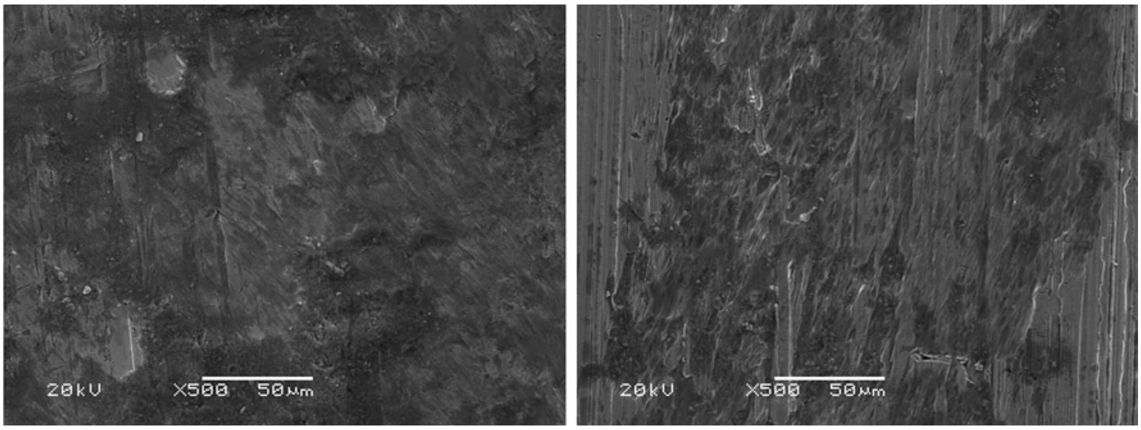

Fig. 11. Base shaft surface wear images, magnified 500x

pits have their origin in adhesion phenomena being an element of fretting wear development mechanism. This mechanism in the discussed case is also connected with the occurrence of relative contact shifts between the surfaces of connected elements. The assumed load generates maximum oscillation amplitude between the shaft and surface at the connection edge.

Obtained wear image proves that the assumed model is correct and reflects work conditions and connected with them failure image of an actual association wheel – axle.

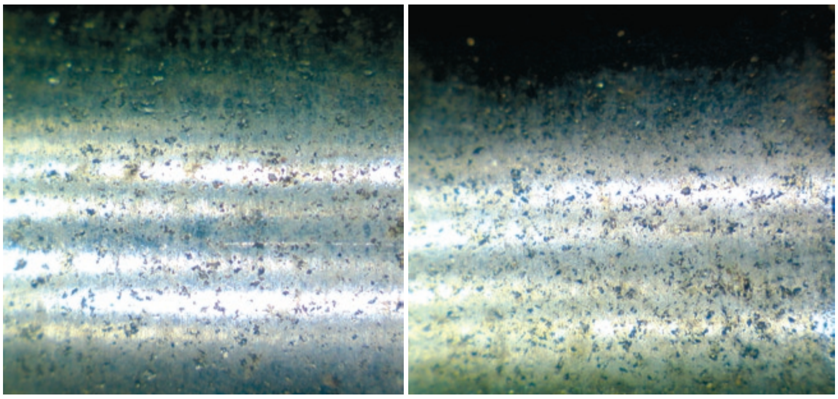

Fig. 13. Molibdenized sample after wear test, magnified about 15x. No traces of fretting wear [6]

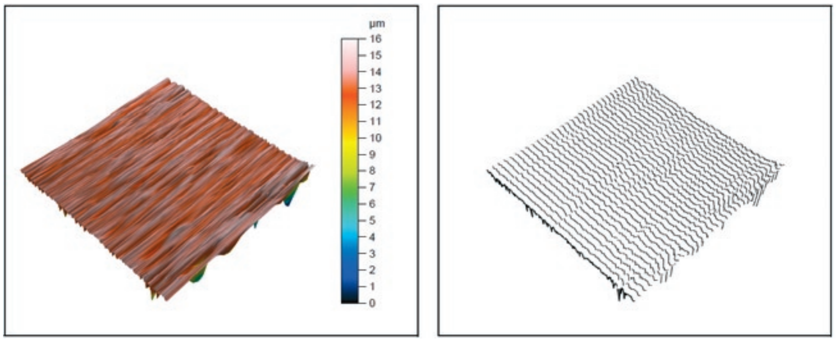

Fig. 14. Spatial roughness profile image of molybdenized shaft surface in the theoretical area of fretting wear

