sciendo

FRETTING WEAR AS AN EXAMPLE OF DESTRUCTION OF RAILWAY VEHICLES WHEELSETS

DOI 10.2478/ntpe-2018-0046

mgr inż. Marcin Dębiński
State Higher Vocational School
in Nowy Sącz, **Poland**
Ing. Miloš Brezáni, PhD.
University of Zilina, **Slovak Republic**

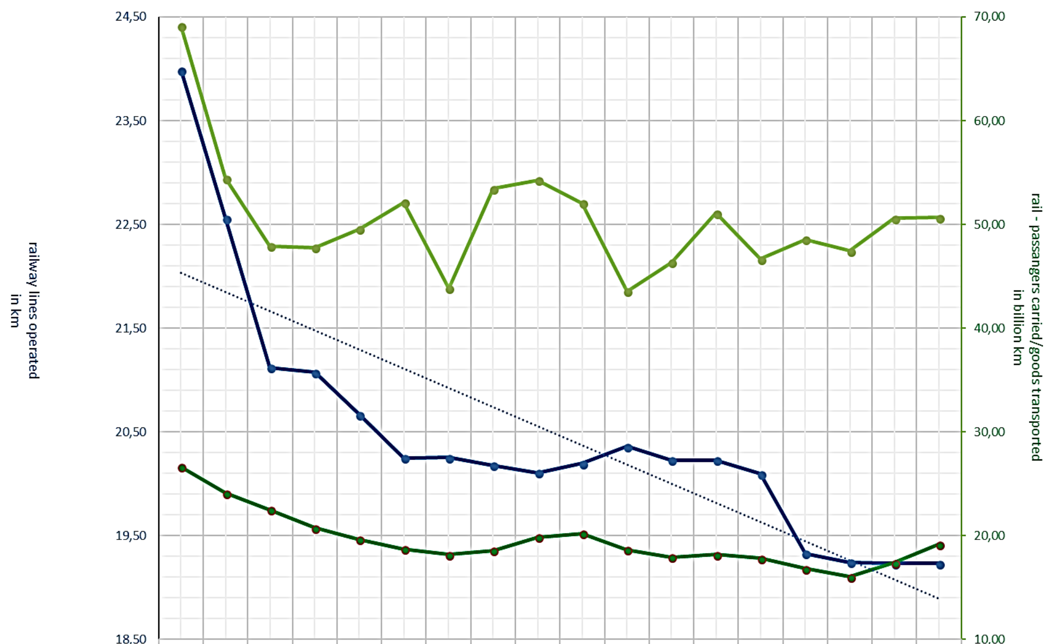
NEW TRENDS IN PRODUCTION ENGINEERING
2018
Volume 1
Issue 1
pp. 371-376

Abstract. The article refers to the importance of the aspect of durability and reliability of wheelsets. It contains a short analysis of railway accidents in which the causes were failures of wheelsets. The paper lists most common faults occurring in the course of the wheelsets operation. The major problem of the paper were laboratory analyses of fretting wear developing in interference joints. The research has been conducted using a wheelset comprising a shaft and a sleeve. Fatigue tests in conditions close to the wheelset operating environment have been conducted. The laboratory analyses included macroscopic observation that indicated fretting wear signs on both sides of the wheel seat in form of a 3.5 mm wide ring around the entire perimeter. The following procedures included microscopic observations in the wear signs area, that indicated numerous material accumulations exposed to plastic deformation and oxidation.

Keywords: wheelset, fretting wear, railway vehicles, operation

INTRODUCTION

In 2015, there length of railway lines operated in Poland was 19,231 km. It is related with the growing popularity of railway services in comparison with the other branches of transport. Figure 1 presents the numbers of carried passengers (passenger-kilometres) and the volume of carried goods (ton-kilometres) in relation to the length of operated railway lines.



	1995	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
railway lines operated	23,99	22,56	21,12	21,07	20,67	20,25	20,25	20,18	20,11	20,20	20,36	20,23	20,23	20,09	19,33	19,24	19,23	19,23
rail - passengers carried	26,64	24,09	22,47	20,75	19,64	18,69	18,16	18,55	19,86	20,20	18,64	17,92	18,18	17,83	16,80	16,02	17,37	19,18
goods transported	69,12	54,44	47,91	47,76	49,55	52,14	43,83	53,43	54,25	52,04	43,55	46,36	51,10	46,67	48,54	47,44	50,60	50,65

Fig. 1. The number of passengers and goods carried in Poland over the years

The analysis indicates a clear decreasing trend in the operation of railway lines. From 1995 until 2014, the mileage covered by railway carriers was systematically decreasing. The observed trend changed in 2014 and currently it is increasing. The growing number of carried passengers and goods results from putting modern rolling stock into operation. The structures of present-day railway vehicles allow to reach the speeds of 160 km/h and more. Higher speeds support the choice of railway transport, as it allows to travel faster, for instance from Kraków to Gdańsk in only six hours. Due to the increasing demand for transport services, railway carriers have to operate more frequently and buy new vehicles.

