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Preliminary communication

Fretting Wear in Selected Elements of Rail Vehicles

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Abstract: The wear of vehicle elements during operation is a natural phenomenon. A dangerous situation occurs when elements more crucial than others wear unexpectedly. Such an element in rail vehicles is, for example, a wheel set. Its main task is to run the vehicle in the track, which directly influences the safety of the journey. Any premature or unexpected damage will lead to train derailing. Then hundreds of lives may be lost. The load on the wheel set from the vehicle weight and the oscillatory micro displacement of the wheel in relation to its axle during travel will be conducive to premature wear. Those conditions will cause the development of fretting wear, whose implication may be fatigue wear or the loosening of the wheel/axle joint. In this article, the results of fretting wear tests conducted in a shaft/sleeve forced-in joint are presented. The results of those tests, given that the relevant probability conditions are met, can be successfully compared to the real wheel/axle joint. The wheel set operation conditions, which will be conducive to the initiation of the development of fretting wear, have been discussed. Test results are presented in the photographs showing the axle seat with an area affected by wear. Both those places, and the place of contact between the connected surfaces, were subjected to micrographic examinations with a view to identifying damage comprised by fretting. Macrographic observations demonstrated fretting on either side of the shaft axle seat, which phenomenon comprises, for example, abrasive wear and adhesion. Visible are micro cracks and material build-ups, which became plastically deformed and oxidised.

Keywords: forced-in joint; fretting wear; operation; rail vehicles; tribology; wheel set

1 INTRODUCTION

Transport by rail is one of the most popular means of transport. Every year, trillions of people and billions of tons of cargo are transported, and thousands of trains are operated the world over. That is why structural engineers build better and better and safe vehicles. Materials used for train construction meet the most stringent comfort and safety standards, and vehicles are often inspected. The reason for that is to provide passengers with appropriate travel conditions.

Unfortunately, in spite of the high engineering level, rail vehicles incidents occur every year. Some of them are caused by the user, but accidents following from the wear and tear of elements do occur as well.

Rail vehicles have a complicated structure, moreover, some elements are subjected to smaller loads, and others to greater ones. Sub-assemblies are also assembled by various methods ranging from gluing and welding to push fit joining. Examples of push fit joints may be found in wheel systems. These include: fitting of brake discs at the wheel set axle and the wheel/axle joint. During operation, however, the wheel set is loaded the most heavily, which follows from the operation conditions more thoroughly discussed further in this article. Following that, the next heavily loaded element is a forced-in joint between the wheel and axle. Hence, that joint is the most susceptible to frequent damage and wear. Any failure of a wheel set during operation will have fatal consequences because a wheel set is directly responsible for travel safety. Over the years, examples of rail crashes can be found, whose direct cause was a failure of a wheel set.

Wheel sets, more than other elements, are exposed to the risk of the development of fatigue wear. One of the factors which may influence the development of fatigue wear is fretting. The observations of the axle seat surface after the disassembly of the wheel set during periodic inspections frequently reveal the occurrence of that kind of wear.

2 FRETTING WEAR

Fretting is one of the destruction processes of the top layer of machine elements. That phenomenon occurs in the case of oscillatory displacement of the mating surfaces of elements under the influence of small-amplitude vibrations. Fretting is included in tribological kinds of wear because it is related to friction processes. Fretting is a phenomenon with a complicated wear mechanism in which the following coincide or follow one another: adhesive wear, surface fatigue, exfoliation, oxidation, abrasion of irregularities with asperities and loose wear products. Fretting wear may be demonstrated by corrosion traces at the surface of the elements, the increase of surface roughness, and pits and microcracks in the top layer.

Damage in the top layer of the elements as caused by fretting wear is often attributed to other kinds of damage. The above follows from the fact that fretting damage, which is initiated as early as at the initial operation stage, often becomes the source of other kinds of damage, e.g. fatigue damage, which causes great difficulties in its identification.

