Current situation on rolling contact fatigue – a rail wear phenomenon

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Abstract

Rolling Contact Fatigue (RCF) is one of the various forms of rail wear and important to consider, concerning rail maintenance and life-cycle matters. One of the RCF types is head checks: small cracks that will initiate on the rail surface before propagating horizontally. In a more advanced stage the cracks will continue vertically through the rail head, causing a rail break and thus potential serious accidents if no remedial measures are undertaken on time.

Detection of head checks is not easy until a certain depth has been reached. Visual inspection is still the main way to detect them, but modern measuring trains with eddy-current measuring devices are getting more common.

Several factors influence surface crack formation on the rail: operating conditions, e.g. train speed, type of rolling stock, axle loads; track lay-out and track geometry parameters, e.g. curve diameter and superelevation; rail material properties, e.g. the steel quality. Also the maintenance policy can be of influence. External factors as temperature or humidity can accelerate of the propagation process.

Preventive and corrective solutions exist, e.g rail grinding, but also solutions to reduce the occurrence in general, e.g. improving rail material properties and rail head geometry. To optimize the rail defect correction and reduce occurrence in the future it is necessary to identify the source(s) of the degradation.

This paper provides an overview of the problem explaining the initiation and propagation of cracks, listing the considerations and the elements that play a major part in Head Checks initiation and propagation and the kind of remedial solution that exists to prevent and correct this rail defects problem.

Keywords

Head Checks – Wear – Rolling Contact Fatigue

On the front page: head-checks on the outer rail of a switch at the St.Benoit junction south of Poitiers in the line Paris-Bordeaux (France)

1. Introduction

The last two decades, rail transport has seen a revival by supplying faster, cheaper, more frequent and more reliable connections both in passenger and freight traffic. However, the increased traffic density, higher speeds and higher axle loads which come with this revival, have their specific effects on the wear of railway tracks and thus on the maintenance and renewal needs. At the same time, maintenance processes are to be optimized and operating cost reduced.

Given the evolution of the way of exploitation, the rail is subjected to more and higher loads, and thus wear phenomena and fatigue defects appear faster and more frequently. These degradations restrict infrastructure productivity: wear might provoke speed limitations or even load restrictions, more frequent inspections, increasing maintenance costs etc. In this way, understanding the wear phenomena can lead to improved design of both rolling stock and track, but also to improved inspection, maintenance and renewal policies for existing and future infrastructure. Limited to the rail only, several wear types exist, e.g. shelling, squats, spalling, corrugation, head checks.

In Switzerland, some serious cases of head-checks have been found in unfamiliar places. Not detected on time, these cracks can cause rail breaks and thus very serious accidents. After the observations of head checks on the Swiss network, this paper has been elaborated with the aim of better understanding this type of degradation and to provide a solution to it. The main source of information was the literature available on this subject.

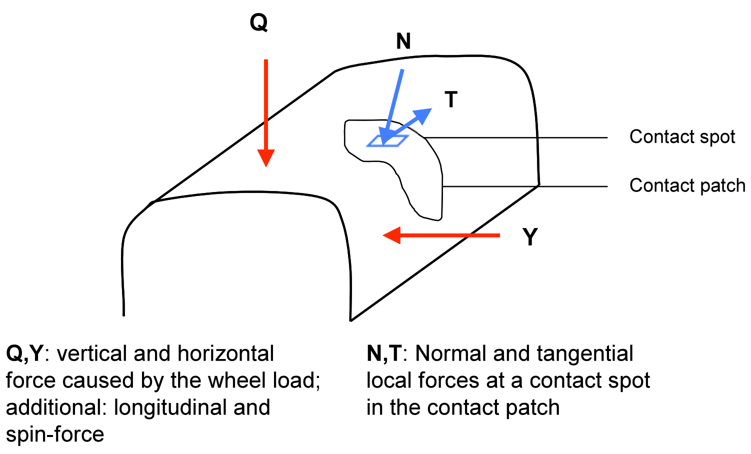
First, head-checks cracks initiation is analyzed, after which the properties of crack propagation are presented. Afterward, the various way of inspection will be surveyed. Then an overview of the specific techniques of preventives maintenances to prevent and control this kind of degradation will be given. Finally curative solutions or more general ways of reducing the occurrence will be presented.

2. Initiation of head-checks

Railway tracks subjected to high loads are subjected to more than 5 million of wheel-rail contacts every 100MGT[1]. Although most of these loads cause hardly any degradation, a number of them will create plastic deformation of the rail. Every additional deformation affects the surface layer, the deformation also cause that the wheel rail contact might not be at its most optimal position. This continues until deformation limits have been reached and fractures occur. The fractures build up in the steel microstructure and (macro) surfaces cracks appear – for head checks these are located in the gauge corner.

In the aim to understand the head-checks development phenomena, it is convenient to understand the crack initiation process, the influent parameters and to identify the sensitive area in the rail.

Figure 1 - Wheel contact strength diagram



Source: The impact of wear rolling contact fatigue on rail- a pragmatic approach, Peter Pointer ZEVrail Glasers Annalen 132 (2008)

2.1 Forming cracks

During this last decades, new technologies and altered ways of exploitation of railroads are facilitating the occurrence of fatigue defects, e.g. increasing traffic density, increasing axle

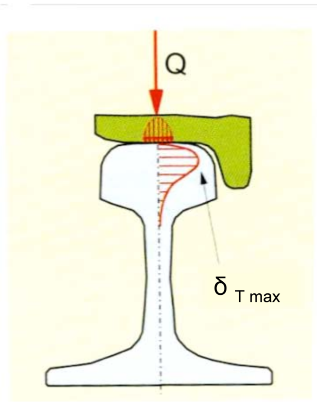
[1] Based on an average axle load of 20 tons. i.e. locomotives and loaded freight wagons 22.5 tons, passenger carriages 11-17 tons.

loads, increasing traction loads due to modern-locomotive characteristics and to improved adherence techniques (traction control), increasing rails and wheels grade and wear resistance, geometrical characteristics of the track, stiffer train suspension systems. The resulting load and straining configuration entail stresses and slip phenomena. Stress and slip combination determines the degradation state.