The increased number of operations causes that railway vehicle components are damaged more frequently and wear faster. An unexpected wheelset failure is a dangerous situation, as these parts are among the most important components determining the safety of the railway vehicle. Any damage to the wheelset will certainly lead to derailing, which results in material loss in the railway infrastructure, or even serious injuries of the passengers.

In 2016, the DSAT system (detection of rolling stock emergencies) installed on the Polish railway tracks received 11,489 fault reports. Most of them were directly or indirectly related with wheelsets. Figure 2 presents the number of received failure reports grouped into proper categories.

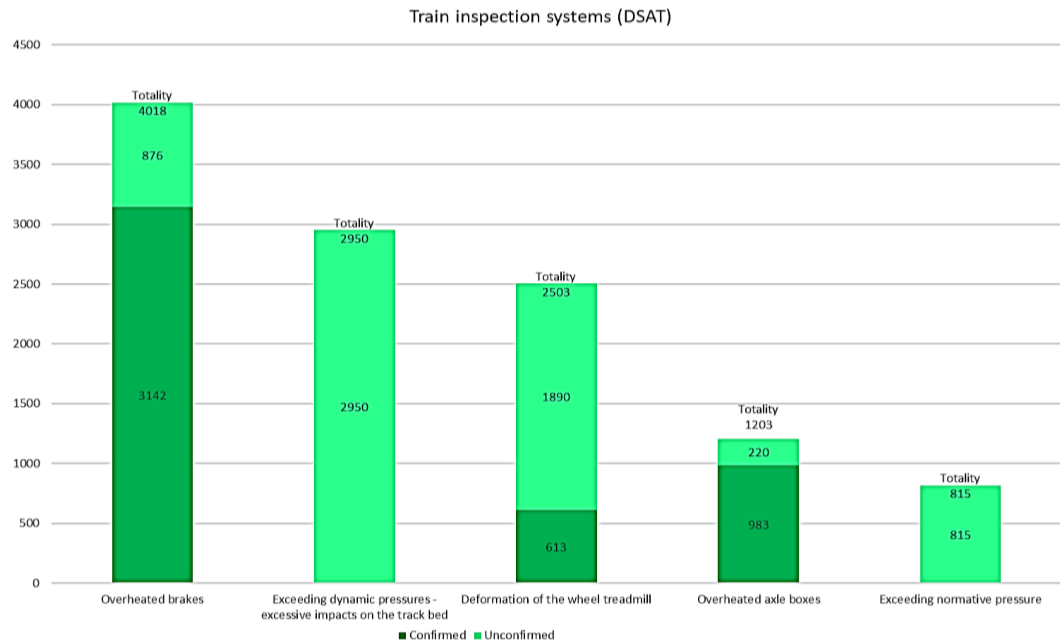


Fig. 2. Number of failures detected by the DSAT

Derailing incidents, caused by wheelset damage, occur not only in Poland. There are many cases known in Europe and around the world. One of the most serious railway accidents took place in Eschede, Germany, resulting in multiple deaths (Esslinger et al., 2004).

Reports of the Canadian railway accident investigation authority also indicate accidents caused by a wheelset damage.

One of the examples is described in the "Railway Investigation Report R07T0240" prepared by the Transportation Safety Board of Canada. On 25 August 2007, a freight train from Toronto to Montreal derailed near Tichborne. The train set contained 24 intermodal cars. Cars No. 12 to 24 derailed. The report contained the following findings: “Inspection of the wheelset revealed that the R-4 axle journal had broken in the area of the axle journal fillet radius (fillet radius) behind the roller bearing backing ring and severed from the axle”.

According to the description, the faulty component was the axle manufactured 12 years before, in 1995 at the Gliwice Steelworks (Poland). It was renovated in 2002 according to the Canadian regulations and remained in operation until the day of accident. The report indicated a break within the R-4 axle journal fillet radius. The fracture was perpendicular to the main stress acting on the axle. The analyses have revealed primary and secondary fatigue cracks.

