

A Cause for Cracking of Head-Check Rails

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Keywords: Head Check of Rail, Rolling Load, Strain Hardening Surface, Chemical Composition of Steels

Abstract. The paper presents the reasons for the emergence of one of the main defects of railway rails, such as cracking, and factors affecting its increase. It was found that vehicle cooperation with the rail and the forming of the rolling surface caused by the load, as well as the resulting rail stresses caused by the dynamics of rolling stock are the cause of the head-check of the rails. The influence of impact resistance on rail cracks in the occurrence of these defects is also presented.

Introduction

Adapting to the increasing requirements of train safety and increasing speed, enforces modernization of the track superstructure and the use of good quality materials, including rails. The existing superstructure, especially on tracks with heavy traffic, requires the use of monitoring, which aims, among others, at assessing the condition of rails as one of the most important factors of safe transport.

One of the disadvantages of rails, which can appear during operation and have a negative impact on traffic safety, is the head check as shown in Fig. 1 and Fig. 2. It is a defect that arises on the running surface of the rail head and is characterized by the parallel arrangement of cracks at a specific angle to the direction of travel of the train. The defect arises mainly on the curves of the tracks near the edge of the rail head, then passing to the rolling surface. It was found that this defect also occurs on straight sections, however only where the rails are heavily loaded.

Carbon is an element that strongly affects the hardness of rails. The conducted tests of formation of head checks in rails made of steel with increased carbon content have shown that as the hardness of rails increases, the density of defects is increased, but the depth of their residualness decreases with a comparable transport load. Thus, the increase in hardness increases the resistance of the material to the rolling surface of the running surface of the rail head as well as the durability and wear of rails [1].

Therefore, as a result of the rail – wheel contact and crush of the running surface of the rail caused by a long exploitation in the track, the resulting crack becomes the beginning of the crack propagating inside the rail. It is then a fatigue type defect. It is visually detected. In contrast, fatigue defects of the rail with dislocation, vacancy and stress mechanisms, are created inside the head of the rail. They do not come to the surface and are detectable by ultrasonic testing [2]. At the same time, due to the difficulty in detecting this type of defect in the rails (Fig. 3), it can affect the safety of rail transport.

The rail manufacturing process used since the mid-eighties has caused a significant improvement in their quality. The introduced vacuum treatment significantly reduced the amount of gases in steel, i.e. oxygen, hydrogen and nitrogen, thereby reducing the number of non-metallic inclusions and hydrogen flakes as potential sources of microcracks in the rails. Thus, rails produced in the analyzed period had much fewer defects, especially those caused by non-metallic inclusions of the material. The problem was and is the defects appearing during operation.



From the analysis of publications concerning the formation of a defect in the operated rail, it appears that this is a process which is influenced by many factors. The basic ones, however, are rolling loads of the rail as well as residual stresses and stresses resulting from rolling stock dynamics.



Fig. 1. Disadvantages of head cracking.



Fig. 2. A defect head check with cracking coming out.



Fig. 3. A defect head check was created inside the head of the rail.

Consequences of rolling loads

Rail steels in the R260 type have a high carbon content of 0.6 - 0.8%, and are classified as hard steels with low plasticity. Multiple cyclic pressures of the wagon wheels cause deformation in the surface

part of the rail head, which results in crumbling and strengthening of the head surface of the rail. Measurements of HV5 microhardness of R260 rails exceeding even 1200 units, made on a strongly hardened surface of the rail head, indicated the local structure of the amorphous martensite texture - the so called white layer. [6]

Strengthening of the rail surface is progressive as the number of load cycles increases. Then strengthened zones are formed, passing from the surface deep into the material. The resulting structure is characterized by a structure similar to the layered system (Fig. 4, 5). The layered system is created by burnishing the material in the direction of the train. Grains in fortified layers are laid at a certain angle to the surface, depending on the material structure. As a result of increasing load cycles, the surface layer of the head first undergoes elastic deformation, then gradual wrinkling and strengthening. It is a phenomenon of plastic deformation that reaches the limit of material tensile strength. After exceeding this limit, the surface layer ruptures and microcracks arise [7, 8]. Cyclical structural stresses are an additional factor. This is the first stage of creating a defect in the rail head check. The further development of microcracks runs through the fatigue mechanism and is dependent on the number of cycles of rolling loads on the rail during track operation [3, 4].

