ROLLING CONTACT FATIGUE IN RAILS; A GUIDE TO CURRENT UNDERSTANDING AND PRACTICE

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For use by all railway civil engineering staff

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Note

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FOREWORD

As we have seen in the tragic derailment at Hatfield, railbreaks in rail with rolling contact fatigue cracks are particularly hazardous. Whatever the cause of the initial break, which may not be due to fatigue cracking, unless identified immediately, it is almost certain that subsequent additional breaks will occur and derailment will inevitably take place. Rolling contact fatigue is therefore an insidious affliction which must be minimised, identified and managed.

Rolling contact fatigue can be minimised by managing the wheel/rail interface, including vehicle suspension, wheel profiles, wheel defects (flats and out of round), friction coefficient, gauge, geometry, rail metallurgy and rail profile.

This document has been prepared in association with Corus Rail, Schweerbau (UK) Ltd. and Serco Railtest Ltd. and outlines current knowledge of the causes of rolling contact fatigue and how it should be managed. Research is ongoing to further our knowledge of the causes which will be used to improve management of the wheel/rail interface.

Further instructions and guidance will be issued as knowledge develops.

David Ventry *BEng (Hons) CEng FICE FPWI*

Professional Head of Track

1. INTRODUCTION

The rolling contact fatigue of rails, whether manifested as head checking, tongue lipping or squats, is a major problem worldwide. Despite considerable research, the problem is still not fully understood and to complicate matters there is often a mismatch between laboratory test results and service performance. However things can be done to manage the problem and minimise the risk of rail breakage.

This document summarises the present understanding of the problem, and sets out a rationale behind effective practices for the management of rolling contact fatigue damage on Railtrack's network. The practices are detailed in current Railtrack Line Standards and Permanent Way Special Instructions.

HEAD CHECKING

2. HEAD CHECKING

2.1 VISUAL APPEARANCE

Head checking[1] can occur on all types of track but is predominantly found on highly canted curves and vertical S&C. (This is one reason why Railtrack, in its RT60 series of turn-outs, has reverted to the use of inclined rails). When a high level of cant deficiency (above 100mm) is combined with a curve radius of 1500m or above, head checking usually occurs near the rail crown. As the curve radius reduces the position of head checking tends to move towards the gauge corner, hence the use of the alternative term, 'gauge corner cracking'. It may be found on rails less than a year old right through the age spectrum to rails that have been in track for 30 years and which have previously shown no signs of head checking.

Isolated head checking does occur but it is much more usual for a substantial length of track to be affected e.g. the highly canted part of a curve. The checking is typically seen as a very fine array of small, closely spaced, nearly parallel cracks, perhaps only 2 - 3mm apart but the longer cracks are more widely spaced (10 - 20mm).

Head checking is typically found near the centre of the running band. They can be seen at a variety of angles (35° to 60°) to the longitudinal axis of the rail and develop into a variety of shapes; some are nearly straight, some have an elongated S-shape with a slight 'hook' at the end; others become V-shaped or C-shaped.

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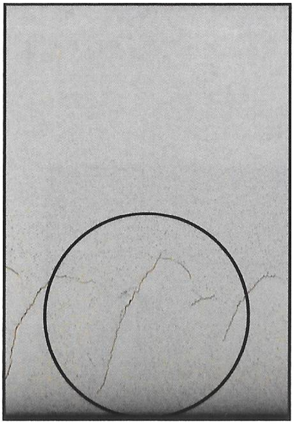
[1] Failure types 124 or 224 in the Railtrack rail failure Handbook (RT/CE/S/057)

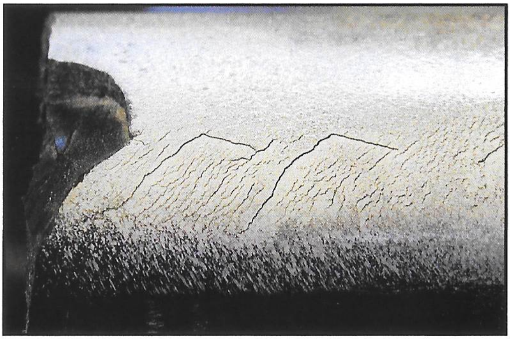
HEAD CHECKING

Direction of traffic



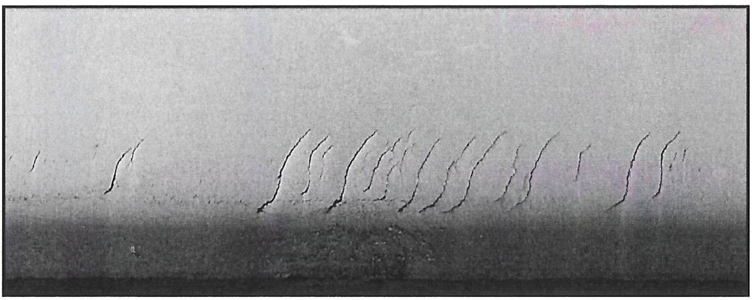
C - Type Head Checks

Direction of traffic



V - Type Head Checks

Direction of traffic



S - Type Head Checks

HEAD CHECKING

It is actually very difficult to see (or feel) head checking in the earliest stages of development because the cracks are small and fine. At a later stage, like squats, they are often spotted because of shadows emerging from slight surface depressions.

Head Check Cracks with "Shadows"

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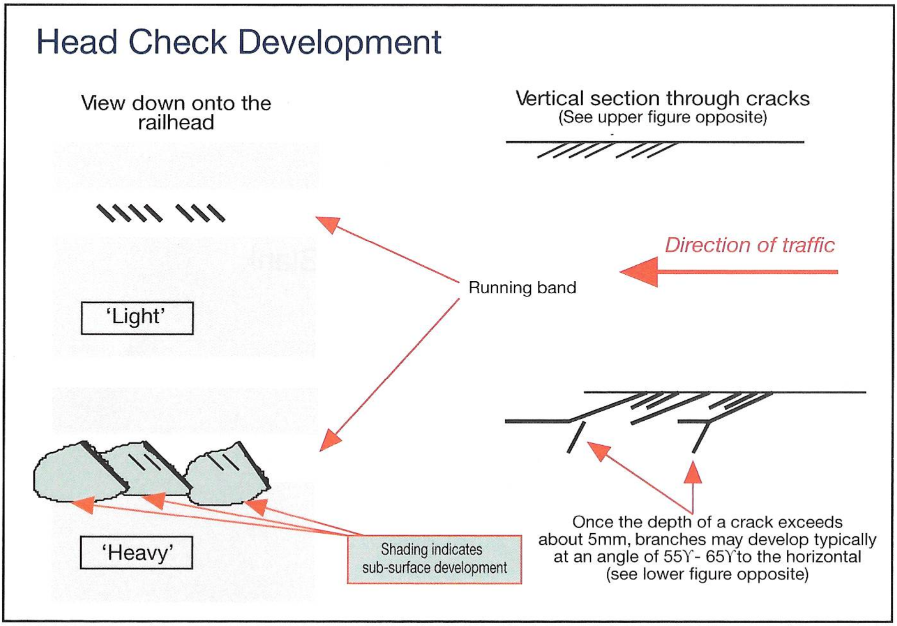
HEAD CHECKING

2.2 INTERNAL DEVELOPMENT

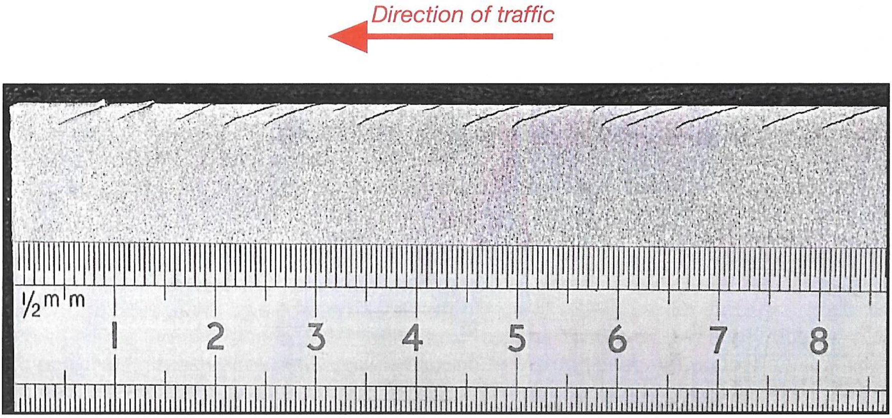
Just as head checks come in a variety of shapes on the surface of the rail, so they develop in a variety of patterns sub-surface. A longitudinal section through a head checked rail and an example of the internal development are shown below.

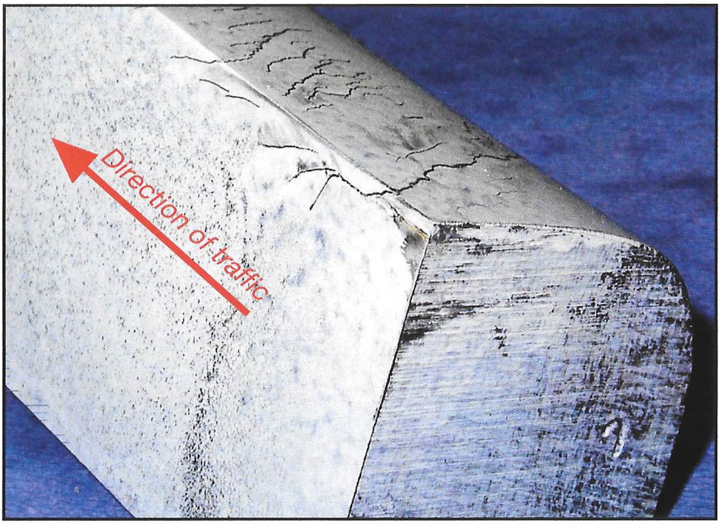


Others develop just like squats (see Section 4).