The complex process of the development of fretting wear is the reason why it has not been defined unambiguously so far. The development of the wear of the top layer of the elements depends on, first of all, the mating conditions of the elements being connected, on the mechanical, physical and chemical properties of the material, and on ambient conditions. Those factors will cause various wear mechanisms.

Push fit joints operating under variable loads are particularly susceptible to the development of fretting wear. The consequences of damage in that kind of joints may include the reduction of assembly pressures and, in an extreme case, the fatigue cracks of joint elements.

The review of available literature on fretting wear in a push fit joint shows how important that issue is because that joint combines in itself all the conditions necessary for the development of wear. Only few scientists attempt to explain the wear development mechanism. This is probably related to problems with observations of the wear images. In the vast majority of cases, joint disassembly causes damage to the wear image or its deformation.

As an example of literature devoted to the fretting wear mechanism in forced-in joints, work [1] can be indicated, in which the author examined the influence of various factors on the development of fretting in push fit joints. Moreover, on the basis of tests and observations, the author postulated the fretting wear development mechanism. In [2], the authors deal with the influence of fretting wear on the development of fatigue wear of wheel set axles as well. Work [3] is devoted to the selection of shaft top layer finish processes, which will permit the reduction or elimination of the development of fretting wear. The author of [4] also analyses the influence of selected axle finish treatment processes on the development of fretting wear, however, in the case of a rotary joint for a wheel set with an automatic wheel track change. As it follows from the observations, the wear development mechanism is very similar to that in a push fit joint.

Fretting wear also occurs in other fields of technology, where a pair of elements touching each other is subjected to oscillatory tangential displacement. It follows from the review of literature that fretting wear is found in, for example, aviation industry [5-7], in medicine [8-10] in orthopaedic items connecting fractured limbs and in artificial joints, as well as in the automotive industry [11].

If follows from literature on the examination of fretting wear that the development of wear is strongly connected with the actual contact of the mating surfaces of the elements and with the presence of wear products in the contact zone, and the oscillation conditions will determine the form of wear development.

3 WHEEL SET OPERATION CONDITIONS

As mentioned previously, external and heat loads coming into being during breaking act on the wheel set during operation. All those factors have an adverse impact on the life of wheel sets.

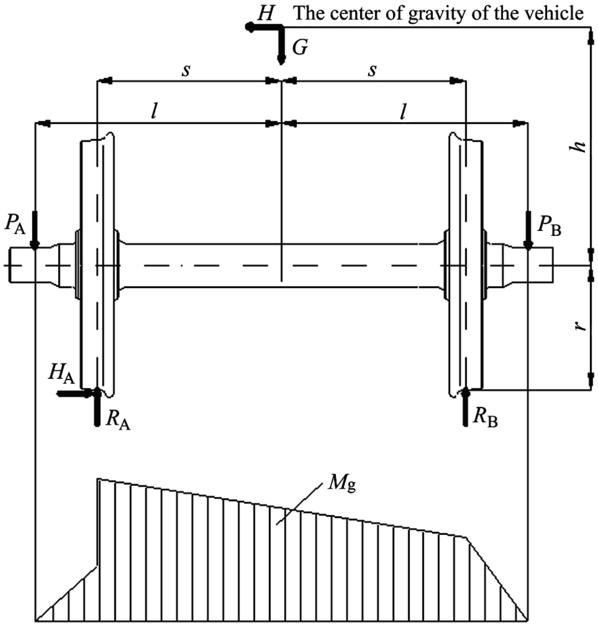


Figure 1 Forces acting on the wheel set during operation

The wheel set is subjected to vertical loads from the weight of a rail vehicle (P_A and P_B), to lateral forces at the contact surface of the wheel edge and rail head (H_A), such forces coming into being as a result of the hunting oscillation of the vehicle, and to dynamic forces at the contact surface of the wheel and the rail. As a consequence of those loads, a bending moment (Mg) occurs, whose diagram is presented in Fig. 1. The maximum value of the bending moment will occur at the axle seat in the plane of operation of reactions R_A and R_B, that is in the area of the connection of the axle with the wheel. Hence, it may be stated that the axle operates in rotational bending conditions, which will, during wheel set rolling, cause the occurrence of oscillation between the axle and wheel.

