Engineering Practices Manual
Civil Engineering

Rail Defects Handbook

Some Rail Defects, their Characteristics, Causes and Control

RC 2400

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Introduction

The life of rails in track is determined primarily by:

- Wear - which occurs primarily on the gauge face of the high rails in the sharper curves, due to the high wheel flanging forces. Some wear also occurs on the running surfaces of all rails due to wheel/rail interaction and also due to rail maintenance (grinding).
- Plastic Flow - which can occur in both high and low rails, primarily in curves subjected to higher axle load operations (> 20 tonnes). Plastic flow is due to the applied wheel/rail contact stresses exceeding the strength of the material.
- Defects - which can develop in all rails (and welds), because of a wide range of reasons. Defects are of major concern since, if not detected in time, they can grow and possibly cause rail failures, or at least necessitate expensive rail maintenance.

The occurrence of rail defects has generally increased because of the much longer rail lives obtained through various improvements, which have reduced the rail wear and hence have allowed the defects to develop.

The main purpose of this Handbook is to describe some of the more common rail defects, their causes, and the possible ways of controlling their development.

Other rail defects occur that are not described in this edition of the Handbook. These defects include

- Head and Web separation
- Foot and Web separation

- Horizontal and Vertical Split Web
- Bolt Hole Cracks
- Piped Rail
- Defective Welds
- Rail Corrosion
- Rail damage

Information on these defects is contained in the CCE Booklet 32.1 "Rail Failures Reporting, Classifying and Computer Programming" published by the Department of Railways, NSW October 1971.

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1 Rail Loads and Stresses

All major rail defects require some form of stress to initiate and develop.

Consequently, before rail defects can be discussed in any detail, it is necessary to have some understanding of the terminology that is commonly used, the loads that are applied to the rails, and the resultant stresses.

Figures 1 (a) and (b) illustrate the terminology used to describe the directions and planes in rails, namely:

Longitudinal direction	:	*along the rail.*
Transverse direction	:	*across the rail.*
Vertical direction	:	*normal to the rail.*
Vertical plane	:	*vertical along the rail.*
Horizontal plane	:	*horizontal along the rail.*
Transverse plane	:	*transverse across the rail.*

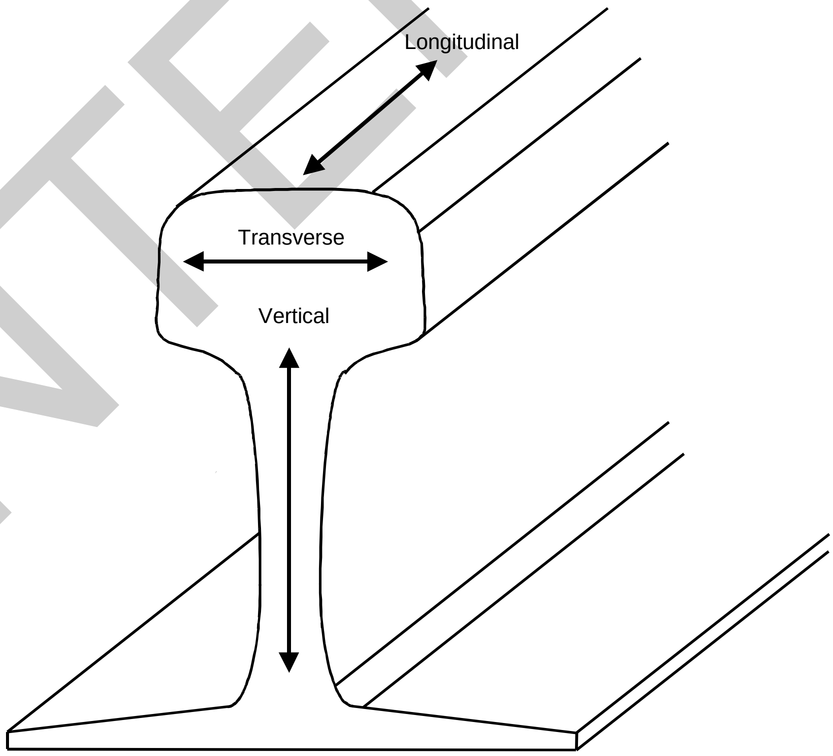

Figure 1 (a) Terminology used for directions in rails

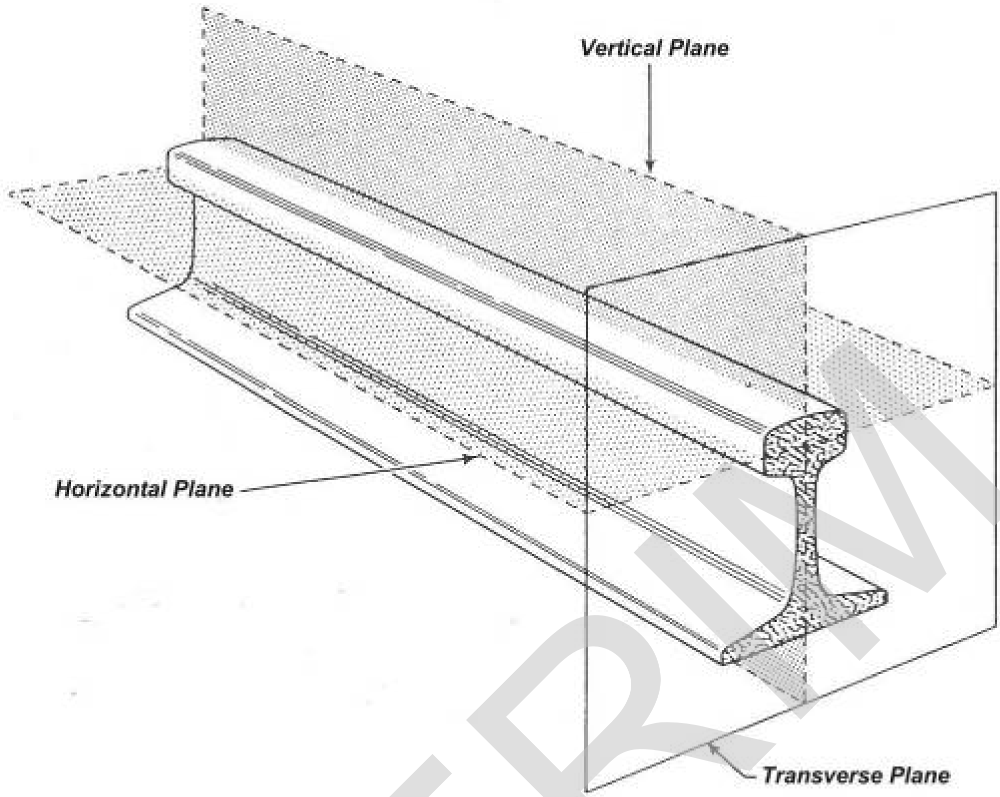

Figure 1 (b) Terminology used for planes in rails

Figure 1 (c) illustrates the terminology used for the common regions in rails, namely:

Running Surface	:	*The zone on top of the rail head, which makes contact with the wheel tread. In tangent and low rails this region can range in width from very narrow (say 20mm) to very wide (say 60 - 70mm) depending on the wheel and rail profiles.*
Gauge Corner Region	:	*The top corner on the gauge side of the rail, which makes contact with the wheel throat region. In high rails, this region can also range in width from very narrow (say 15mm) to wide (say 25mm) depending on the wheel and rail profiles.*
Gauge Corner	:	*The single point in the gauge corner region, the tangent of which is at 45° to the horizontal (with or without cant).*
Field Corner Region	:	*The top corner on the field side of the rail. Contact can occur in this region depending on the wheel and rail profiles.*
Fishing Surface	:	*The region at the bottom of the rail head, which makes contact with fish plates.*
Rail Centre Line	:	*The vertical centre of the rail section.*
Rail Head	:	*The region of the rail that is above the extensions of the fishing surfaces to the rail centre line.*

Rail Foot	:	*The region of the rail that is below the extensions of the top of foot surfaces to the rail centre line.*
Rail Web	:	*The region of the rail that is between the rail head and the rail foot.*
Head/Web Transition	:	*The transition region between the rail head and web sections.*
Neutral Axis	:	*The vertical distance of the rail at which the Second Moment of area of the section above is the same as the section below. This is the point at which, in bending, there is no tension or compression.*
Web/Foot Transition	:	*The transition region between the rail web and foot sections.*
Top of Rail Foot	:	*The region on top of the rail foot, which makes contact with rail fasteners or insulating biscuits.*
Bottom of Rail Foot	:	*The region on the bottom of the rail foot, which makes contact with sleeper plates or rail pads.*
Toe of Foot	:	*The edge region of the rail foot.*

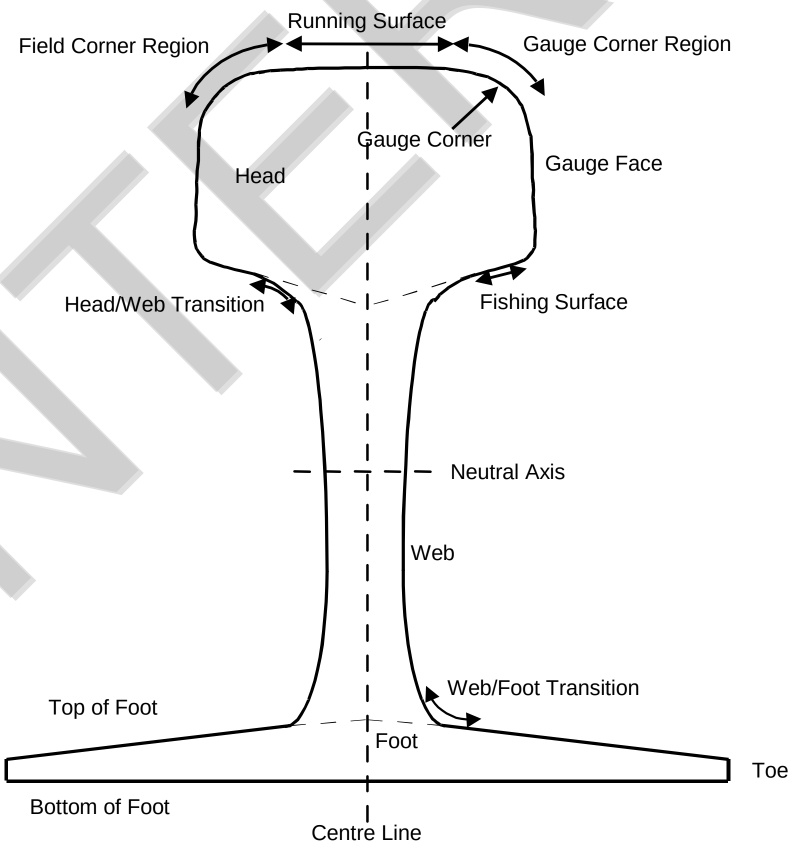

Figure 1 (c) Terminology used for rail locations

Figure 1 (d) illustrates the terminology used for the loads applied to the rails by the wheels, namely:

Vertical : *This is the load applied by the wheel tread to all rails under normal operations. However, the vertical load can be made up of 3 main components, namely:*

- *The static or nominal component: which is equivalent to the gross weight of the vehicle divided by the number of wheels, for example: the nominal wheel load in 120 tonne loaded coal wagons would be 15 tonnes. It should be noted that nominal axle loads are usually quoted. However, in the development of rail defects, the wheel loads are the more relevant parameter.*

  It should also be noted that in curved track, depending on the track superelevation and operating speeds, the nominal wheel loads applied to the high and low rails can be quite different (by up to about 20-30%).

- *The dynamic component, which is the increase over the static load that occurs as the vehicle speed increases, because of the vertical dynamics of the bogies interacting with the track geometry.*

- *The impact component, which is the additional increase over the static and dynamic components that occurs either when a wheel travels over short vertical rail irregularities, such as dipped welds, mechanical joints, corrugations, severe wheel burns, etc, or if a wheel contains wheel flats or is out of round.*

The actual vertical load applied to the rail is, therefore, determined by adding all of the above components. It is evident that the actual vertical loads can be considerably greater than the nominal loads.

Lateral : *This is the load usually applied by the wheel flange to the high rails in curved track because of the wheelset/bogie curving forces.*

In relatively sharp curves (with radii less than about 600 - 800 m), the lateral load is relatively stable throughout the curves.

In relatively shallow curves, however, or even in tangent track, considerable dynamic lateral loads can be produced when the wheelsets, bogies and/or vehicles exhibit high lateral dynamic behavior, such as hunting.

Creep : *Creep forces are generated at the wheel/rail contact patch, by the very localised action of the wheel rolling on the rail.*

Creep forces in the longitudinal direction are generally obtained when the wheels apply some traction to the rail, or when the solid wheelset tries to engage a sharp curve and compensate for the different wheel diameters contacting the rail.

Creep forces in the lateral or transverse direction are generally obtained when the wheelset oscillates laterally on the rail.

Often, both longitudinal and lateral creep forces are produced, for example: when a wheelset attempts to engage a curve in a misaligned mode, ie crabbing.

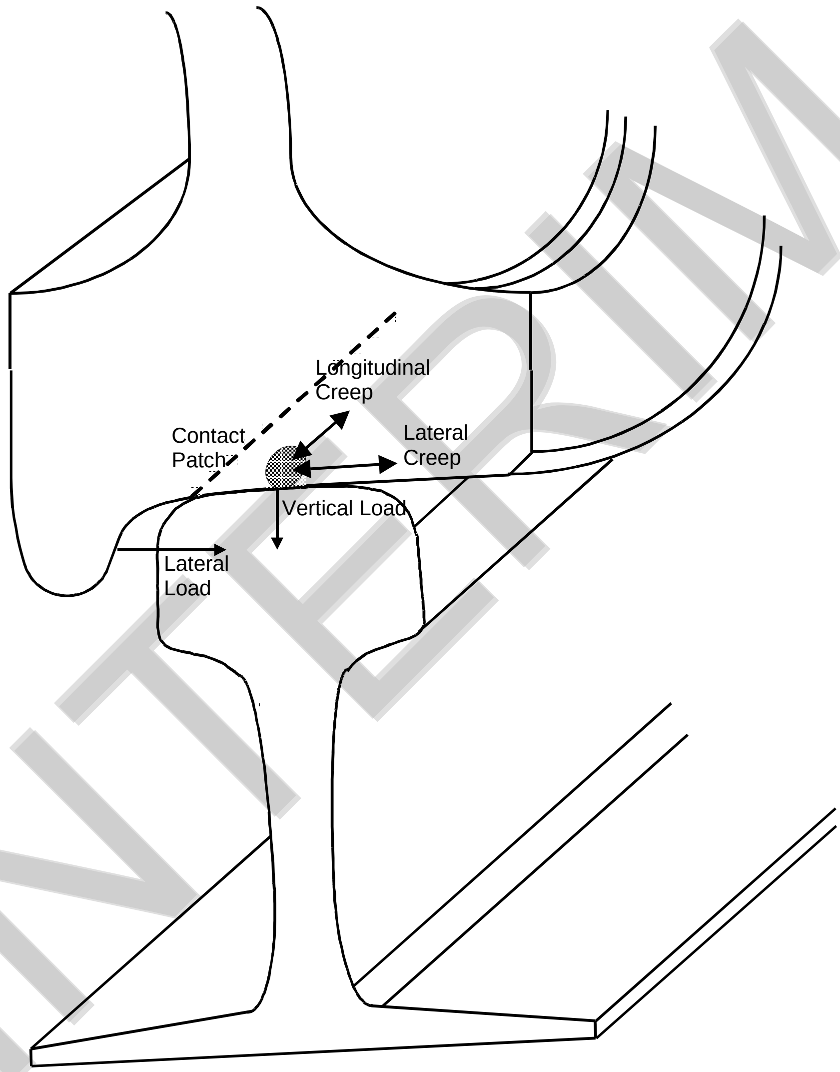

Figure 1 (d) Terminology used for loads

Figure 2 (a) illustrates the various bulk stress that can be applied to the rails, namely:

Bending Stresses : *Bending of the rails can occur because of a range of factors, including:*

- *The applied vertical wheel loads, which cause the rail to bend vertically between the sleeper supports. This leads to tensile longitudinal stresses in the rail foot.*

  The vertical loads also cause the rail head to bend vertically on the web support. This leads to tensile longitudinal stresses on the fishing surface.

- *The applied lateral wheel loads, which cause the rail head to move laterally relative to the foot. This leads to tensile vertical stresses in the rail web. The lateral wheel loads also increase the tensile longitudinal stresses on the fishing surface located on the field side.*

- *The vertical loads that are applied at some distance from the rail centre line, for example: when hollow wheels make contact with flat rails. This leads to torsion of the rail, which can also cause additional tensile vertical stresses in the rail web and tensile longitudinal stresses on the fishing surface*

Thermal Stresses : *These stresses occur in long welded or continuously welded rails because of the longitudinal thermal expansion and contraction that occurs as the actual rail temperature increases above or reduces below the stress free temperature at which the rails are field welded.*

- *When the rail temperature is above the stress free condition, compressive longitudinal stresses are established.*

- *When the rail temperature is below the stress free condition, tensile longitudinal stresses are established, which influence the development of rail defects particularly in the transverse plane.*

Residual Stresses : *These stresses occur in prime rails because of the manufacturing processes that are applied. In particular roller straightening and head hardening.*

Localised residual stresses also occur during both flash butt and aluminothermic welding of rails because of the differential expansion and contraction of the metal that occurs.

The characteristics of the residual stresses are highly variable. For example: both Head Hardened rails and aluminothermic welds can exhibit very high tensile vertical stresses in the rail web.

On the other hand, Head Hardened rails can exhibit tensile *longitudinal stresses on top of the head and the foot, and compressive longitudinal stresses in the web and the side of the head.*

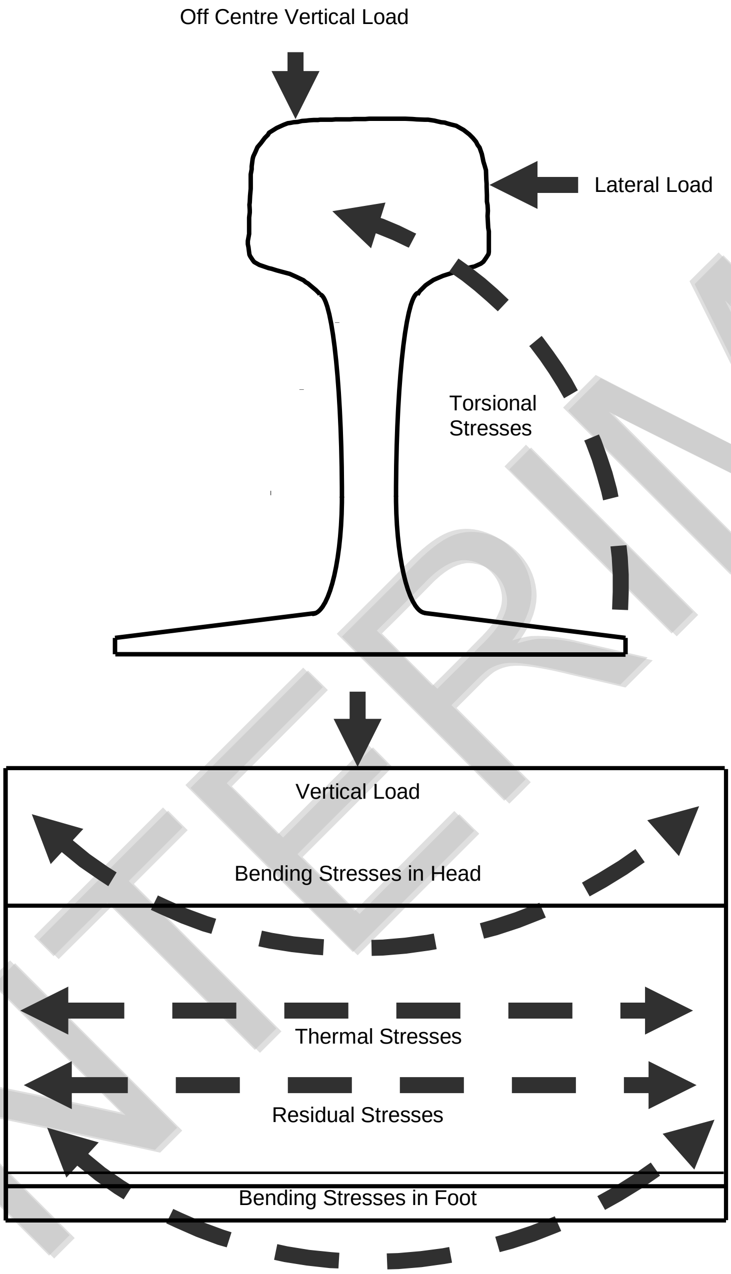

Figure 2 (a) Major rail bulk stresses

Figure 2 (b) illustrates the conditions that prevail in the wheel/rail contact patch. It is of particular interest to note that generally the contact patch is elliptical in shape, and relatively small, for example: the longer longitudinal axis may be 10-12 mm, while the shorter transverse axis may be 5-8 mm. It is this small patch that supports the whole wheel load.