Head checking rarely occurs in isolation and the growth pattern of any particular head check will be affected by that of its neighbours.

HEAD CHECKING





Longitudinal Section Through Head Check Cracks

HEAD CHECKING

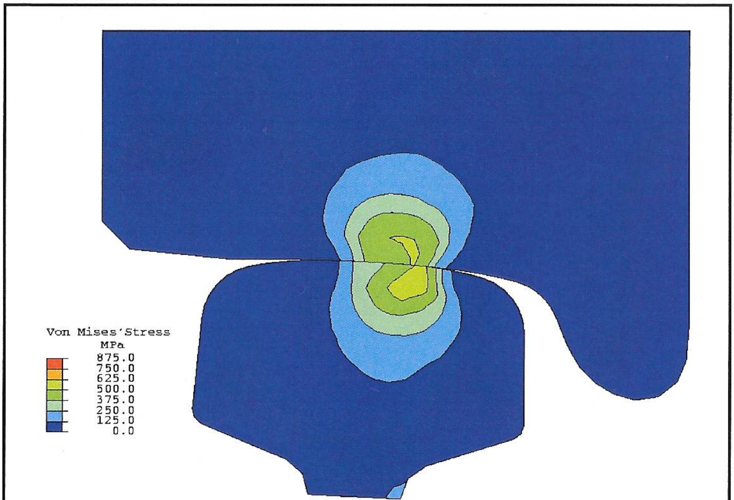
2.3 CAUSES

2.3.1 CONTACT STRESSES

Head checks occur in all types of track and are not necessarily associated with any obvious rail head irregularity. They can however be found clustered near welds. Sometimes the reverse is the case i.e. the zone near a weld is free whereas the adjacent rail is head checked. Also, where a short length of rail has been installed, it may be found to behave quite differently from its neighbours.

Welds, both alumino-thermic and flash butt, are ground locally after welding, this can produce a slightly different profile around the weld from that of the rest of the rail. Similarly a closure rail is unlikely to match perfectly the profile of the section into which it is welded. These observations suggest that quite subtle changes in rail profile have a significant effect on the development of head checking. Calculation bears this out; quite subtle changes in the shape of the rail (or wheel) can have a big effect on the contact stresses between the two and high contact stresses encourage rolling contact fatigue.

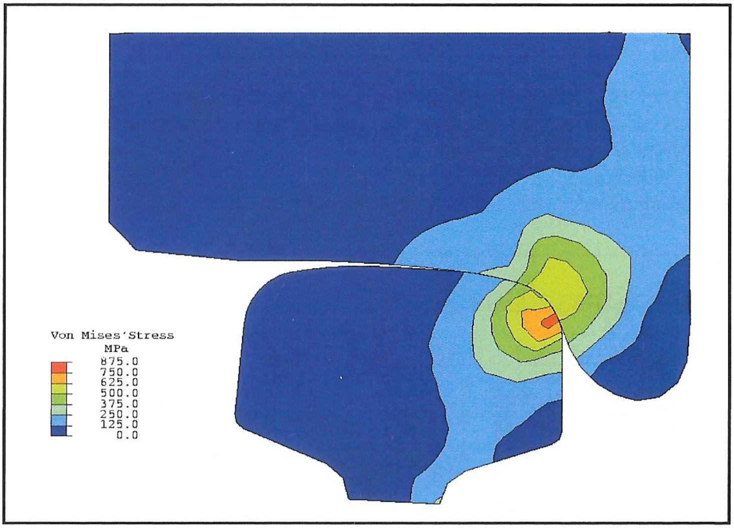
This explains why cracking is prevalent on curves and vertical S&C. The radius of the head of a new rail gets progressively smaller as you go from the rail crown to the gauge corner. If a vehicle is running straight, it tends to run down the centre of the rail where the radius of the rail head is large. Similarly the wheel is usually running on the centre of its tread, hence the contact stresses are generally low.



Contact Stresses on Straight Track

HEAD CHECKING

If a vehicle is curving, contact on the outer rail tends to move towards the gauge corner of the rail and the flange root on the wheel, giving high contact stresses.



Contact Stresses on Tight Curved Track

Similarly if a vehicle is hunting, it will move cyclically from riding on one gauge corner to another. As a generality then, curves are the expected location for head checking but hunting vehicles can also create problems if there are enough of them. Because of the rail inclination, vertical S&C also encourages the wheel to ride towards the gauge corner/wheel flange.

Wear changes the shape of wheels and rails. One consequence of this is that the severity of head checking at any one time may not tie up with current estimates of contact stress. This is because the head checking will reflect the history of a site, not just conditions now.

High contact stresses between the wheel and rail encourage cracking and in combination with high creepages (continuous slight slippage between the wheel surface and the rail) are seen to be major factors in development of head checking. Often, for example on curves, the two go together. Lines carrying a high volume of heavy axle load freight traffic with modern 'creep controlled' locomotives will also experience both.

HEAD CHECKING

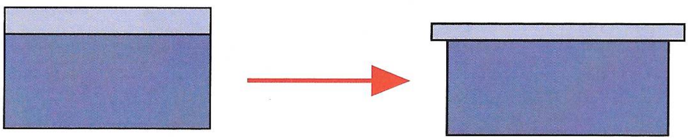
2.3.2 WATER AND LUBRICANTS

Laboratory tests have shown that it is very much easier to initiate rolling contact defects under dry, high friction conditions. However, to make the defects grow requires the presence of a fluid within the cracks, for example water or oil. On track, water can obviously come from rain, snow or dew but it can stay trapped in the cracks even if the rail appears dry. Oil may come from lubricators but oil and diesel may also be dropped by power units.

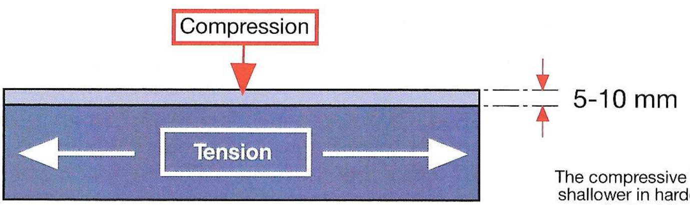
In track, the running surface of a rail gets rolled out by the passage of wheels which result in the creation of a zone of residual compressive stress at, and just below the surface. Normally cracks will not grow through a compressive stress field, witness the way that when a conventional tache ovale breaks, (Appendix 2, page 44) the near surface 'crust' of the rail remains intact until the very last moment.

Residual Stress Development

Traffic tries to 'roll out' the top surface of the rail head



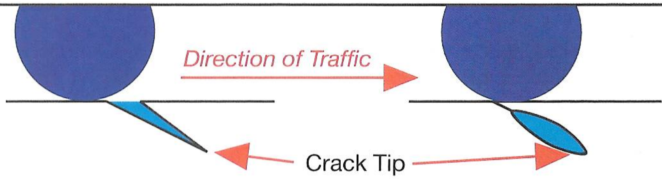
Because the top surface is attached to the metal beneath, it can't expand freely (as shown on right); the effect of rolling out is therefore to put the top layer of the rail in compression; the layer below this is also put into tension to balance this.



The compressive layer tends to be shallower in harder steels, but the magnitude of the stresses higher.

Once however, cracks have initiated due to high contact and creep stresses, the presence of fluid in conjunction with the passage of trains will cause cracks to grow. This results from entrapped fluid within the closed crack introducing a very high localised pressure at the crack tip, greater than the compressive stress.

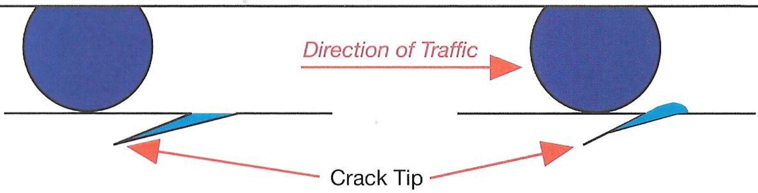
This helps to explain why profile grinding rails, to move the running line away from the visible cracks, can stop cracks growing even though they are not fully removed by grinding. If the contact patch is moved away from the cracks, the 'squashed balloon' mechanism, needed to drive the cracks through the compressive layer, can no longer operate.



Wheel approaching; the crack mouth opens up to draw water in.

As the wheel passes over the crack it closes up the entrance of the crack mouth, trapping water inside so that the crack tip stays open allowing further growth.

The 'squashed balloon' mechanism also helps to explain why head checks normally grow in the direction of traffic flow. If you reverse the traffic flow, the wheel will force water out of the crack rather than trapping it within and hence minimise further growth in this direction.



If cracks try to develop against the flow of traffic, the passage of a wheel will tend to force water out from the tip first, so that no water is trapped and the crack shuts.

HEAD CHECKING

We cannot avoid wet rails but the question arises as to whether the deliberate lubrication of the rails for the control of sidewear, may encourage head checking.

There are two distinct scenarios to consider here.

The first is where the cracking is near the rail crown; lubricant is less likely to reach these cracks so the only effect of reducing lubrication will be increased sidewear and not reduced head checking.

If contact is on the gauge corner and lubricant is present, wear will be reduced. It could be argued that this may be detrimental as wear tends to result in low contact stresses. On the other hand, if lubricant is present from the outset and consistently applied, the initiation of cracking may be substantially delayed as the dry, high friction conditions that facilitate the initiation of cracking will be avoided. To achieve this however, lubrication must be continuously maintained; lubrication failure will result in the benefit being lost.