The wheel set axle is subjected to deformation shown in Fig. 2 under the influence of the external loads described above. Tensile stresses occur in the upper axle layers, and compressive stresses in the lower layers.

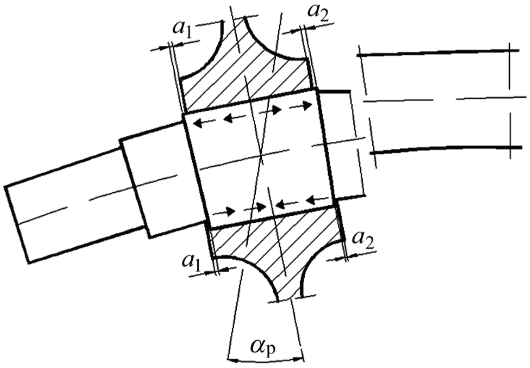


Figure 2 Deformation of the wheel set axle [1]

That kind of axle deformation would be insignificant if the wheel axle length were subjected to similar deformation. For the deformation of the axle seat and wheel hub to occur at the same time, the unit friction forces at the joint contact surface must be greater than or equal to normal stresses in the axle seat [1].

4 TEST METHODOLOGY

Testing a real object is too time consuming and difficult because of wheel set dimensions, and additionally connected with high costs of the tests. Moreover, wheel disassembly might distort the wear image.

Given that certain features of model similarity to the real object are retained, tests may be conducted on a model of the wheel/axle joint, which will be the shaft/sleeve forced-in joint. To achieve similarity to the real object, models were made of the same material as the one from which wheels and axles are made, and proportional loads on the samples were used. The sleeve/shaft tolerance is 0.02 mm, and that is a value for which surface pressures are close to those occurring in real wheel sets. Moreover, to ensure the geometrical similarity of the model to the real object, the dimensional proportions between the sleeve and shaft axle seat were retained. The model of a forced-in joint subjected to wear tests is presented in Fig. 3.

Figure 3 The model of a wheel/axle forced-in joint

During tests, the forces acting on the wheel set during a ride along a curve (force H_A) were not taken into consideration because they occur sporadically and do not significantly influence the final result of the tests.

Wear tests were conducted on a fatigue testing machine, whose construction enables the generation of a periodically variable load with pure bending of a rotating sample.

The sample was loaded in such a way that the appropriate distribution of the bending moment, which will lead to shaft deflection, could be achieved. Owing to that, oscillatory tangential displacement will occur between the connected surfaces, which is necessary for the development of fretting wear.

The sample wear test parameters were as follows:

- revolutions: $n = 1360$ rpm
- load on the sample: $Q = 550$ N
- number of cycles: 7×10^6.

The distribution of normal stresses at the shaft surface originating from the assumed parameters will not cause plastic deformation. This was confirmed by a strength analysis conducted with the use of the ANSYS software. The maximum value of the stresses in the joint being tested is 70 MPa.

Following wear tests, the joint was disassembled in conformity with a preprepared scheme enabling the removal of the sleeve from the shaft without putting the wear damage to have occurred at risk of additional deformation.

After wear tests, macroscopic observations were conducted which concerned the condition of the surface, and microscopic observations enabling the identification of wear comprised by fretting. An EDS analysis enabling the determination of the chemical composition of wear products was also conducted. The purpose of the tests was to identify the actual physical changes in the top layer of the connected elements after wear tests, as well as the place of initiation of fretting wear and the range of its development.

