



Two-material rail development: field test results regarding rolling contact fatigue and squeal noise behaviour

Martin Hiensch^{a,*}, Per-Olof Larsson^b, Olof Nilsson^c, Didier Levy^d, Ajay Kapoor^e, Francis Franklin^e, Jens Nielsen^f, Jonas W. Ringsberg^f, B. Lennart Josefson^f

^a AEA Technology Rail bv, PO Box 8125, 3503 RC Utrecht, The Netherlands

^b Banverket Northern Region, Box 43, SE-97102 Luleå, Sweden

^c Duroc Rail AB, Kontorsgatan 37, SE-97342 Luleå, Sweden

^d RATP Infrastructure Department, Rue Roger Salengro, 94724 Fontenay Sous Bois, Paris, France

^e The University of Sheffield, Department of Mechanical Engineering, Mappin Street, Sheffield S1 3JD, UK

^f Chalmers University of Technology, Department of Applied Mechanics, SE-41296 Göteborg, Sweden

Received 13 June 2003; received in revised form 28 November 2003; accepted 1 March 2004

Abstract

Results from the European 5th Framework project “InfraStar” are presented. The InfraStar project is developing a two-material rail to increase the productivity and reliability of rail infrastructure. The two-material rail aims to be rolling contact fatigue (RCF) resistant and to reduce squeal noise.

The InfraStar consortium has built a high level of wheel–rail expertise and understanding regarding RCF initiation and development, level and position of wheel–rail contact forces, and new interface materials and has gained experience in both laboratory and field test operating conditions. Within the project a validated theoretical train–track interaction model and a fatigue design model for two-material rails have been developed.

This paper focuses on the field test results of the two-material rail, and how the predictions and expectations from the selection process match with the results observed in track. Results are very promising. The two-material rail prototypes, now over 1 year in track, show no RCF damage where the non-treated rail shows clear RCF damage. The development of the application process and other objectives of the InfraStar project are discussed.

© 2004 Published by Elsevier B.V.

Keywords: Rolling contact fatigue; Squeal noise behaviour; Rail surface coating; Shakedown limit

1. Introduction

The demand on today’s rail system is an ever-increasing one. Further increase of railway productivity, and thus system capacity, is one of the main challenges the railway society is facing. To reach this target, a qualitative and quantitative improvement of the wheel/rail system is essential. When looking at today’s capacity and productivity restraining factors it can be seen that:

- Maintenance intervals and life of railway components are shortened due to increasing demands (higher axle loads, train speeds and traffic intensity).
- Accessibility of track is becoming more and more difficult. This calls for components with low maintenance demands.
- Rolling contact fatigue damage is increasing all over Europe, increasing the safety risk and reducing the availability.
- Noise levels are too high to allow for the necessary growth in capacity. Without a noise reduction, the “Noise Production Ceiling” will become a bottleneck.

* Corresponding author. Tel.: +31 30 300 5213; fax: +31 30 300 5150.
E-mail address: martin.hiensch@nl.aeat.com (M. Hiensch).

48 All the factors above are addressed in the European 5th
 49 Framework project InfraStar, which started in April 2000.
 50 The main goal of the project is to develop a railhead with
 51 an additional surface layer (the InfraStar two-material rail),
 52 which prevents rolling contact fatigue (RCF) and reduces
 53 noise emissions in small-radius curves (Fig. 1).

54 Rolling contact fatigue is currently one of the major limi-
 55 tations of railway infrastructure productivity. Squats, shelling
 56 and head checks are all forms of RCF, but head checks
 57 are prevalent in curves and switches where flange contact
 58 towards the gauge corner may result in increased tangen-
 59 tial force/slip and decreased wheel–rail contact area. These
 60 surface-initiated cracks can ultimately lead to complete frac-
 61 ture of the rail (Fig. 2). In addition to RCF, high noise emis-
 62 sion (up to 100–110 dB) caused by stick-slip at the wheel–rail
 63 interface is one of the main environmental problems in Eu-
 64 rope.