2.1.1 Stress

The rail is subjected to important dynamic loads, transmitted for the biggest part at the rail-wheel interface, a very small zone. Loads on this spot are vertically and longitudinally transmitted as shown in figure 1.

Figure 2 - Contact stress in the wheel and thus tangential stress in the rail (δ_{Tmax})



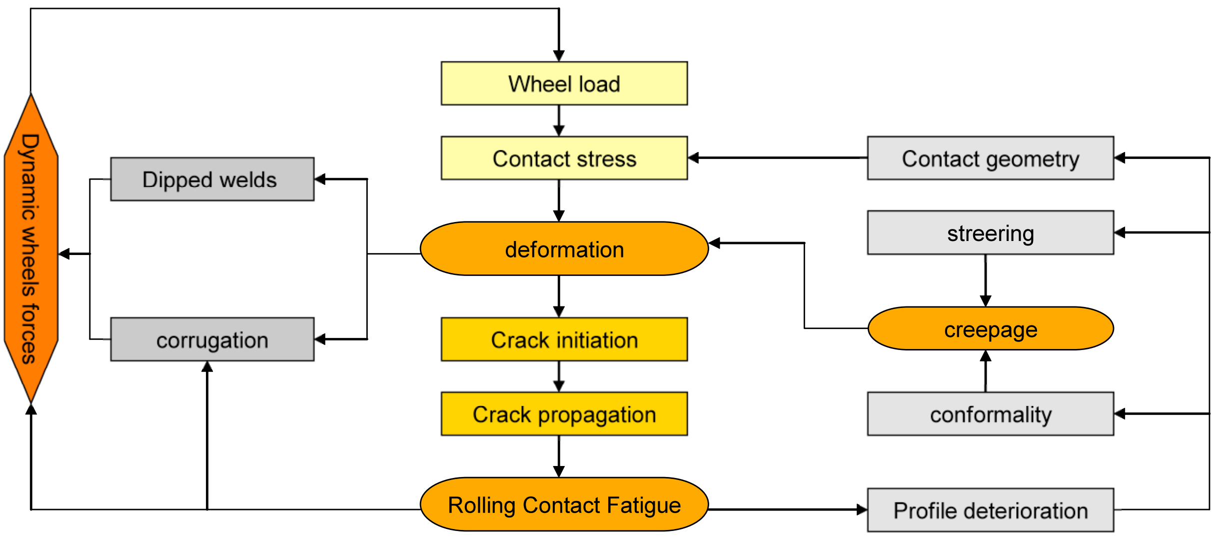
Source: Modern Railway Track, Esveld 2001

Repeating loads provoke internal cyclic stress, which will gradually damage the material and will initiate the crack development; it will begin from the damaged zones. Under the influence of this cyclic stress, the material works in an elasto-plastic regime, initially hardening, which leads to higher residual stresses in the material. These residual stresses lead to pure elastic behavior until the shakedown limit has been reached.

Irregularities on micro scale caused by strains will provoke gradually an increase of the contact strengths, which will generate additional stresses and so on. Mentioned by Böhmer, Ertz and Knothe (2003), is also the temperature influence on this process, generating extra stresses in the material. This is especially related to slip, when high temperatures can occur, which is explained in the next paragraph.

Figure 3 explains the stress cycle.

Figure 3 - Stress-strain vicious circle



Source: The application of contact mechanics to rail profile and design Eric E.Magel, Joseph Kalousek Wear 253 (2002) p.315

2.1.2 Slip

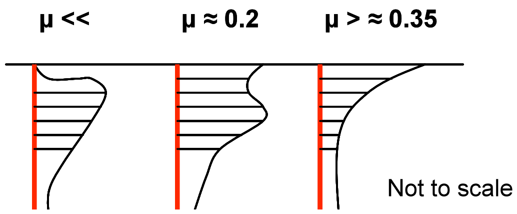
At the same time, sliding caused by wheel stress on the rail is also going to create or at least facilitate these damages, especially in case of very high tangential strengths. Some modification process will ensue from it:

- a structural change of rail material, that can decrease its wear resistance;
- a modification (increase) of temperature combined with the rate of deformation;
- the previous combination can lead to the formation of martensite on the wheel, which might cause the wheel-rail contact be more abrasive.

Adherence, and thus rail lubrication, influences in a consequent way the degradation type. The local coefficient friction μ connects tangential stress δ_T and normal stress δ_N. It depends on the position of the shear stress maxima (Figure 4).

Figure 4 - Lubrication state, position of maximum shear stress and type of defects

$L_T \approx \mu = T/N$	Lubrication state	$\delta_{T\ max}$ position	Types of defect
<0.1	High lubrication	Under the surface	According to the localization: subsurface defects
$0.1 < L_T < 0.35$		There is two maxima: under and then on the surface	Crack are formed on the surface and once the second maxima is reached, a second crack appears parallel with the surface : spalling
>0.35	Poor lubrication	On the surface	Defects develop on the surface: head checks



Source: The impact of wear rolling contact fatigue on rail- a pragmatic approach Peter Pointer ZEVrail Glasers Annalen 132 (2008)

2.1.3 Stress-slip combination

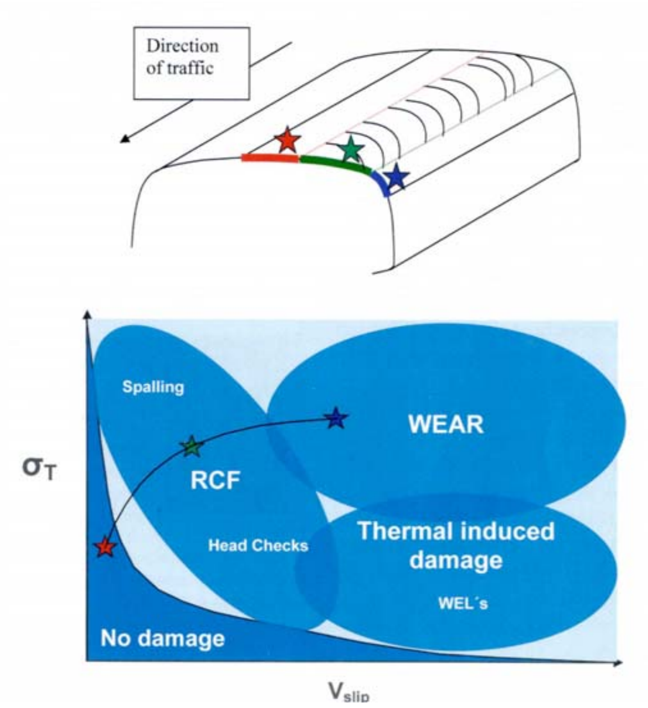
Finally the combination of tangential stress δ_T and slip velocity V_{slip} will determine the type of degradation, which will affect the rail, as shown in figure 5.