5 WEAR TEST RESULTS

Badania Macroscopic examinations reveal fretting wear occurring on either side of the axle seat, at the distance of approximately 2 mm. Wear occurs at the entire axle seat surface circumference in the form of a ring which is 2-3 mm wide. Operation tests of real wheel sets also demonstrate a similar nature of wear. In that case, wear comprises the area from the hub front deeper into the joint, and the ring width is approximately 30 mm [1].

The macrographic image of fretting wear occurring at the surface of the shaft and sleeve is presented in Fig. 4.

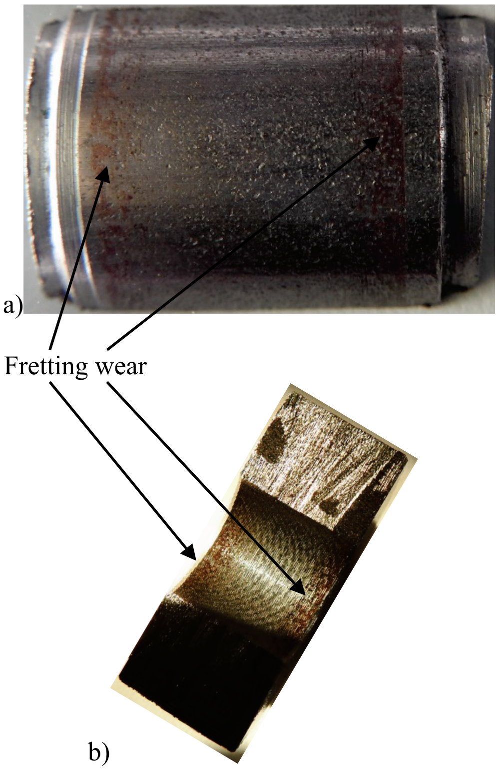


Figure 4 The image of fretting wear at the surface of the shaft (a) and sleeve (b)

The occurrence of fretting wear, observed close to the edges of the axle seat, is related to the assembly process and to the wear development mechanism.

Products coming into being during assembly, which are called the third body, and following from the shearing of the micro irregularities of the sleeve and shaft top surfaces, separate both of these surfaces, owing to which their direct contact does not occur during model cyclical bending. In the case of occurrence of oscillatory tangential displacement, the third body will fulfil the function of an agent taking over the relative displacement of the surfaces of both elements. Such a situation will take place in the central part of the joint. Close to joint edges, as a result of the cyclic relative slips of the mating surfaces, the removal of wear products will take place, owing to which the direct contact between the surfaces will occur [1]. The places of wear were observed under a scanning microscope, and the sample results presented in Fig. 5.

The presented scanning images demonstrated the occurrence of material build-ups, their source being adhesion, which is one of the components of fretting wear. Considerable surface abrasion and micro pits may also be observed, which are most probably the result of micromachining processes.

The wear traces observed at macroscopic images are brown, which is typical of the atmospheric corrosion of iron. This is evidence of a gap, which comes into being between the surface of the shaft and sleeve as a result of sample deflection, thus enabling the contact of the damaged area with oxygen, and the oxidation of plastically deformed micro build-ups. That phenomenon is confirmed by the EDS analysis conducted at the shaft surface. The results of the analysis are presented in Fig. 6 as an element distribution maps.