When rails on curves are ground with an intention of moving the contact band away from existing cracks, the result is also often to cause heavier gauge face contact (the load has to go somewhere) and lubrication is necessary if the result is not to be an increase in sidewear.

It should be noted that head checking can occur on curves flatter (1000 - 1200m) than those traditionally identified as needing lubrication.

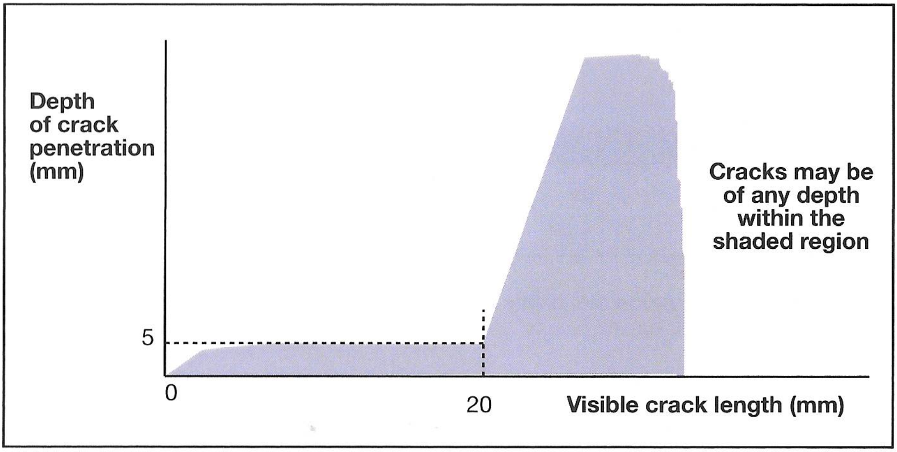
HEAD CHECKING

2.4 CONTROL MEASURES, INSPECTION

Railtrack's management of the breakage risk associated with head checking has three elements to it:

- Inspection
- Rail grinding
- Planned re-railing

Inspection involves both the visual classification of the head checking and ultrasonic examination. The visual categorisation of sites is based on a relationship that has been established between visible crack length and depth of penetration of the cracks down into the rail.



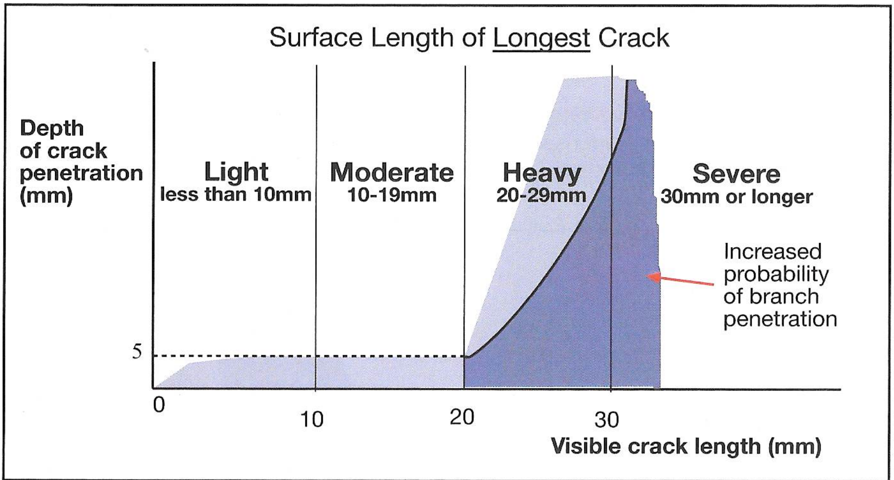
The significant visible crack length is 20mm. If the surface length is 20mm or greater it is possible that a downward branch has developed and with it a significant breakage risk (see diagram on Page 8).

If the visible crack length is less than 20mm, the evidence is that the associated crack depth will be less than 5mm and no significant 'downward branch' will have developed. Thus a visible crack length of less than 20mm is considered to be a low risk situation.

HEAD CHECKING

2.4.1 SITE CATEGORISATION

The Railtrack instruction has four categories for head checking, reflecting the above situation, based on the visible length of the longest crack on the site.



Photographs of light, moderate, heavy and severe head checking are shown over.

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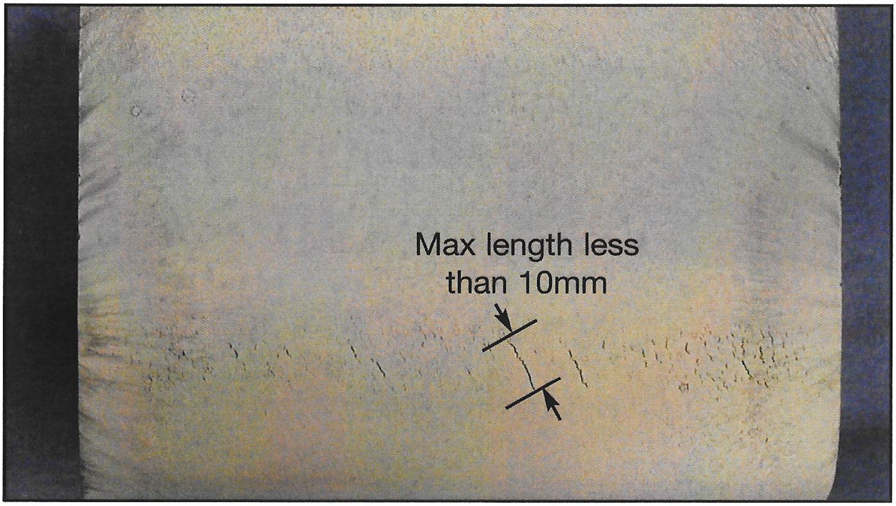
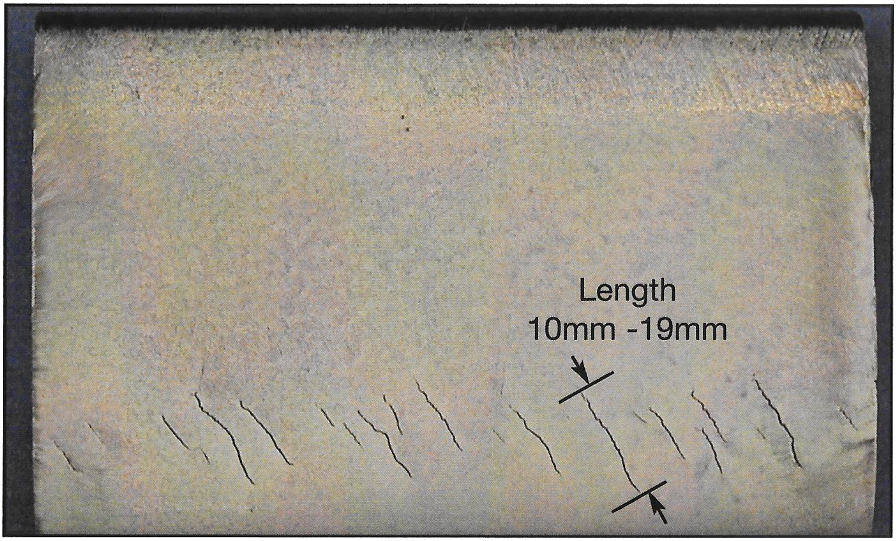
HEAD CHECKING