2.2 Influential parameters of crack initiation

The combined effect of contact stresses (rail wheel contact strength) δ_N and δ_T, traction surface T and normal strength N (due to powered axles or breaking) and shear resistance of the steel K, which generates friction, determines the fatigue process. It is thus essential to identify the loads of the rail and the way they depend on representative parameters of traffic condition and of infrastructure constitution

According to the previous paragraph, it is possible to distinguish parameters that are influencing the stress state and slip and finally the rail metallurgy parameters and thus to the material resistance (Control of Rolling Contact Fatigue of Rails, Eric Magel, Kevin Sawley and Joe Kalousek, 2004).

Figure 5 - Damage map according stress state and slip speed[2]



Source: The impact of wear rolling contact fatigue on rail- a pragmatic approach Peter Pointer ZEVrail Glasers Annalen 132 (2008)

2.2.1 Influential parameters regarding contact stress δ_Q

Several parameters influence the stress state in rails: loads and their distribution, track geometry and its irregularities. A non-exhaustive list of these parameters might be:

- axle load: directly influences state stress;
- asymmetric loadings: the strain will also be posed asymmetric on the rail head and the rail wheel contact will get irregular and discontinuous;
- wheel diameter including mismatched wheel diameters;
- track gauge: “tight gauge in tangent track provokes gauge corner contact, hunting of the bogies and thus rolling contact fatigue […]. In curves, controlling wide gauge is essential for mitigating low rail damage associated with hollow wheels”[3];

[2] This damage map have been established for medium radius curve but conceptually it can be extend to other track configuration

- wheel transversal profile;
- rail transversal profile and profile irregularities;
- cant[4] excess/deficiency: wheel sets will tend to shift and to heavily offset to the inner or outer rail respectively;
- welds: at too soft/flexible welds a dip will be produced or, in case too hard high spots will be produced this will both leading to geometry irregularities;
- hunting of wheel set in tangent tracks;
- string lining forces on grades tie plate cut in and poor fastening;
- skewed trucks.

2.2.2 Slip linked parameters

Wheel surface and rail surface are separated by an interface layer constituted of wear fragments and environmental contamination. The relative sliding between wheels and rails generates an interface layer shear strength in the contact area. These shear strengths cannot be higher than the available adherence[5]. Controlling interface layer properties allows to reduce the traction forces to a certain extend.

The ratio tangential strength / normal strength, T/N, depends on several parameters:

- curve radius: “angle of attacks and creep (both lateral and longitudinal) increase with increasing curve radius and increasing wheelbase”[3] and thus, rolling contact fatigue defects formation increases also with curve radius and truck wheelbase;
- bogie suspension: a stiff suspension will resist to wheelset movements. “The stiffer the suspension, the greater the potential for favourable steering movements to reduces the yaw angle in curves and thereby RCF[…]. However, to respond to unfavourable steering movement and increase the yaw angle, especially in the case of trucks/bogies that have been poorly maintained”[3];

[3] Eric Magel, Kevin Sawley and Joe Klousek in the article " Control of Rolling Contact Fatigue of Rails

[4] cant [Eng.] = superelevation [American english]

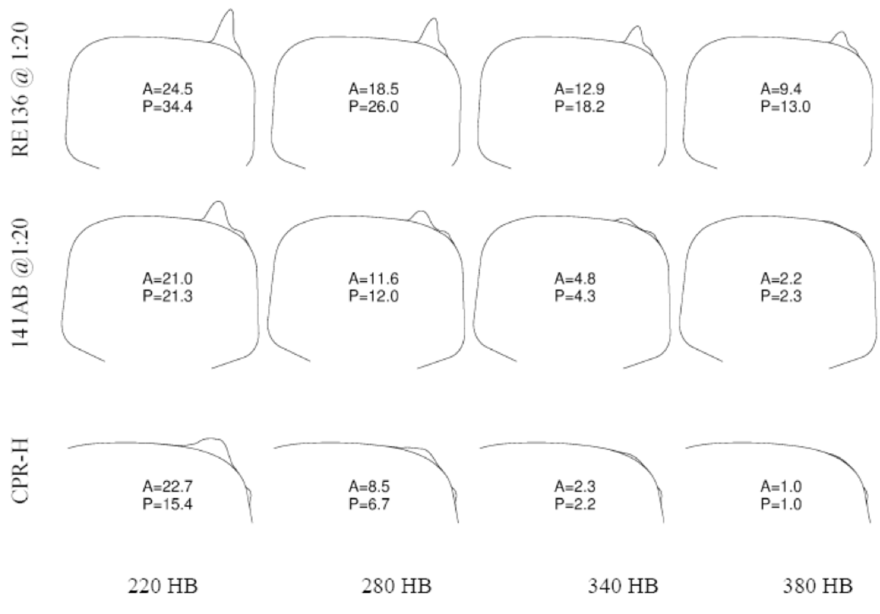
[5] The available adherence or adhesion depends on the normal force between wheel and rail multiplied by the friction coefficient.

- friction coefficient: minimizing friction coefficient with lubrication results in minimizing the traction strength maxima;
- cant deficiency: the axle will offset their movement on the outer rail and thus will increase traction strength.

2.2.3 Rail metallurgy linked parameters

Resistance to rolling contact fatigue RCF differs according to steel grade, in particular according to their grade. Indeed, a higher steel grade will reduce the number of contacts higher than the elasto-plastic stable state and thus will decrease RCF damage. Nevertheless, when a certain limit is passed, the situation gets inversed (Handbook of railway vehicle dynamics-Tribology of the wheel rail contact - Simon Iwniki)

Figure 6 - Predicted distribution of RCF damage on three different rail sections for four different hardness values based on 300 measured worn wheels.