4.2. Molybdenized sample

High molybdenizing costs, in spite of good tribological properties, limit its usage only to traction units axle and the cars of high speed trains. Molybdenum coating was put onto a sample by means of a metal spraying method after having completed the peening process of the shaft seat surface layer, what influences adherence of the coating to the base. Thickness of the coating was about 37.5 µm, that is about 0.58% of the shaft diameter. In the case of actual axle it was about 0.54%. Fig 12 presents the image of molybdenized shaft seat surface, associated in a running fit connection with a steel sleeve, after fatigue tests. Molybdenized surface hardness was 460 HV, while that of the steel shaft 210 HV. It is visible that fretting wear was completely eliminated.

Carried out tests prove the theses in works [2, 7, 9], that molybdenizing, as a modification method of the surface layer used in contact nodes exposed to fretting, limits the tendency for adhesive associations, causes diminishing of the frictional force, increases resistance to mechanical impact and increases the corrosion resistance.

The images of molybdenized surface presented in Fig. 15 show lack of characteristic for fretting wear failures in the form of micro-pits or growths with their subsequent oxidation. Large surface hardness of the molybdenum coating, and surface roughness of 1.1 µm cause that at the tested number of cycles 6.57 x 106 fretting wear on the seat does not occur.

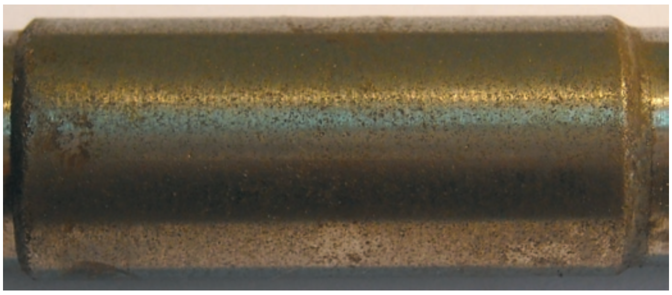

Fig. 12. Molyibdenized shaft surface after fatigue tests – no fretting wear, magnified about 3x

In spite of the lack of fretting wear traces on the shaft surface, wear products gathering in the micro-gaps (the effect of shot peening) as a result of fretting wear on the inner surface of the sleeve will cause an increase of frictional properties of the connection.

4.3. Surface hardened sample

One of the methods of surface after- machining of the axle of wheel sets, having influence on increasing the fatigue strength, is hardening. For model tests a sample was used, subjected to surface hardening by induction, which is the most popular method and has good technological properties. The process of sample hardening con-