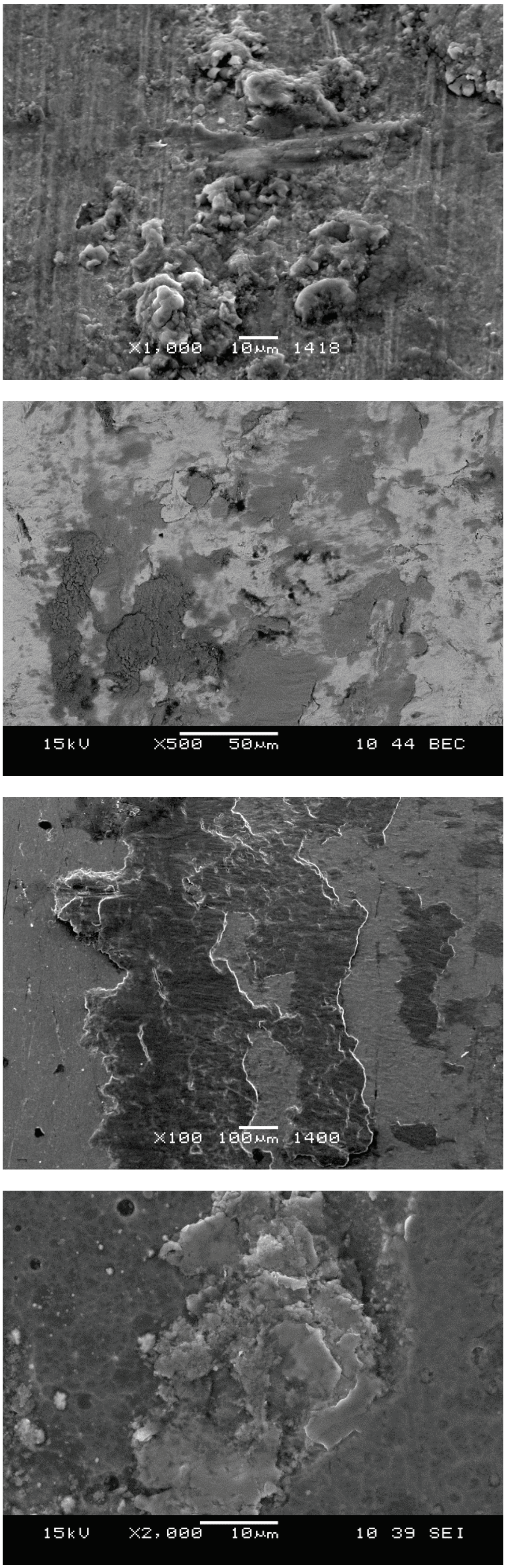


Figure 5 The sample images of fretting wear

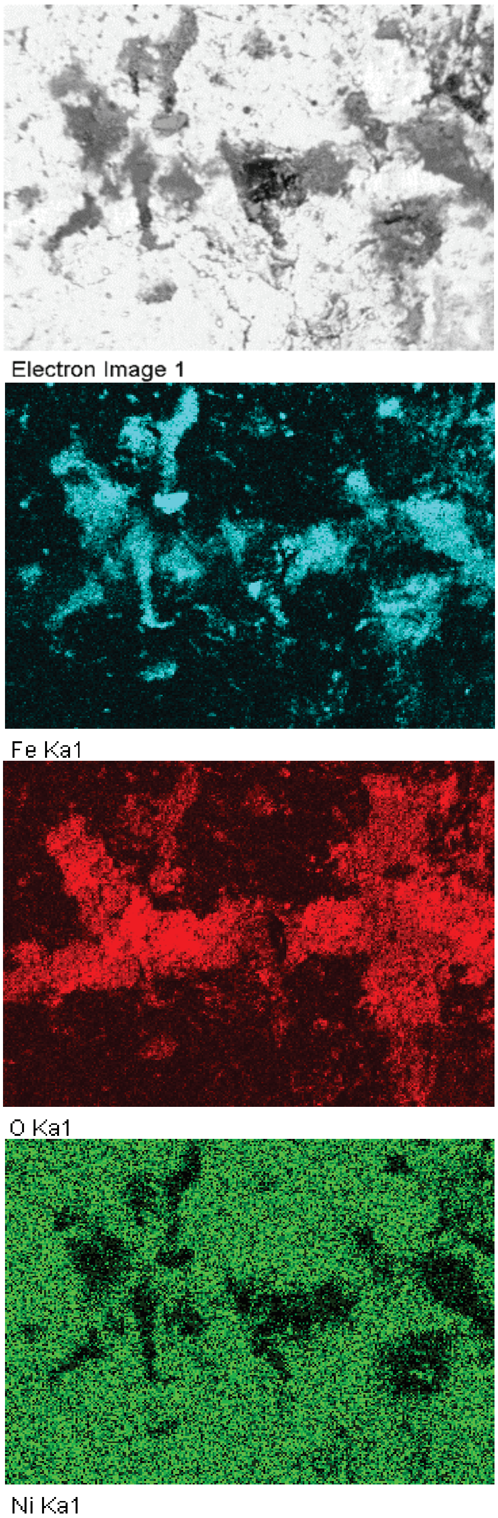
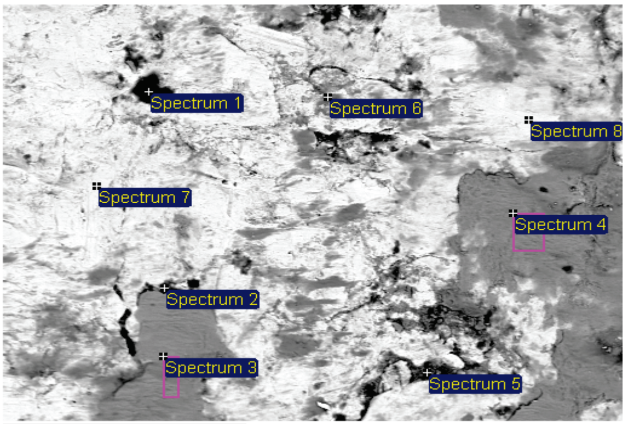