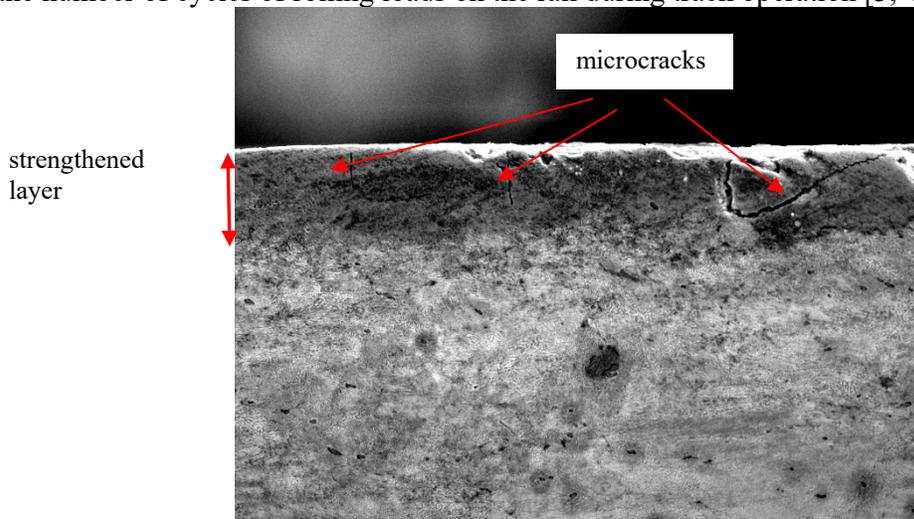


Fig. 4. Strengthened layer of the running surface on the cross-section of the rail head (SEM, 500x).

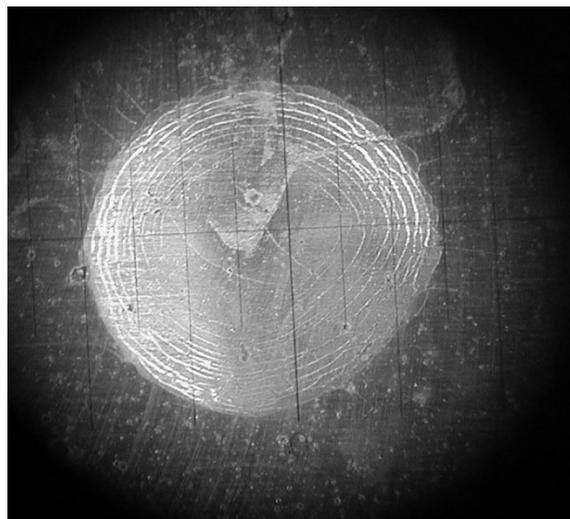


Fig. 5. Imprint of hardness with a 10 mm ball on the rail surface with a visible trace of crushed layers.

The above course of the defect formation occurs on straight sections, in the central part of the surface of the rail running head. The formation of this defect at the edge of the rail head located in the curve of the track causes additional lateral forces impacting the rail. Their impact depends on the size of the curve radius. The larger the radius, the smaller the number of head checks at the edges of the rail.

Parameter K_{1c} explicitly specifies the resistance requirement for R260 rails material for cracking after the crack is formed, according to EN 13674-1+A1: 2017, w ($\text{MPa m}^{1/2}$), and the speed of crack growth in the fatigue compartment, i.e. propagation determines the parameter da / dN expressed in m/Gc [5].

The material of the rails has a pearlitic structure with a trace of cementite content along the grain boundaries, as well as trace amounts of non-metallic inclusions in the form of oxides, silicates and sulphides produced in the smelting process. A large number of non-metallic inclusions contribute to the formation of microcracks under the influence of cyclic bus rails by weakening the cohesion of the material. In contrast, sulfide inclusions in the vicinity of other inclusions, arranged parallel to the plastic processing direction may also contribute to the formation of fatigue microcracks, but after a large number of load cycles.

One of the ways to eliminate surface imperfections of rails, including head checks, is the technological process of grinding the rail head. The most convenient period for removing cracking by grinding is the initial period of formation of this defect on the surface of the rail, when the head check has not sufficiently developed and is at a depth of about 0.5 - 1.0 mm. The use of rail grinding process, however, is associated with high economic costs, which makes it important to determine the right time to decide to grind the rails.

Impact resistance of rail steel

The rails in tracks exploited as a result of passing rolling stock are ~~subject~~ subjected to natural wear due to friction caused by rolling load and dynamic impact of the rail and wheel. Travels characterized by high dynamics, mainly caused by unevenness of the railway surface, are particularly dangerous. The parameter useful to determine the resistance of rail material to impact is impact strength.

Due to the increased number of rail cracks in winter and the need to replace them on the route, impact tests of rails were carried out at a temperature of -60°C to 40°C (Fig. 6), with a temperature increase of 20°C .

The research material was rails made and operated in the seventies marked - A1, in the nineties - A2 and made at the turn of the century - A3. The chemical compositions of the rails are given in Table 1. The impact strength was tested on KCU samples.