The numbers on each plot represent the relative peaks *P* and areas *A* of the RCF distribution.

Source: Control of Rolling Contact fatigue of rails Eric Magel, Peter Sroba, Joe Kalousek, The American Railways Engineering and Maintenance-of-way Association annual conference, 2004

To conclude, the most revealing parameters are: curvature radius, cant deficiency, section type, the section of the rail and the traffic and rolling stock type and traffic structure. Besides, the more the rail - support system is stiff, the less it will absorb shocks elastically, and as a consequence it will be more subject to the head-checks.

2.3 Sensitive areas

Certain elements of rails are more exposed to wear phenomena and to rolling contact fatigue, mostly because of dynamics effects. In curves and switches, wheel rail contact area is smaller and flange contact toward the gauge corner can increase tangential forces and slip.

In curve, the outer rail is particularly exposed, especially in mild curves (800-1500 meter radius).

- rail wheel contact zone is small: it is the 5 eurocent equivalent[6];
- dynamic loads due to centrifugal forces and axle oscillation due to curve guidance become important.

The main function of switches and crossings is to guide the train from one track to another one. At least one of the directions is therefore curved. This track discontinuity provokes an irregularity in the support and guidance of a moving train, thus causing important loads impacts due to train passage:

- rail inclination differences between the normal track rail and the rail in the switch or crossing leads to a deviation of the rail wheel contact;
- simultaneous wheel contact on the point rail and the stock, rail provides areas where high vertical and horizontal dynamic loads are concentrated on a very small area;
- generally switches are stiffer than plain track, thus the energy and force dissipation is different, as a consequence.

[6] Handbook of railway vehicle dynamics-Tribology of the wheeled rail contact - Simon Iwnik

3. Crack propagation

Once the crack is initiated, it propagates due to stress influences, which are determined by rolling stock and environmental conditions.

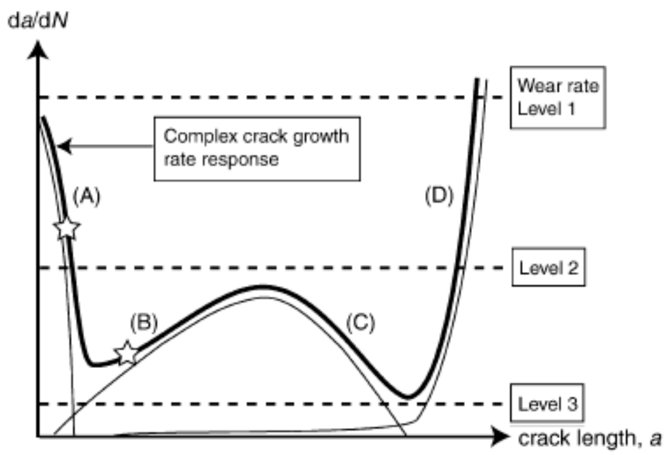
To have a good understanding of the distribution cracks phenomena, it is necessary to integrate the phenomenon itself and afterwards list the influential parameters. Finally the characterization of cracks allows the propagation speed and the gravity of the situation estimating.

3.1 Process description:

First, cracks propagate slowly in the surface plain of the rail in the same direction as the plastic deformation, i.e. generally under a 15º to 25º angle to the running surface of the rail, until reaching a depth of 3 to 5 mm deep. Then it will grow only in the head of rail with an approximate speed a speed of 1mm / MT[7], crack distribution is then determined by stress and strain acting at the crack mouth.

It is possible to decompose the distribution process into four phases (figure 7).

Figure 7 - Crack propagation phases



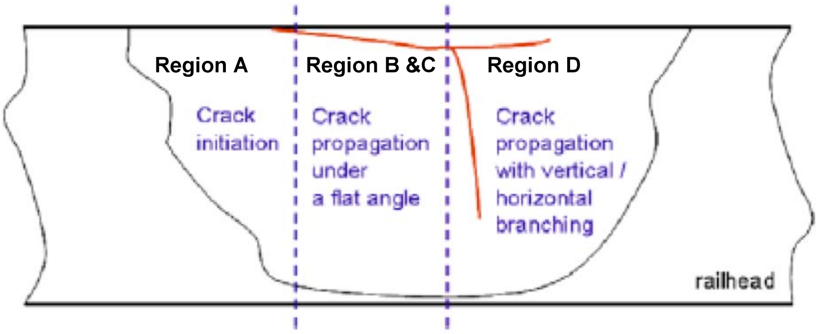
Source: Shear mode growth of short surface breaking RCF cracks Jonas W Ringsberg Wear 258(2005) 955-963

[7] Dr. Peter Pointer, The impact of wear and rolling contact fatigue one rails – a pragmatic approach, ZEVrail GLASERS Annalen in 132 (2008) August 8th

The tables[8] below help in understanding the figure 7.

Region	Phenomena
A	Crack initiation by low-cycle fatigue; deformation and the propagation process starts
B	As crack lengthens, stresses near the crack tip increases and the crack growth rate increases
C	Beyond a certain critical crack length, the tip of the longest crack moves away from the highly localized contact stress field and the stress intensity drops, leading to a reduction of crack growth rate
D	Crack is subjected to flexion and the residual traction stress facilitates the crack growth rate

Figure 8 - Crack propagation phases in the railhead



Source: Application of fracture mechanics methods to rail design and maintenance J. Plu, S. Bondeux, D. Boulanger, R. Heyder, Engineering fracture mechanics, 2009

Wear rate level da/dN	Characteristics
Level 1	The very high wear rates do no permit crack formation: crack mouth truncation is higher than the rate of advance of the crack
Level 2	The slightly lower wear rate rubs out the initiating crack faster than they from ; hence cracks are hindered from growing
Level 3	Very low wear rates thus that is not affecting crack growth at all

[8] according to Ringsberg, Jonas W *Mode growth of short surface breaking RCF cracks* Wear 258 (2005) pp.955-963

3.2 Influential parameters of crack propagation

Crack propagation mostly depends on propagation stresses, which are determined by loading conditions, steel resistance and lubrication.