The major stresses that are produced within the contact patch are shear in nature (ie they act at an angle to the loading direction), and depend on a range of factors, in particular:

- The vertical wheel load (as illustrated in Figure 3 (a)).
- The radii of the contacting surfaces, including the wheel radius and the rail crown radius (as illustrated in Figure 3 (b)).
- The creep (or traction) forces (as illustrated in Figure 4).

The figures also show three very important aspects related to the stresses produced in the contact patch, namely:

- For relatively low traction levels, the resultant stress occurs within the rail head to a depth of up to 10 mm from the wheel/rail contact surface.
- For relatively low traction levels, the maximum stress occurs within the rail head at a depth of 2-4 mm from the wheel/rail contact surface.
- As the traction level increases, the maximum stress also increases and its location moves closer to the wheel/rail contact surface.

The discussion of the various rail defect types in the following Sections will make frequent reference to the various rail loading and stress conditions.

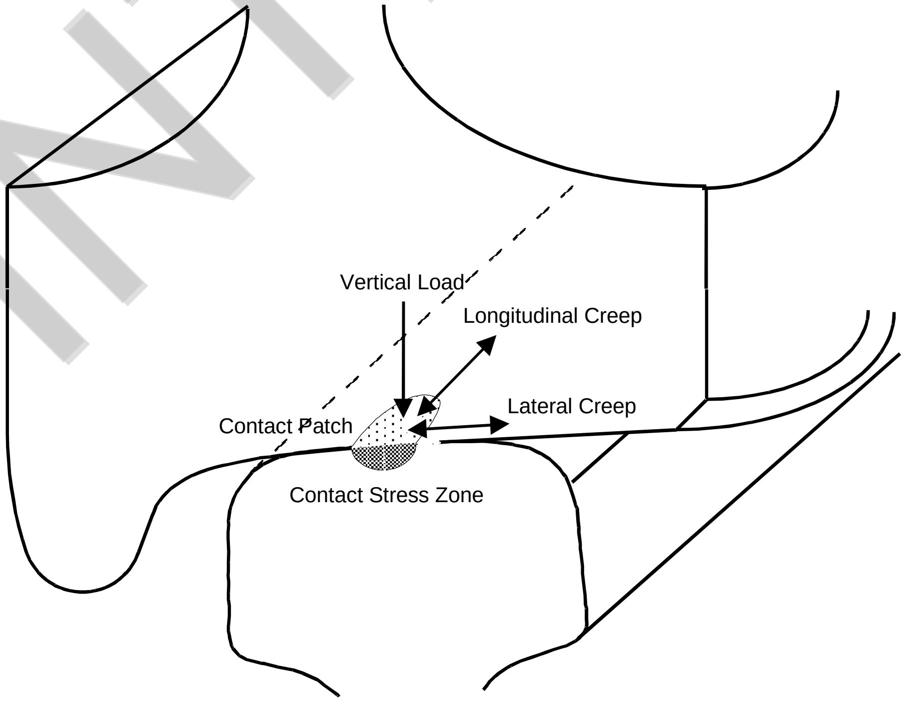

Figure 2 (b) Rail Contact Stresses

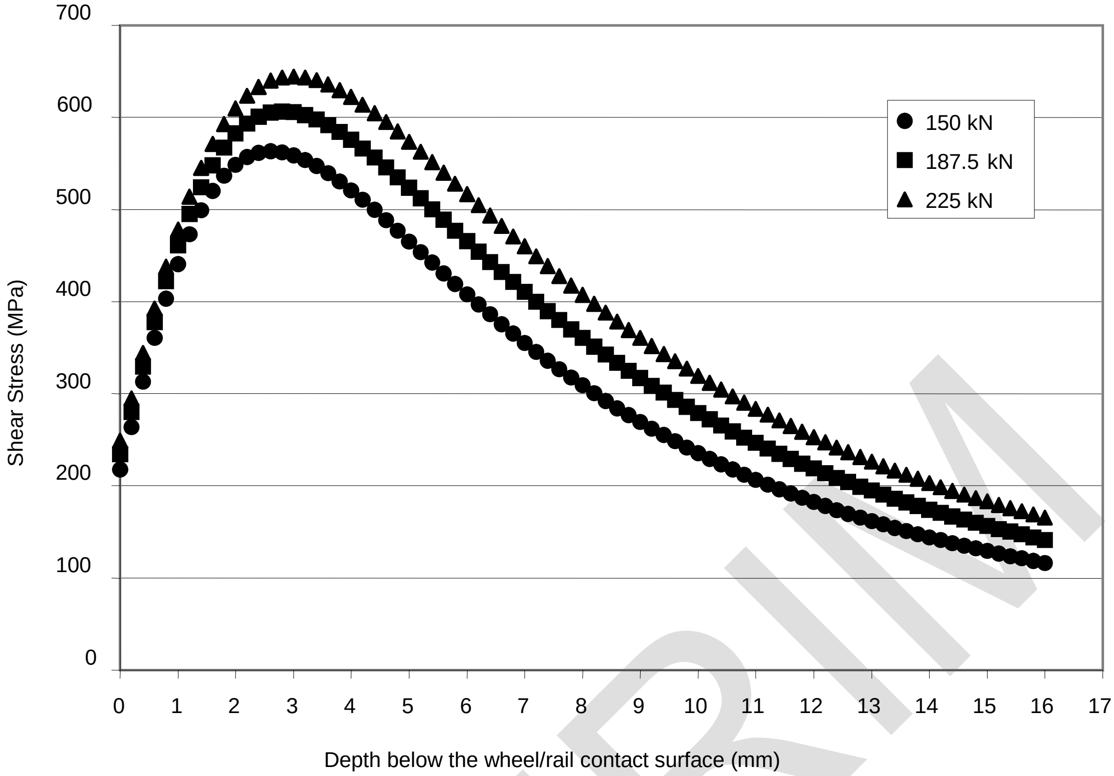

Figure 3 (a) Influence of wheel load on contact shear stresses

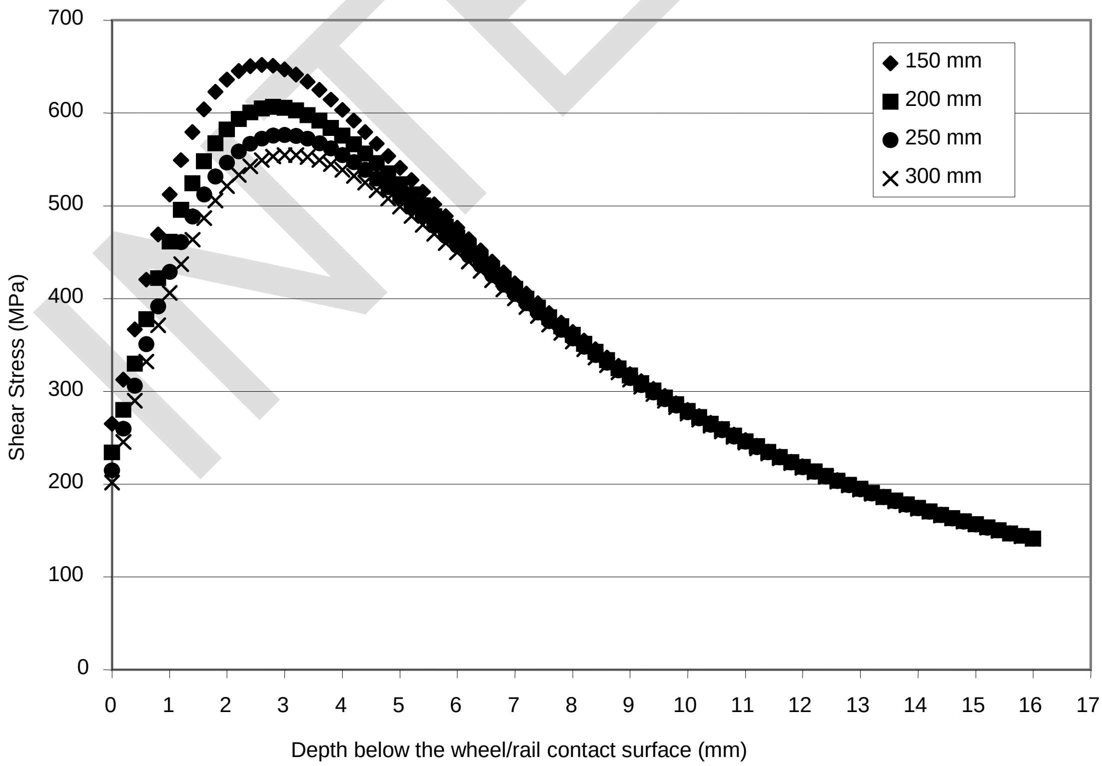

Figure 3 (b) Influence of rail crown radius on contact shear stress

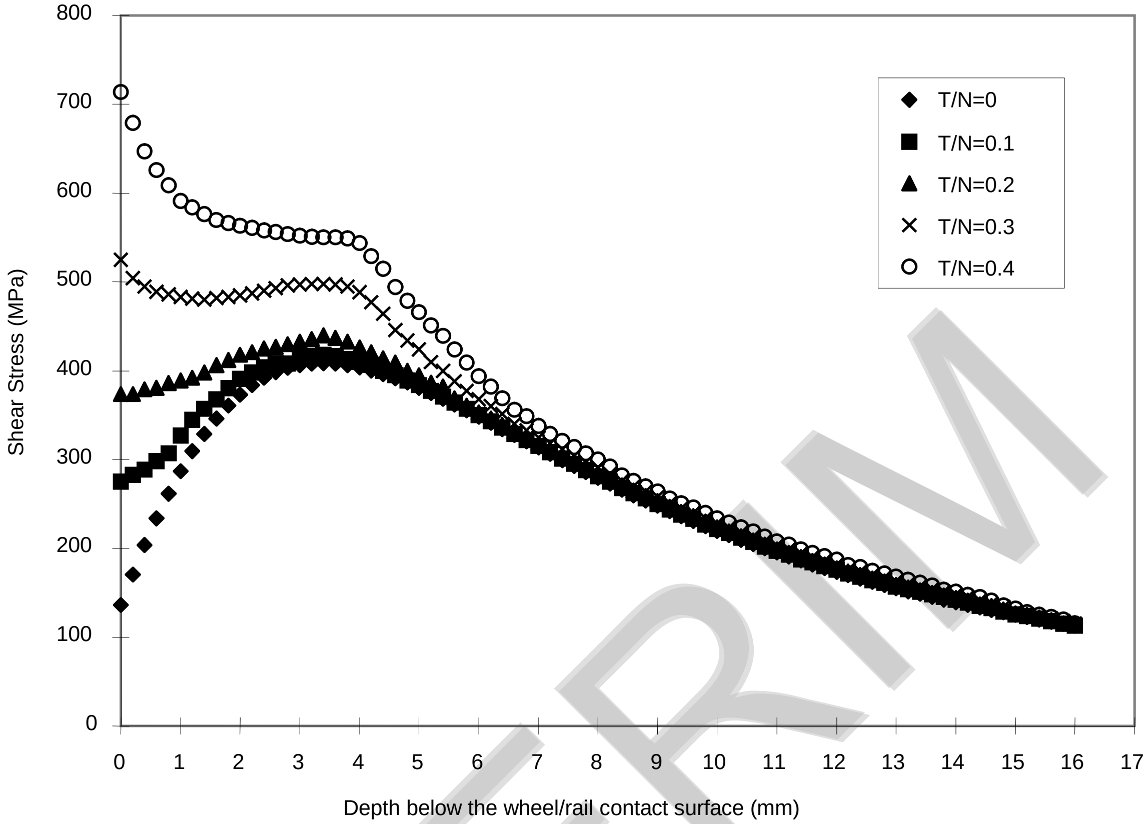

Figure 4 Influence of traction on the contact shear stress

2 Rail Corrugations

2.1 Characteristics

Rail corrugations are cyclic (wave-like), generally vertical, irregularities on the running surface of the rails.

Corrugations are of two main types:

- Short pitch - from about 30mm to 90mm in wavelength, as illustrated in Figure 5; or
- Long pitch - above about 300mm in wavelength, as illustrated in Figure 6(a), 6(b) and 6(c).

Short pitch corrugations generally develop under lighter nominal axle load (< 20 tonnes) passenger operations. The depth of these corrugations is usually less than 0.2-0.3mm.

Long pitch corrugations generally develop under higher nominal axle load (> 20 tonnes) mixed freight or unit train operations. The depth of these corrugations can range from 0.1mm to above 2.0mm, and can be variable as illustrated in Figure 6 (b).

Figure 5 Short pitch corrugations on the running surface

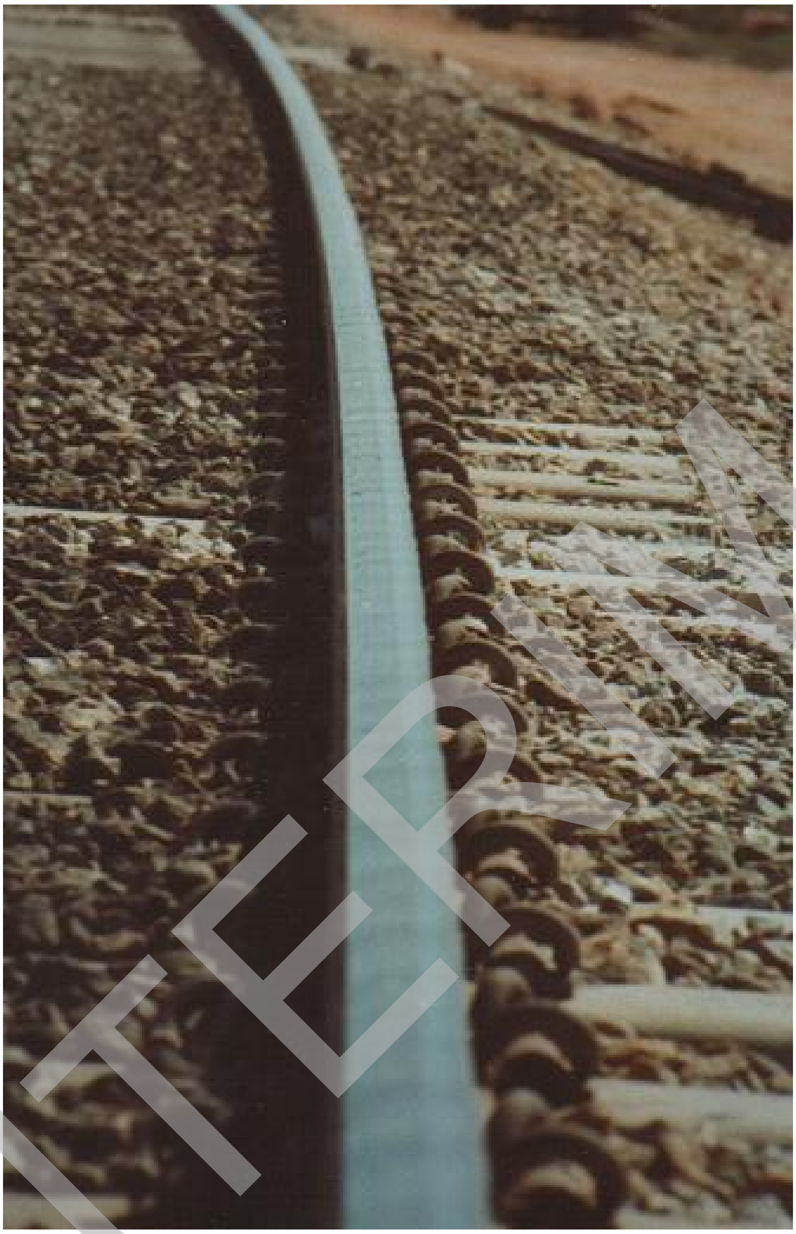

Figure 6 (a) Long pitch corrugations on the running surface

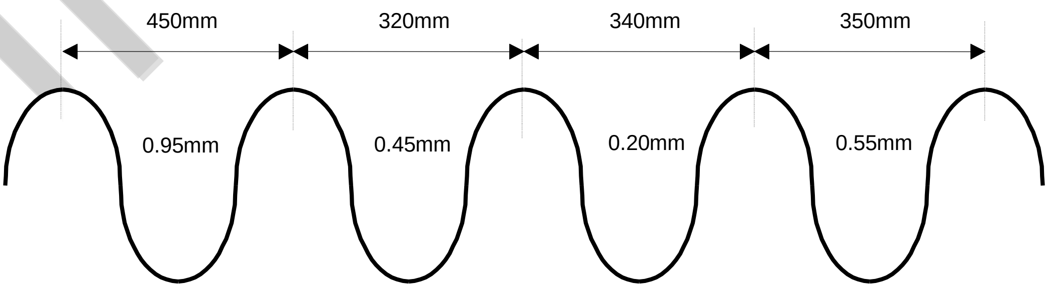

Figure 6 (b) Vertical profile of some long pitch corrugations

Figure 6 (c) Rail plastic flow associated with long pitch corrugations

2.2 Causes

Short pitch corrugations are thought to form from the differential wear caused by a repetitious longitudinal sliding action of the wheel on the rail, whether through acceleration, braking or lateral motion across the rail. The longitudinal oscillations can develop due to the excitation of the torsional resonance of the wheelset. This may be enhanced by the stick-slip phenomenon that may occur at the wheel/rail contact patch in tight curves, because of the differential wheel diameters in a solid wheelset.

Long pitch corrugations, on the other hand, develop because of the plastic flow of the rail material (as illustrated in Figure 6 (c)), which is due to excessive wheel/rail contact stresses and the combined vertical resonance of the wheelset unsprung mass and the track. The phenomenon is therefore exacerbated by all of those factors which lead to higher dynamic loadings and hence contact stresses, and plastic flow of the rail material, including:

- Higher nominal wheel loads.
- Higher vehicle speeds, which increase the dynamic loads.
- Larger vertical dips at welds/joints, which increase the impact loads.
- Higher track stiffnesses (concrete sleepers are much stiffer than timber sleepers), which increase the dynamic/impact loads.
- Higher rail pad stiffnesses, which increase the dynamic/impact loads.
- Higher bogie suspension stiffnesses, which increase the dynamic/impact loads.
- Smaller wheel radii, which increase the wheel/rail contact stresses.
- Higher friction/creep at the wheel/rail contact.

- Softer rails, which increase the propensity for plastic flow of the material.
- Poor matching of wheel and rail profiles, which leads to narrow wheel/rail contact and hence higher contact stresses.

However, it is still not certain why in a particular track or even section, different corrugation pitches may occur. Some possible reasons are:

- Different traffic types/suspension characteristics.
- Different traffic speeds.
- Different grades and hence traction.
- Different braking and acceleration.
- Different track geometry (curve radius).
- Different rail support conditions:
  - Concrete Sleepers.
  - Timber Sleepers.
  - Continuous support.

The long pitch corrugations are sometimes observed on the low rails of curves, sometimes on the high rails, and sometimes on both. This is mainly a function of the superelevation of the track, which may lead to the loading of one rail more than the other.

2.3 Effects

Rail corrugations are of concern because they increase the dynamic wheel loads (and vibration), and therefore the rate of deterioration and failure of various track and vehicle components, such as:

- Rails and defects (such as shelling).
- Welds.
- Bolt holes at insulated rail joints.
- Rail pads.
- Sleepers, particularly in the rail seat region.
- Ballast, which tends to powder and become rounded.
- Rail clips (which also become loose).
- Track geometry (mainly because of the vibration and the ballast deterioration). Indeed, corrugations can lead to the skewing of sleepers.
- Wheels and defects.
- Bearings.

- Bridges and abutments, particularly when the track is not ballasted.

The higher dynamic loads also increase the rate of corrugation development and the rate of rail profile deterioration. The rails therefore require more maintenance effort (grinding) at shorter intervals.

Corrugations also increase, considerably, the wheel/rail noise.

2.4 Treatment

The main procedures commonly used for reducing or eliminating rail corrugations entail the treatment of some of the causes. In particular:

- Use of higher strength (mainly heat treated) rail steels, particularly in sharper curves that are more sensitive to corrugation development. The higher strength rails can of course sustain higher contact stresses without exhibiting gross plastic flow, and hence corrugation development.