Direction of traffic

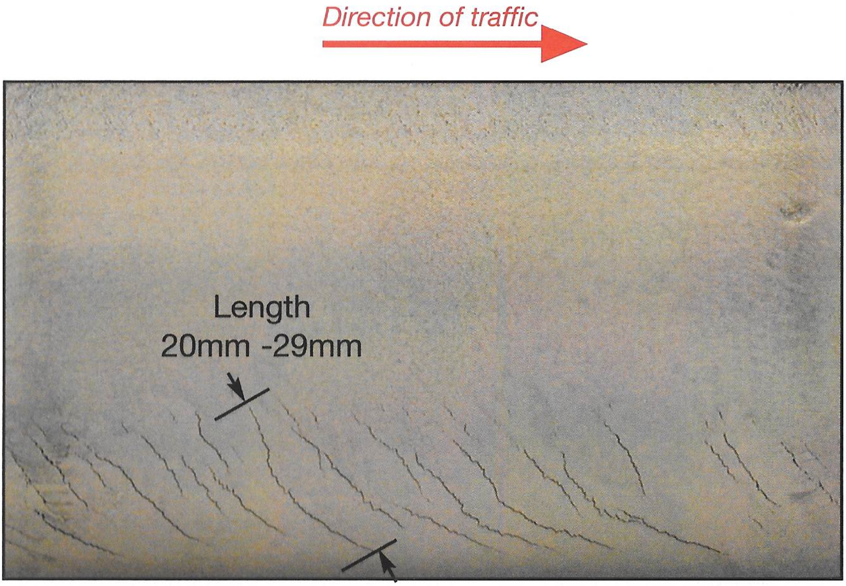


Light Head Checking

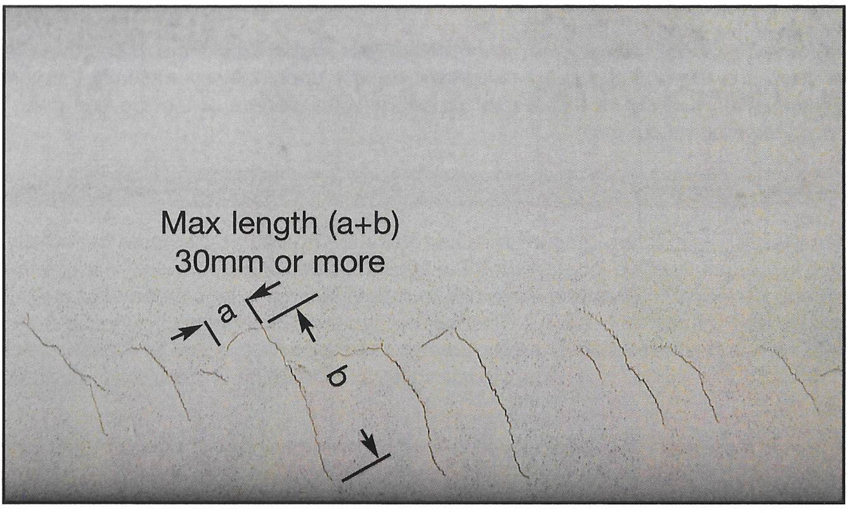


Moderate Head Checking

HEAD CHECKING



Heavy Head Checking

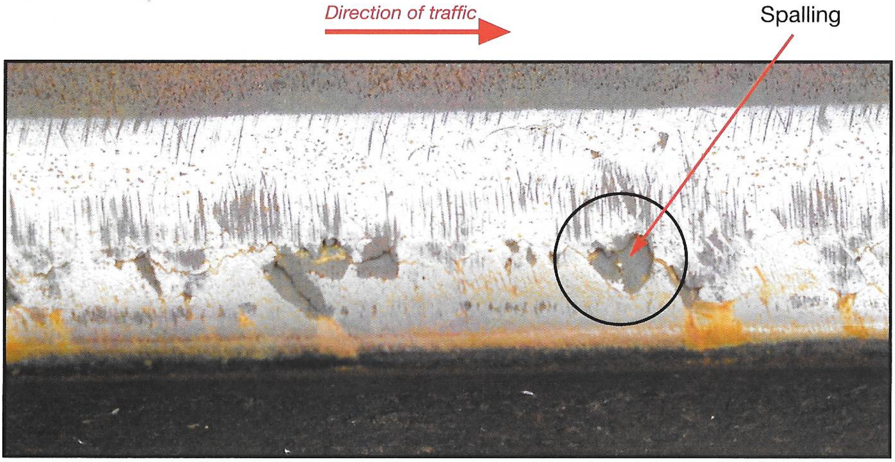


Severe Head Checking

HEAD CHECKING

'Severe' represents the case where cracks could be present that are in excess of 25 - 30mm in depth and there may be an immediate breakage risk.

Sites where the surface has spalled are also categorised as 'Severe'. Spalled rails are untestable using currently approved ultrasonic inspection techniques, hence it must be assumed that the spalling hides severe cracking and action taken accordingly. Likewise rails found to be ultrasonically untestable for any other reason are to be treated as 'Severe'.



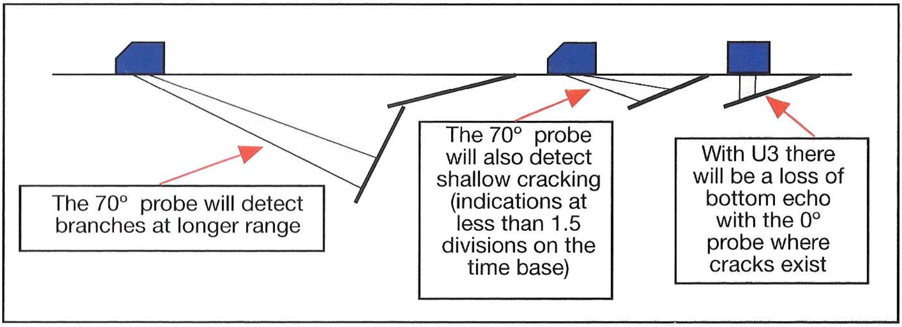
Where the cracking is 'Heavy', fewer of the shallow angled cracks are expected to have branched and the branches on average will be less deep. However, clearly it is a very small step from the top of the 'Heavy' category to the bottom of the 'Severe' one. The actions required reflect this.

2.4.2 ULTRASONIC INSPECTION

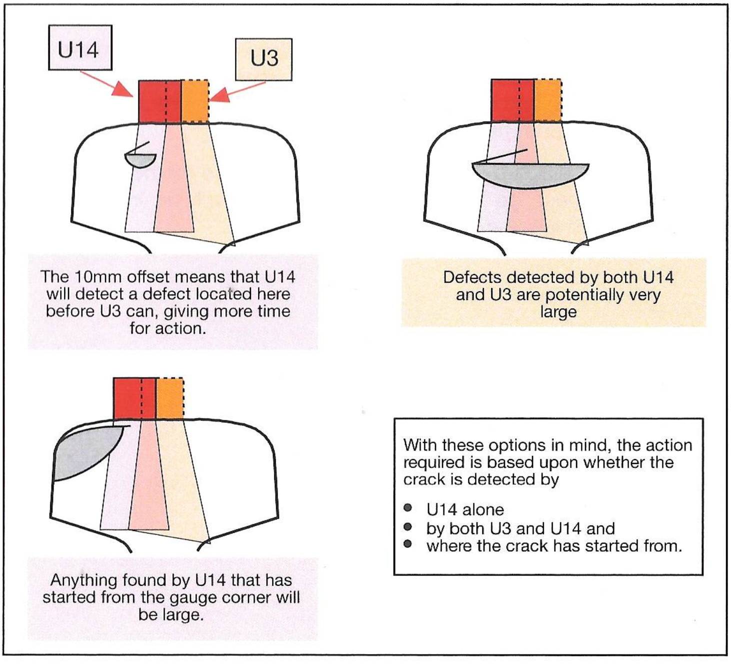
The ultrasonic inspection of head checked track is required at the same periodicity as visual inspection and it is intended that the two take place together. Visual inspection can never be perfect and ultrasonic examination should pick up a large defect that may have been missed visually. It is always much easier to 'see' things when you know they are there! Hence this approach provides greater assurance that a site has been properly categorised. For the same reason, visual inspection should be undertaken in daylight on a dry rail.

Ultrasonic inspection of head checked rails requires the use of both the U14 and the U3 procedures. These both use the 070 Rail Testing System (the 'walking stick'). In the case of U3 the probes are positioned along the centre line of the rail while with U14 the probe pack is offset as far as possible towards the gauge corner.

HEAD CHECKING



Offsetting the probe pack in U14 enables cracking to be picked up at an earlier stage than if U3 were used alone. It also enables the size of the defects to be estimated.

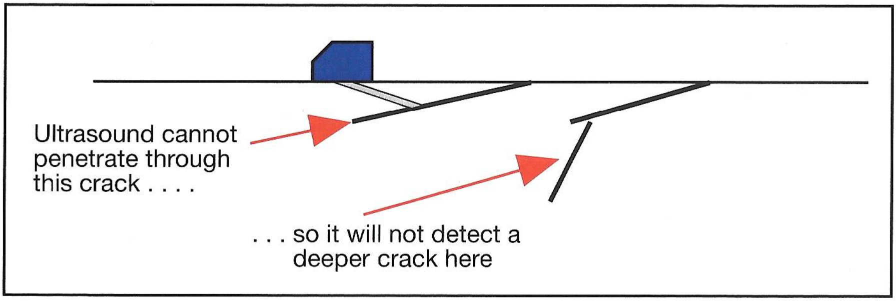


With these options in mind, the action required is based upon whether the crack is detected by

- U14 alone
- by both U3 and U14 and
- where the crack has started from.

HEAD CHECKING

There is a particular risk with head checking that 'shielding' can occur, i.e. that one crack will prevent the ultrasonic beam from 'seeing' another defect.



To deal with this, the actions to be taken following ultrasonic inspection are based partly on what has been found ultrasonically and partly on what might have been missed. This is why action is required in some cases, based only on visible crack length, even though no defect of significant depth has been found ultrasonically.

Railtrack has taken the initiative in developing more effective methods for detecting and sizing head checks. These do not use ultrasound and will be introduced when the equipment has been proven and is commercially available.

2.5 CONTROL MEASURES - GRINDING AND RE-RAILING

In the future, the intention is that rail shall never reach a stage where 'heavy' or 'severe' cracking is present. This will require action in the form of either grinding and/or re-railing.

2.5.1 PREVENTATIVE GRINDING

The 'preventative' grinding of rails seeks to remove cracks before they are even visible. To be effective, it has to be undertaken soon after installation and thereafter repeated periodically. It is also possible to modify the rail head profile to reduce the contact stresses (particularly on curves) to reduce further the chance of cracking.

2.5.2 REMEDIAL GRINDING OF SITES WHERE CRACKING ALREADY EXISTS

'Remedial' grinding is required for sites where the visible length of cracks is no greater than 15mm. The intention here is not to remove the cracks but to move the contact patch away from them, (see Section 2.3). Once cracks are visible it is generally too late to remove them completely and economically by grinding.

Having achieved this, periodic re-grinding remains necessary to maintain this situation and to ensure that cracking does not have the chance to develop in the new contact zones.

There is a benefit in remedial grinding of lightly cracked sites but with only limited grinding resources available the priorities are

- the preventative grinding of re-railed sites (see below)
- 'Light / Moderate' sites up to 15mm visible crack length

2.5.3 RE-RAILING

Remedial grinding is helpful only if the cracks are still growing through the layer of compressive residual stress (see Section 2.3). Once the cracks have grown through this layer, they will continue to grow regardless of whether there is fluid trapped in them or not. As a rule of thumb, sites with 'Heavy' cracking will have reached this stage and should be re-railed, not ground.

Where 'Moderate' cracking exists it is preferable to undertake remedial grinding rather than re-railing but there is no point in planning to grind rails if there is a risk that, by the time a grinding train can be brought to site, the cracking will have developed to the stage where it would be categorised as 'Heavy'.