65 Two application technologies for processing the two-
 66 material rail are studied in the project: in-rolling technol-
 67 ogy for application to new rail during the production process
 68 (Corus), and laser cladding technology for application to the
 69 existing infrastructure or in the production process of new
 70 rail (Duroc). So far in the project only the Duroc applica-
 71 tion process has delivered prototypes that could be tested in lab-
 72 oratory and track. For this reason the in-rolling technique is
 73 not discussed in this paper.

74 The Duroc laser cladding technology (Fig. 3) is a surface
 75 and materials treatment process by which alloying materials,
 76 and even ceramic additives, in powder form can be com-
 77 bined to produce unique materials. The materials are chosen
 78 to provide the desired tribological properties, and the coat-
 79 ing is applied on the rail surface where such properties are
 80 required.

81 *1.1. Surface material selection process*

82 The choice of surface material is very important. Two sam-
 83 ple layer materials prepared by Duroc (Duroc 222 and Duroc

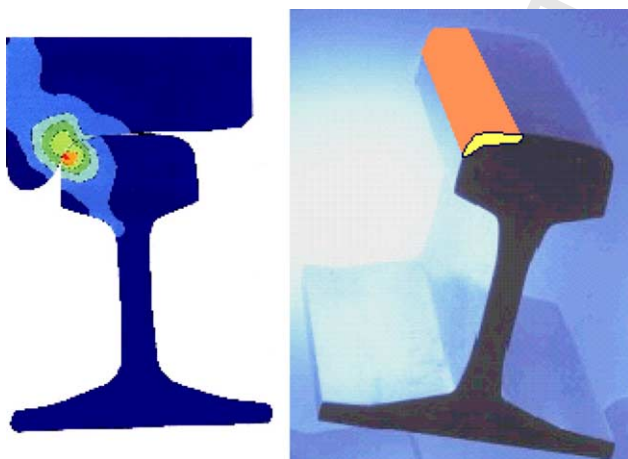


Fig. 1. Use surface layer with new alloys only where superior properties are required.

508) have been laboratory-tested for RCF resistance, bonding
 and traction coefficient (the ratio of the traction creep force,
 measured using a torque transducer, to the normal load). In
 addition, to remove the need to test every new potential layer
 material (either in the laboratory or in the field), a theory
 of coated rails has been developed. It requires a model of
 train–track dynamics to calculate wheel–rail contact loads
 and the dimensions and location of the contact patch, a fi-
 nite element model for determination of railhead stresses,
 and shakedown theory together with material properties and
 geometric characteristics of the two-material railhead. After
 successful laboratory trials, two short length prototypes were
 put into track for 3 months. Analyses of these prototypes
 gave confidence to start a larger scale field testing program
 in September 2001. See Refs. [1,6] for a detailed overview
 of the surface material selection process, modelling approach
 and first field test results.

This paper focuses on the results of field testing and appli-
 cation development. The approach and results of the material

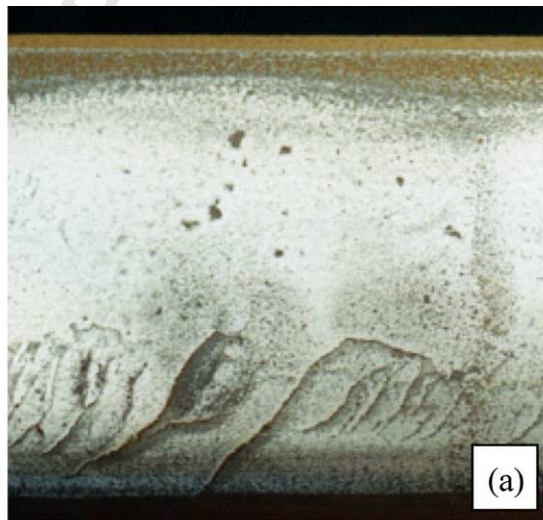


Fig. 2. (a) Head check cracking at gauge corner (top view of railhead); (b) transverse rail fracture from a head check.