Primary cracks occurred in corrosion pits within the fillet radius. As a result of rotating bending stresses, cracks propagated through approx. 80 percent of the axle cross-section surface (source: http://tsb-bst.gc.ca/eng/rapports-reports/rail/2007/r07t0240/r07t0240.asp).
Another incident, described in the “Railway Investigation Report R11T0034”, was caused by overheating of roller bearings of a passenger train. The train set on route from London (Canada) to Toronto, composed of a locomotive and 7 cars, was stopped at Oakville by a station worker who smelled a specific odour and noticed smoke coming from the bearing. The train was removed from operation, the bearing was demounted and analysed in order to determine the causes of the incident. The installed bearing overheat detection system had not indicated exceeding of warning parameters. As a result, trains fitted with this type of bearings were equipped with an on-board temperature control system (source: http://bst-tsb.gc.ca/eng/rapports-reports/rail/2011/r11t0034/r11t0034.asp).
These examples indicate that wear of wheelset components is an essential aspect of the safety of passengers.

WHEELSET OPERATING CONDITIONS AND EXAMPLES OF WEAR AND DAMAGE

Wheelsets are among the most loaded components of railway vehicles. Figure 3 presents the distribution of forces acting on a wheelset. During the operation, the wheelsets are subject to static loads caused by the weight of the vehicle (forces P_A and P_B), guiding and centrifugal forces (H_A), forces caused by braking, lateral forces as well as dynamic loads resulting from the disturbances in the vehicle motion, that include: impacts on rail joints and track unevenness, loads caused by geometrical irregularities of shape and wheelset imbalance, as well as load caused by flange overrun on the rail.

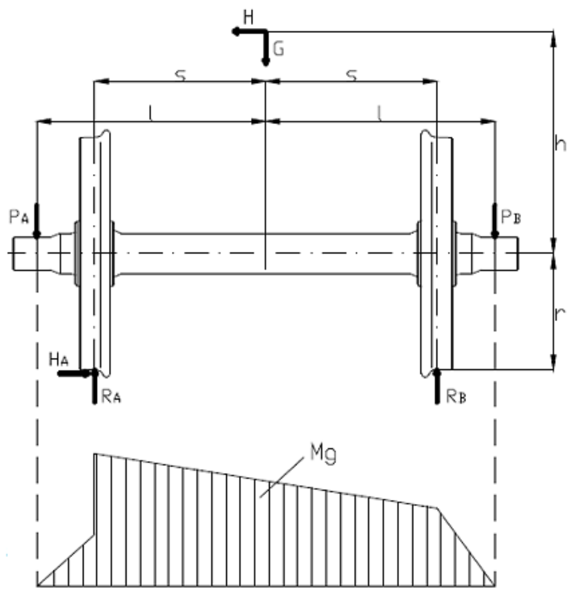


Fig. 3. Forces acting on the wheelset during the operation

Source: Guzowski, 2003.

The action of these loads causes that wheelsets wear more rapidly and are damaged more frequently than the other components of the railway vehicle. The most frequent wheelsets destructions include: abrasive wear on the wheel tread, flange relief, tread rolling, flat areas and build-ups, fatigue chipping of tread, wheel ovalisation, wheel disc deformation, fatigue thermal fractures within the wheel tread and axle box damage (Spangenberg, 2018).
The wear types listed above have already been analysed in detail and broadly described in the literature. Another example of wheelset damage is fretting wear that develops within the wheel-axle joint and may be the cause of fatigue fractures and reduction of assembly pressure, which results in loosening within the joint. Fretting wear propagation mechanism has

not been explained in detail. It is mainly related with the problems with obtaining test results that will be described briefly in the research methodology presentation.

WHEEL-AXLE INTERFERENCE JOINT WEAR

This type of wear is tribological. Considering the large number of factors determining its initiation and propagation, as well as the still unexplained mechanism of development, that is described largely on the basis of the assumed research methodology and operating conditions, no exact definition of fretting wear has yet been presented.

The fretting phenomenon occurs when two objects in contact are exposed to low-amplitude relative motion that causes damage to the contact surface. Depending on the scale of stresses, fretting may cause catastrophic damage of these parts (Llavori, 2016).

Waterhouse R.B. distinguished three types of fretting:

- fretting wear - meaning the loss in the mass or volume of the top layer and accumulation of wear products within the contact area,
- fretting fatigue - as wear occurring in the presence of fatigue tension in components subject to variable internal stresses, causing fractures propagating deep into the material,
- fretting corrosion - a type of fretting wear. Occurs when the accumulated wear products and the top layer within the worn area oxidise.