Figure 6 Chemical element distribution maps for the shaft surface in the fretting wear zone

The presented element distribution maps depict the oxidation of 80% of the surface being examined. Visible nickel is the effect of sample preparation for the analysis.

The results of the EDS microanalysis of the chemical composition of wear products in the place of fretting wear are presented in Fig. 7. That analysis also confirms the occurrence of material build-ups, which became oxidised.



Spectrum	Fe	O	C	Na	Si	Mn
Spectrum 1	23.8	14.9	59.2	1.3	0.8	-
Spectrum 2	53.8	16.7	26.4	1.4	1.3	0.4
Spectrum 3	64.4	34.8	-	-	0.3	0.5
Spectrum 4	60.7	38.5	-	-	0.4	0.4
Spectrum 5	56.2	27.7	14.7	-	0.5	0.9
Spectrum 6	61.9	32.2	3.7	-	1.7	0.5
Spectrum 7	99.3	-	-	-	-	0.7
Spectrum 8	99.4	-	-	-	-	0.6

Figure 7 The microanalysis of chemical composition at the shaft surface in the place of fretting wear (all results in weight %)

Laboratory observations also covered the examinations of the shaft top layer and the sleeve at the contact surface of the connected elements. The objective of those examinations was the assessment of the actual contour of the contact surface of both connected elements with its deformation and damage. Sample results of those observations are shown in Fig. 8. Images vary depending on the fragment of the analysed joint. In the central part of the joint, the direct contact between the shaft and sleeve surfaces prevails. Towards the edges of the joint, a gap filled with the third body, which came into being as a result of the shearing of micro irregularities during forcing, is observed (Fig. 8a). The plastic deformation of the sleeve top layer is observed in places (Fig. 8b).

The examination results mentioned above indicate that the contact surface between the shaft and sleeve is very complex. The ultimate shape of that surface will be influenced by many factors, including the roughness of the top layer of the connected elements, tolerance, the presence of a lubricating medium etc.

The micro cracks of the sleeve top layer were found in places, as shown in Fig. 8c. Those cracks run deeper into the material each time at 20°. During operation, they may pose a hazard and contribute to the faster development of fatigue wear.