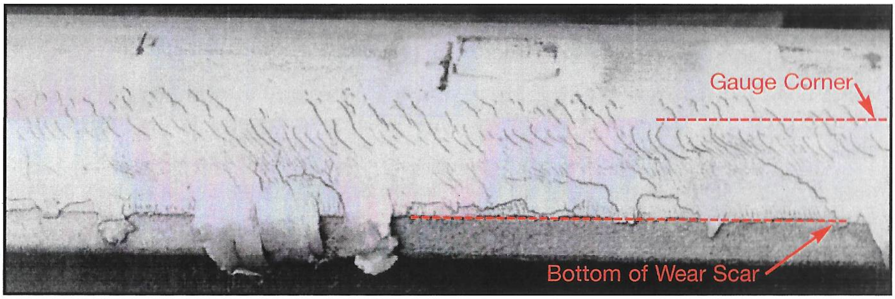
It is sensible therefore to plan re-railing if there is 'Moderate' cracking and the visible crack length exceeds 15mm.

TONGUE LIPPING

3. TONGUE LIPPING

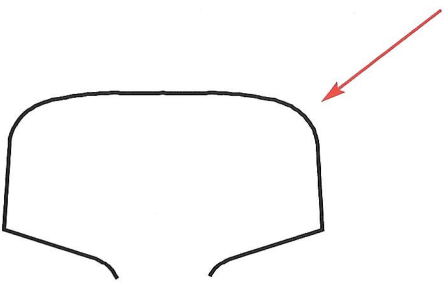
3.1 VISUAL APPEARANCE

In 1999 a stock rail in a diamond crossing at Hemel Hempstead broke in six places as a train passed over it, fortunately without derailment. Magnetic Particle Inspection (MPI) would have revealed some head checking but visually it was almost impossible to see. Normal ultrasonic investigation using U14 (see RT/CE/S/055) would not have given a signal such as to warrant action under Railtrack's then rules. There was a history of bad ride at the site but otherwise there were only two exceptional features. One was a considerable, short range, periodic variation in the level of side wear; the second was the existence of extruded tongues of metal extending down the gauge face of the rail.



Extensive Tongue Lipping

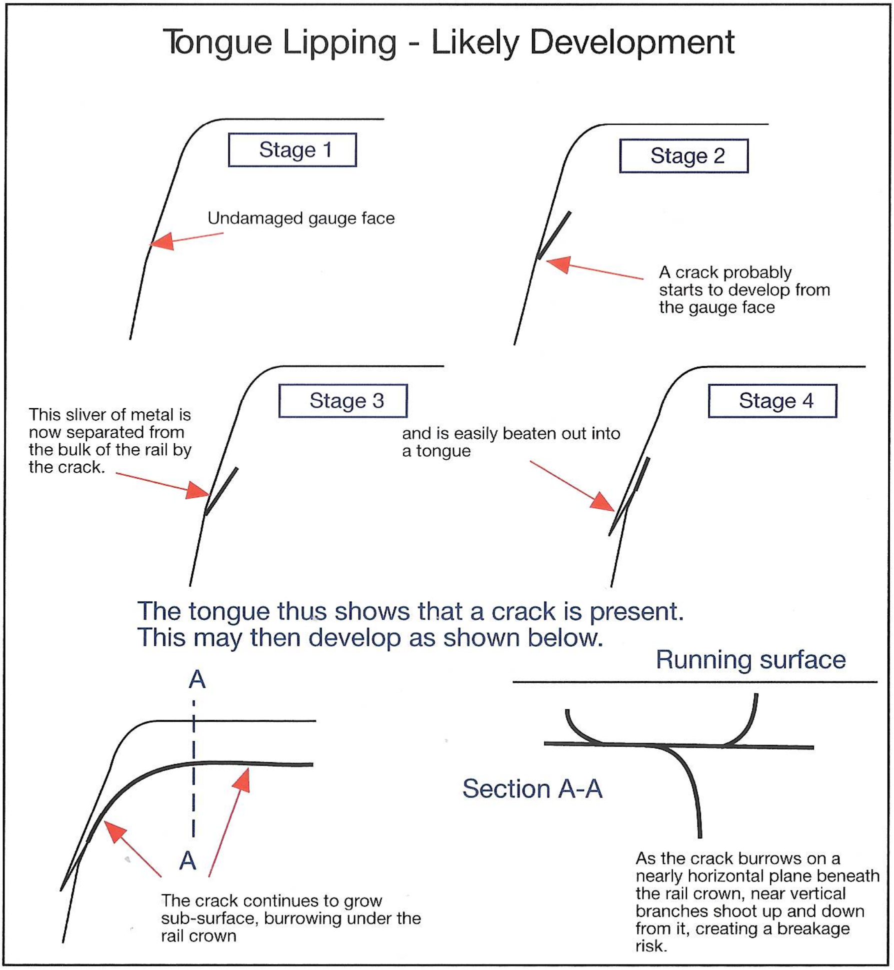
Photograph shows view here



TONGUE LIPPING

3.2 INTERNAL DEVELOPMENT

Tongue lipping develops because cracks are already present.



TONGUE LIPPING

3.3 CAUSES

Whilst the cause of the tongue lipping itself is clear, the reason for the development of the underlying cracks is not. Taking account of the very unusual side wear pattern on the Hemel Hempstead rail it is plausible that it is associated with abnormal side loading conditions but at the moment nothing concrete can be said.

3.4 CONTROL MEASURES - INSPECTION

The presence of tongue lipping shows that the rail is cracked. Because of the shape, size and angle of the cracks causing tongue lipping, they cannot be detected reliably ultrasonically. Hence a worst case scenario must be assumed i.e. that the rail is severely cracked, and action taken accordingly.

3.5 CONTROL MEASURES - GRINDING

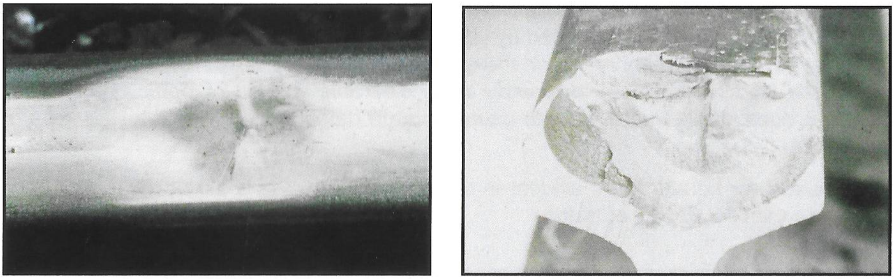
Where conventional lipping occurs in S&C, Railtrack requires that it is ground off by approved manual methods and the dressed rail inspected using MPI to ensure that no cracks remain.

4. SQUATS

4.1 VISUAL APPEARANCE

The first type of rolling contact fatigue defect recognised in the UK was the so-called 'squat'. Squats can occur anywhere but according to historic research 75% are associated with one of the following features

- Corrugations
- Welds
- Small periodic holes in the rail running surface (periodic squats)



Surface & Fracture Face Appearance of Squat Type Defects

Historically most squats are removed prior to failure, only a very low percentage propagate to branching and result in breakage.

Distinctive features are the dark shadowy area within the running band and an associated widening of the running band. The shadow results from the crack growing on a nearly horizontal plane just below the running surface. This means that the running surface over the crack is detached from the rest of the rail and as a result can flow sideways under wheel loading more easily - hence the widening of the running band. As the metal flows out sideways however, a slight dip develops over the crack allowing corrosion products and dirt to accumulate, resulting in the 'shadow'.

Squats[1] were first identified as a distinct type of failure in the 1970's; it is probable that any that occurred before then were categorised as taches ovales[2] or wheelburns[3]. Confusion still occurs but with a true tache ovale there is no 'shadow' on the running surface, with a squat there is.

[1] Failure types 127, 227 and 427 in the Railtrack Rail Failure Handbook (RT/CE/S/057)

[2] Failure types 111 and 211

[3] Failure types 129 and 229

SQUATS

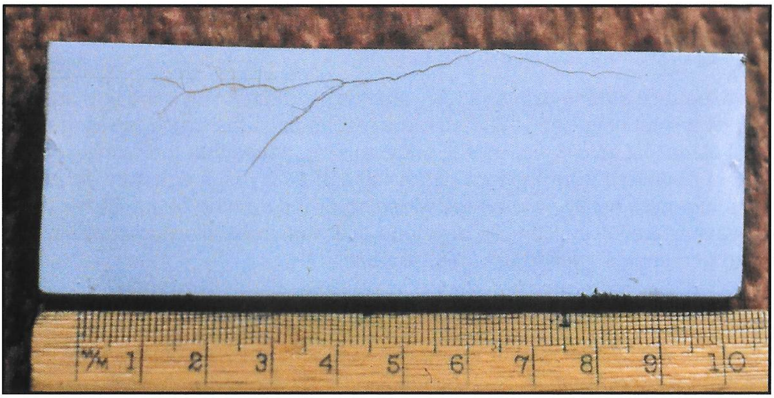
A regular comparison between squats and wheelburns is that wheelburns most commonly occur in pairs, one on each rail, squats do not. Both squats and wheelburns can however lead to spalling of the surface.

Typically, visible cracking starts near the edge of, and at an angle to the running band on the gauge face side. As it develops the visible crack may become U, V, Y or horseshoe shaped; in some instances it may also break out to the surface on the far side of the running band; as stated above, spalling of the surface may also occur. Where corrugations are involved, squats tend to be found in corrugation troughs.