The presented chemical compositions of the rails show that the sample no. A1, contained the increased aluminum content binding in the previously produced rails, while samples no. A2 and A3 had a chemical composition in accordance with the standard PN-EN 13674-1+A1: 2017 [5].

As a result of testing the impact strength of the rail material at subzero temperatures, no sudden reduction of impact strength or a clear brittleness threshold in the tested temperature range from $+40^{\circ}\text{C}$ to -60°C was observed.

Fig. 6 shows that, after 30 years of exploitation, the material of the A1 sample rail, has lower impact strength in the entire temperature range, proportionally lower in relation to the impact resistance obtained from the other rails of the A2 and A3 samples. The difference in impact resistance of rails at below zero temperatures is about 40% lower than at temperatures in summer. The size of the impact strength which determines the impact resistance of the material in the case of existing head checks, may indicate the possibility of rail cracks, especially at high fluctuations in the ambient temperature.

Table 1. The chemical composition of the tested rail steel in the R260 grade.

Sample number	Chemical composition, %											
	C	Mn	Si	P	S	Cr	Ni	Cu	Al	V	N	H(ppm)
A1.	0,75	1,17	0,27	0,033	0,009	0,01	0,02	0,01	0,019	0,010	0,010	-
A2	0,73	1,08	0,29	0,014	0,016	0,01	0,02	0,05	0,004	0,010	0,010	1,9
A3	0,73	0,90	0,39	0,020	0,014	0,05	0,02	0,08	0,004	ślad	ślad	1,6
R260 acc. EN-13674-1	0,60 0,82	0,65 1,25	0,13 0,60	max 0,030	max 0,030	≤0,15	max 0,10	max 0,15	max 0,004	max 0,030	max 0,01	max 2,5

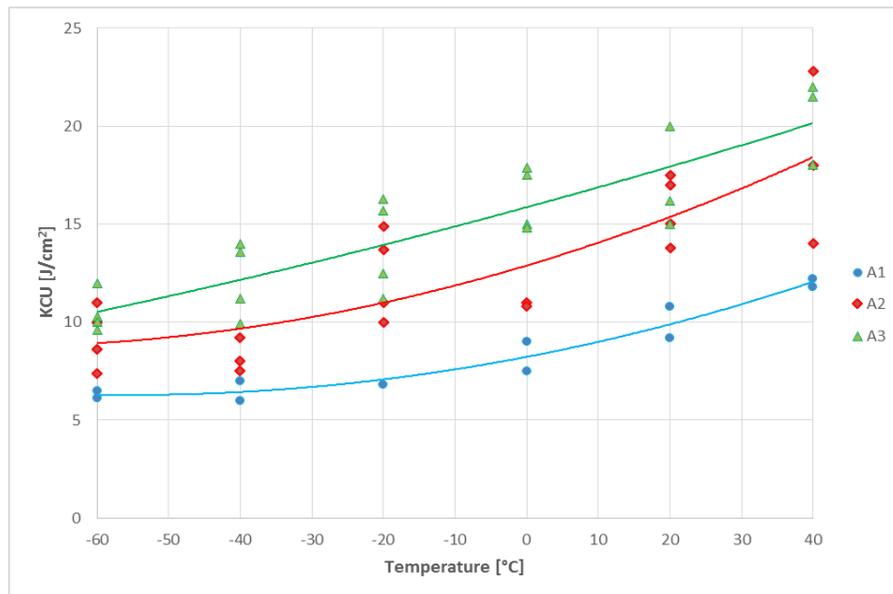


Fig. 6. The impact resistance on the R260 rails.

Summary

It was found that in order for the head check to be created in the rail, the condition must be fulfilled, i.e. the wheel-rail load action, resulting in a corresponding degree of surface strengthening of the rail head and the simultaneous action of stresses, mainly bending in the rail. These factors lead to the formation of micro-cracking of the rail head, and then as a result of repeated load-stress cycles caused by the dynamics of rolling stock, the development of a crack inside the rail head with fatigue mechanism. Non-metallic inclusions play a negative role in the formation of microcracks inside the material. However, currently due to the high technological level of rail production, the causes of defects will disappear, and in their place there will be defects caused by increased speed and greater load on the rails.

Analyzing the mechanism of formation crack rails, and especially the first stage of strengthening the surface layer in terms of plasticity with simultaneous stress, it should be stated that this is one of the most important stages of crack formation in the rail. It follows from the above statement that steel

types should be used for the production of rails with a high elasticity and plasticity limit, while maintaining the current parameters of elongation and narrowing of steel. This will allow for a longer period of initial defect formation and will prolong the service life of the rails.

An even drop in impact strength of R260 rails was found with a drop in temperature over the entire temperature range. This has a negative effect on the strength of the material, in particular contributing to rails cracking in winter at below zero temperatures.

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