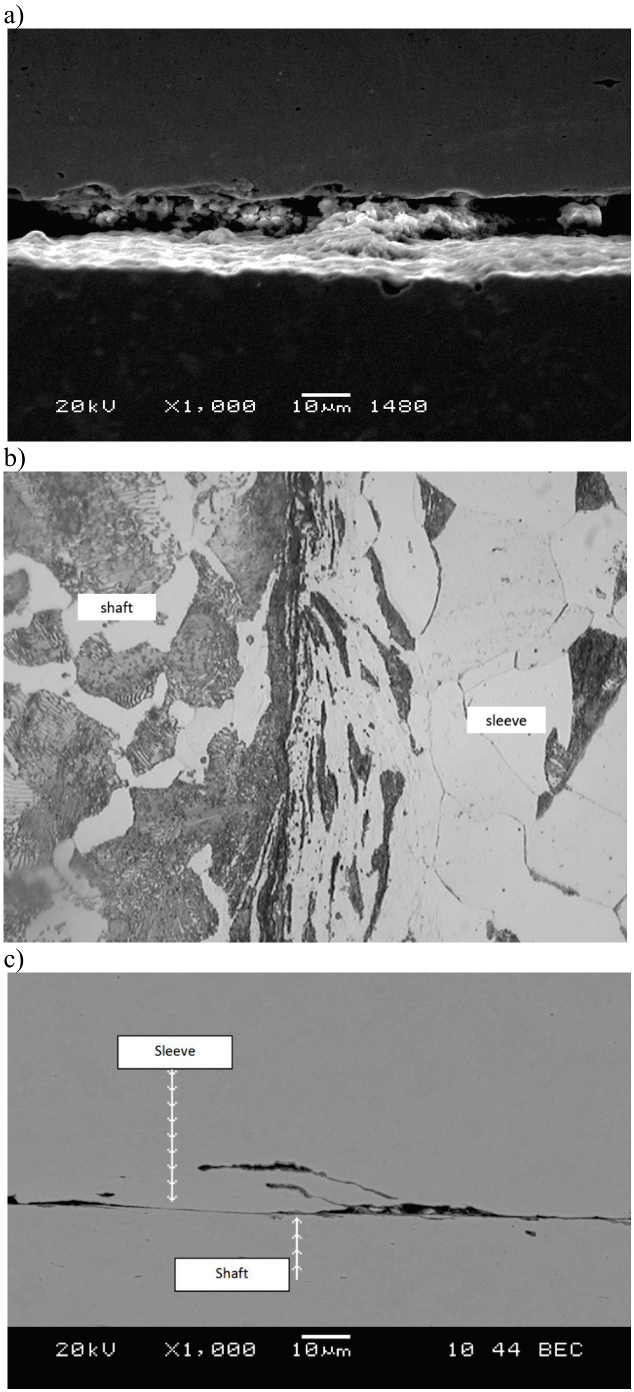


Figure 8 Sample images of the joint contact surface of the connected elements: a, c) unetched samples, b) a sample etched with nital, 1000× magnification

6 CONCLUSION

Fretting wear tests on a model of a push fit joint of a rail vehicle wheel\wheel set axle demonstrated the traces of fretting wear on all tested samples. Each time, wear occurred at the edges of the axle seat and adhesion played a dominant role in the development of wear. In the case of a forced-in joint, the magnitude of wear will depend on the tolerance, and also on the hardness and roughness of the surfaces being connected. Low hardness will cause the actual contact of the surfaces being connected, which will be conducive to the creation of adhesive bonds, which will, in turn, initiate fretting wear. Other wear processes such as plastic deformation, oxidation and micromachining, only aggravate damage in the top layer of the elements in the area of adhesion damage, which occurred before. Research conducted by the author of [1] demonstrated that the measurable traces of damage at the surface of the examined elements occur as early as at approximately 10^3 load cycles. When the number of cycles becomes greater, wear intensity increases as long as the cycle number reaches over 10^6.

Bearing in mind the safety of passengers, which is an implication of a correctly operating wheel set, methods mitigating the development of fretting wear should be allowed for at the wheel set design and manufacturing stage and, in particular, adhesion should be prevented.

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