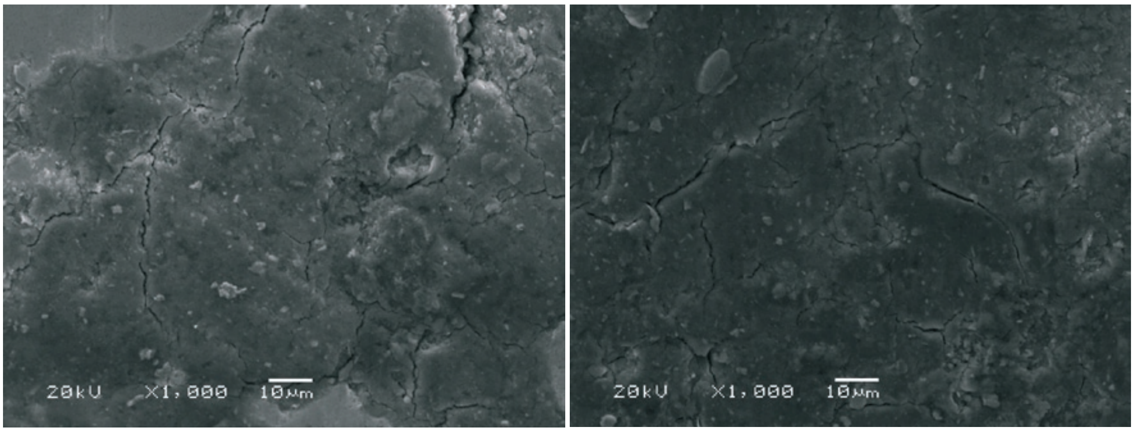

Fig. 15. Images of molybdenized sample surface, magnified 1000x

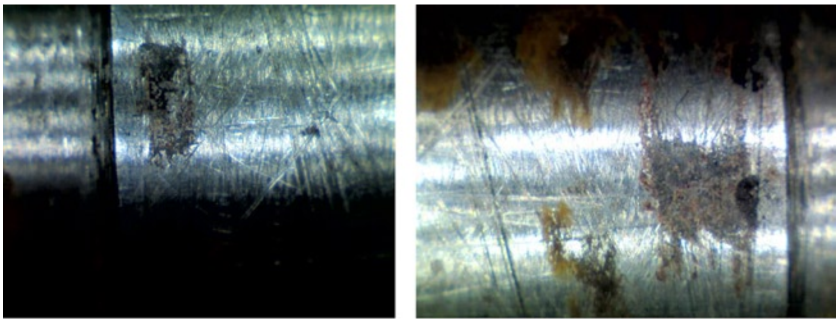

Fig. 16. Surface hardened sample after wear test, magnified 15x. Visible large areas of fretting wear

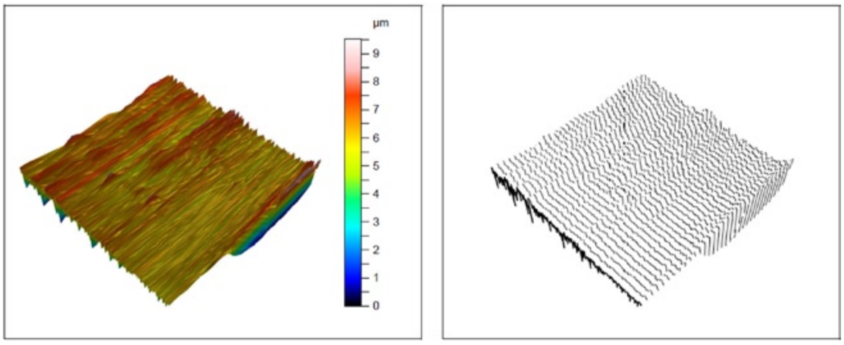

Fig. 17. Spatial roughness profile image of the hardened shaft surface in the fretting wear area

sisted of heating the surface layer to a hardening temperature, then rapid cooling followed. The samples were heated for about 1.5 minutes by means of the current induced in the magnetic field. After the induction hardening process the sample was subjected to tempering for one hour in a PEH -2 furnace at a temperature of about 380°.

The images of presented in Fig. 16 wear on the surface hardened shaft show that despite the high gradient of the surface layer hardness of the two associated elements there are numerous failures on the surface layer (fretting mainly), which led to the sleeve blocking and prevented its sliding on the shaft.

During macro- and microscopic tests material growths susceptible to plastic deformations and oxidation were identified. The growths, due to their properties and local physical and mechanical conditions, have a strong tendency for cracking and breaking off. As there were numerous wear products in the form of worn away material particles and a large range of deformations, the sleeve on the shaft was blocked. The above results disqualify the possibility of applying the tested set of friction pair elements in an actual wheel set.

4. Conclusions

The image of fretting wear in the studied connection of base sample (Fig. 8) is similar to the wear in forced-in shaft-sleeve connection subjected to analogous load conditions [2]. In a forced-in connection of

a. b.

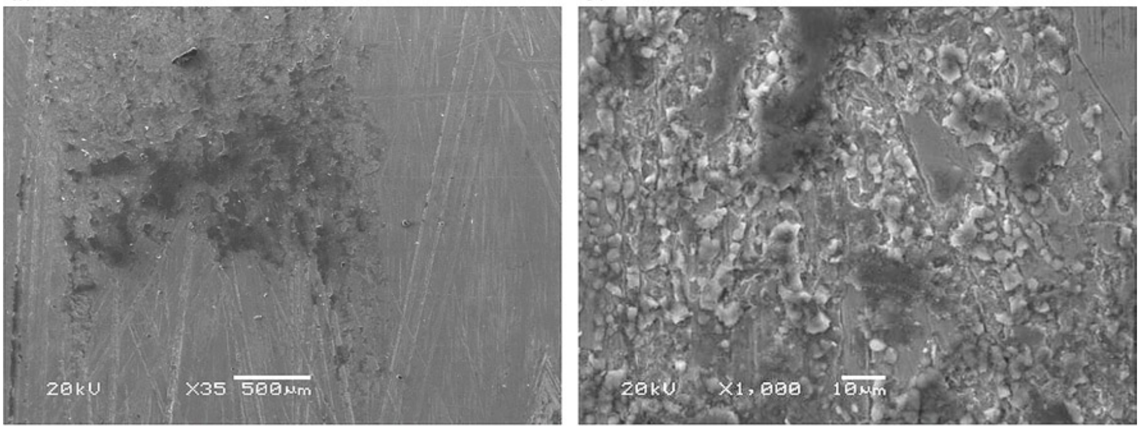

Fig. 18 Images of wear on the hardened shaft surface, a) magnified 500x, b) magnified 100x