Periodic squats can be seen at about a 3 m spacing for considerable lengths of track and develop from what initially are relatively deep indentations in the running band. The likelihood is that these are produced by something very hard picked up on a wheel tread, its image is then being imprinted on the rail head once every wheel revolution. This can eventually lead to cracking; fortunately a considerable volume of traffic has to pass before it does. Ballast scars do not cause enough damage to give rise to this type of cracking.

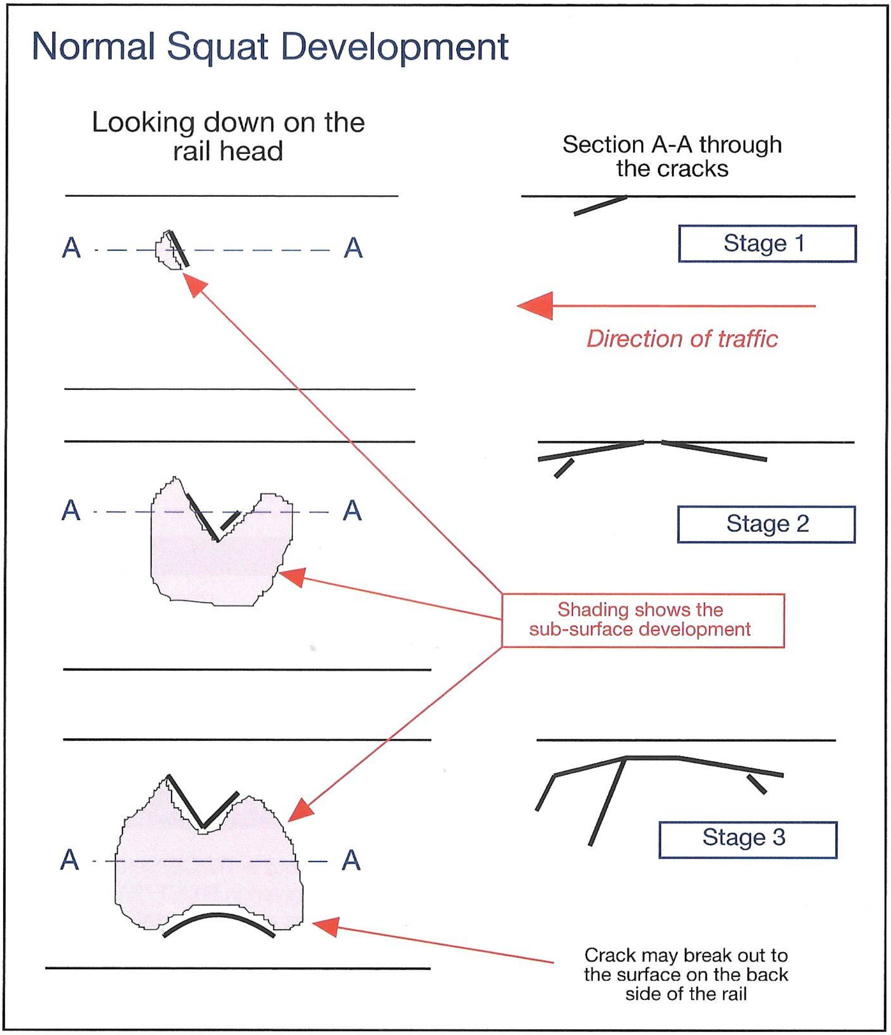
It is unusual for squats to be evident in rails less than 10 years old or those that have seen less than 150EMGT of traffic.

4.2 INTERNAL DEVELOPMENT



Section Through a Squat Defect with Tache Ovale Type Branch

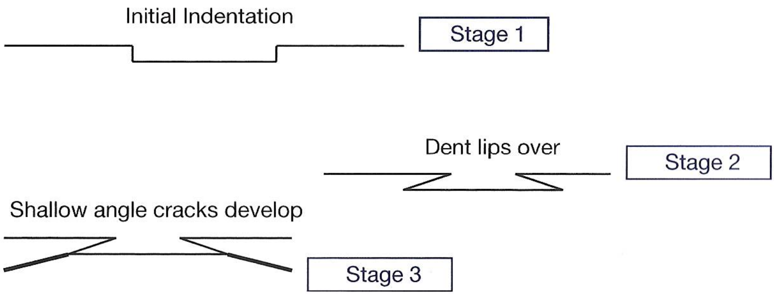
The figures below show the pattern of development of 'normal' squats and 'periodic squats'.



SQUATS

In the case of the periodic squat, the initial 'horizontal' crack develops by quite a different mechanism: -

Periodic Squat Development



All diagrams show longitudinal - vertical sections through the rail head; after Allery and Clayton 1979.

4.3 CAUSES

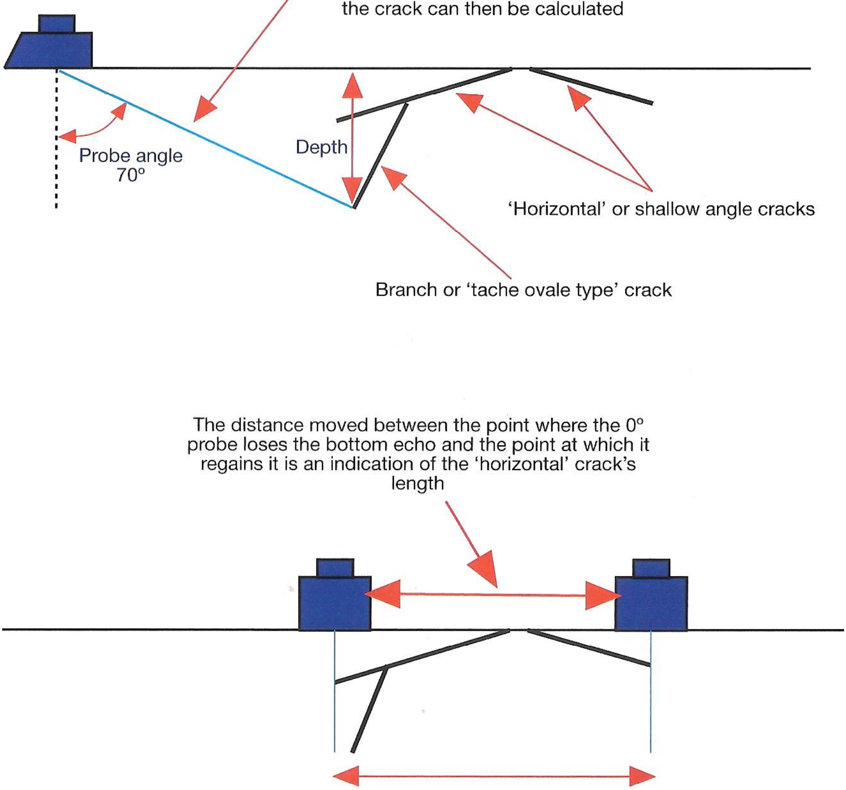
'Normal' squats develop from generally the same causes as head checks. The difference is that squats usually develop at a point where high contact stresses occur as a result of a local irregularity in the rail head e.g. at a worn weld. In the case of periodic squats, the mechanics of early growth are quite different (see Section 4.2) but once a 'horizontal defect' has been established, subsequent growth follows the same pattern.

4.4 CONTROL MEASURES - INSPECTION

Railtrack's requirements for the inspection of track are set out in RT/CE/S/103. For plain line, away from bolted joints, the U3 ultrasonic procedure given in RT/CE/S/055 is used, involving the use of 0° and 70° probes. If, at the location of a squat, a defect indication is obtained with either probe or there is a loss of bottom echo with the 0° probe, the U5 procedure is employed.

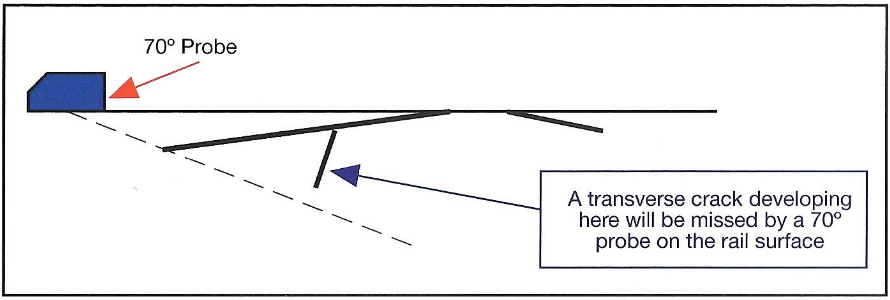
SQUATS

U.5



Minimum actions are also given in RT/CE/S/103 and are based on either the length or depth of the squat. The reason that the length of the squat is significant as well as its depth is that a long horizontal defect can mask the existence of a transverse fatigue crack.

SQUATS



By limiting the length of the horizontal defect (50mm), the length of an undetectable transverse crack is also limited.

4.5 CONTROL MEASURES - GRINDING

There are many similarities between head checking (see Section 2) and squats. In particular, both are fatigue cracks which are initiated at or very close to the rail surface under the influence of contact stresses. The evidence is also strong that small cracks grow by the same "squashed balloon" mechanism (see Section 2.3.2) to become bigger cracks, which develop at a shallow angle to the rail surface until the crack works its way through the shallow region of residual compressive stress close to the surface.

It should therefore come as no surprise that the development of squats can also be controlled by regular, light grinding to remove incipient cracks. Grinding is in fact used for this purpose in Japan, where squats have, for some time, been a more severe and widespread problem than in the UK. Provided that squats remain at their present levels in the UK, there is little justification for a widespread grinding campaign to treat the problem.

4.6 CONTROL MEASURES - WELD REPAIR AND RERAILING

Historic practice has been to repair rails containing small squats by excavating the zone affected and rebuilding the rail running surface by arc welding. It is however very difficult to do this type of welding under site conditions and a number of recent failure investigations have highlighted weld repairs of this type as the cause of breakage. It is preferable therefore to cut out the affected section completely and replace it with a wide gap weld if its size permits (length less than 60mm) or to replace the rail.