  The high strength rails have now become an essential component in high axle load and/or high tonnage operations.

- Application of improved wheel and rail profiles, which reduce the wheel/rail contact stresses.

  As illustrated in Figure 7, the aim of the improved profiles is to produce a relatively large and conformal contact band, rather than narrow contact bands that lead to very high contact stresses, and consequently enhance corrugation development.

  Wheel and rail profiles can also be designed to improve the dynamic characteristics (hunting) of wheelsets/bogies, particularly in the shallower curves, and hence reduce the creep forces at the wheel/rail interface.

- Application of regular rail maintenance in the form of grinding, to control the growth of corrugations. Rail grinding is also required to implement the improved profiles.

  At this stage the growth rates of corrugations cannot be predicted. Consequently, the grinding cycles that are required must be determined from actual field observations, the level of damage being caused by the corrugations, and the grinding effort necessary to control/remove the corrugations.

  Another major benefit of cyclic rail grinding is that it allows the softer rail steels to deform in a controlled manner. Such deformation leads to the development, over time, of a work hardened layer below the rail contact surface, which may be up to 8-10 mm deep as illustrated in Figure 8. The higher hardness (strength) material is more resistant to the further development of corrugations.

- Reducing the track stiffness characteristics, with the implementation of softer and thicker rail pads, may also inhibit corrugation development. However, this also requires careful consideration of the whole rail fastening assembly, since the application of rail clips with high toe loads compresses the pads and may reduce their benefits. Softer pads also tend to deteriorate at faster rates.

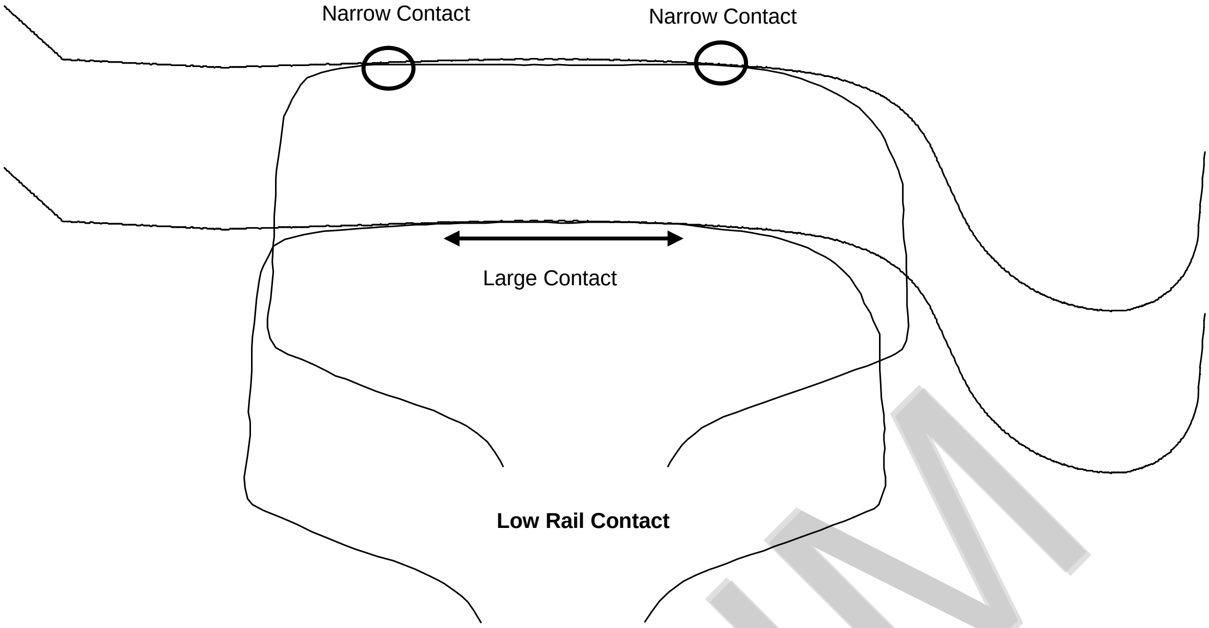

Figure 7 Some wheel/rail contact conditions

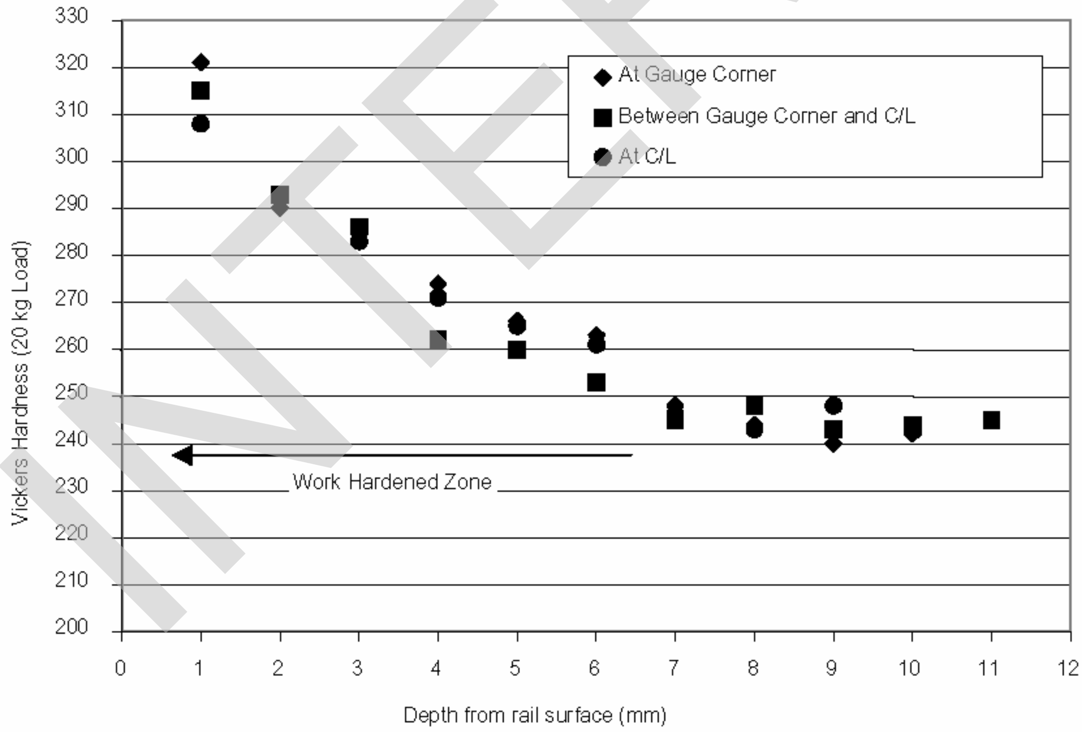

Figure 8 Hardness traverses in worn 53 kg/m standard rails, at nominal axle loads < 25 tonnes

3 Rolling Contact Fatigue Defects

3.1 Characteristics

Rolling contact fatigue (RCF) defects develop in rails on most Railway Systems.

The term rolling contact fatigue is generic in nature and used to describe a range of defects, that are due, basically, to the development of excessive shear stresses at the wheel/rail contact interface.

RCF defects that occur in the gauge corner region of the rails, and which are of most concern, may be of the following types:

Gauge corner checking

This is a surface condition that occurs mainly on the high rails in sharper curves, and can be described as being like "fish scales".

As illustrated in Figure 9, the cracks are initiated at or very close to the rail surface, typically occur at about 2-5 mm intervals along the rail, and can grow to 2-5 mm in depth, at a downward angle of about 10º-30º to the rail surface, gradually spreading across the rail head. Once this occurs they usually break out as small "wedges or spalls".

Figure 9 (a) Transverse section of a rail showing the initial stages of development of checking cracks and spalls

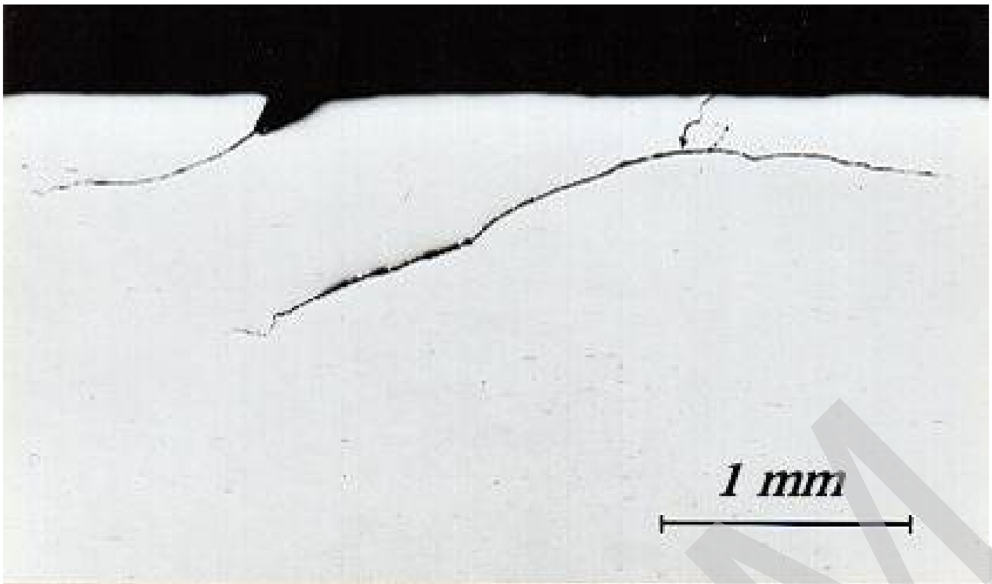

Figure 9 (b) Longitudinal section of a rail showing the initial stages of development of checking cracks and spalls. Note how the crack initially grows into the rail head but then levels out.

Figure 10 shows various stages in the development of gauge corner checking.

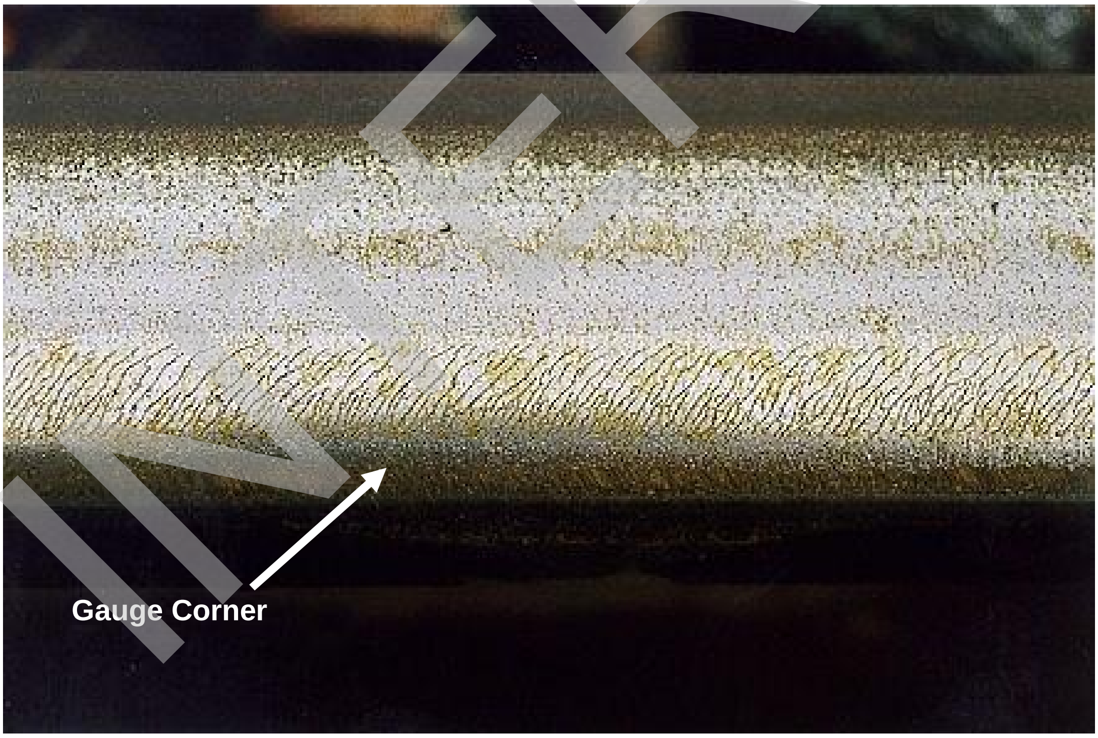

Figure 10 (a) Initial stage of development of gauge corner checking cracks

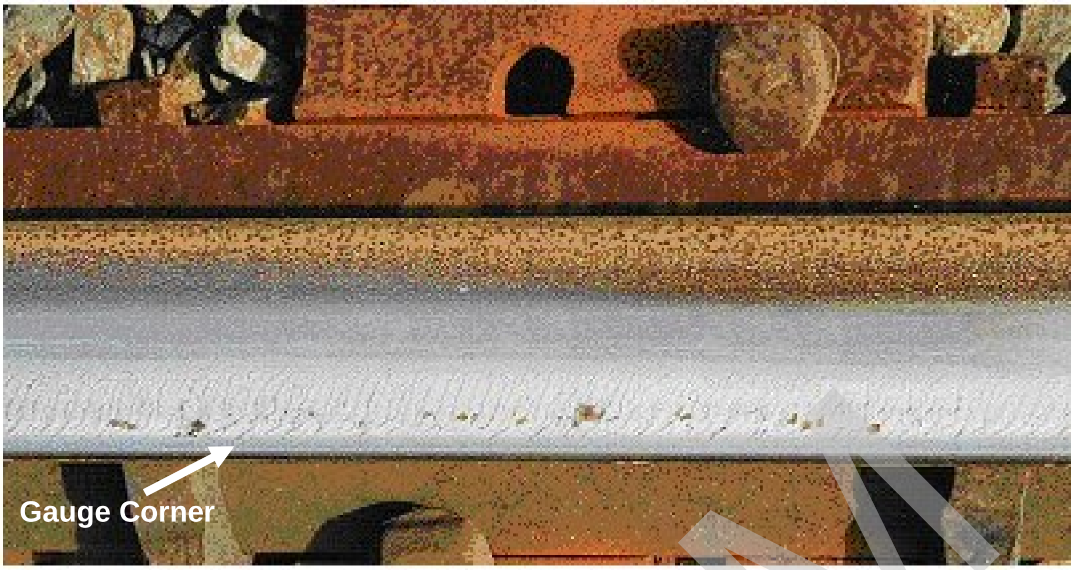

Figure 10 (b) Intermediate stage of development of gauge corner checking cracks and spalls

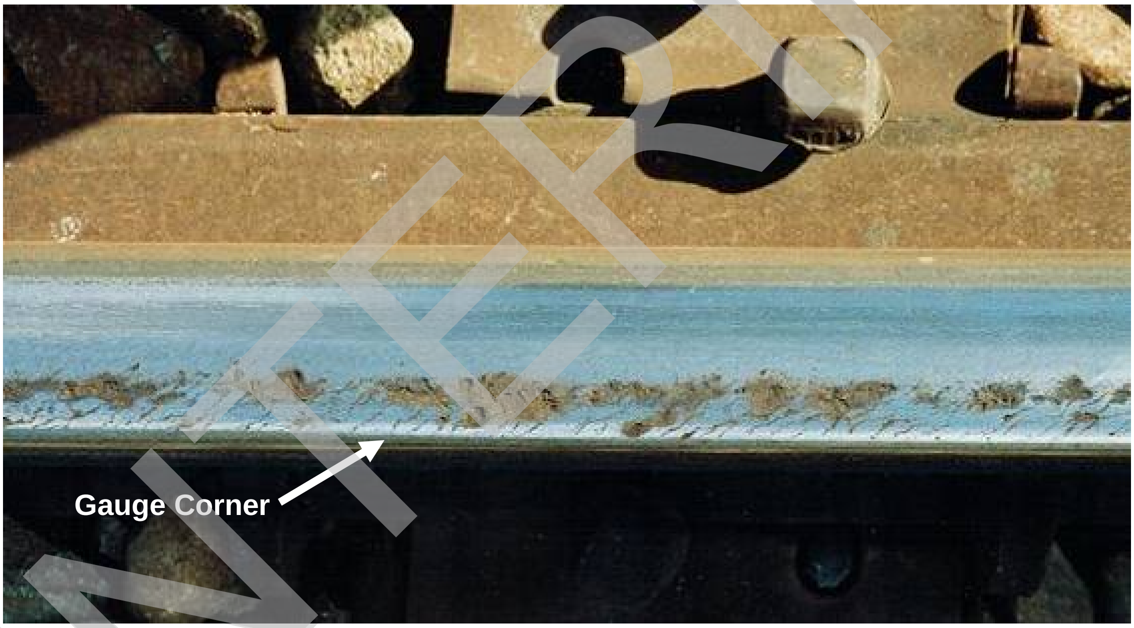

Figure 10 (c) Severe stage of development of gauge corner checking cracks and spalls

Gauge corner checking can also occur in shallower curves and tangent track, where wheelsets/bogies/vehicles tend to exhibit hunting behavior.

Shelling

This is an internal defect that initiates at a depth of 2-8mm below the gauge corner of, generally, the high rails in curved track.

In the initial stages of development, shelling defects become noticeable as dark spots in the gauge corner region of the rails.

Shelling defects do not form as regularly along the rail as gauge corner checking defects.

Shelling cracks develop on a horizontal or longitudinal plane consistent with the shape of the rail on the gauge corner. The cracks can continue to grow in a longitudinal direction on that plane for some distance at an angle of about 10º-30º to the rail surface, and then either spall out into a shell or turn down and form transverse defects which can continue to grow on a transverse plane and, if not detected in time, eventually lead to rail failure.

It should be noted that sometimes transverse defects may also directly initiate from irregularities in the steel (inclusions) and grow in a transverse plane, without the need for a prior shelling defect.

Examples of shelling and transverse defects are illustrated in Figures 11 and 12 respectively.

Because of their internal nature, transverse defects cannot be visually detected, and hence must rely on regular ultrasonic rail inspection.