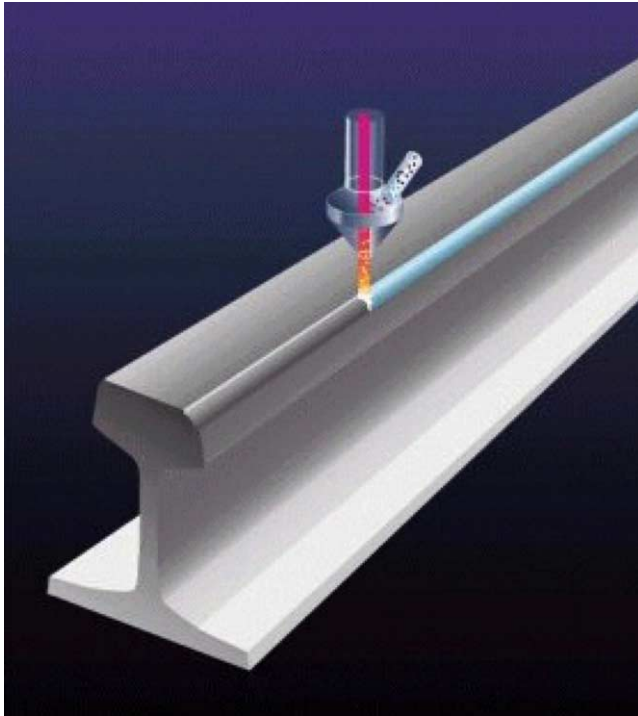


Fig. 3. The Duroc laser cladding application process.

selection process will be briefly addressed. Results from the selection process in relation to track results and further objectives of the InfraStar project are discussed.

2. Design of the InfraStar two-material rail

Leaving aside consideration of surface roughness, “smooth” wheel–rail contact can still cause plastic flow. If the elastic limit is not exceeded, then no plastic flow will occur. If it is, the rail material will strain-harden and protective residual stresses will form. This means that if the applied load does not exceed the elastic shakedown limit then, although there will be some plastic flow in the early cycles, ultimately the load will be supported elastically and failure will occur by high cycle fatigue. Above the elastic shakedown limit, there will always be some plastic flow. There is also a plastic shakedown limit, and applied loads which fall between the elastic and plastic shakedown limits will cause a closed cycle of plasticity, i.e., there will be no net accumulation of plastic strain, and the material will fail eventually by low cycle fatigue (LCF). Finally, if the applied load is above the plastic shakedown limit (also known as the ratchetting threshold), then there is an open cycle of plastic strain, and generally there is a direction in which the plastic strain accumulates. Failure may occur by LCF or by ductility exhaustion (Ringsberg and Josefson [2], Kapoor [3]).

One objective of the InfraStar project is to analyse two-material rails with respect to RCF performance. The material that is cladded to the railhead surface (i.e., the coating)

has higher hardness, higher yield stress limit and, ideally, lower friction than the rail material (i.e., the substrate). These coating characteristics reduce (or prevent) plastic flow, and thus RCF, in the railhead. The RCF performance of the two-material rail is further influenced by the thickness of the coating and by the combination/interaction of coating and substrate material properties.

3. Laboratory tests

The rolling contact fatigue and wear performance of the Duroc 222 and Duroc 508 coatings were tested using a twin-disc machine for dry and water-lubricated conditions. Tests were conducted with -1% slip to simulate a driving wheel. The contact pressure was 1500 MPa in most cases; three tests were performed at 2500 MPa. The water-lubricated tests were performed with an initial 1000 dry cycles, which is enough to initiate cracks in uncoated specimens after only 4000 cycles but which had no apparent effect on the coated specimens even after 200,000 cycles; the mixed lubrication tests started with 15,000 dry cycles and during the subsequent water-lubricated cycles the 508 coating was densely cracked within about 100 μm (the test was stopped after 6000 water-lubricated cycles) of the surface whereas the 222 coating showed no signs of cracking. During the (water-lubricated) high-pressure tests, the 508 coating performed well but the 222 coating delaminated at the interface with the pearlitic substrate after 25,000 cycles—probably caused by plane-stress conditions at the edge of the test specimen. The results of these tests are presented in detail in a companion paper to this one [4]. The conclusions are that both selected coatings have a greatly improved resistance to RCF damage compared with the UIC 900A (260-grade) material: this material is hereafter denoted as 900A. The 222 material is regarded as the more promising of the two tested coatings since none of the performed tests resulted in crack initiation. Bonding quality was also found to be excellent for both coatings.