Table 4. Results of measurements

No	Sample	Shaft – sleeve association	Force indispensable to slide the sleeve down [N]		Shaft hardness [HV]	Sleeve hardness [HV]	Shaft surface state after test
			Before tests	After tests			
1	base	Steel - stel	1,4	24,3	210	189	Distinct fretting wear
2	modified	molybdenum - steel	8,1	43,2	460	190	Lack of fretting wear
3	modified	hardened steel – steel	1,7	>50	549	192	Traces of fretting wear

fretting wear development the adhesion phenomenon plays a domineering function in wear initiation. Formation and breaking off of the adhesive tacking [2]. The condition for adhesive tacking development is forming actual areas of the first bodies contact in result of forcing-in of one element into another one (micro-irregularities, plastic deformation of the surface layer and oxides layer removal). In the case of running fit connection, because of the connection character, forming of the actual contact areas of the first bodies will take place only in the course of rotary bending of a sample. In result of relative displacements of the sleeve and shaft surface, whose amplitude is the highest at the edge of connection, there occurs frictional wear of the associated surfaces. It is the result of micro-machining of the surface micro-projections. Wear products are removed from the contact connection in the course of a sample half rotation. The actual contact surface formed in this way (after having removed the oxide layer and the so called third body) will be susceptible to form adhesive tacking and initiate fretting wear. Therefore, analogously to the fretting wear development mechanism in a forced-in connection, a similar mechanism of running fit can be proposed as a few stages process whose most important elements are:

- forming areas of actual contact of the first bodies in the course of generating relative displacements of very low amplitude on the elements contact surface as a result of bending.
- forming adhesive tacking in the areas of actual contact, especially at the connection edge (the highest amplitude of relative slides), which then undergo disruption, forming gaps and growths on the contact surfaces,
- oxidation of the earlier damaged area,
- micro-machining by oxidized tops of the growths on the opposite surface.

Adhesion processes will be an indispensable condition in the proposed mechanism of fretting wear development in a connection of running fit. Formation and disruption of adhesive tacking. According to M. Hebda [3] a special tendency to form adhesive tacking will be displayed in the case of associating material of the same kind and of similar mechanical properties. This explains, among others, such an intensive fretting wear image on the base sample (steel – steel). However, according to [3] an increase in adhesive wear resistance can be achieved, among others, by high mechanical properties (hardness, yield point).

Limiting fretting wear development is, first of all, connected with not allowing adhesion phenomenon to occur. Limiting oscillation, because of the association work conditions, is practically impossible.

In the studies two ways were accepted to increase the hardness of the shaft surface – by coating with molybdenum and by surface hardening. Table 4 presents the results of hardness measurements on the surface of associated elements, the force necessary to move the sleeve axially on the shaft and the identified wear image.

Quoted measurement results and observations indicate that the influence of a high hardness gradient of the associated surfaces on the fretting wear limitation is a complex one. While in the case of the same kind of materials and similar surface hardness (steel – steel) fretting wear development is a very intensive one, in the case of molybdenum coated and hardened surface the situation is different. In spite of the fact that the hardness gradient of the shaft surface with molybdenized coating in relation to the sleeve is about 20% lower than the shaft with hardened surface, fretting wear for this association has been fully eliminated. Whereas on the hardened shaft surface distinct traces of fretting wear appear. The above may indicate that as well as the high hardness of the surface, the chemical composition of the material and crystallographic structure of the surface layer of the associated materials will limit fretting wear.

It must be stressed that the main aim of the article was to present the research results on limiting fretting wear on the shaft surface by means of available technological processes. The main focus was on the shaft surface as in an actual connection wheel – axle of the wheel set with an automatic wheel track change, the axle is just an element which determines durability of the whole wheel set.

The examples of the shaft surface states after fatigue tests show that among the tested technological processes aiming at increasing the fatigue durability of the connection only molybdenizing favourably influences fretting wear elimination. Whereas surface hardened surfaces are susceptible to fretting wear development, and what is more, they do not allow for a free movement of the sleeve on the shaft.

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