Following the fatal broken rail at Hatfield (UK) in late 1999, where a train derailed and killed 4 passengers, the management of small cracks, known as Rolling Contact Fatigue (RCF), has become one of the highest priority task for track engineers responsible of the day to day safety of operational railway systems.

RCF can form in any rail, in any hardness of rail, under any operating conditions (ie metro, tram, high-speed and heavy haul), unless specific monitoring and remedial actions are applied.

The track designer holds significant responsibility to consider the wheel-rail interface in the design of any system. This becomes a combination of the rail hardness, the track geometric forces being applied for the given line-speed and the type of rolling stock using the system.

- Rail Hardness
  - Rail hardness is measured in units called the Brinell Scale.
  - Conventional rail hardness, ie untreated in the natural manufacturing process, ranges between 220-260 Brinell.
  - Through specialist intervention methods to the manufacturing process, rails can be surface hardened to 3 other recognised Brinell values. These are 310, 350 and 390.
- Rail Hardness Principles
  - The process of hardening only affects the outer case of the head of the rail, normally through water cooling methods.
  - In some circumstances other metallurgic steels are added to the core carbon steel to enhance the wider whole rail properties.
  - The benefit of the hardened rail is to extend the rail life where the rail wears under significant wheel/axle load forces.
  - If hardened rail is used where such forces are not being imparted into the rail-head from the wheels/axles etc, the hardened metal will become brittle leading to accelerated failure through intense RCF cracking.
  - Wheel forces induced, where the track geometry has cant deficiency values over 80mm, will generally keep the rail work hardened and prevent accelerated RCF growth and metallurgic deterioration.

- Wheel-Rail Interface

  - The interaction between the wheel and the rail is dependant upon their individual profiles being matched (to a significant degree) to allow the conical forces to do the specific roles, ie to allow the wheels to turn on the rail whilst gaining purchase to move and for the rails to guide the train. If this interface is not matched to an acceptable degree, the conical effects cause the wheels/axles to move across the rails looking for a neutral position. If they do not find this neutral position the ride becomes very aggressive. This phenomena is called equivalent conicity, and the failure causes an ride effect called "hunting".
  - Hunting of the wheels leads to rail-head defects called corrugations. These are a surface defect that can only be removed through rail grinding methods. If left untreated, the corrugations can go very deep into the rail requiring complete replacement. They also cause significant surface contact noise from the wheels as they pass, and can accelerate the failure of wheel/bogie components.
  - On curves the lack of a robust wheel-rail interface will lead to RCF cracks appearing and will accelerate their growth.
  - In a well balance wheel-rail interface the rail and wheel will slowly wear, both can be visually monitored and measured and replacements planned before failure. This is why the design line-speed, the curve radius, the rail hardness and the wheel profile/bogie features need to be aligned to work in harmony.

- Management of RCF
  - RCF can form in any grade of rail hardness, but is less prevalent in normal 220-260 grade steel.
  - Initial forming of the cracks is within the rail surface and is not visible to the human eye until they are over 3mm long. They can be detected by rail ultrasonic's if the operator is well trained.
  - In some cases the passage of the wheel will wear the tail off a crack slowing its development, but it will not remove it.
  - Once cracks are above 5mm, rail-head grinding can be undertaken (by a rail mounted machine) which cuts off approx. 005-0.1mm of metal during grinding activities. This will recue the cracks but will not remove them.
  - Rail-head grinding is effective for cracks between 5 -15mm only, and will only slow the propagation rate.
  - Once cracks exceed 15mm, then rail replacement must be planned and completed before the cracks reach 25mm. After this, the rail is at risk of shattering.
  - The growth rate of a crack is not exponential.

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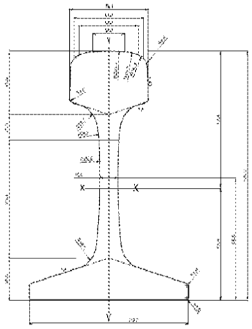
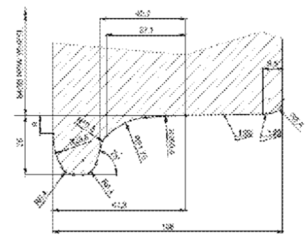
The PA defines that a 115RE rail section is used, as per AREMA standards. This has been provided.

The minimum grade of rail hardness made under AREMA standards is 310 Brinell. This is because the majority of the system that is managed by AREMA standards is heavily trafficked by American freight trains., and a slightly harder rail does provide some lifecycle benefit.

The 115RE rail has been installed on concrete sleepers that provide a 1:40 inwards inclination of the rail (UK is 1:20, Europe is 1:40) (see section below). The wheel profile of the Citadis B15 tram (shown below), is a complex profile that does not obviously align to a 1:40 profile.





NEW WHEEL PROFILE
CITADIS B15

The use of a 310 Brinell rail throughout the OLRT system means that in some locations the grade of hardness will provide a robust rail lifecycle (ie sharp curves where the curving forces push out to the rail).