Figure 11 (a) Initial stage of shell development (dark spots)

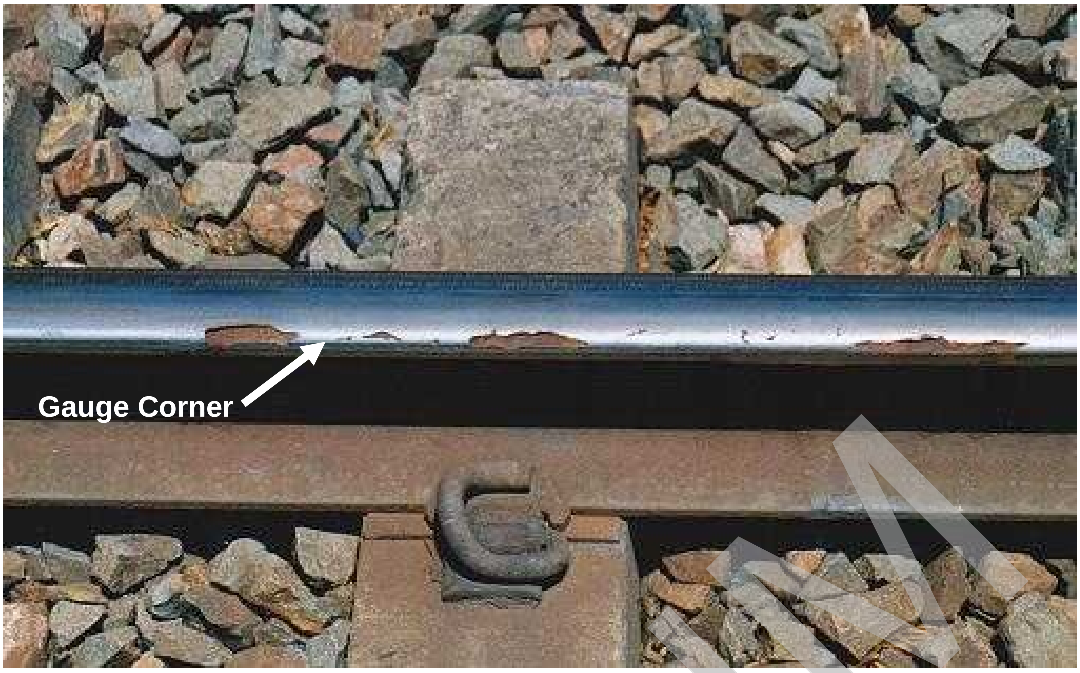

Figure 11 (b) Intermediate stage of shell development

Figure 11 (c) Severe stage of shell development

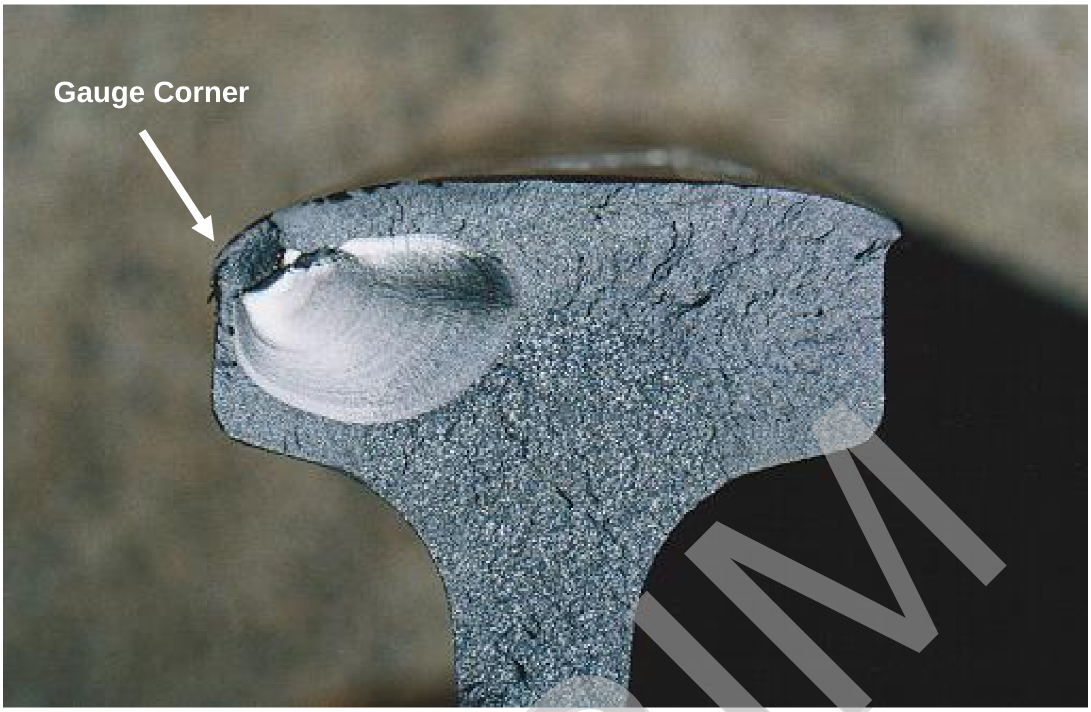

Figure 12 Small Transverse defect in the rail head initiated from shelling

Running Surface Checking

The other type of RCF defect is known as flaking, or running surface checking. This is also a surface condition that occurs on the running surface of the low and/or high rails. Initially, the defects appear as a mosaic or snakeskin like pattern on the rail head. In the latter stages of growth the cracks produce “spalls”, that can be up to about 10-15 mm wide, up to 3 mm deep, and can be continuous along the rail length. Examples of flaking and the associated minor spalling are shown in Figure 13.

Figure 13 Flaking or running surface checking defects with minor spalling

3.2 Causes

Both checking (gauge corner and running surface) and shelling defects are initiated by the high shear stresses that can develop at the wheel/rail contact region when such stresses exceed the allowable limits for the rail material.

A number of factors can influence the shear stresses, including:

- The nominal, dynamic and impact wheel loadings (refer to Figure 3 (a)), and the range of factors that influence such loadings, including: track geometry, bogie characteristics, wheel and rail vertical irregularities, track superelevation, etc.

- The respective radii of the wheels and rails at their contact region (refer to Figure 3 (b)), and consequently the wheel and rail profile characteristics.

- The diameter of the wheels (smaller diameters result in higher stresses).

- The traction/creep forces (refer to Figure 4).

The difference in the initiation characteristics of the checking and shelling defects (namely surface or sub-surface) is primarily due to the influence of the traction coefficient (ie the ratio of tangential to normal forces, T/N) on the resultant shear stresses. Thus, as shown in Figure 4, it is evident that at the lower T/N values (up to about 0.2) the maximum shear stresses are obtained at some depth from the rail contact surface, which corresponds to the region in which shelling generally develops. Higher axle loads increase the normal forces and hence may reduce the T/N values, which in turn would enhance sub-surface crack initiation.

On the other hand, the higher T/N values which are obtained in relatively sharp curves (due to wheelset steering forces), or relatively shallow curves and tangent track (due to adverse vehicle dynamics, such as hunting) or at lower axle loads, lead to both considerable increases in the resultant maximum shear stress and also a shift in the location of the maximum shear stress closer to the rail surface, where the checking cracks initiate.

It is also suggested that the main reason for the difference in the general growth characteristics of the checking and shelling cracks is the work hardening of the rail steel which occurs due to the plastic deformation of the rail material, particularly at the higher axle loads. As illustrated in Figure 8, the work hardened layer can be up to 8-10 mm in depth. The plastically deformed material in the work hardened layer exhibits high compressive residual stresses. Such stresses inhibit fatigue crack growth, and therefore generally prevent the growth of the much shallower checking cracks into the rail head. On the other hand, the deeper shelling cracks may be able to penetrate through the compressive work hardened layer and continue growing on a transverse plane, thus developing into transverse defects, under the action of other stress environments, including rail bending, thermal stresses, and residual stresses due to rail manufacture.

For the same reason, it is possible that the checking cracks have been able to advance into the rail head, and sometimes lead to rail failures, under lower axle load, high speed passenger track, since such conditions would lead to a very limited (if any) work hardened compressive layer, particularly in newer rails that are subjected to adverse wheel/rail contact conditions.

As illustrated in Figure 14, higher axle loads (>30 tonnes) lead to higher levels of deformation and hence work hardening in standard carbon rails. Figure 14 also shows how the work hardening develops gradually over tonnage/time.

It is also of interest to note that under poor wheel/rail contact conditions (resulting in excessive shear stresses), new higher strength rails may actually be more susceptible to the growth of checking cracks into the rail head, since the material would be more resistant to plastic flow and hence work hardening and the development of a deep compressive residual stress layer.

Contamination of the rail surface, predominantly by water, (but also lubricating grease, which is often found in the vicinity of lubricators), can accelerate the propagation of checking cracks into longer and deeper cracks.

The adverse influence of contamination has been explained in terms of the entrapment of fluid within the crack causing firstly a reduction in the friction between the crack faces, which enhances the shear mode of crack propagation, and secondly causing hydraulic pressurisation at the crack tip (similar to a wedge) which provides large tensile stresses, leading to rapid crack propagation.

It is of particular importance to note that the development of checking defects may also be exacerbated by a range of factors that reduce rail wear, and consequently allow the fatigue cracks to grow, rather than being worn away, including:

- Reduced track curvature.
- Very effective lubrication.
- Higher hardness/strength rails.
- Wheel and rail profiles designed to reduce wear.

Consequently, some controlled rail wear is preferable to having no wear.

Together with the high wheel/rail contact stresses, the initiation of shelling cracks can also be greatly exacerbated by oxide/silicate inclusions or 'stringers' of such inclusions that may be present in rail steel. Under the plastic deformation that occurs in the steel near the wheel/rail contact surface, these inclusions can crack because of their brittle nature (as illustrated in Figure 15), and consequently form ideal initiation sites for shelling fatigue cracks or transverse defects.

The initial development of such cracks occurs internally within the rail head, as illustrated in Figure 12 by the shiny non-oxidised surface of the transverse defect. When the cracks reach the surface of the rails, however, the presence of lubricants (water and grease) can enhance their growth, particularly in the presence of head checking.

As mentioned above, the growth of transverse defects occurs under the combined actions of rail bending, thermal and residual stresses. However, it is still not certain why only certain shelling defects turn down into a transverse plane and form transverse defects.

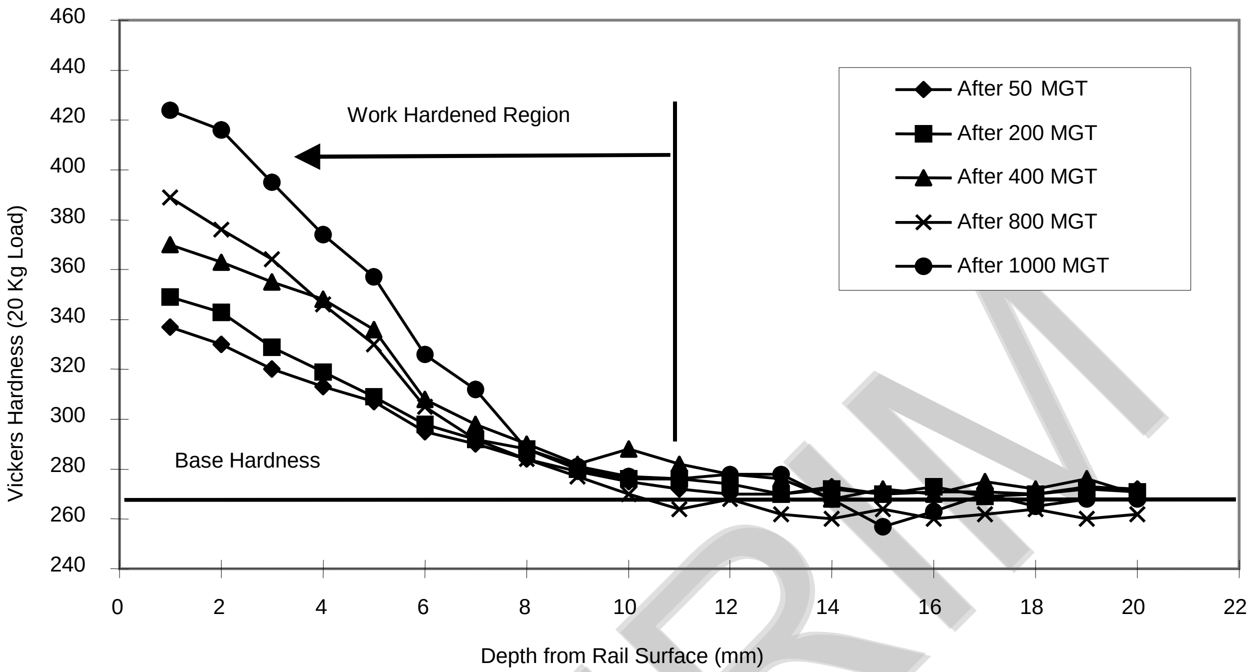

Figure 14 Hardness distributions in standard carbon rails showing work hardening developed in tangent track at 30 to 35 tonnes axle loads

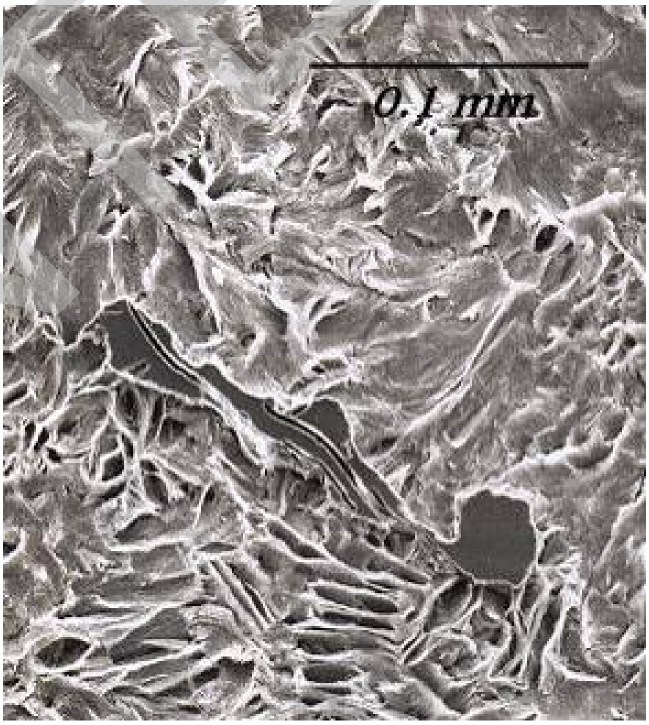

Figure 15 Example of cracked oxide/silicate inclusion which can act as an initiation site for shelling and transverse defects

3.3 Effects

RCF defects are of particular concern for two main reasons:

- They may lead to rail failures if not detected in time, particularly in the case of transverse defects.
- They can mask the ultrasonic signal during routine inspection and hence prevent the detection of larger and deeper defects that may be present within the rail head, including any such defects that may have developed from the shallower initial cracks.

The removal of severe RCF defects, and in particular gauge corner and running surface checking, also entails extensive and expensive rail maintenance (grinding).

3.4 Treatment

The following are some of the main procedures that can be adopted for reducing the potential development of RCF defects, and, consequently, the associated potential risk of rail failure:

Higher strength rail steels

Install higher strength rail steels in the more critical track locations, to increase the allowable shear stress limits.

Higher strength head hardened rails have been particularly successful in reducing the development of shelling and transverse defects in well maintained, higher axle load situations.

The hardened rails not only exhibit reduced wear, but also reduced plastic deformation. Consequently, if the wheel/rail contact conditions are not favorable, such conditions will be retained for a very long time. Standard rails, on the other hand, will tend to wear and/or deform plastically to accommodate non-conforming wheels.

Consequently, when hardened rails are used, it is essential that the appropriate (low stress) profiles are implemented soon after their installation, and that regular preventive maintenance is applied.

Improvements in the cleanliness of the rail steels

This will reduce the number of inclusions that can act as initiation sites for the defects. This aspect is of particular relevance to shelling and transverse defects, rather than to gauge corner and running surface checking defects.

In this regard, the recent steel making and quality control procedures adopted by all of the major rail manufacturers have led to much cleaner steels.

Improvements in the wheel/rail lubrication procedures

This will reduce the risk of rail contamination and hence the enhancement of fatigue crack growth.

Where applied, the new strategies have included the modification of lubricant type, lubricant application and lubricator location. The importance of appropriate lubricator maintenance has also been emphasised. The new strategies have led to a more efficient lubrication regime with a reduction in the number of lubricators providing the required protection against excessive rail and wheel wear.

Application of appropriate rail maintenance strategies

This will provide control over the development of RCF defects.

This aspect has been recognised as the most essential control procedure, particularly for gauge corner and running surface checking defects.

It should be noted that the design of such maintenance strategies, is based on the balance required between rail wear and fatigue. It is widely accepted that excessive wear should be prevented because it wastes the wheel and rail material, but insufficient wear which allows fatigue cracks to initiate and propagate, also reduces component life and increases the risk of rail failures. This has introduced the concept of the optimal or “magic” wear rate, which occurs when the surface material wears (or is removed by grinding) just enough to prevent small fatigue cracks from propagating at an accelerated rate in the rail and causing fatigue failures. The achievement of the “magic” wear rate is of course the basis for preventive or cyclic rail grinding, which aims to remove relatively small amounts of metal at more frequent intervals, and in so doing prevent the fatigue cracks from propagating at accelerated rates. The concept is illustrated in Figure 16, which shows how the grinding cycles are applied to prevent the rapid growth of the cracks. Rail grinding thus becomes a tool for preventive rail maintenance, not merely a means for correcting severe rail damage once it has occurred.

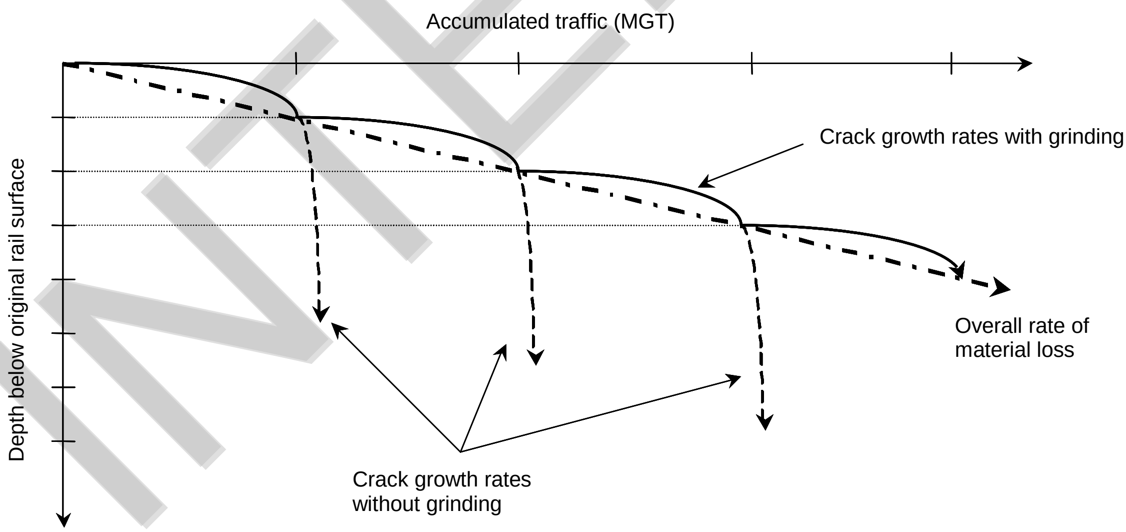

Figure 16 Preventive grinding to limit crack depth

One important aspect that has also been covered is the rail grinding that is required for new rails, since these often lead to very localised and hence adverse wheel/rail contact conditions with some current wheel profiles in both the new and worn conditions, as illustrated in Figure 17.

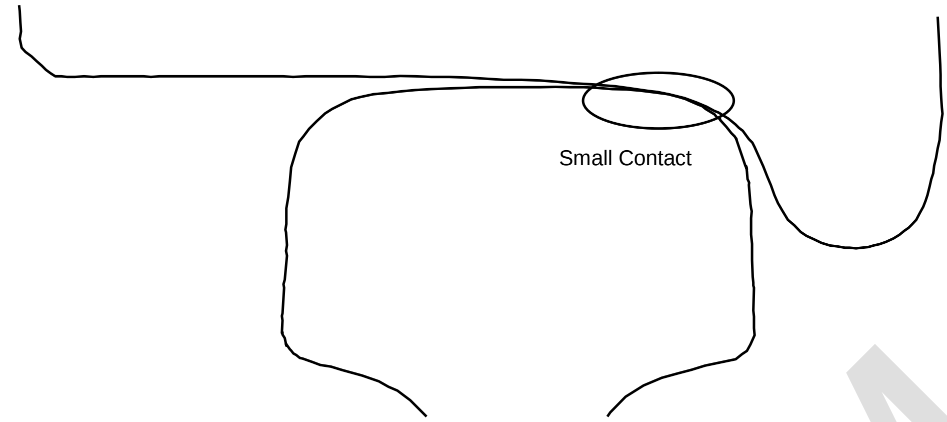

Figure 17(a) New 60 Kg rail/new Mod 2 wheel combination high leg of curves

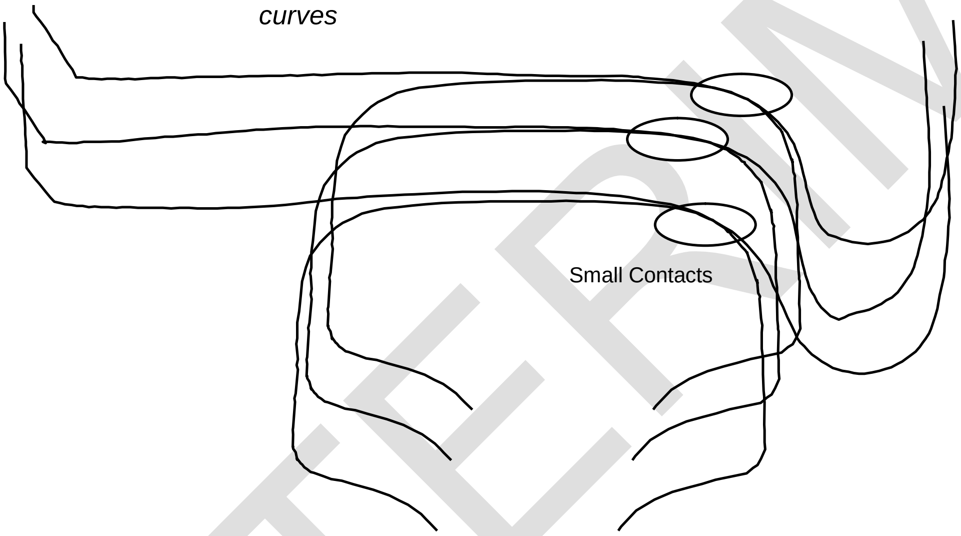

Figure 17(b) New 60 Kg rail/worn wheel combinations high leg of curves

Similarly corrective rail maintenance strategies are applied to rails that have been in track for a long time without maintenance, and which exhibit RCF defects.