The review of the reference materials leads to a conclusion that the number of factors having effect on the development and intensity of fretting wear is hard to determine. It mainly results from the complexity of the wear mechanism, that requires an individual approach in every attempt of fretting wear analysis, and also from the conditions of components operation as well as the interrelations of all factors. Three groups of factors that may affect fretting propagation are most frequently taken into account in the analyses, they are: environmental conditions, tangential displacement oscillation conditions, material properties.

Fretting wear is present on many components, such as: aircraft parts, cars and railway vehicles parts, prostheses and orthopaedic bone screws, wind turbines, nuclear warheads, space rockets. The literature review indicates that fretting wear of interference joints used in the wheelset assembly has been the subject of only a few analyses. Guzowski S. proposed a probable interference joint fretting wear propagation mechanism, based on his own research, that may be presented as follows (Guzowski, 2003):

- forming of actual contact areas of primary objects as a result of the produced interference joint,
- generating oscillatory tangential displacements within the contact of surfaces, as a result of the bending moment load in rotary bending conditions,
- formation of adhesion contacts within the primary objects actual contact areas, that are subsequently ruptured, forming gaps and accumulations within the contact surfaces,
- shearing or spreading of surface damage resulting from the rupture of adhesion contacts,
- oxidation of the damaged area,
- microcutting of the opposite surface with the oxidised accumulation peaks,
- formation of wear products, as a result of microcutting and cracking of the thin oxides film - occurrence of the third object and stabilisation of the wearing process,
- if oscillatory motion is continued, removal of the third object from the contact area, but only at the joint edges, which leads to repeated formation of adhesion contacts and continuation of the wearing process.

Guzowski S. continued research using a model of the wheel-axle interference joint of the wheelset. However, as it has been demonstrated by Kowalski S., keeping certain criteria of model similarity to the actual wheelset, including: identical structural materials, dimensional proportions, identical operating conditions, allow to refer the test results to the wheelset (Kowalski, 2016).

The signs of fretting wear may be traces of corrosion on the surface of components, increasing surface unevenness height, microcracks, micropits, etc. The consequences of such damage, in case of interference joints, include reduced surface forces lowering the quality of the joint.

RESEARCH METHODOLOGY

As it has already been mentioned, the analysis of fretting wear in wheel-axle interference joints of wheelsets is very difficult, which results from the size of the wheelset and reconstruction of operating conditions. Large wheelset dimensions would require designing a special test station, which would entail high costs and extend the time required for testing. Thus, fretting wear has been analysed using a simplified wheelset model, comprising a shaft and a sleeve. The parts of the model have been joined by means of pressing the sleeve on the shaft with the interference of 0.04 mm. The model has been built with the same structural materials as those used in the actual wheelsets. Fatigue tests have been performed using a fatigue machine that allowed bending of the model and obtaining rotary bending forces resulting in oscillatory tangential displacements of joined components, necessary for the development of fretting wear. A similar research methodology has been proposed by Guzowski S. and Kowalski S. After completion of fatigue testing, macroscopic and microscopic observations have been performed in order to determine the scale of fretting wear.

RESULTS OF RESEARCH

Figure 4 presents an exemplary macroscopic image of fretting wear observed on the wheel seat of the shaft.

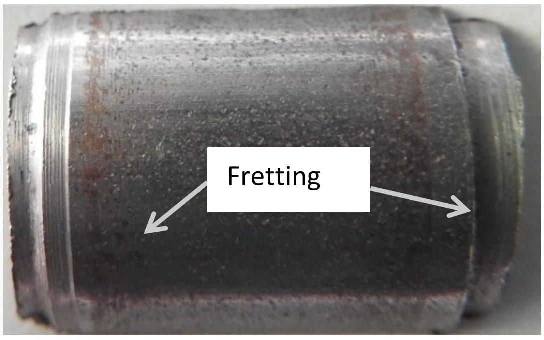


Fig. 4. Signs of fretting wear on the surface of the wheelset axle

Signs of fretting wear appear on both sides of the wheel seat in form of a 3.5 mm wide ring around the entire wheel seat perimeter. Wear signs are brown, which indicates oxidising of wear products present in that area. The literature contains research works in which authors describe the wear mechanism and explain the characteristic brown colour.

The areas with wear signs were observed using a scanning electron microscope. Sample results are presented in Fig. 5.