FALSE FLANGE DAMAGE

5. FALSE FLANGE DAMAGE

5.1 VISUAL APPEARANCE

A false flange is a term referring to a train tyre where the middle has worn to a concave 'hollow' shape (see Section 5.3), forming a flange effect to the outside of the wheel.

False flange damage appears as a crushed zone on the rail head on the stock rails of S&C and also on the wing and nose of crossings. On a stock rail the zone starts at the outside of the rail and gradually migrates across to the four foot side. Where the problem has been present for a long time, virtually the whole of the rail head may be worn concave at the centre of the affected region. Cracking may develop both longitudinally and transverse to the rail head.

False Flange Damage

Under certain circumstances false flange damage is possible in plain line, in which case it will be evident as crushing or cracking on the field corner of the rail head, rather than the gauge corner.

FALSE FLANGE DAMAGE

5.2 INTERNAL DEVELOPMENT

Historically, this form of damage has not been seen widely on Railtracks infrastructure and at present there is relatively little information on crack propagation inside the rail. In stock rail examples examined so far, the cracking has been found to be relatively shallow in relation to its surface length, cracks with a surface length of 30mm or more only penetrating 2 to 3mm into the rail. The cracks also grew at a very shallow angle (10°) to the horizontal. The considered opinion is that the larger cracks are made up from a number of smaller cracks which join together over time.

FALSE FLANGE DAMAGE

5.3 CAUSES

Wheels do not wear evenly; most of the time they run on the centre of the tread so that this area wears most quickly. This tends to make the tread 'hollow' and will eventually produce a 'false flange'.

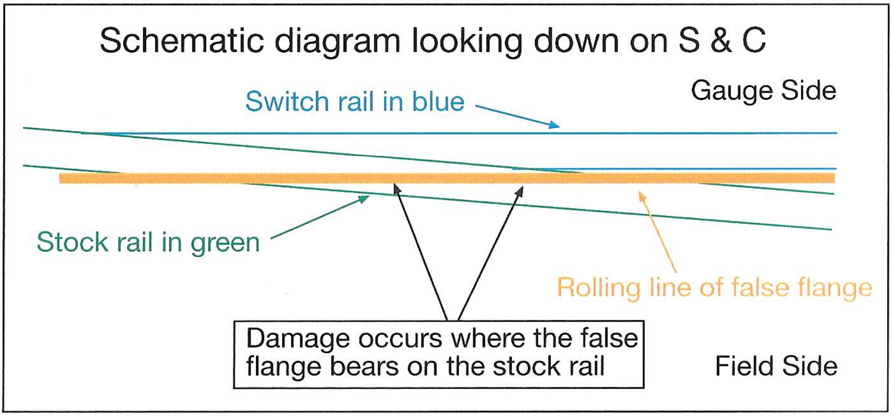
Diagram showing the development of hollow treads and false flanges; exaggerated for clarity.

Excessive hollow tread wear will encourage vehicle hunting and if enough vehicles are affected, this of itself can encourage head checking (see Section 2.3.1).

On plain line the false flange normally runs outside the rail but in S&C, where the wheel crosses over the stock rail (or crossing nose) the false flange may contact the rail head. This results in most of the wheel load being concentrated in a small area, and hence high contact stresses which result in crushing and potentially, rolling contact fatigue.

The outside of a wheel i.e. the area where a false flange can develop, always rides on the wing rail of a crossing just before (or after) the load is transferred to (or from) the nose. If a false flange exists however, the contact area will be much reduced, resulting in the potential for damage in just the same way as on the crossing nose and on stock rails.

FALSE FLANGE DAMAGE



5.4 CONTROL MEASURES - WHEEL TURNING

This form of damage is wholly attributable to the condition of the wheels, hence the problem should be brought to the attention of the Train Operators at the earliest opportunity. Until the condition of the wheels is improved, any remedial action taken will be of limited value as the damage will simply recur.

5.5 CONTROL MEASURES - INSPECTION

Normal visual inspection procedures for S&C apply.

For ultrasonic examination, Procedure U5 is considered to be the most efficient for detection and identification of associated defect types.

5.6 CONTROL MEASURES - WELD REPAIR

Crossings should be weld-repaired, using procedures recommended by the crossing manufacturer and approved by Railtrack.

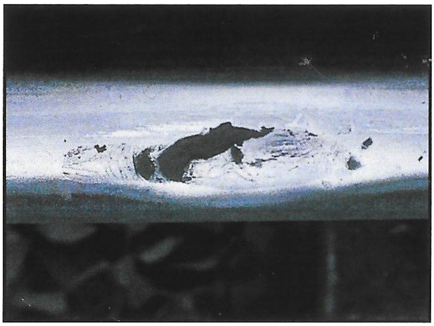
6. WHEELBURNS

6.1 WHEELBURN EFFECTS

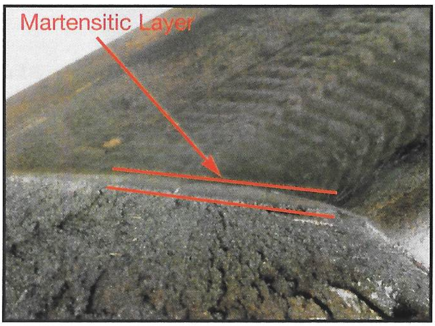
Wheel burns are the result of frictional heating produced by a spinning wheelset. If the wheelset remains stationary, a generated set of isolated wheelburns occur. If the vehicle manages to make some progress whilst spinning the damage is spread over a longer length of rail and a 'continuous' wheel burn is produced.

The effect of very rapid heating produced by the spinning wheel and subsequent rapid cooling is to change the structure of the rail head top layer into 'martensite'. The martensite can be seen as a shallow, smooth layer close to the rail surface in the right hand photograph below, where a rail with a continuous wheelburn has been deliberately broken open. The presence of the martensite layer makes the rail untestable ultrasonically. Hence a site on which head checking and continuous wheelburns coexist must be categorised as 'Severe'.

The martensite is also very brittle with the result that it tends to spall off very easily (see the photograph of an isolated wheelburn on the left). This also results in the rail being locally untestable and again the site should be categorised as 'Severe'. Additionally, the railhead surface irregularity will significantly increase dynamic impact forces and the likelihood of rail breakage will be raised.



Wheelburn



Wheelburn -Martensite Layer

APPENDIX 1

ROLLING CONTACT FATIGUE AND WEAR; THE INFLUENCE OF RAIL METALLURGY.

The demands placed on the rail and consequently the attributes required in the rail are governed by the wide variety of operating conditions existing on the different railways throughout the world. The move towards greater axle loads and increased tonnage traffic has brought about the use of higher hardness and more wear resistant rails in the pursuit of a more cost effective rail transportation system. The figure below shows a range of rail steels that have been developed over the years to meet these demands.

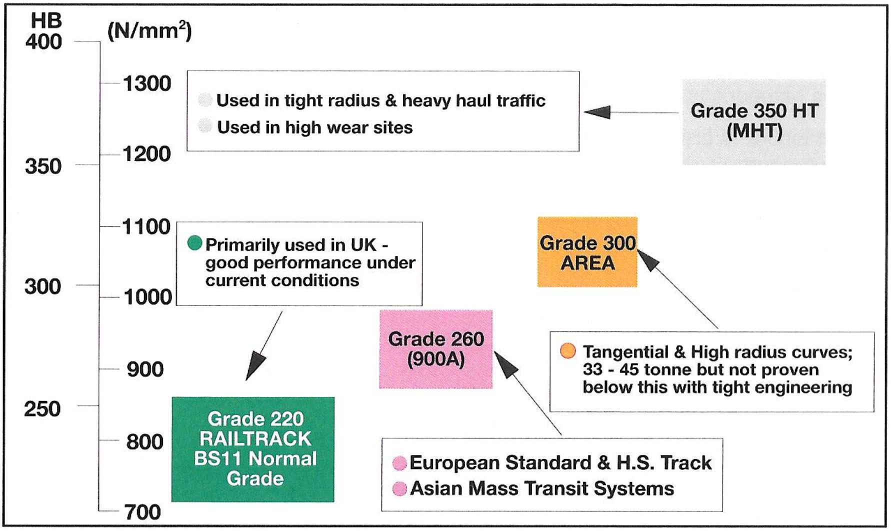


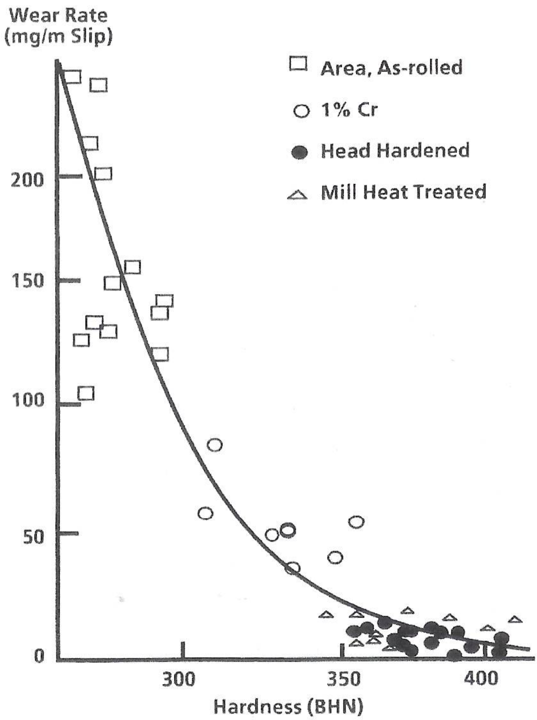
Figure A.1 Rail Steel Grades - Properties & Applications

Although seldom used, a softer grade 200 is also available and a further variety of steels within a hardness range of 300 to 330 HB[1] have been developed. Clearly, the focus of rail steel developments has been to achieve increasing wear resistance through the use of harder steels. This dependence of wear on the hardness of the steel, established under laboratory conditions is shown below. Clearly, for hardnesses >350 HB, the rate of wear has been significantly reduced even under the very high axle load of 44 tonnes.