The loading condition in the rolling contact surface influences the rail material’s reaction and the crack tip development. Indeed, for example, high tangential strength creates stresses and strains of which the maxima are located in the head of the rail while smaller strength transfer maxima are found subsurface.

Tangential stress can also affect cracks orientation.

Beside this, it is necessary to point out that in the heat-cooling processes (e.g. due to slip), martensite will be eventually created on the rail wheel, which increases its hardness and thus the stress: the crack formation process in the rail will be boosted due to this.

When the loads move due to the rolling movement and to slip on a lubricated rail with a small crack area it can facilitate crack propagation. If the cracks grow in traffic direction, this crack is pushed open just before the contact load reaches this crack. Due to the capillary effect, the cracks will fill with water. Water can result from the ambient humidity, condensed, then liquefied due to ambient or locally generated heat (due to slip). In case the crack would develop in the opposite direction of traffic, the phenomenon would be inverted: the fluid would be forced to go out then the crack would close.

Then, once the contact load moves, some water can get trapped in the crack because it tends to close.

There are thus three effects possible:

- the fluid lubricates crack faces of the crack but no pressure is exerted;
- the trapped fluid exerts a pressure towards the outside of the faces of crack: lips get separated;
- the trapped fluid stop crack to be closed when a force is applied.

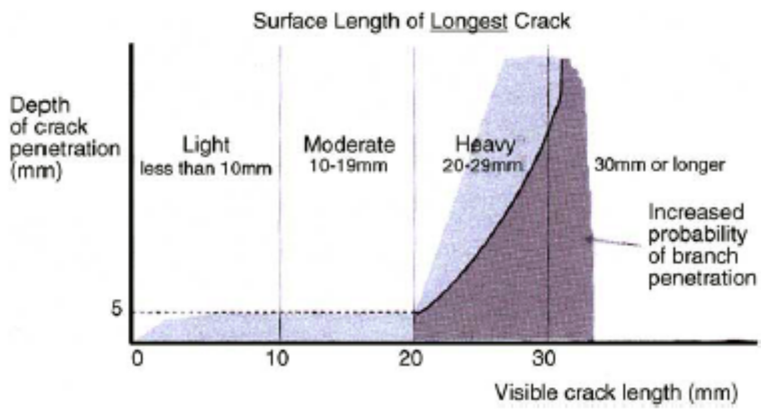
The last two of the three are in particular influenced by the crack length (too small crack will struggle to open, too long cracks will struggle to get close)

3.3 Crack classification: length, depth and gravity defect

Crack propagation will depend, among others, of its characteristics: length, depth, and angle with surface. It is thus necessary to identify cracks characteristics.

As mentioned before, passed a certain critical depth, 3 to 5mm, the crack will propagate only vertically.

Figure 9 - Correlation between length, depth and crack gravity



Source: Rolling contact fatigue on the British railway system: treatment, S.L. Grassie, Wear 258 (2005) 1310-1318

Four rolling contact fatigue gravity level can be distinguished, depending on crack length and depth:

- light: ≤ 10mm length of visible crack;
- moderate: from 10mm to 19mm length of visible crack;
- heavy: from 20mm to 29 mm length of visible crack;
- critical: ≥ 30mm length of visible crack.

If the crack length exceeds 20mm and the depth overtakes 5mm, it is very certain that the crack is quickly going to increase and will be with great difficulty recoverable. This will certainly cause severe safety problems (e.g. the Hatfield accident in Great Britain in October 2000).

4. Maintenance and treatment procedures

If head checks are not detected and treated on time they can provoke a rail break, an extremely critical situation, from a safety point of view (e.g. the Hatfield accident, Great Britain, in October, 2000). Regular inspection is therefore compulsory and corrective maintenance measures must thus be programmed and carried out if necessary to cope with the damages on the rail as quickly as possible. However, adapted initial designs or preventive maintenance strategies can reduce the probability of head checks significantly. This chapter deals with inspection, preventive strategies and –if head checks have occurred anyway– the corrective measures, that can be taken.

4.1 Inspections

The inspection interval of rails must be defined by taking into account exploitation constraints and the gravity of situation. For example, ProRail (Netherlands) and SBB Infrastructure (Switzerland) carry out automized rail inspection with a measuring train, every 6 months. However, much more often track inspections on foot are carried out. Damage must be accurately located and their gravity (cf. §3.3) must also be clearly defined.

4.1.1 Inspection types

In correspondence with financial resources and the precision degree wished, several inspection systems exist; they will be reviewed in the following paragraphs.

- visual inspections by experts walking along the rail or by automated tools based on a linear camera system embarked on an inspection cart;
- "HC Grinding scanner" developed by Speno: it scans the track and can determine the depth of the defect;
- ultrasonic inspection, although this has the handicap, that it is not precise enough: it is unable to detect cracks under 4-5mm depth and thus it can be too late for head checks;
- noise level inspection: train rolling noise can indicate the presence of surface defects, grave defect will be hardly identified but this method is interesting to evaluate the efficiency of a grinding campaign;
- Magnetic particle inspection: it makes use of an externally applied magnetic field or electric current through the material. The magnetic flux will leave the part at the defect area: defects cause magnetic flow distortion.

Finally, it is generally necessary to combine several inspection methods.

4.1.2 Crack characterization

Once the inspection has been carried out and the defect is located, it is necessary to evaluate the situation. The necessary information on the cracks is:

- length of the crack;
- depth of the crack, defined by the vertical distance from the surface of the rail to the tip of the crack[9];
- spacing of the crack: depending on rail tensile strength: the higher the tensile strength of the rail material, the closer is the spacing of head checks;
- angle between crack and rail surface: depending on and the curvature radii and traffic direction. Visible surface crack direction is perpendicular to the tangential stress direction;
- localization on the railhead.

These characteristics are, in a certain measure, revealing the load, the friction conditions and the geometry of the wheel-rail contact, which can help to determine the cause of the problem. It is important to remember that if a 5mm crack depth has been exceeded, head checks become too dangerous and it is too late: the only solution left is rail removal, that is why inspection must be precise.