Commonly, very severe initial grinding has been applied for defective rails such as those illustrated in Figures 10 (b) and (c). In certain cases, a transverse rail profile has been applied to deliberately “unload” existing shallow cracks, without grinding sufficiently deeply to remove them completely. This has proven successful, particularly in extending the rail life. It should be emphasised, however, that care needs to be taken with such procedures, particularly since if no further rail maintenance is conducted there will be a tendency by the rail material to flow into the gap between the rail gauge corner and wheel throat, as illustrated in Figure 18, and create initiation sites for fatigue defects particularly if the grinding applied is severe and leads to sharp transitions in the profile.

The establishment of a considerable gauge corner undercut also increases markedly the wear rate in the wheels and rails, and enhances the contamination of the gauge corner and running surface by the lubricant.

Figure 18 Example of plastic flow in the high rail with excessive gauge corner relief

Rail grinding procedures have been successfully applied to control the gauge corner checking defects, which entail producing a slight gauge corner relief of 0.5-0.8mm below the profile template to reduce the gauge corner contact for a limited time. This procedure has also been implemented during the transition between corrective and maintenance grinding, which can take a number of grinding cycles. The grinding also entails the removal of 0.1-0.3mm of metal during each cycle.

The other rail grinding procedure that has been successful in improving the ultrasonic testing, without the need for removing large amounts of material, has consisted of the following steps:

- Remove a minimum of 0.2 mm (and usually more than 0.4-0.5mm) of metal from all contact surfaces including the gauge region.

- Ensure that all gauge corner checking cracks have been removed from the running surface above the rail web, and preferably from a distance of 20-25 mm from the gauge corner towards the field side. Figure 19 illustrates how the presence of the gauge corner checking cracks may inhibit the detection of small transverse defects. The figure also shows that by having a “clean” surface above the rail web ensures that at least the medium transverse defects can be readily detected. As illustrated in Figure 20, no attempt is made to completely remove the severe gauge corner checking cracks and spalls that are present.

- Establishing the recommended profiles, but allowing a gauge corner relief generally of 0.2 mm but in some cases up to 0.5 mm in the high rails.

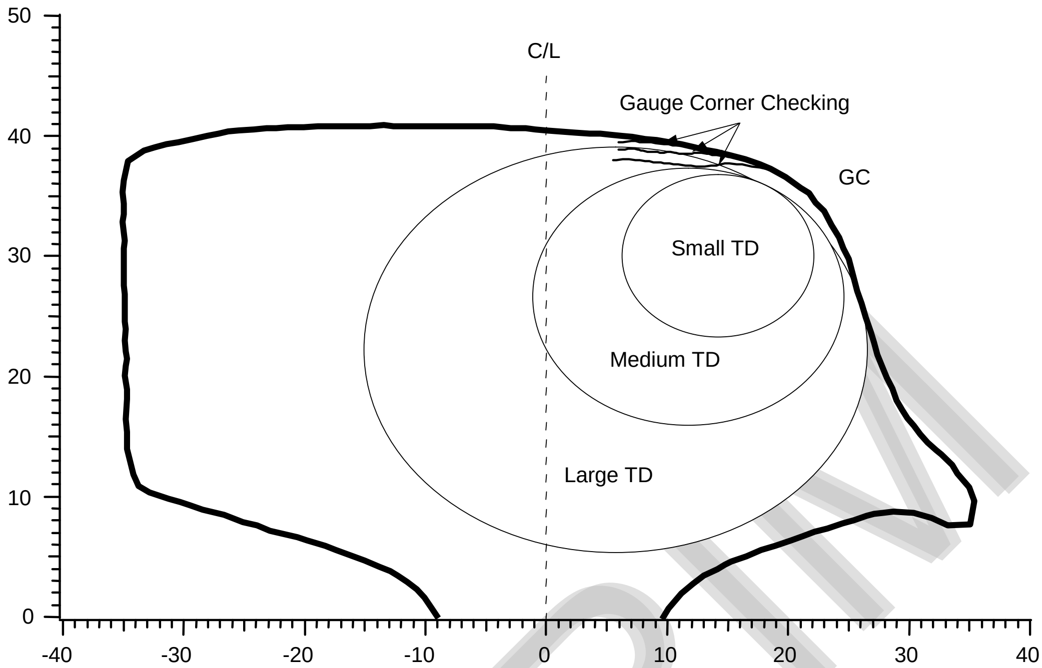

Figure 19 Schematic of a worn 53 kg/m rail with gauge corner checking and various transverse defects

Improvements in the wheel/rail interaction characteristics

This will reduce the wheel/rail contact stresses and improve the wheelset steering characteristics and hence reduce the lateral traction at the rail surface.

In this regard, Figure 17 has already illustrated the very narrow contact conditions that currently occur with new rail profiles in combination with some new and worn wheel profiles. There is no doubt that such contact conditions would exacerbate the development of RCF defects, particularly in the gauge corner region of the rails.

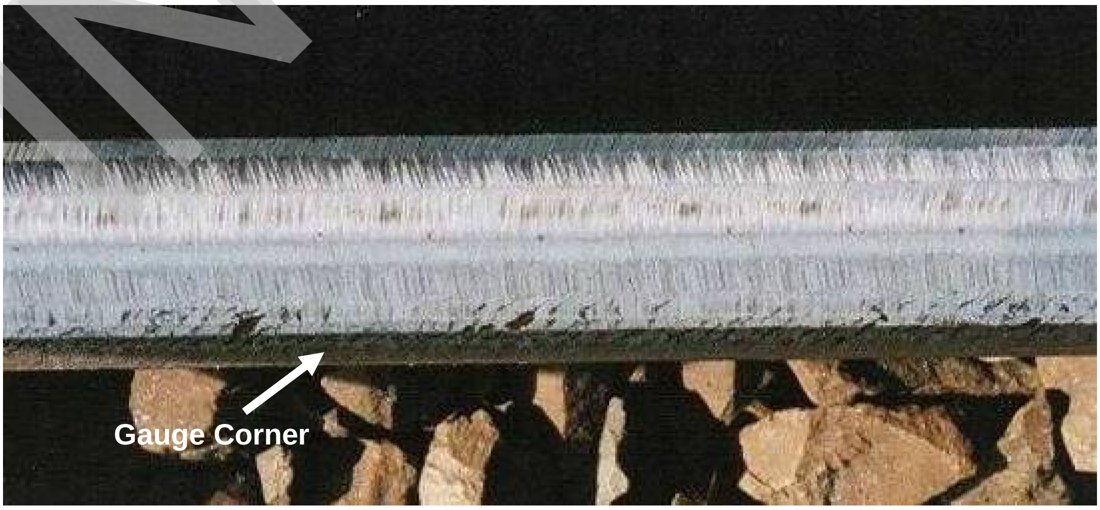

Figure 20 Examples of rail defects left in the gauge corner region of the rails after grinding

As illustrated in Figures 21 and 22, some of the modified wheel and rail profiles used to date, although providing improved wheel/rail contact conditions relative to the new rail profiles, still concentrate the contact in the gauge corner region of the rails in the sharper curves or produce contacts on 2 points in the shallower curves. This is because they were developed with the primary aim of reducing wear. However, in so doing they would have some adverse influence on the development of RCF defects.

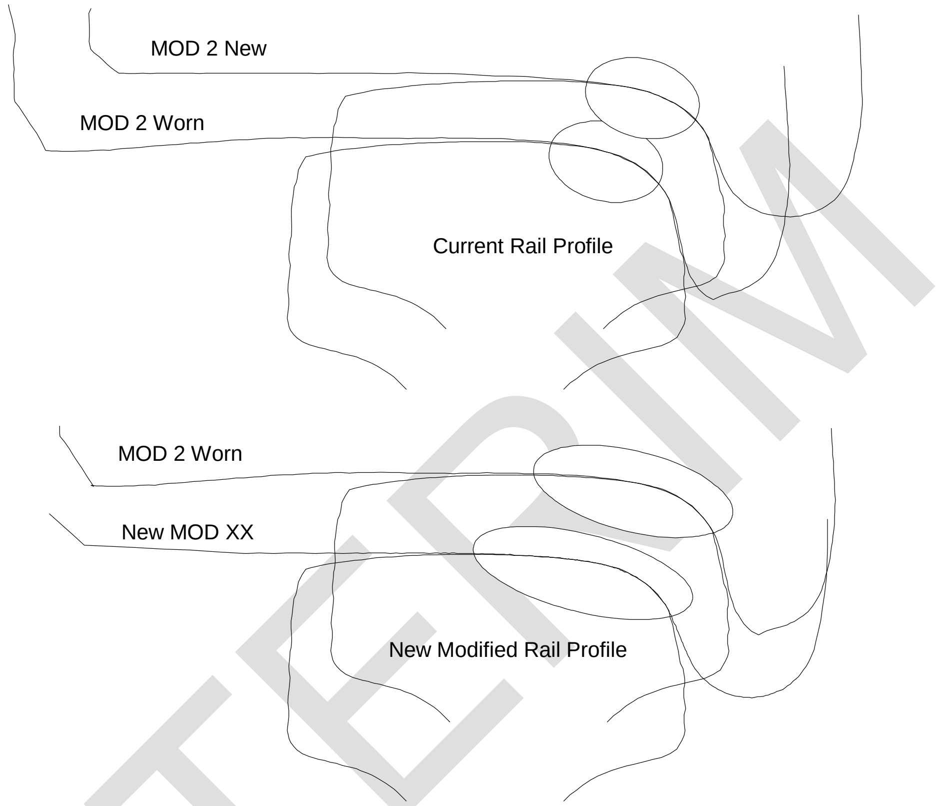

Figure 21 Current modified and worn wheel profiles and high rail profiles in sharp curves (radius <1000 m)

As also illustrated in Figures 21 and 22, application of the current modified wheel and rail profiles (as documented in C.3200) leads to a much broader conformal contact (and hence lower stress) in the gauge corner region of the rails in the sharper curves, and a broader contact on the running surface region of the rails in the shallower curves.

Application of suitable ultrasonic testing procedures

This will ensure that the fatigue cracks do not reach their critical sizes and hence lead to rail failures.

Regular ultrasonic inspection of rails is currently applied in all critical regions of the ARTC network.

The frequency and efficiency of testing needs to be reviewed at regular intervals to ensure that the risk of rail failures is minimised.

Improvements in the rail field stressing procedures

This will reduce the risk of fatigue crack growth in the transverse plane.

In this regard, ARTC have detailed procedures that account for the conflicting requirements between track stability (which requires higher stress free temperatures) and rail failures (which require lower stress free temperatures). The procedures have been successful in reducing/minimizing track buckling, which is regarded as the highest priority.

Nevertheless, the field welding procedures need to be reviewed at regular intervals, particular in terms of the above conflicting requirements.

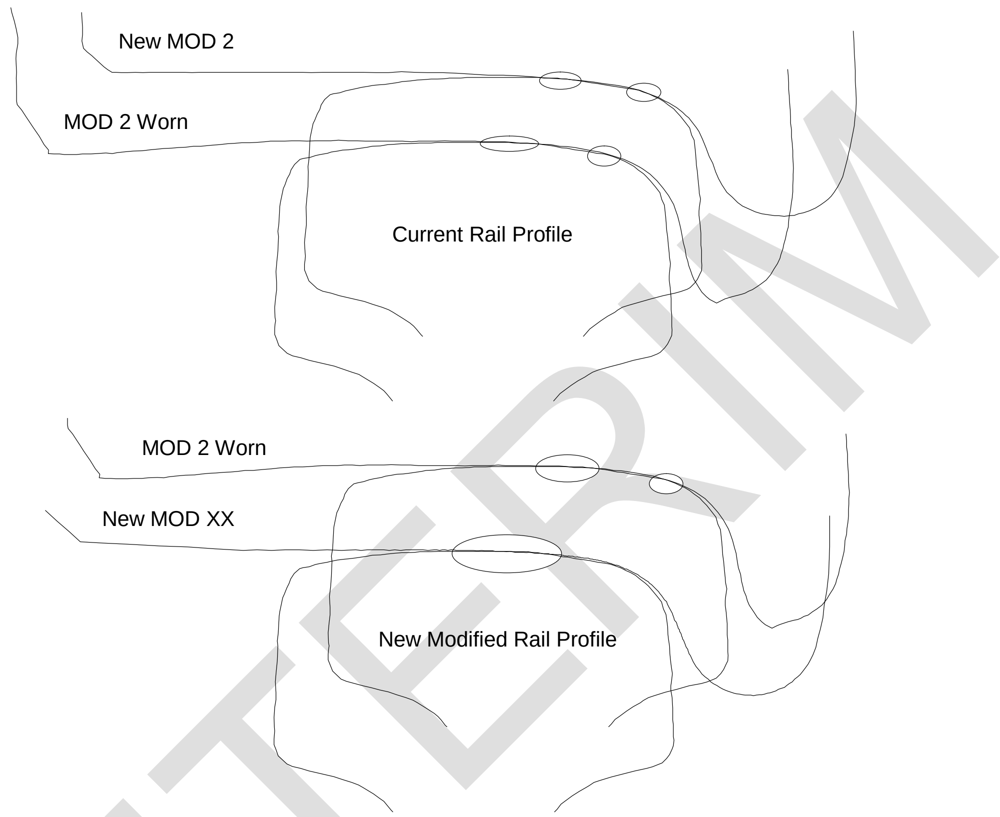

Figure 22 Current modified and worn wheel profiles and high rail profiles in shallow curves (radius >1000 m)

4 Squat Defects

4.1 Characteristics

Squats are surface or near-surface initiated defects, which can be of two types:

- The more common type of squats, which are initiated on the crown or ball of the rail head.

  As illustrated in Figure 23, these are easily identified visually, as they appear as dark spots or "bruises" on the running surface of the rails.

  The defective area seems darkened because of the sub-surface cracking which, as illustrated in Figure 24, occurs typically on a horizontal plane, approximately 3-5 mm below the rail surface, and which causes a depression on the rail surface.

  Each squat consists of two main sub-surface cracks, a leading one that propagates in the direction of train travel, and a trailing one that propagates in the opposite direction. The leading crack is usually several times longer than the trailing crack and contains one main crack with a number of secondary or minor cracks branching off that crack, as illustrated in Figure 24.

- Squats that are initiated from the gauge corner checking cracks.

  As illustrated in Figure 25, these eventually grow laterally and spread towards the crown of the rail head, and in their advanced stages appear very similar to the rail crown squats.

  Both types of squats develop mainly in shallower curves and tangent track, and in hardened rails.

  As illustrated in Figures 23 and 25, both types of squats can occur as discrete defects or as closely spaced multiple defects.

  The actual depth and length of the primary sub-surface cracks associated with squats can be readily measured using an ultrasonic depth gauge on top of the rail head, as illustrated in 26.

Figure 23(a) Examples of Rail Crown Squats - Small

Figure 23(b) Examples of Rail Crown Squats - Medium

Figure 23(c) Examples of Rail Crown Squats - Large

Figure 23(d) Examples of Rail Crown Squats - Multiples

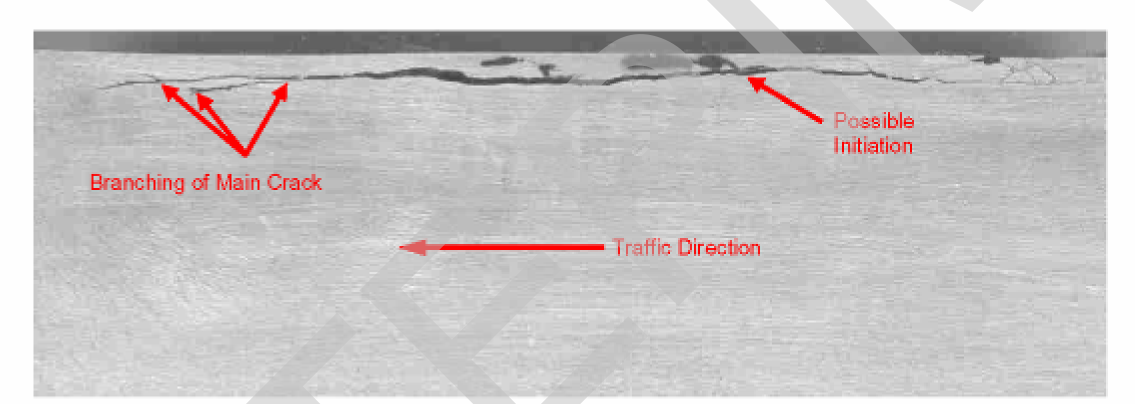

Figure 24 Sub-surface cracking associated with squat defect

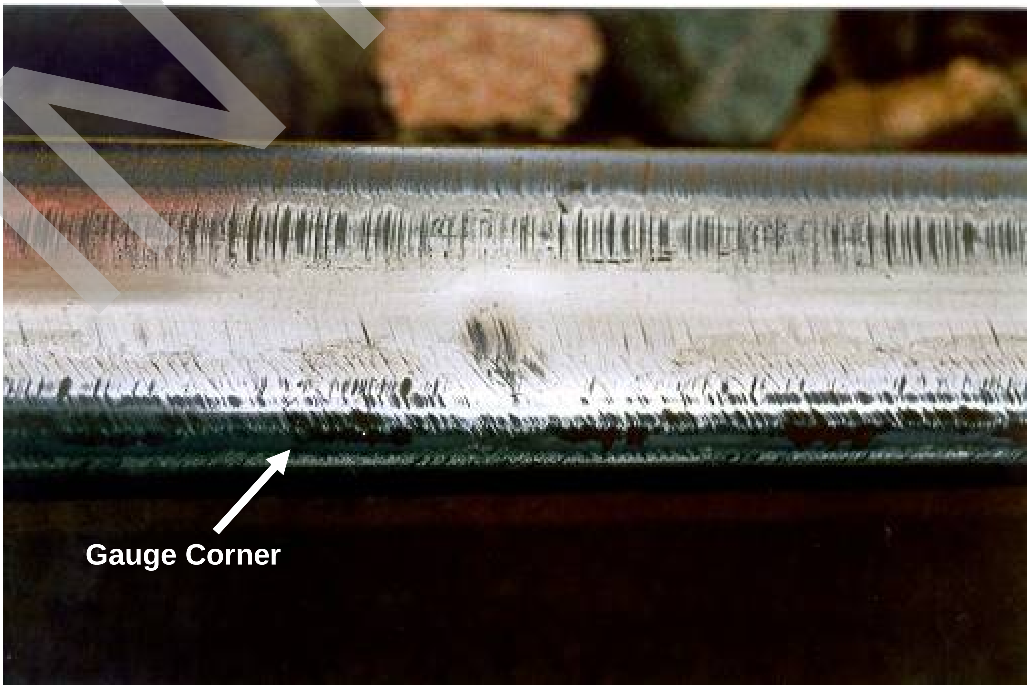

Figure 25(a) Examples of Gauge Corner Checking Initiated Squats - Small

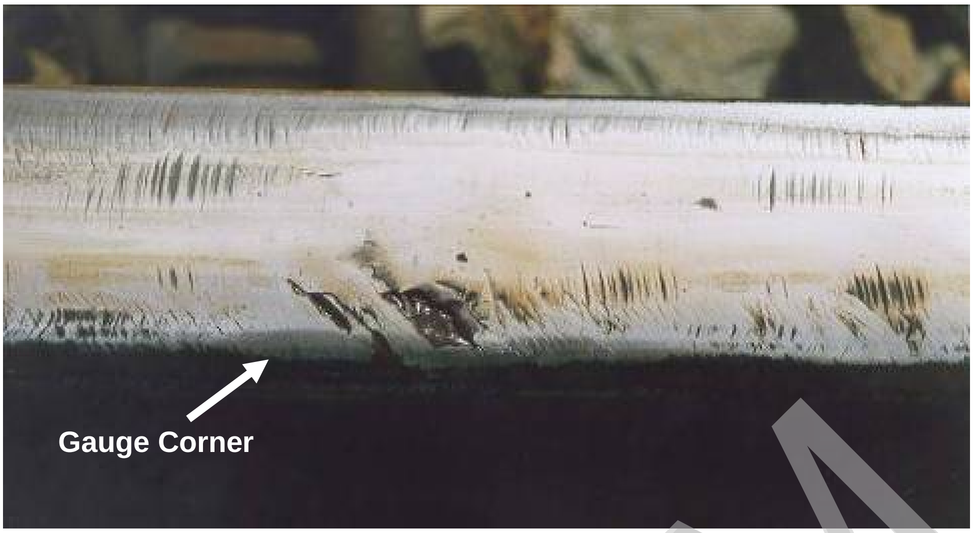

Figure 25(b) Examples of Gauge Corner Checking Initiated Squats - Large

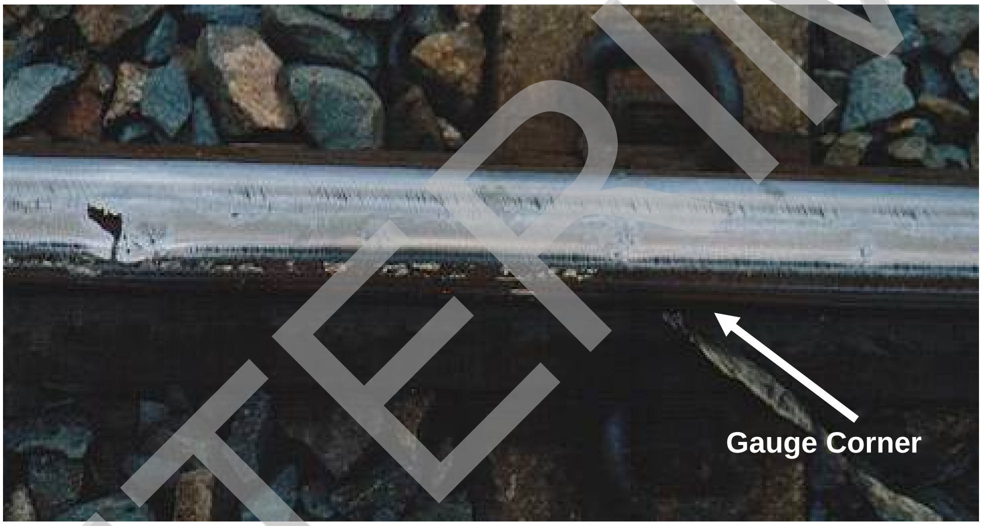

Figure 25(c) Examples of Gauge Corner Checking Initiated Squats - Multiples

Figure 26 Ultrasonic Depth Gauge Used to Measure the Depth and Length of the Squat Sub-surface Cracks

4.2 Causes

Historically squats have been classified as part of rolling contact fatigue defects.