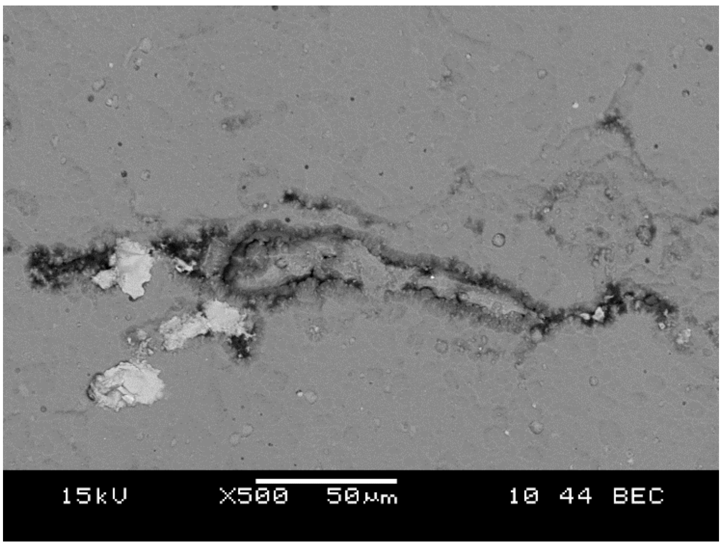


Fig. 5. Microscopic image showing the cracks on the surface and accumulations

The presented scanning images of shaft wheel seats indicate that fretting wear appears mostly in form of accumulation of materials that are subject to plastic deformations and oxidising. The observation of the surface also indicated local abrasion and micropits. The observed surface abrasion is the result of the microcutting process.

CONCLUSION

The described example of fretting wear is only one of many problems that have to be faced by rolling stock operators and service companies. However, contrary to other types of wheelsets damage, fretting wear is very hard to diagnose during the regular inspection and impossible to detect in the course of the operation. Thus, the mechanism of fretting wear development needs to be analysed in detail in order to limit its scale or eliminate it completely.

Due to the fact that the consequence of fretting wear is reduction of assembly pressures and loosening the joint, which in the course of operation may lead to derailing, the possibilities to introduce new technologies of axle production are being analysed. The results of the research on additional reinforcement of the axle surface by means of rolling, surface harderning or molibdenising, were not satisfying. In case of rolling, fretting wear signs were more visible due to the planishing effect of the rolled surface (Kowalski, 2016). Another method to reduce wear may be applying PVD coats on the axle. The tests of the CrN+OX coating indicated reduced wear. In that case, wear occurs in form of a regular ring around the entire hub perimeter and wheel seat on the right side of the axle (Kowalski, 2018).

REFERENCES

Esslinger V., Kieselbach R., Koller R., Weisse B. (2004). The railway accident of Eschede – technical background. Engineering Failure Analysis 11 (4), 515-535

Guzowski S. (2003). Analiza zużycia frettingowego w połączeniach wciskowych na przykładzie osi zestawów kołowych pojazdów szynowych. Monografia 284. Kraków: Wydawnictwo Politechniki Krakowskiej

Huang, Y.B., Shi L.B., Zhao X.J., Cai Z.B., Liu Q Y., Wang W.J. (2018). On the formation and damage mechanism of rolling contact fatigue surface cracks of wheel/rail under the dry condition. Wear 400-401, pp. 62-73

Kowalski S. (2016). Application of dimensional analysis in the fretting wear studies. Journal of the Balkan Tribological Association, Vol. 22, No 4, pp. 3076-3088

Kowalski S. (2018). Assessment of the possibility of the application of a CrN+OX multi-layer coating to mitigate the development of fretting wear in a press-fit joint. Wear 398-399, pp. 13-21

Kowalski S. (2016). Influence of molybdenum coating on fretting wear development in clamped joint. Journal of the Balkan Tribological Association, Vol. 22, No 2A-I, pp. 1741-1752

Kowalski S. (2018). The influence of selected PVD coatings on fretting wear in a clamped joint based on the example of a rail vehicle wheel set. Eksploatacja i Niezawodnosc – Maintenance and Reliability 20 (1), pp. 1-8

Kwaśnikowski J., Małdziński L., Borowski J., Firlik B., Gramza G. (2007). Analysis of reasons for accelerated wear of rolling surfaces of SA 108 (215M) rail bus wheels. Pojazdy Szynowe 2, pp. 1-13

Llavori I. (2016). An all-in-one numerical methodology for fretting wear and fatigue life assessment. Frattura ed Integrità Strutturale 37, pp. 87-93

Naeimi M., Li S., Li Z., Wu J., Petrov R. H., Sietsma J., Dollevoet R. (2018). Thermomechanical analysis of the wheel-rail contact using a coupled modelling procedure. Tribology International 117, pp. 250-260

Spangenberg U., Fröhling R.D., Els P.S. (2018). The effect of rolling contact fatigue mitigation measures on wheel wear and rail fatigue. Wear 398-399, pp. 56-68

Date of submission of the article to the Editor: 05/2018
Date of acceptance of the article by the Editor: 08/2018