4.2 Preventive strategies

Since the previous chapters show that in recent years more is known about head checks occurrence, design measures and preventive maintenance strategies can be adopted. The most interesting design feature would be to limit the amount of curve radii subjected to head checks, but in this article the focus is limited on design alterations on existing tracks. Complementary with the track inspection campaign, a preventive strategy or improved design helps in preventing the rail degradation. Maintenance programs have to be planned by taking into account the exploitational, logistical and financial constraints. Grinding and lubrication are the two main preventive operations dealt with in this chapter. Beside this, a proper choice of steel grade is presented, which might be a possibility if rail replacements are due.

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[9] Comparing the life cycle costs of standard and the hardened rail, Gregor Girsch Rene Heyder Nicole Kumpfmüller Rupert Belz, Railway Gazette International September 2005

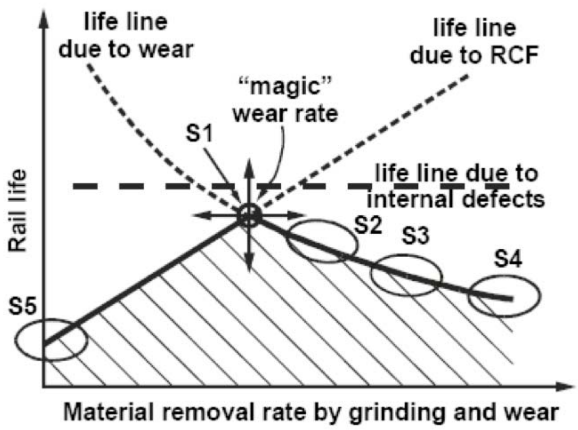
4.2.1 Grinding

Grinding eliminates rail corrugation while re-profiling it simultaneously, thus reducing the crack distribution process and wear:

- it unloads the crack mouth: their growth is no longer possible and fluid can not be trapped anymore;
- through rail re-profiling, the wheel-rail contact spot is moved to the top of the rail; the gauge corner is not subjected anymore to fatigue;
- it reduces flange wear on the outer rail, improving train stability and as a result of all this, it also reduces the amount of rail-wheel contact points and rolling noise.

The grinding type (initial, systematic preventive and corrective) and the intervals are set up according to the potential degree of exposure, the extent and the gravity of the defects (figure 10). Concerning tolerances, it is essential to determine the acceptable tolerances, in particular according to rail profile type of and its steel. In some rail sections such as switches or expansion joints this operation can be very delicate – in some countries grinding is therefore prohibited in these situations.

Figure 10 - Grinding strategies according rail cycle life



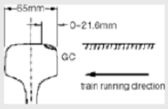
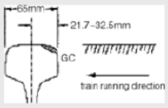
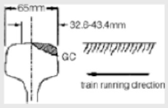
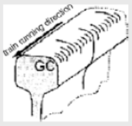
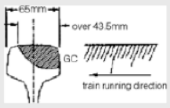
strategy S1 : initial preventive; strategy S2 : preventive systematic; strategy S3 : maintenance; strategy S4 : corrective; strategy S5 : no grinding

Source: Control of Rolling Contact fatigue of rails Eric Magel, Peter Sroba, Joe Kalousek The American Railways Engineering and Maintenance-of-way Association annual conference, 2004

For head checks, grinding intervention must be done as soon as possible after track laying to avoid the development of head checks. If cracks are visible, it is generally too late to solve it by grinding totally and in an economic way. When cracks exceed 15mm of length, it is necessary to remove the rail or the switch component.

Figure 11 summarizes the actions that can be taken, according to the crack type.

Figure 11 - Cracks classification and propagation and tasks to undertake

Contents	Appearance	Inside	Action
Head check can be found at gauge corner			Recording
Head check propagate on the other corner of rail head			Marking
Head check propagate up to thirds of the breadth of rail head			Installing fish plates and scheduling replacement
A crack of head check propagates more and comes to be transverse fissure			Replacing as soon as possible

Source: Laboratory simulations with twin disc machine on head check, M. Takikawa, Y. Iriya, Wear 265 (2008) pp.1301

4.2.2 Lubrication

In absence of lubrication, an important friction occurs, what could cause a surface plastification followed by the formation of cracks.

There are two types of lubrication:

- Track mounted rail lubricators: rail is lubricated by direct application of the grease on the rail side;
- Wheel flange lubricators on the train: grease is first applied on the flange, which, in its turn, will be transferred to the rail.

A project between 1988 and 2001, carried out by the Laboratory of Contact Mechanics the National Institute of Applied Sciences, INSA, Lyon within the framework of the research project to optimized greasing (GOURROU), has demonstrated the importance of a regular lubrication. The project also showed that an extended absence of lubrication results in irreversible damage. The friction coefficient μ depends on the lubrication type used.

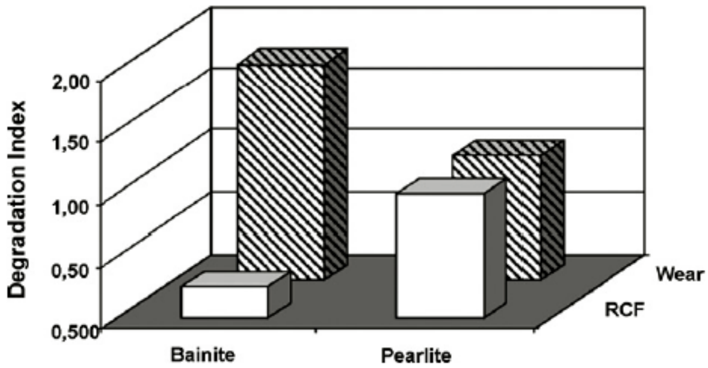
As noticed in chapters 2 and 3, concerning influential parameters in crack formation and crack propagation, lubrication can also be problematic: a lubricated surface will reduce in most cases significantly the crack formation but once the crack is formed, lubrication can facilitate crack propagation.

4.2.3 Properties of the steel used

Characteristics of the chosen rail material can have an important influence on fatigue defects. In this paragraph particular attention will be paid to alloyed steel, head-hardened and heat-treated steel and steel grade. Finally the two-materials rail will be presented.