This may be true for the squats that are initiated from the gauge corner checking cracks, shown in Figure 25.

However, more recent work has shown that the more common squats that form on the crown of the rail head (refer to Figure 23), are actually initiated from a “white etching”, hard and brittle layer, as illustrated in Figure 27, which is most commonly found on infrequently ground rail, is 5-60µm deep (0.005-0.060mm), and can have a hardness of up to 900 HV. Figure 27 also shows the fine cracks present in the hard surface layer.

The “white etching” layer can form on the rail surface because of adiabatic (low temperature/high strain rate) shear between the rail and wheel surfaces, caused by the microslip of the locomotive wheels that are under traction.

The microslip process is illustrated in Figure 28. It can be seen that for traction in the direction of rolling, adhesion occurs in the leading region of the wheel/rail contact patch and some slip occurs in the trailing region of the contact patch. As the generated traction increases, the level of longitudinal creepage increases, and the slip zone also increases, until total slip is produced.

In other words, the development of squats appears very similar in nature, but not in degree, to the development of wheelburns, which are of course associated with the much more severe final stage of the slip mechanism shown in Figure 28(b). The very severe slip conditions associated with wheelburns, lead to much higher temperatures, and much greater depths of transformation and hardening (up to 4-6mm, rather than the 0.03mm observed with the squats).

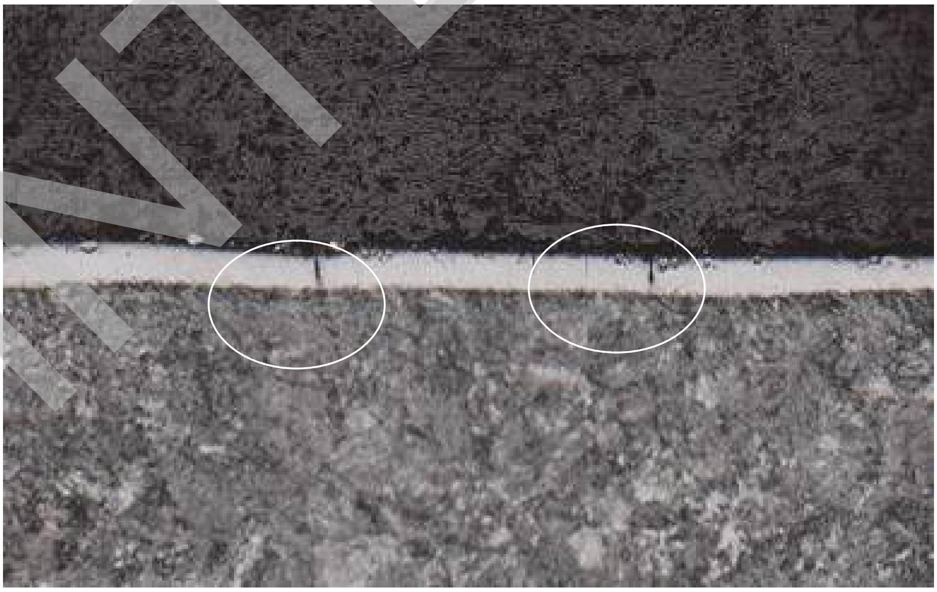

Figure 27 White etching layer on rail surface showing cracking (x 200)

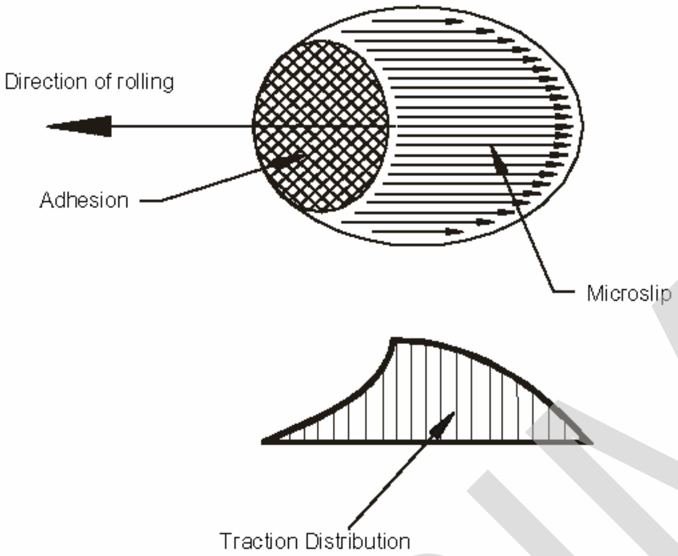

Figure 28 (a) Adhesion and microslip zones in the wheel/rail contact patch

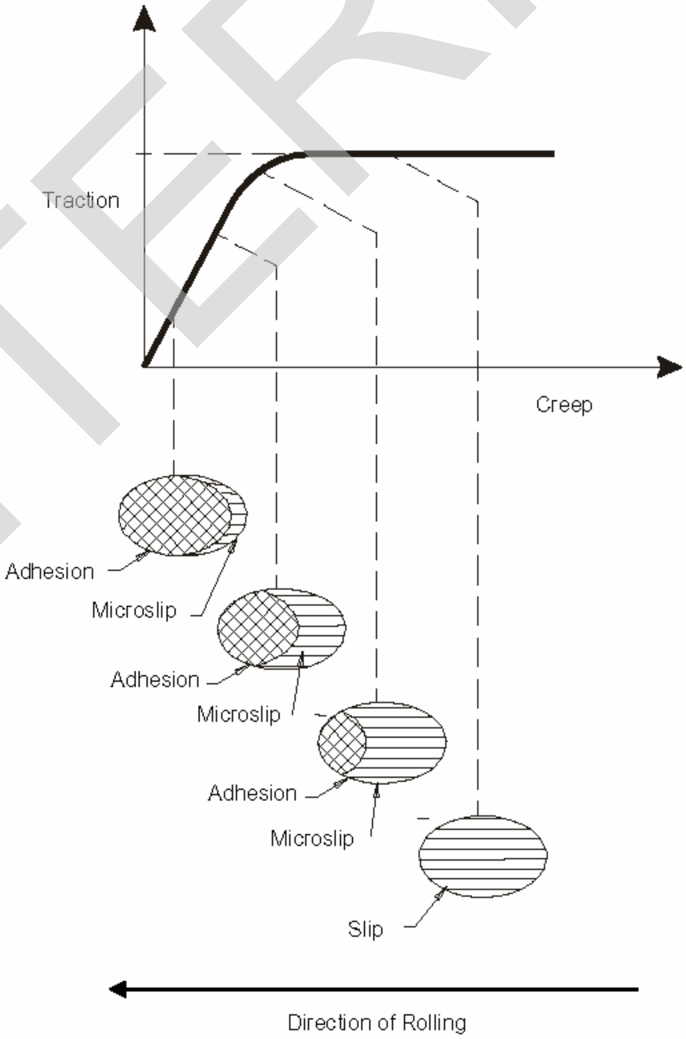

Figure 28(b) Relationship between traction, creep and slip

The presence of microslip has also been observed near the gauge corner of the rails, as illustrated in Figure 29. The similarity in shape with the zone shown in Figure 28(b) is evident. This could enhance the development of the gauge corner squats.

It is thought that the squat defects develop mainly in shallower curves and tangent track, and in hardened rails primarily because of the reduced rail wear that occurs under these conditions. Higher rail wear rates would tend to remove the thin “white etching” layer before the longer sub-surface cracks have time to develop.

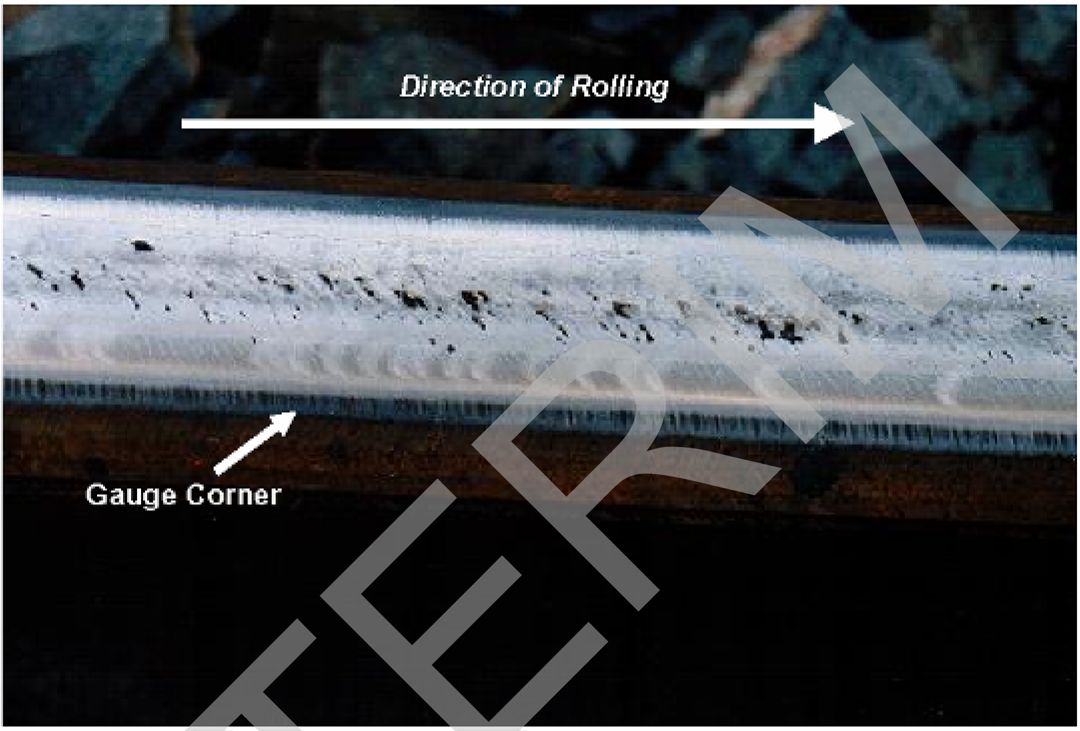

Figure 29 Possible microslip at the gauge corner of low rails

4.3 Effects

Squat defects are of concern because of the following main reasons:

- There is a danger that the secondary or minor sub-surface cracks (illustrated in Figure 30) may turn down and grow on a transverse plane similarly to transverse defects, with the possibility of resulting in a complete rail failure if not detected in time.

- The depression on the running surface associated particularly with large squats (refer to Figure 23(c)) also increases the vertical impact wheel loadings applied to the rails, and consequently exacerbates the deterioration of both track and some vehicle components, in a similar way to dipped welds, rail corrugations and rail joints.

- The rail life is decreased, through the need for aggressive and expensive defect grinding.

- The possible shielding of ultrasonic signals from deeper defects during normal ultrasonic inspections.

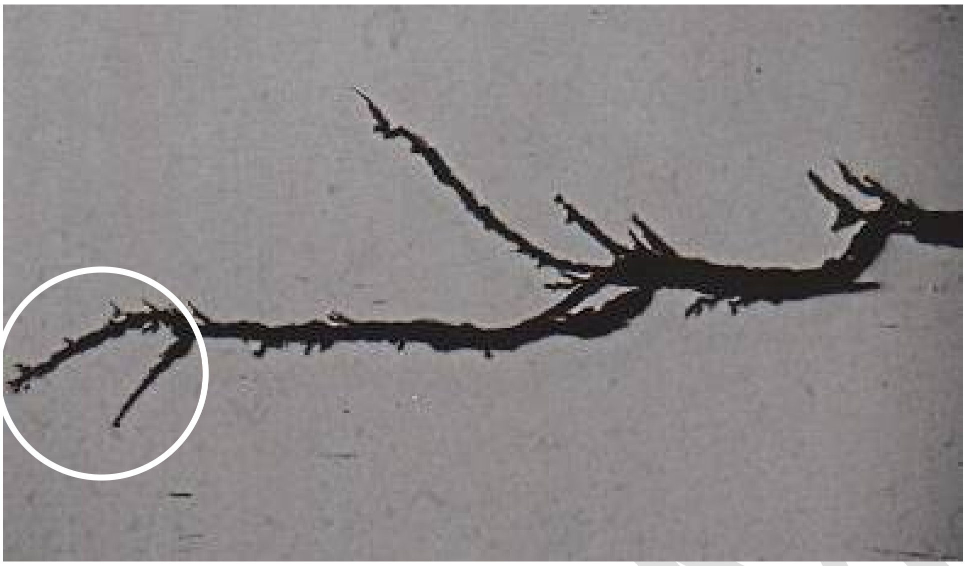

Figure 30 Sub-surface cracking associated with squats
(Longitudinal Section, rail contact surface is at the top of the photographs, x 50)

The development of transverse failures from squat defects has occurred in lighter axle load, passenger operations. To date, however, a similar behavior has not occurred in rails subjected to higher axle loads freight or coal operations. The reason for the difference is thought to be similar to that discussed in Section 4.2 for gauge corner checking cracks, namely: the development of a plastically deformed and work hardened region near the surface of the rails subjected to the higher loads, which exhibits a compressive residual stress, and hence would resist the growth of cracks into the rail head.

4.4 Treatment

The main preventive measures for squat defects are:

- Regular (cyclic), preventive rail grinding to remove the surface layer, which contains the most severely damaged material, including small cracks and/or hard and brittle phases, so that accelerated crack propagation can be prevented. This concept has already been illustrated in Figure 16, which shows how the grinding cycles are applied to prevent the rapid growth of the cracks. During each preventive grinding cycle, a minimum amount of metal (such as 0.2mm) needs to be removed from the contact surface of the rail. In this way, grinding acts as an artificial rail wear mechanism.

- The development of improved rail/wheel lubrication procedures, which aim primarily to reduce the contamination of the running surface and gauge corner of the rails, and hence reduce the adverse influence of lubrication on the growth of surface initiated fatigue defects.

- Improving the geometry between rails and wheels, and consequently reducing the wheel/rail contact stresses and the sensitivity to wheelset/bogie hunting.

- The possible implementation of high positive friction or very high positive friction modifiers to the running surface of the rails, to improve the locomotive traction characteristics, and in particular the sensitivity to microslip.

- This process is illustrated in Figure 31, which shows how under normal conditions (negative friction) wheel slipping will start to occur if upon reaching creepage saturation the friction/traction at the wheel/rail interface reduces. On the other hand, the addition of high positive friction (HPF) modifiers can increase the friction/traction after the initial creepage saturation, and consequently prevent, or at least minimise, the occurrence of the wheel slip.

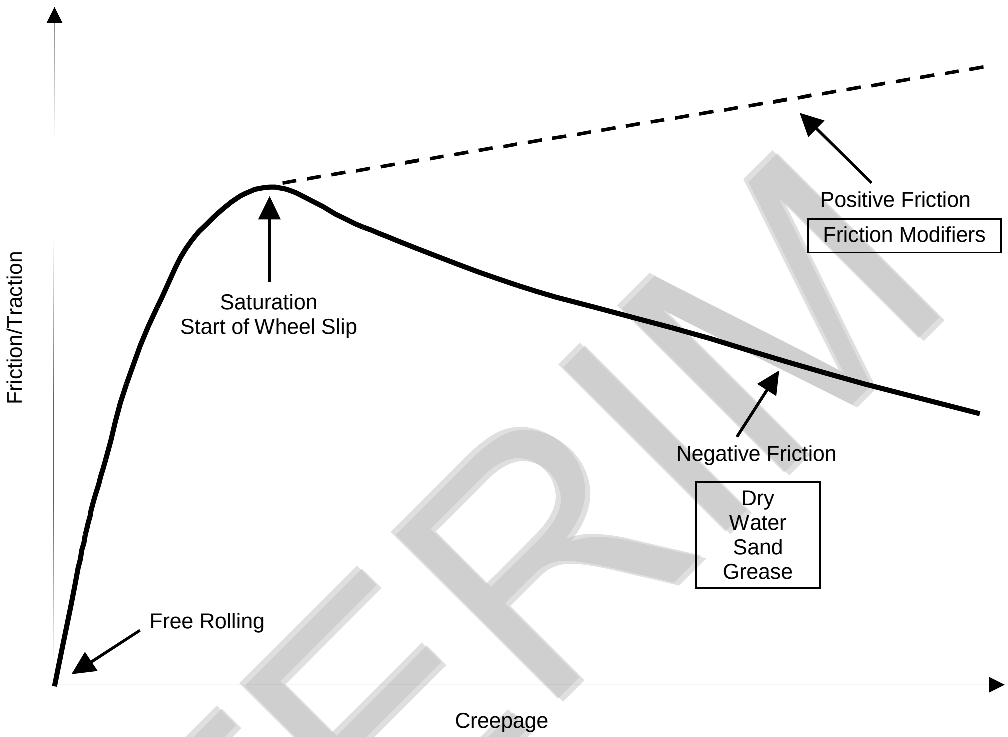

Figure 31 Traction/Creepage Relationship

5 Tache Ovale or Shatter Cracking

5.1 Characteristics

Tache ovales or shatter cracks (also known as transverse fissures) are internal defects that initiate near the center of the rail head, and grow transversely as illustrated in Figure 32. Their growth plane is therefore similar to transverse defects, however they initiate at much greater depths and not in the gauge corner region.

As for transverse defects, because of their internal nature, tache ovales cannot be visually detected, and hence must rely on regular ultrasonic rail inspection.