[1] Hardness Brinell

APPENDIX 1

The predictions of the laboratory wear test have been validated by regular monitoring of the profiles of rails situated in chosen test sites. The measurements were undertaken for Grade 220 and 1% Cr steel grade rails.



VARIOUS RAIL STEELS TESTED UNDER
A SIMULATED AXLE LOAD OF 44 TONNES

The rail grades currently used within the Railtrack network are:

* Grade 220 (BS11 Normal)
* Grade 260 (Grade 900A)
* Grade 320 Cr (1% Cr) and
* Grade 350 HT (MHT)

APPENDIX 1

Primarily, 'Grade 220' is the most widely used grade of rail steel in both tangential and curved track and is believed to have provided relatively long rail life.

Although Grade 260 is the most widely used grade throughout Europe and elsewhere in the world, its use within the Railtrack network has been restricted with limited installations in S&C and curved track.

The 1% Cr steel grade has been employed in the past but it has not been used for a number of years.

The adoption of the heat treated grade 350HT (MHT) was slow in the late eighties, but increasing use has been made of the grade in recent years. British Rail's guideline, was to deploy the heat treated grade in locations where the life of a BS11 normal grade rail was expected to be less than 10 years due to sidewear. Again the emphasis was to increase rail life through the use of more wear resistant heat treated grade.

Recent experience within all major railways is that the life of the rail is increasingly governed by its ability to resist rolling contact fatigue (RCF). Problems have been encountered with all the grades cited above. However, there is a need for further research to understand the interactions between the various components of the track system and the influence of operating conditions on the complex rail wheel interface to facilitate the optimum selection of rail steel grades and the associated maintenance practices.

As in the case of laboratory wear studies, the resistance to rolling contact fatigue is assessed in the laboratory using a twin disc system which is capable of simulating various axle loads and slippages. In the RCF test, water is applied as a lubricant without which it has been difficult to develop RCF cracks. The test is designed to study the initiation of RCF cracks and although no correlation between laboratory and in-service behaviour has been established, the tests can be used to provide a relative ranking of the various rail steel grades to the resistance to initiation of RCF. The RCF resistance established in this manner is shown over.

APPENDIX 1

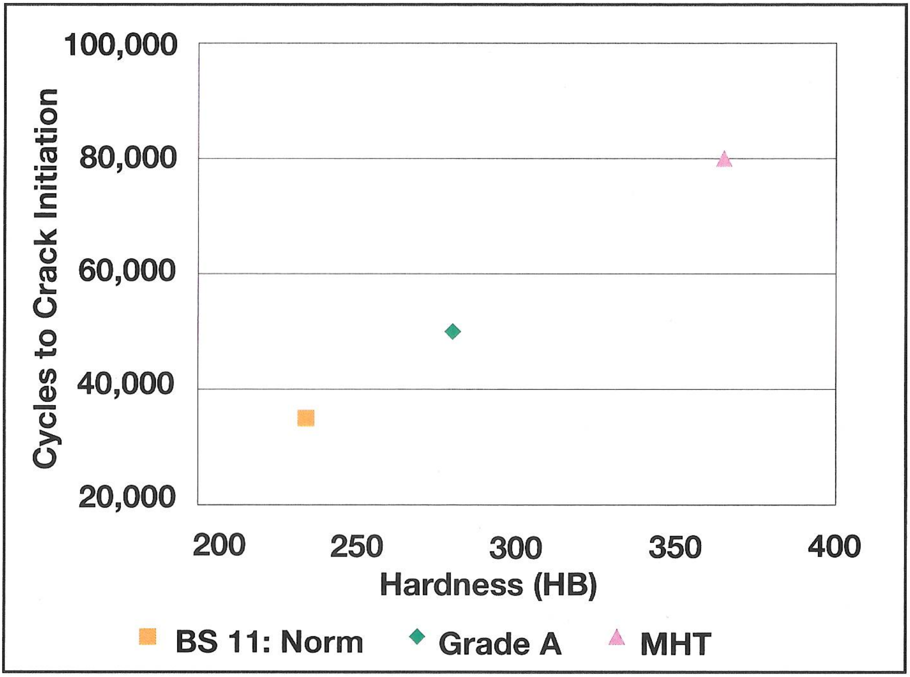


Figure A.3 RCF Resistance of Rail Steel Grades

Clearly, laboratory evidence suggests that the resistance to the initiation of rolling contact fatigue cracks or head checking increases with increasing hardness i.e. Grade 350 HT (MHT) is more resistant than Grade 260 (900A) which in turn is more resistant than Grade 220- (BS 11 Normal). However, the higher hardness also increases wear resistance and hence delays the removal of the fatigued or near fatigued layer, and also reduces the ability of the rail to wear into a profile which is more conformal with that of the wheels which pass over it. The net effect is that RCF cracks may appear earlier in the harder grades of steel if the transverse profiles of wheel and rail are such as to lead to high contact stresses. Consequently an appropriate preventative and profile grinding regime (enforced wear and contact stress management) must be instituted to fully exploit both the higher RCF resistance and the greater depth of hardening of heat treated rails and thereby enhance rail life.

APPENDIX 1

However, the precise interaction between wear and RCF is still not fully understood and the laboratory testing techniques for wear and RCF resistance are not suitable for simulating the balance of the competing processes of wear and fatigue occurring in service. Consequently in-service assessment of the initiation and development of RCF cracks is essential to establish a correlation, if any, between the in-service and laboratory results.

The above laboratory data on wear and fatigue resistance and the general in service experience of a range of steel grades suggests that greater attention needs to be given to the other parts of the track system to increase rail life. It is recognised that profile grinding can be employed to minimise stresses at the rail wheel interface (see Section 2.5). For this reason, grinding has in fact been used routinely for some years, particularly with hard rail, on so-called "heavy haul" freight lines. This has helped to reduce stresses, remove incipient fatigue cracks, and thereby substantially reduce the occurrence of defects and rail breaks from rolling contact fatigue. By these means, the full benefits of the reduced wear rate of hard (and particularly head hardened) rail have been realised without incurring the penalty of increased defects from rolling contact fatigue.

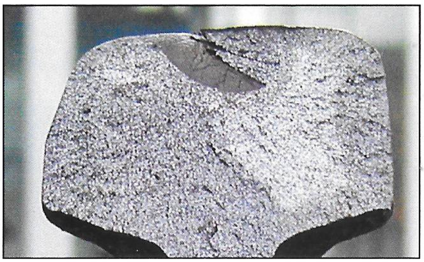
Other factors such as variability in support stiffness may also influence the development of fatigue cracks but further work is required to understand the interactions between the matrix of key factors that influence rail life e.g. rail steel grades, duty conditions, rail section and running surface profile, ground profile and grinding frequency, and support conditions.

One of the most significant improvements in rail steel metallurgy has been the move from ingot cast to continuously cast, vacuum de-gassed steels, which are cleaner and have very low and carefully controlled levels of hydrogen. This has eliminated one major historic cause of rail failure, taches ovales. True taches ovales are fatigue cracks which develop from small hydrogen cracks in the centre of the rail head. They should not be confused with the 'tache ovale like' defects that sometimes develop from squats and head checks. Failure to make this distinction has undoubtedly led to confusion about the scale of the problem of head checking on some networks.

APPENDIX 2

FURTHER EXAMPLES OF BROKEN AND DEFECTIVE RAILS

Broken Rail From a Head Check Defect (Originating from Gauge Corner)

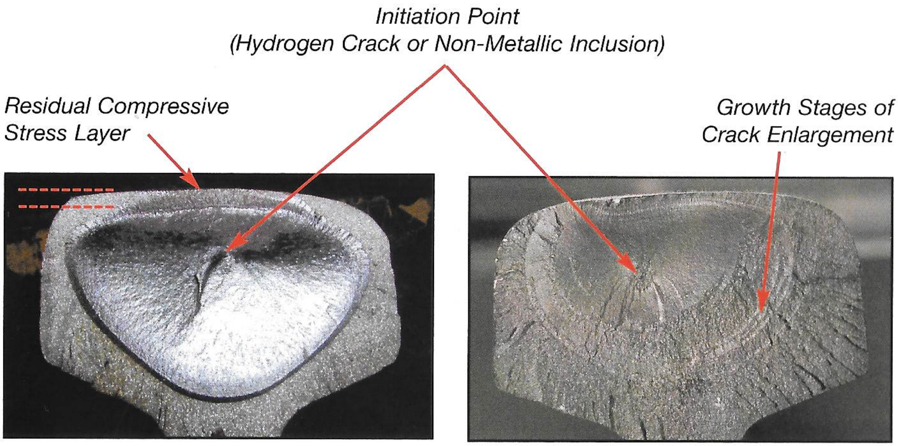


This Shows the Development of a Crack From a Squat.
(This rail was removed as defective and broken open in a laboratory).

This Shows the Two Stage Development of a Crack from a Head Check.
(This rail was removed as defective and broken open in a laboratory).

APPENDIX 2

FURTHER EXAMPLES OF BROKEN AND DEFECTIVE RAILS



True Tache Ovale Rail Fractures

Multiple Squats