Alloyed steel exists in various steel grades. The wear and surface defects resistance will depend on their type. There is pearlitic (ferrite and cementite agglomerate) and bainitic (oriented ferrite and cementite agglomerate) alloyed steel. Figure 12 shows the difference of resistance between the two grades.

Figure 12 - Degradation index[10] for rolling contact fatigue and wear behaviour of pearlitic and bainitic rail steel with the same grade



Source: High strength rail steels - The importance of material properties in contact mechanics problems, Peter Pointer Wear 265 (2008) pp.1373-1379

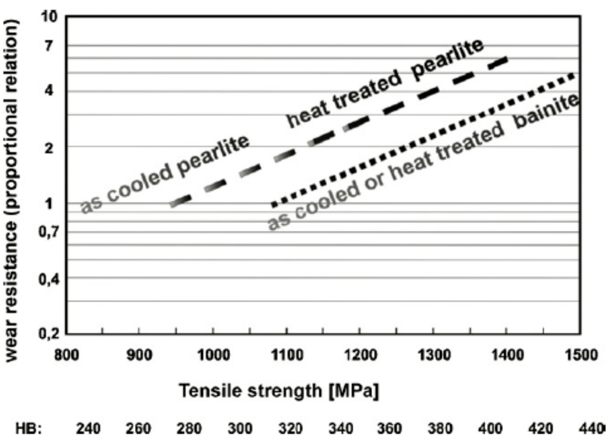
Head-hardened steel for the rail is specially treated steel. The more the rail hardens with a low and homogenous residual stress level, the higher will be its resistance. The use of this kind of rail is especially reserved for the very loaded outer rail in curves to resist against creep. Studies led by Deutsche Bahn and Speno, published in the *Revue Générale des Chemins de Fer* of June 2000, show that with head-hardened rails, the crack spacing is

[10] The degradation index is the relative resistance, pearlitic resistance to wear assumed to be 1

reduced. The crack field is therefore denser but the cracks are smaller and stay more at the surface.
A concrete example is the micro-alloyed head hardened rail, also known as MHH rail: pearlitic hardened steel with a high grade. It has improved resistance characteristics compared to normal rails. There is also the special head hardened rail, HSH rail, developed by Voestalpine: its wear resistance is three times higher than a basic steel rail grade (900A or 260).

As mentioned before, heat-treated steel will reach a wear-adapted profile slower and thus loadings can in this way be considered as a disadvantage. A combination of a wear-adapted profile and heat-treated steel might therefore be a solution, however, these rails have to specially produced, which increases costs.

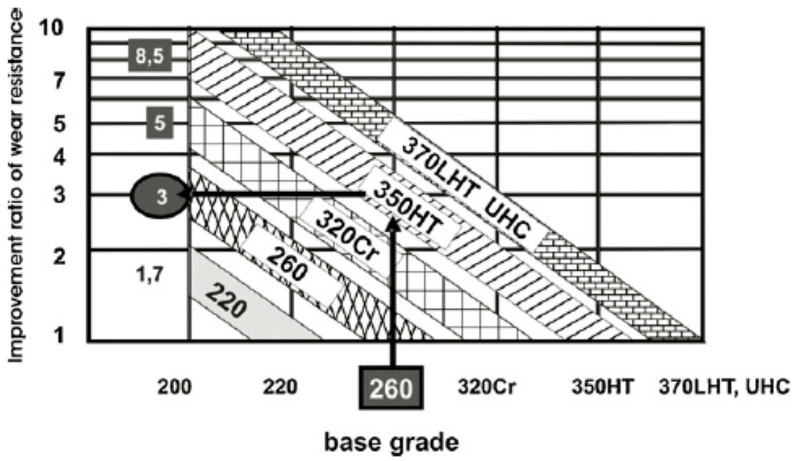
Figure 13 - The dependence of wear resistance on rail grade/tensile strength for pearlitic and bainitic rail steels



Source: High strength rail steels The importance of material properties in contact mechanics problems Peter Pointer wear 265 (2008) pp.1373-1379

The following figure shows the influence of the **steel grade** (expressed in Brinell-hardness) on wear resistance.

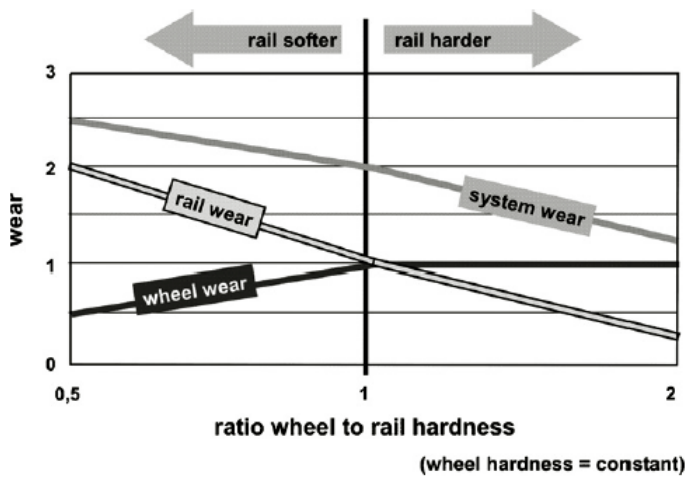
Figure 14 - The ratio of improvement of wear resistance as a function of rail harness for pearlitic steel



Source: High strength rail steels The importance of material properties in contact mechanics problems Peter Pointer wear 265 (2008) pp.1373-1379

Nevertheless, choosing steel grade with the aim of increasing wear resistance cannot be made to the expense of wheel wear resistance: the interaction rail wheel must be taken into account. The next figure shows the effect of the rail grade on the wear of the system rail wheel.

Figure 15 - Wheel, rail and combined wheel rail wear as a function of rail grade: wheel grade is kept constant



Source: High strength rail steels The importance of material properties in contact mechanics problems Peter Pointer, Wear 265 (2008) pp.1373-1379

As shown in this figure, increasing the rail grade will increase wear resistance but will not influence wheel wear.

The influence of rail tensile strength on the development of rolling contact fatigue defects is nevertheless a controversial subject: ever increasing wear resistance does not guarantee that crack development will not occur.

More over, it is necessary taking into account that the higher the rail steel's resistance, the longer it will take a wear-adapted profile is obtained. It is thus necessary to find a compromise.