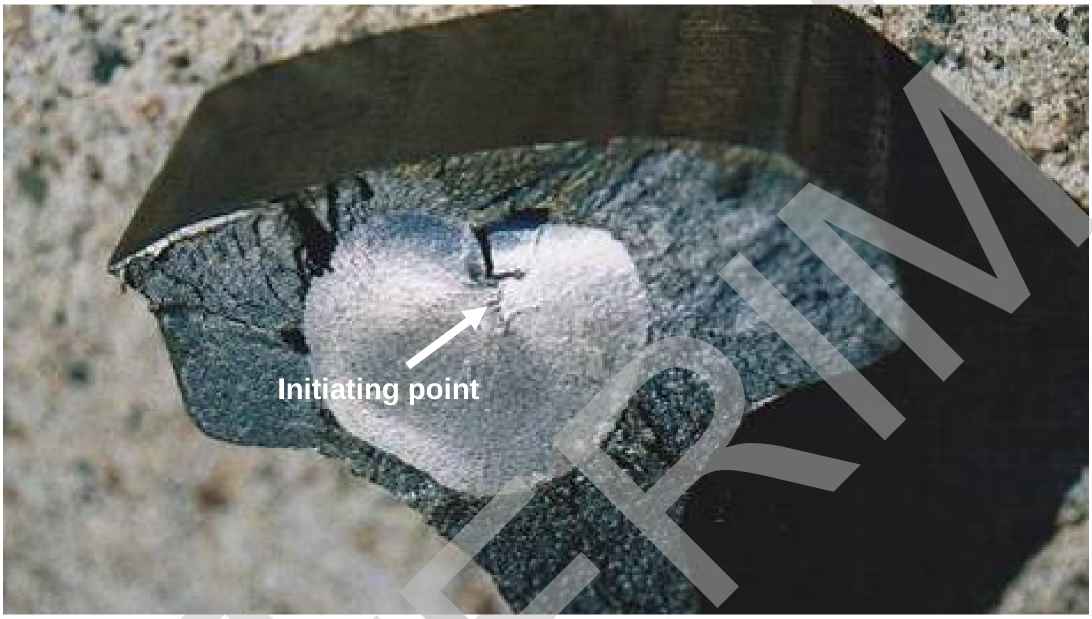

Figure 32(a) Example of Tache Ovale defects

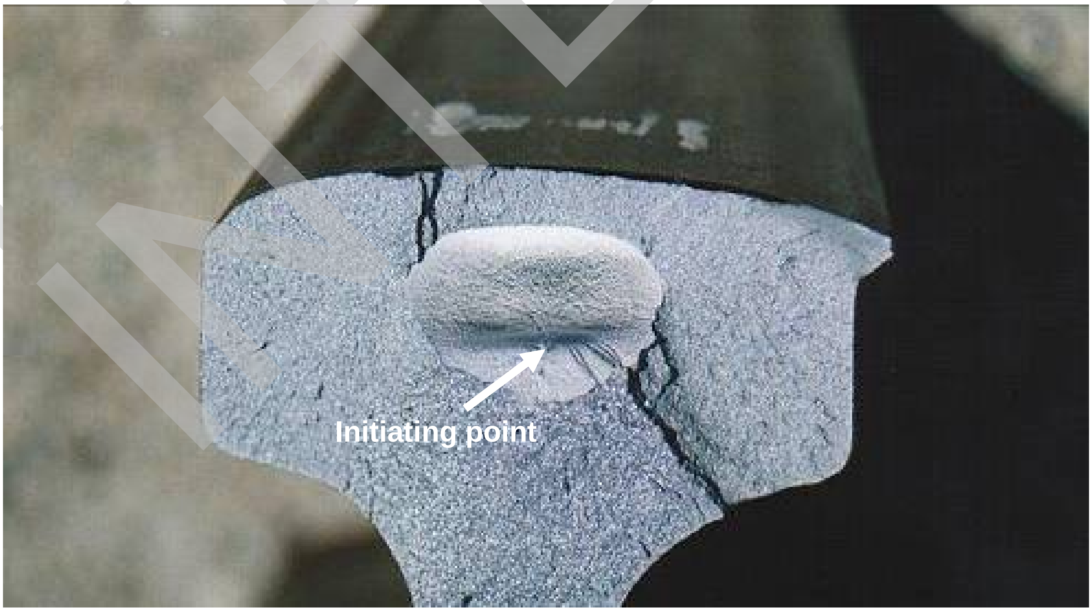

Figure 32(b) Example of Tache Ovale Defect

5.2 Causes

The initiation of tache ovale defects is due to the presence of excessive levels of hydrogen in rail steel (or welds).

Under normal circumstances, the steel blooms from which the rails are made or even the rails are slowly cooled over a long time to allow most of the hydrogen to diffuse out of the steel. If, however, the slow cooling process is inefficient, some hydrogen remains in the steel. The hydrogen atoms combine at preferred sites, such as grain boundaries or inclusions, and form molecular hydrogen. This process leads to marked increases in the internal pressure associated with the pockets of molecular hydrogen, which greatly enhances the risk of crack initiation. The initial, hydrogen induced, shatter cracking is illustrated in Figure 33.

Improvements in steelmaking procedures have greatly reduced the risk of shatter crack development. Ironically, the reductions in the inclusion levels in the steel have also increased the potential for shatter cracks since there are now far fewer preferred sites for hydrogen segregation.

Once the shatter crack develops, it can grow in a transverse plane through the combination of cyclic bending stresses, and longitudinal tensile thermal and residual stresses, in a similar fashion to transverse defects. In the case of tache ovales, wheel rail contact stresses have a negligible influence, because of the considerable depth from the wheel/rail contact surface of the initial shatter crack.

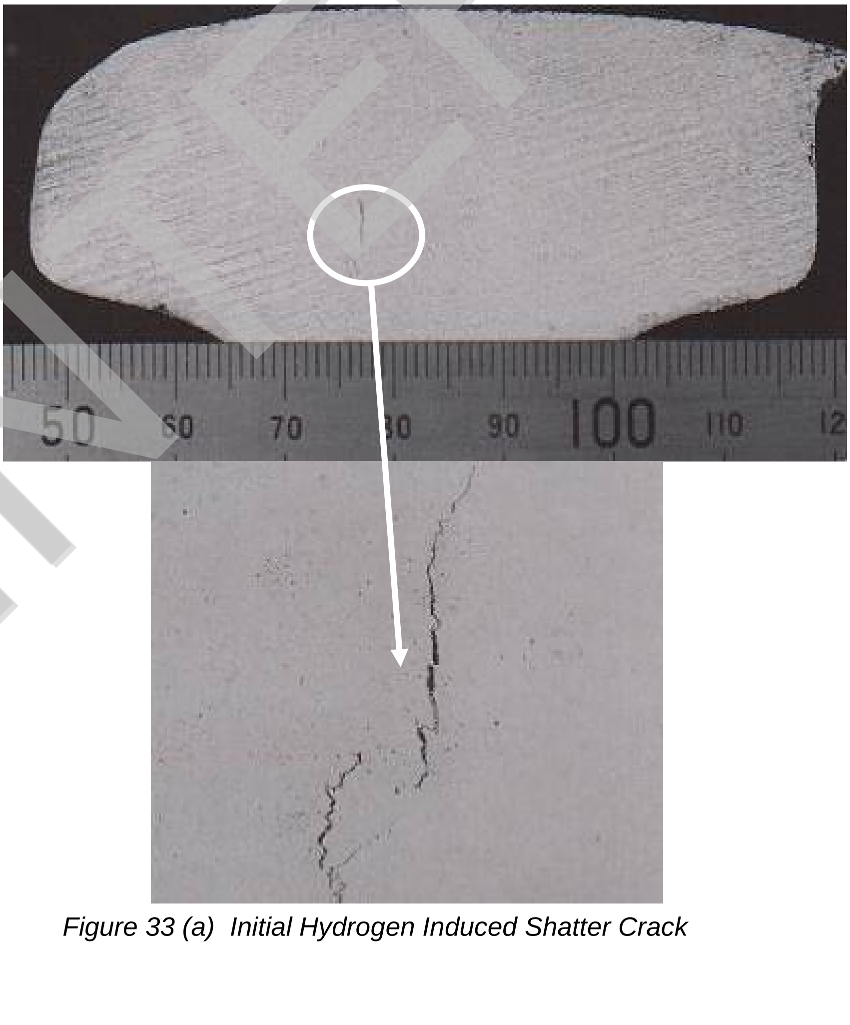

Figure 33 (a) Initial Hydrogen Induced Shatter Crack

5.3 Effects

Tache ovale or shatter crack defects are of particular concern because one or more rails in a particular batch may contain hydrogen cracking at multiple sites, each having the potential to initiate a transverse defect. Consequently, multiple transverse defects could develop in the same rail length and lead to a catastrophic rail failure if not detected in time, particularly under the high impact loads associated with some wheel irregularities.

The concern associated with shatter cracking is emphasised in the Australian Standard for Steel Rails (AS 1085.1 – 2000), which clearly specifies that “The rail shall be free of hydrogen induced cracks”.

An additional concern is that the current ultrasonic inspection cycles have generally been determined with some idea of growth rates in the normal transverse defects. On the other hand, the growth rates of tache ovales are not known, and consequently may not suit the current cycles.

5.4 Treatment

The principal treatment for tache ovale defects is to reduce the critical hydrogen content of the steel, by appropriate steelmaking and/or heat treatment procedures.

The ultrasonic procedures adopted by rail manufacturers must also exhibit sufficient accuracy to allow the detection of any hydrogen cracking within the rail head. In this case, the ultrasonic testing needs to be conducted several days following rail manufacture, to allow sufficient time for any hydrogen cracking to fully develop.

Once the affected rails are in track, the initiation and growth of the tache ovale defects may be inhibited by reducing the levels of applied nominal, dynamic and in particular impact wheel loadings (refer to Section 2).

Finally, the ultrasonic rail testing procedures must be capable of detecting the tache ovales before they reach a critical size, that may cause rail failure.

6 Vertical Split Head

6.1 Characteristics

As their name implies, vertical split head defects are vertical separations in the rail head, which tend to split the rail head in two parts, as illustrated in Figure 34.

Figure 35 illustrates cross sections of the rail head containing a medium and a large vertical split head. It can be seen that in Figure 35(a), the vertical crack is contained within the rail head, while in Figure 35(b) the crack has almost joined the head/web transition region.

Vertical splits head defects generally form near the centre line of rails, and can be of considerable length (>0.5-1.0m).

Generally, small and medium defects cannot be detected visually.

However, as illustrated in Figure 36(a), very large defects may exhibit the following visual characteristics:

- A dark streak on the running surface (1), indicating sagging of the rail head.
- Widening (bulging) of the rail head (2), and the contact band along the defect (refer to Figure 36(b)).
- A rust streak (3) and some bleeding (4) in the head/web fillet region, which occurs when the crack nears the rail surface (refer to Figure 36(c)).

The actual length of the vertical split head defects can be readily measured using appropriate ultrasonic equipment, including the ultrasonic depth gauge illustrated in Figure 26, particularly if the measurements are taken from the side of the rail head.

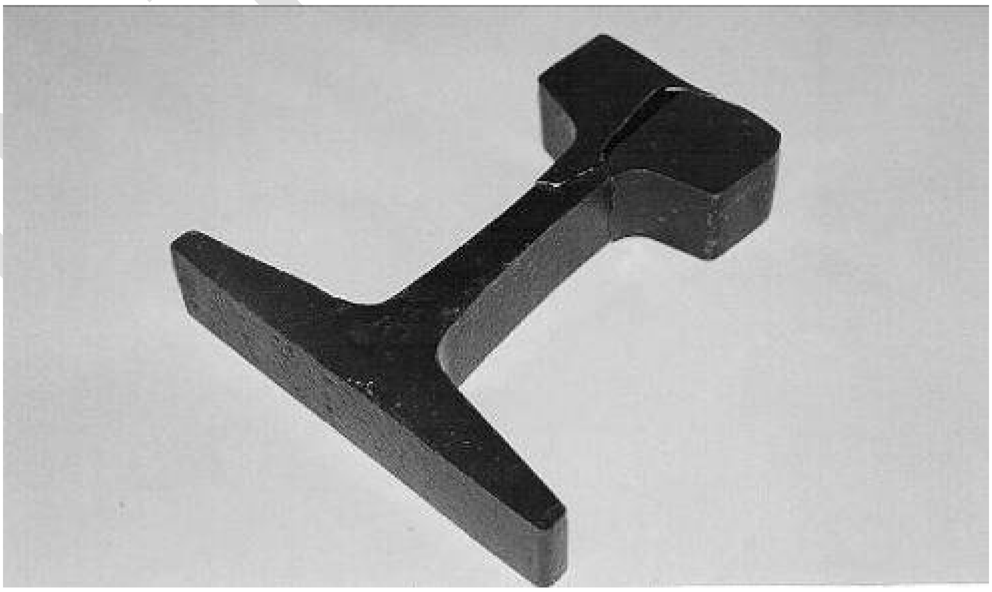

Figure 34 Vertical Split Head defect

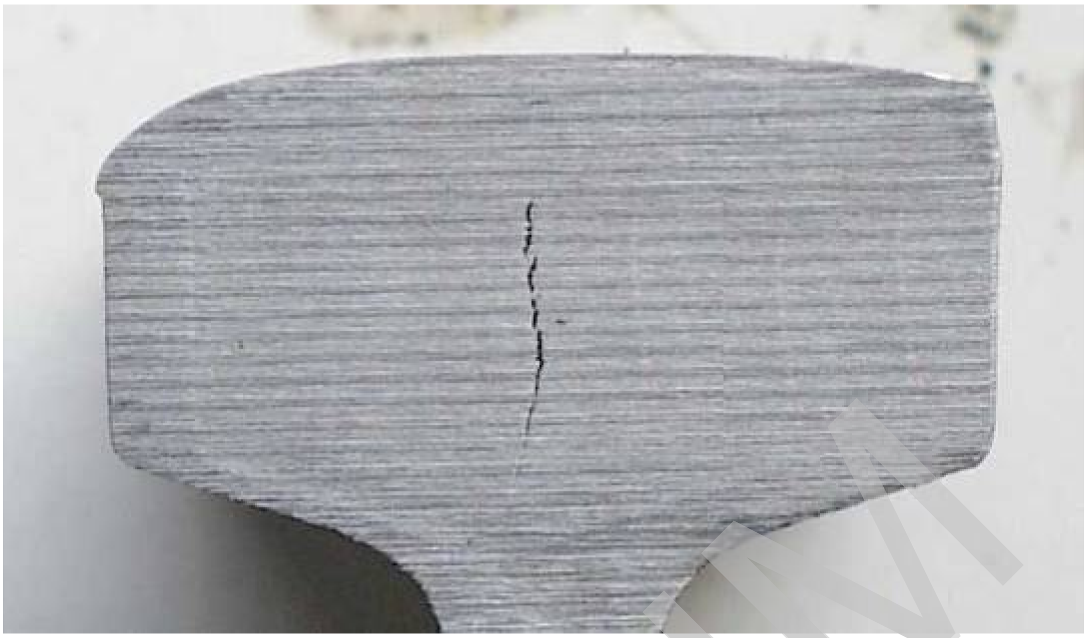

Figure 35(a) Medium Vertical Split Head defect

Figure 35(b) Large Vertical Split Head defects

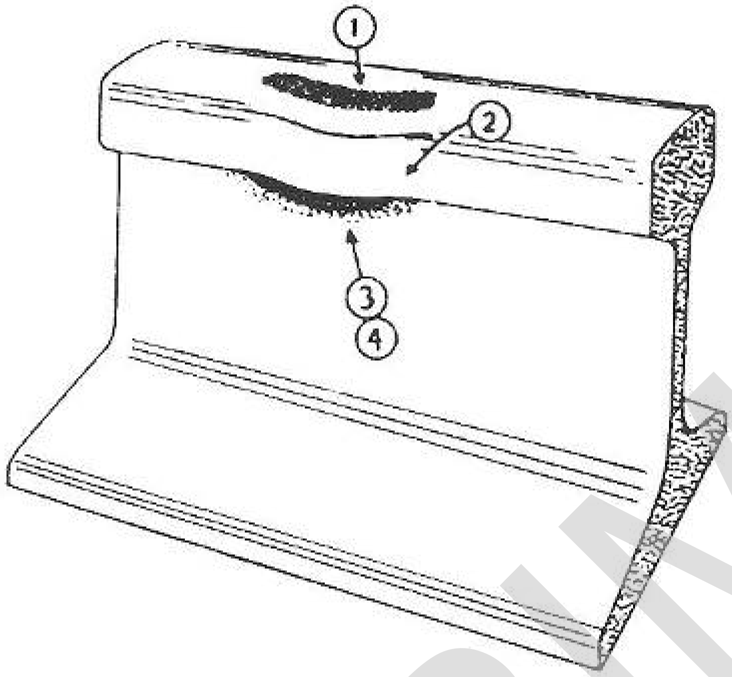

Figure 36(a) Visual indications of large vertical split head defects

Figure 36(b) Widening of the wheel/rail contact band that occurs on top of the large vertical split head defects

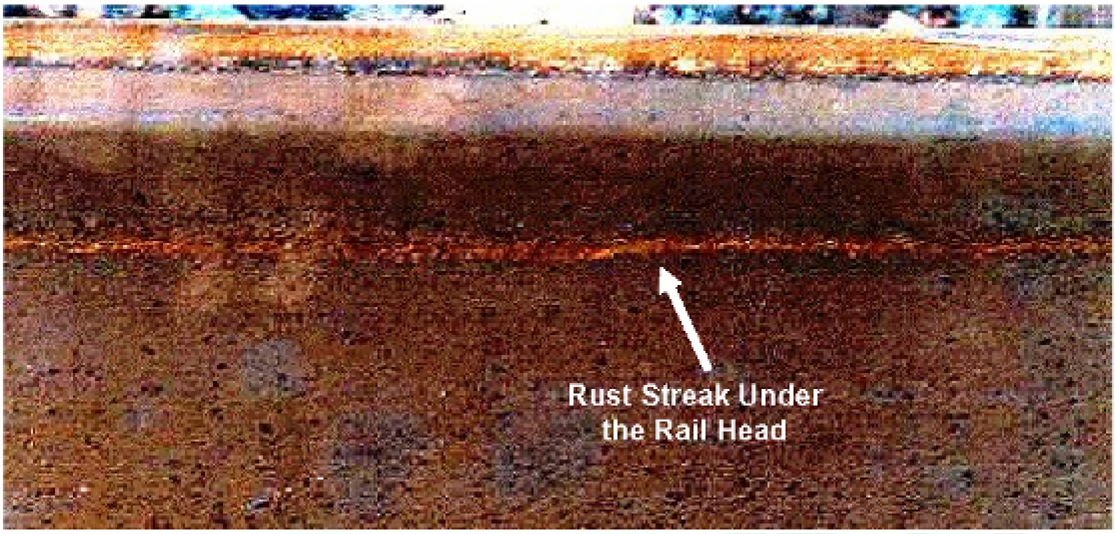

Figure 36 (c) Rust streak in the head/web transition associated with the breakout of the large vertical split head defects

6.2 Causes

As illustrated in Figures 37 and 38, the vast majority of vertical split heads initiate at elongated seams, inclusion stringers or highly segregated regions. These occur particularly in the older rails produced by means of ingots (rather than the current continuous casting), which generally exhibited much higher levels of irregularities. The inclusion band is generally very evident visually on the fracture surface of the defect, and may be 1-2 mm in vertical height.

The initial crack growth occurs vertically from the elongated irregularity, both towards the running surface and the head web transition region. The actual stress condition that produces such crack growth is primarily the result of heavier axle loads in association with impact loads and, sometimes, with extremely eccentric loads from tread hollowed wheels and flat rail.

Vertical split heads may also occur in clean 60kg/m steel under extreme rail wear conditions.

It is also not clear to what extent and by what mechanism the cracks actually extend along the rail. In particular, whether the cracks associated with the elongated irregularities actually grow longitudinally into the rail material, in which case the growth rate could be relatively low; or whether the longitudinal growth consists of the joining up of adjoining pre-existing cracks, in which case the growth rate could be relatively high.