Analysis of the design parameters indicates that the rail hardness will be beneficial for only less than 1% of the system. This is due to the slow speeds and the low values of cant deficiency that have been provided. However, there are numerous very sharp curves on the route (1 km on each line) that will benefit from the harder rail but will exhibit a mix of side wear and medium RCF growth.

This means that nearly 90% of the OLRT system has rail that is too hard and has the potential to become brittle under normal traffic operations, unless the correct maintenance tasks are carried out.

Wheel hardness is also set at 310 Brinell. This should lead to matched wear occurring on both steels, and can lead to RCF occurring in the wheel surface. The speed of the system at 80 -100kmp/h is slow, the axle loads at 10t are very light, thus the natural mechanics of the system in normal conditions does not impart much force on the rail. This will accelerate the metallurgic failure of the harder outer shell.

The wheel profile is a mix of 1:60 and various radii. This does present a potential mis-match for the conicity requirements for a smooth ride, and increases the potential that corrugation will occur.

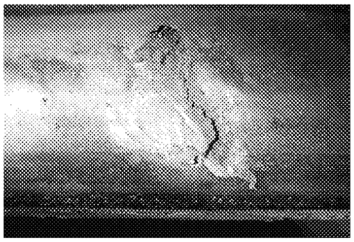
This also reduces the surface contact forces on the rail and increases the potential for RCF to occur.

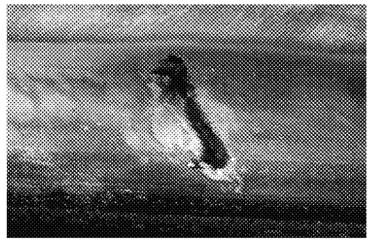
Our Track assurance engineer has significant prior experience of this hazard occurring in other similar systems.

1) Hong Kong Metro

Rail hardness is 350 Brinell, linespeeds are faster at 140Km/h, axle load are slightly heavier at 13t.

Rail in photos below is only 6 years old. The maximum crack measured is 44mm. RCF cracks had been monitored during growth, grinding had been undertaken from 6mm up to 31mm. The growth from 31mm to 44mm took only 3 months. The rail has other lesser cracks (over 25mm) for over 1500m of the length of the curve. Total failure was imminent.





2) Dubai Metro

Rail hardness is 350 Brinell, linespeeds are faster at 100Km/h, axle loads are similar at 11t

Rail is now being replaced after 6 years of operation due to a lack of monitoring and rail grinding.

In both cases the design specification had not considered the geometric forces that were being applied. Instead they have applied harder rails on the basis that they should give a prolonged rail life.

The track maintenance manual [RES-22-0-0000-Man-003] defines the following guidance for rail management

- Ultrasonic Testing

Chapter 4, Section 4.5, page 60 of 344 states "*Ultrasonic test shall be made at least once a year and more often in the event of a significant increase in an incidence of failure or detection.*"

- Rail Grinding

Chapter **11**, Section **11**.2.1, page 174 of 344 states "*The purpose of the **initial** grinding operation is to remove mill scale, rust, surface imperfections and rail head irregularities. The 0.3 mm removal of metal from the rail surface is enough to achieve the above. Furthermore the rail in curves with radius less than 200 m will be ground to optimize the rail head profile. For the rest of the line running rail can be ground as per specified template, if necessary.*"

OLRT Track Maintenance manual, cont'd

The track maintenance manual [RES-22-0-0000-Man-003] defines the following guidance for rail management

- Rail Grinding

Chapter **11**, Section 11.2.2, page 175 of 344 states *"Rail grinding is carried out during downtime on revenue operating systems to maintain noise and vibration at acceptable levels and to reduce the levels of track assembly vibration and vehicle interior noise. An additional reason for grinding the rail is to restore the rail head profile as per specified template, usually caused by normal wear on the gauge side and running surface.*

It is a generally accepted rule that rail grinding should be carried out on a basis which is frequent enough to delay the onset of rail corrugation, that once allowed to develop, grows rapidly to a level that requires time and cost intensive trackwork and vehicle repair.

There is, therefore, a need to monitor track surface condition as a part of a rail grinding/polishing frequency determination."

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Based upon the design characteristics of the wheel and rail as an interface system, there is significant potential for rail defect hazards to develop within the OLRT system, that could lead to accelerated RCF growth and the premature failure of the rail component.

The proposed maintenance activities may not initially be at the correct periodicity to monitor and detect the early signs of defect propagation. This would lead to RCF cracks gaining a strong hold in the rail prior to ultrasonic and grinding activities occurring, and the potential for cracks within the wheel surface. Both of these issues would lead to an increased potential for a broken rail and a tram derailment.

For the initial period of passenger operation (circa 2 years) the following changes to the maintenance activities are recommended [see OLR-22-0-0000-0003]:

- Ultrasonic testing to be every 3 months to establish defect initiation and growth rates
- Initial rail-head grinding of the whole system within 2 months of the start of passenger services
- Routine rail grinding of the whole system every 6 months for profile control and reduce corrugation
- Specific rail grinding of sharp curves every 3 months to control wear and RCF rates

The above should be supported by the development of a wheel/rail interface working group to capture the relevant data, monitor trends and to agree remedial actions.

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