For the two-material rails, an additional surface layer is applied on the head of the rail to prevent rolling contact fatigue defects. One of the developments of such a rail was the European funded, scientific consortium, which ran the research project "Infrastar". Corus and Durox have also developed two different application of this layer. Coating materials have a higher grade, thus preventing plastic flow and, as a consequence rolling contact fatigue. Rolling contact fatigue resisting performance depends on the coating thickness, and the chosen coating material combination.

4.3 Corrective measures: head checks treatment

Once head-checks are discovered, corrective measures have to be carried out. It is possible to act in several ways: modification of maintenance techniques by re-profiling or friction modifiers.

4.3.1 Compensatory grinding or re-profiling

The purpose of compensatory grinding is to optimize the size and place of the wheel-rail contact point, resulting in a better distribution of stress and even a decrease of these stresses in the gauge corner area involved. A rail profile optimization will help in controlling wear and fatigue defects development; in certain cases, it can also facilitate curve guiding; the rail is artificially worn and then gets an adapted profile with a bigger zone of contact

An example is the "Balliges profile" developed in Austria, asymmetrically grinded rails. Another example is the anti-head checks profile elaborated within the framework of 54E1 rails (European research program on rails in collaboration with Speno). This profile relieves the gauge corner by displacing the rail-wheel contact point more to the top of the rail.

4.3.2 Frictions modifiers

Decreasing the friction coefficient in the rail wheel interface is a way to cope with tensile strength. This is possible by using friction modifiers (FM). As a reminder, the friction coefficient, μ, was defined in chapter 3: $\mu = \frac{T}{N}$ with tensile strength *T* and normal strength *N*.

Lubrication helps in reducing the tensile strength maxima; it is especially efficient for the gauge corner. On the other hand on the top of the rail, the friction coefficient should remain optimal, i.e. higher than 0.3 to guarantee good braking and acceleration conditions.

Friction modifiers are a thin layer consisting of water and one or multiple composite polymer(s) to be applied to rail material surface periodically.

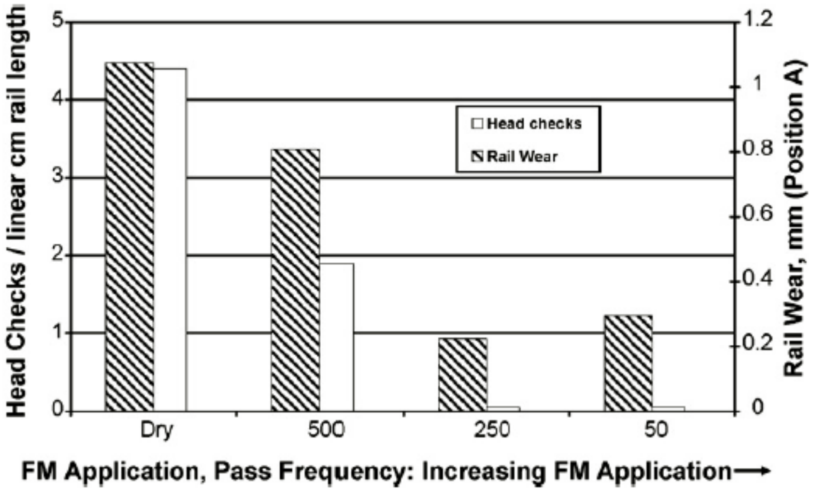
They present two interesting characteristics:

- reach an intermediate friction coefficient. Tensile strength will be reduced without affecting adherence and braking resistance;
- once water is evaporated, friction modifiers help in setting up a thin dry film which will remedy, to a certain extent, crack propagation problems.

So friction modifiers reduce crack formation and do not facilitate crack propagation. It is important to remember, as already mentioned on §2.2, that the friction coefficient must be neither too high nor too low.

Tests led by Voestalpine (The effects of top rail friction to modify wear and rolling contact: full scale rail test wheel rig evaluation, analysis and modeling, Wear 265 (2008), pp. 1222-1230) have estimated the influence of the friction modifier KELTRACK on the rail wear and on head checks. Results are presented in figure 16.

Figure 16 - Application rate effect on wear and head checks



Source: The effects of top of rail friction modifier on wear and rolling contact fatigue: full-scale rail wheel test rig evaluation, analysis and modeling Donald T.Eadie, Dave Elvidge, Kevin Oldknow, Richard Stock, Peter Pointer, Joe Kalousek Peter Klauser, Wear 265 (2008) pp. 1222-1230

4.4 Long term measures

In the long term, measures involving rolling stock should be taken into consideration, unfortunately, the split-up between railway undertakings (RU’s which run the trains) and infrastructure management (IM, responsible for the network maintenance, renewal and management) does not make this easier. New worldwide standards can be introduced regarding e.g. rolling stock characteristics (anti-skidding techniques, softer suspension systems), wheel and rail profile (e.g. equivalent conicity).

5. Conclusion

For various reasons head checks initiate and propagate. In general the reasons are related to:

- infrastructure properties like track geometry (e.g. curve radius), rail shape (e.g. 54E1), and rail material (e.g. microstructure, steel hardness);
- train properties like dynamic and static load, stiffness of the bogie and wheel material properties;
- usage properties like speed, admitted uncompensated lateral accelerations etc.

Specifically for the propagation phase, the ambient humidity and temperature also have to be mentioned.

To tackle the problem of head checks, the problem can most easily be attacked as early as possible. For a new-to-build railway line or metro network, that is already in the design phase. A completely independent, new-to-build rail network could even be optimized in such a way that head-checks will not even occur – also not in curves with radii in which the rail will almost surely suffer from head checks – by adapting the wheel design.

On existing networks, immediate measures that can be taken after discovery of head-checks are grinding and the installation of track-mounted lubrication. Also the introduction of asymmetric rail profiles to optimize the wheel-rail contact might bring a solution.

More structural long-term solutions are equipping all trains with wheel flange lubrication and optimizing the steel grade of the rail or applying head-hardened or heat-treated rail or two-material rails.

For the specific situations as recently discovered in Switzerland, one of these solutions will have to be adopted to increase the life of the rail. However due to the uniqueness, probably only a combination “therapy” will bring a solution.

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