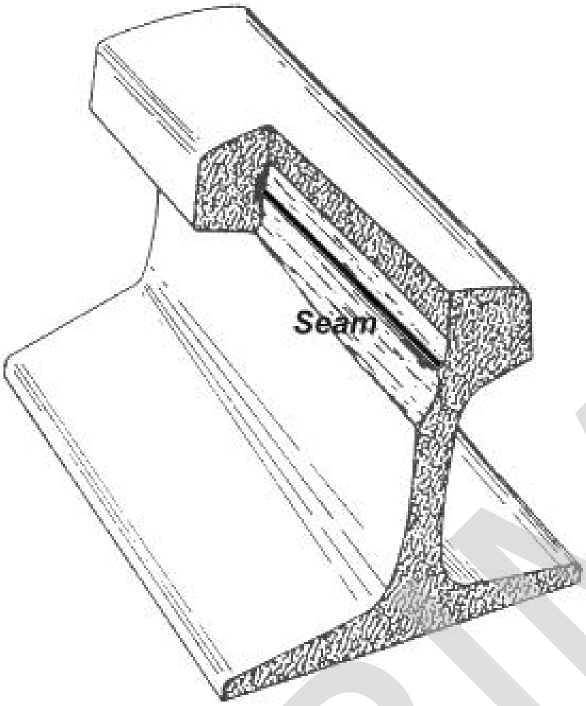

Figure 37 General appearance of Large Vertical Split Head defects

Figure 38 (a) Inclusion band at initiation of Vertical Split Head defects

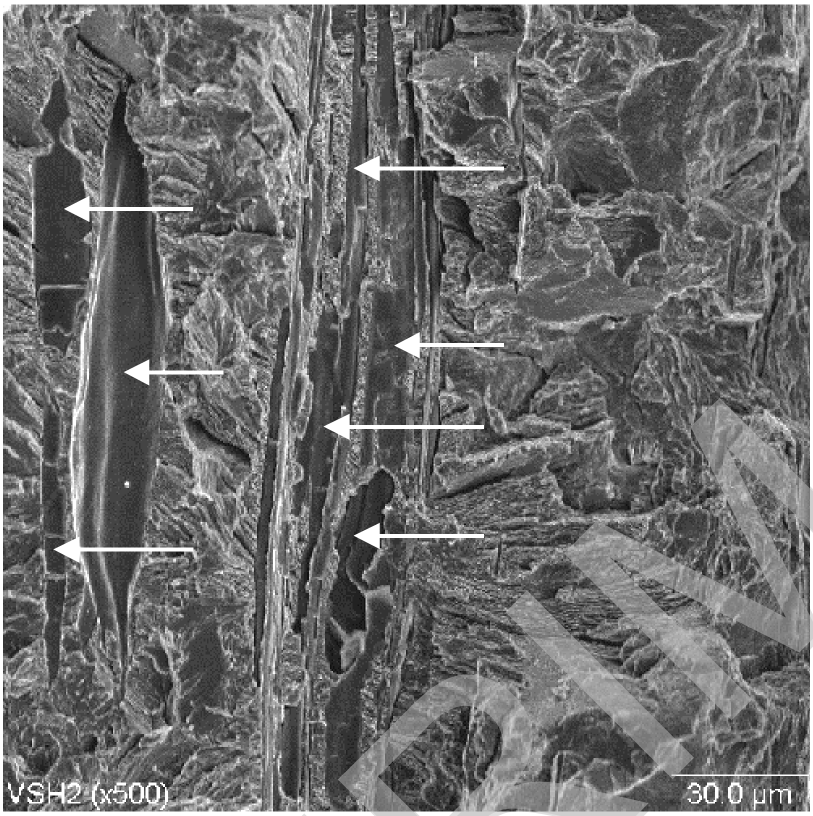

Figure 38 (b) Inclusion stringers at initiation of Vertical Split Head DEFECTS (indicated by arrows)

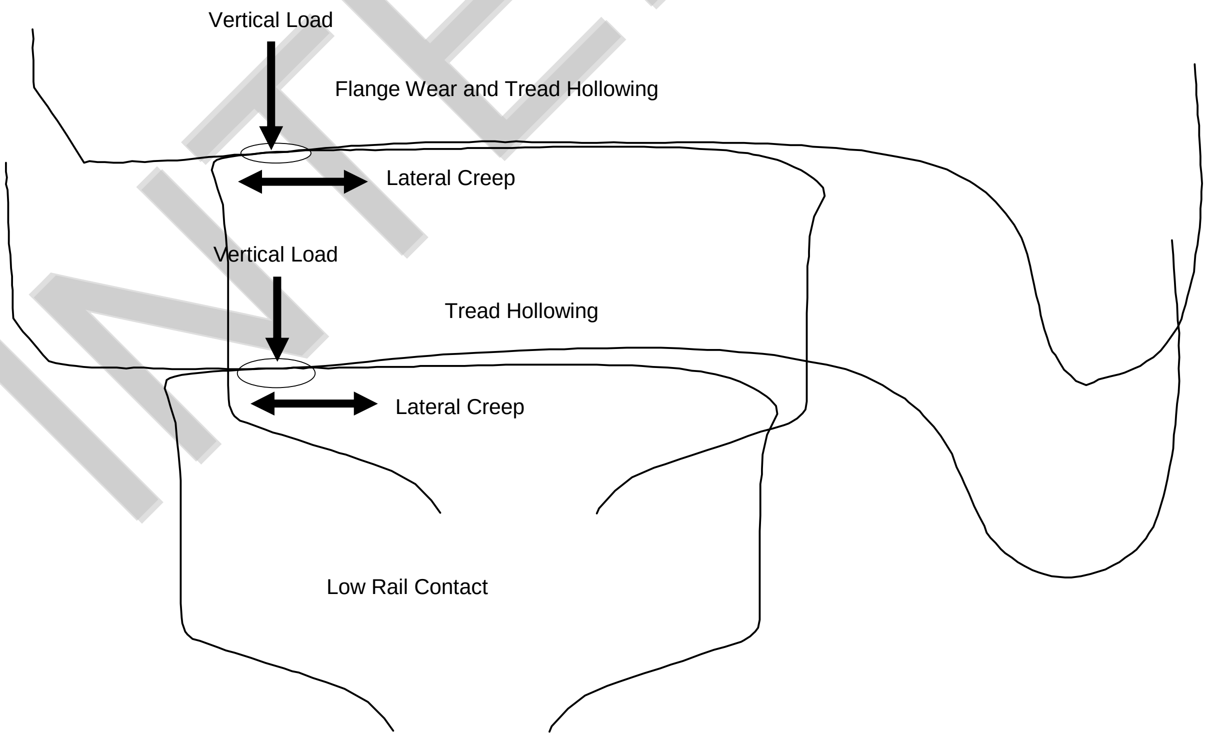

Figure 39 Off Centre contacts between hollow wheels and worn low rails

6.3 Effects

The major concerns associated with vertical split head defects are:

- Generally the defects cannot be visually detected until they become very large, and hence must rely on detection by ultrasonic inspection.

- The defects can be very long, and consequently a considerable proportion of the rail head becomes weakened.

- If the defects are not detected in time, a complete vertical failure of the rail head may occur. This becomes critical particularly if the failure is on the gauge side of the rails, since the condition would increase the risk of wheel climb and derailment.

6.4 Treatment

As indicated in Section 7.2, vertical split heads generally occur in the older rail steels. The improved cleanliness associated with the newer rails reduces considerably the risk of defect development.

The ultrasonic procedures adopted by rail manufacturers must also exhibit sufficient accuracy to allow the detection of any elongated seams or large inclusions within the rail head.

Once the affected rails are in track, the initiation and growth of the vertical split head defects may be inhibited by:

- Reducing the levels of applied nominal, dynamic and in particular impact wheel loadings (refer to Section 2).

- Reducing the levels of wheel hollowing, so that off centre loading of the rails is minimised.

- Grinding the rails, so that the wheel loading is concentrated near the centre of the running surface.

Finally, regular ultrasonic rail testing must be carried out to detect the vertical split heads before they reach a critical size, which may cause rail failure.

7 Horizontal Split Head

7.1 Characteristics

As their name implies, horizontal split head defects are horizontal separations in the rail head, which tend to split the rail head in two parts, as illustrated in Figure 40 and 41.

The defects initiate on the field side of the rails, at a considerable depth from the running surface (10-15 mm) and grow horizontally (parallel to the running surface), both across and along the rail head.

The defects can be of considerable length (>50-100 mm).

Generally, small and medium defects cannot be detected visually.

However, as illustrated in Figure 42, the very large defects may exhibit the following visual characteristics:

- A flat spot or dark streak on the field side of the running surface (1), indicating sagging of the rail head.
- A slight widening (bulging) of the rail head along the defect (1).
- A fine horizontal hairline crack, which is sometime accompanied by a rust streak (2), at least one third of the way below the top of the rail head and usually on the field side.

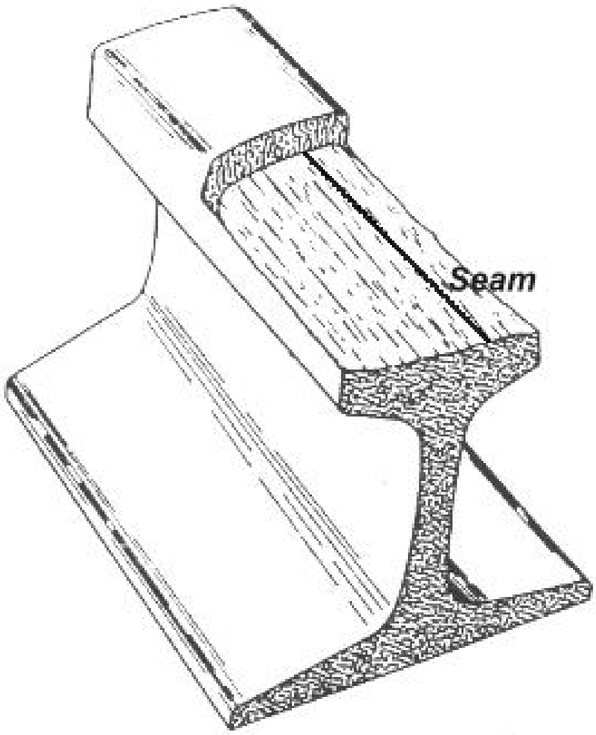

Figure 40 General appearance of large Horizontal Split Head defects

Figure 41 (a) Horizontal Split Head defect

Figure 41 (b) Fracture surface of Horizontal Split Head defect

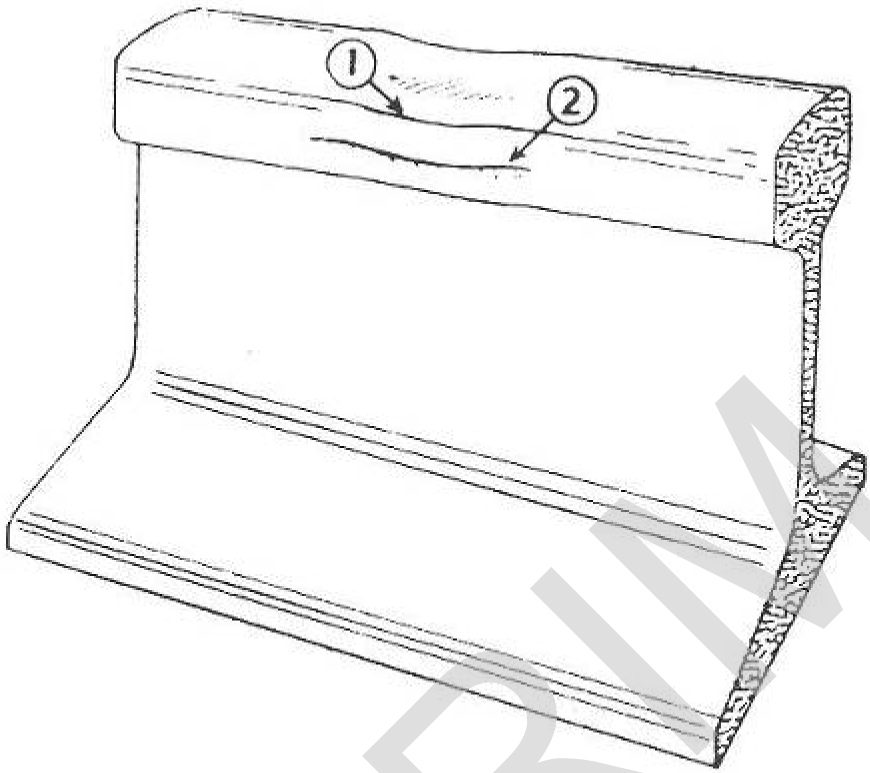

Figure 42 Visual indications of large Horizontal Split Head defects

7.2 Causes

As illustrated in Figures 40 and 41(b), horizontal split heads initiate at elongated seams or inclusion stringers, which may be present in the rails, in much the same way as vertical split heads (as illustrated in Figure 38). These occur particularly in the older rails produced by means of ingots (rather than the current continuous casting), which generally exhibited much higher levels of irregularities.

The initial crack initiation and growth occur horizontally from a major elongated irregularity, towards both the gauge and field sides of the rail head. However, there are often other sites that act as crack initiators, which eventually join up with the main crack front.

The crack growth occurs by a fatigue mechanism, as indicated by the striations in Figure 41(b).

The actual stress condition that produces such crack initiation and growth is not certain, but it is known that the crack development may entail a shear stress component. This is supported by the fact that, as illustrated in Figure 43, a “white etching” phase has been observed on the surfaces of the cracks. The presence of this phase indicates that the surfaces have been rubbing during crack growth as would be obtained in the presence of shear stresses, rather than simple crack opening as would be obtained in the presence of tensile stresses.

The following processes may be involved:

- The field side localized loading of the rails that occurs with hollow wheels and worn rails, as illustrated in Figure 39, could give rise to relatively high wheel/rail contact shear stresses, even at considerable depths from the running surface (as illustrated in Figure 3). These stresses may be sufficiently high to initiate cracks, particularly from the very large inclusions that are known to be present.

- Lateral displacement of the rail head due to the lateral creep forces that are produced as the wheelsets oscillate from one side of the track to the other, as illustrated in Figure 39. These would result in a shear component on a horizontal plane within the rail head, which could enhance the initiation process, and provide sufficient stress to cause the fatigue growth process.

It is also not clear to what extent and by what mechanism the cracks may actually extend along the rail. Indeed, most of the evidence suggests that the length of the defects along the rails does not extend beyond the length of the original initiating irregularity. It is possible of course that if there are several such irregularities in line, the cracks associated with each of these irregularities may join together and form a longer horizontal split head defect.

Figure 43 "White Etching" phase present on crack face

7.3 Effects

The major concerns associated with horizontal split head defects are:

- Generally the defects cannot be visually detected until they become very large, and hence must rely on detection by ultrasonic inspection.

- The defects can be very long, and consequently a considerable proportion of the rail head becomes weakened.

- If the defects are not detected in time, a complete horizontal failure of the rail head may occur. This becomes critical particularly if the failure is on the gauge side of the rails, since the condition would increase the risk of wheel climb and derailment.

7.4 Treatment

As indicated in Section 7.4, horizontal split heads generally occur in the older rail steels. The improved cleanliness associated with the newer rails reduces considerably the risk of defect development.

The ultrasonic procedures adopted by rail manufacturers must also exhibit sufficient accuracy to allow the detection of any elongated seams or large inclusions within the rail head.

Once the affected rails are in track, the initiation and growth of the horizontal split head defects may be inhibited by:

- Reducing the levels of applied nominal, dynamic and in particular impact wheel loadings (refer to Section 2).

- Reducing the levels of wheel hollowing, so that off centre loading of the rails is minimised.

- Grinding the rails, so that the wheel loading is concentrated near the centre of the running surface.

Finally, the regular ultrasonic rail testing procedures must be capable of detecting the horizontal split heads before they reach a critical size, which may cause rail failure.

8 Wheel or Engine Burns

8.1 Characteristics

As illustrated in Figure 43, wheel burns are defects that form on the running surface of the rails.

Small wheel burns are very similar in appearance to small squats (compare Figure 43 with Figure 23(a)). However, unlike squats which can form at discrete locations, wheel burns always occur in pairs directly opposite to each other on the two rails.

Severe wheelburns, which can be more than 50 mm in length, exhibit what seem to be longitudinal gouging marks on their surface.

Wheelburns can also occur while the locomotives are in motion. In this case, as illustrated in Figure 44, the damaged region can extend over a substantial length of the rail surface.

Figure 43(a) General appearance of Wheel Burns - Small

Figure 43(b) General appearance of Wheel Burns - Medium

Figure 43(c) General appearance of Wheel Burns - Large

Figure 43(d) General appearance of Wheel Burns - Multiples

Figure 44 Wheel Burns produced by wheel slip on moving locomotives

8.2 Causes

Wheelburn defects are caused by the continuous slipping of the locomotive wheels on the rails. As illustrated in Figure 31, this occurs when the longitudinal creepage reaches saturation.

The slipping action of the wheels increases the temperature near the surface of the rails to very high values. The subsequent fast cooling cause the rail material to transform to a hard and brittle martensite phase, which in severe cases can extend to depths of 4-6mm from the running surface.

The main factors that enhance wheel slip are:

- Excessive track grades.
- Poor train driving procedures, such as rapid acceleration.
- Insufficient locomotive power.
- Contamination of the running surface of the rails, which can reduce the friction to undesirable levels (less than about 0.30-0.35). This may occur when the rail lubrication is not applied efficiently, particularly close to track mounted lubricators, as illustrated in Figure 45.

Adverse running surface contamination and loss of traction may also occur when some light rain follows a long hot dry spell. Under these conditions, it is suggested that the running surfaces of rails become contaminated with a range of deposits, including oils and pollens. The subsequent light rain can then form a lubricating film, which may reduce the friction on the running surface of both rails to unsatisfactory levels even in the absence of wheel/rail lubricant. Heavier rain would clean the running surface and lead to higher friction values.

Figure 45 Running surface contamination of rails by lubricant

8.3 Effects

As illustrated in Figure 43, small and medium wheel burns generally break up and spall out. This is the typical behaviour of the very brittle martensitic phase.

The major concerns associated with the larger wheel burn defects are:

- The depression and/or spalling that occur at the wheel burns lead to very high impact loadings on the rail, and consequently exacerbate the deterioration of both track and some vehicle components, in a similar way to dipped welds, squats, rail corrugations, rail joints and wheel flats.

- The cracking that occurs within the very brittle martensitic phase may initiate transverse defects in the rails, as illustrated in Figure 45, particularly if the martensitic layer is relatively deep. In their early stages of development, such defects cannot be detected visually. Their detection therefore relies on the ultrasonic inspection of the rails.

- As for normal transverse defects, if the defects from wheel burns are not detected in time, a complete vertical failure of the rail head may occur, as shown in Figures 46 (a) and (b).

- Because of the high impact loads, the defects from wheelburns can propagate at much faster rates, and are therefore potentially more serious. This is evident in Figure 46 (c), which clearly shows the fast growth bursts at the edges of the normal elliptical fatigue growth area.

Figure 46 (a) Transverse fracture from a Wheel Burn defect

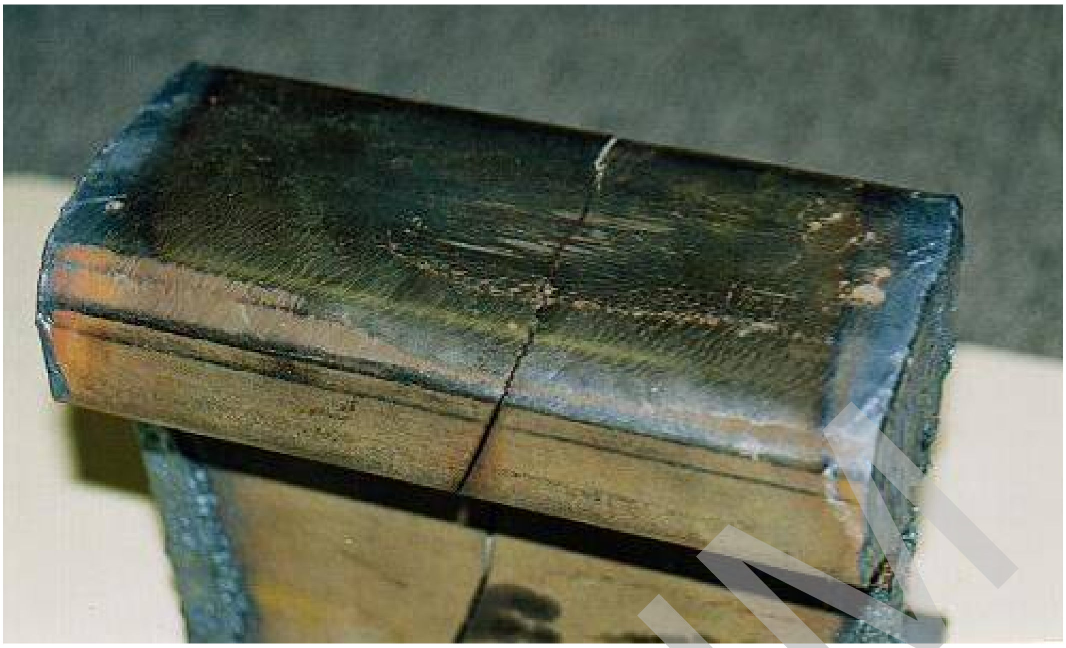

Figure 46 (b) Transverse fracture from a Wheel Burn defect

Figure 46 (c) Transverse defect initiated from a Wheel Burn defect

8.4 Treatment

The risk of obtaining wheel burn defects may be reduced by ensuring that:

- The influencing operational factors are minimised.
- The wheel/rail lubricant does not contaminate the running surface of the rails. In this regard, several procedures have been recommended, and are included in RC.2410 Rail Lubrication Guidelines. These include:
    - Positioning of lubricators next to relatively medium and shallow curves (with radii in the range 400-1000m), rather than next to sharp

curves or in tangent track.

- Ensuring that excessive lubricant is not being pumped out.
- Separating the lubricators on the Up and Down rails by a distance of at least 500 m and preferably 1 km.

In the absence of any contamination by the wheel/rail lubricant, if traction and wheel slip problems still occur, the risk of having such problems could be reduced by cleaning the rail surfaces using high pressure spray water, particularly after relatively long spells of hot and dry weather.

Finally, regular ultrasonic rail testing procedures must be capable of detecting the transverse defects below the wheel burns before they reach a critical size, which may cause rail failure.

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