4. Model simulations and RCF evaluation

The model simulations and RCF evaluation are presented in detail in Hiensch et al. [1,5] and Kapoor et al. [6]. Three steps comprise the design of the two-material rail:

- For any (representative) train traffic situation: calculation of wheel–rail contact forces, spin moments, contact positions, contact load distributions and contact dimensions using a dynamic train–track interaction model.
- The results from Step 1 are used in a finite element (FE) tool to estimate rail stresses.
- The rail stresses calculated in Step 2 are used to carry out shakedown calculations, to study RCF performance of different coatings and train traffic situations.

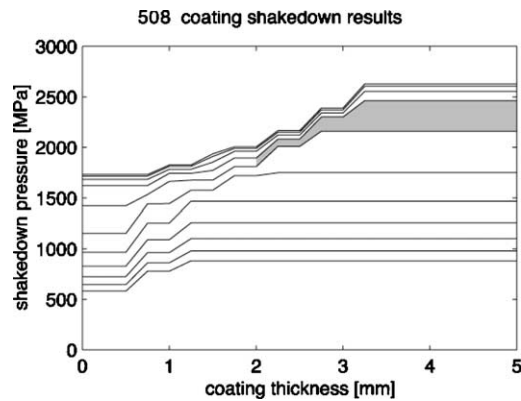


Fig. 4. Shakedown map for wheel–rail contact for the Duroc 508 coating. Results are based on 3D finite element calculations for friction coefficients from 0.0 to 1.0, from top to bottom.

Three 20 m length prototype rails, laser clad with Duroc 222 and 508 (with two coating widths each), were installed in track. Results from this field trial showed that coating width needs to be further optimised in order to minimise wear and plastic flow, and also that laser clad rails need to be reprofiled (ground or milled) before installation in track. The rough elevated surface after laser treatment would otherwise cause too much stress to the coating and base materials. Start/stop areas (of the laser treatment) must also be avoided, which means that the rails have to be continuously clad the entire rail length. Further development and tests with thermite welding have showed that it is possible to thermite weld laser clad rails.

6. Field tests and results

6.1. RCF performance at the Malmbanan test site

The test-site has a history of RCF damage: a 5-year interval in which 60 Million Gross Tonnes (MGT) passes over the railhead. Rail replacement owing to head check damage. Track specifications are: 595 m curve radius, maximum axle load 30 t, cant 0 mm, speed 40 km/h, rail profile UIC 60, no lubrication. Loading is 12 MGT/year.

Two field trials were performed at Malmbanan. First a 6 m prototype rail, laser clad with two different coatings, was tested. This test was performed to evaluate whether the preliminary results from modelling, twin disc testing and the newly developed coating application method were in agreement with performance under real train/track conditions. Visual inspections, railhead hardness readings and railhead profile measurements were taken every 4–6 weeks to monitor and detect any initial plastic deformation or surface initiated contact fatigue.

Findings from the first field test were used to develop the second set of test rails (see previous section). The second test set-up was designed to study the influence of different coating material, coating thickness and coating width. Also an updated version of the coating production method was implemented in these three 20 m test rails in May 2002.

6.1.1. First field test (6 m prototype rail)

The 6 m prototype rail was laser clad with two different coatings: Duroc 222 and Duroc 508 (1 m each). During the testing period, from 2 July to 27 September 2001, 2.5 MGT was transported and 168,684 axles passed over (axle load in the range of 25–30 t). Visual inspections showed that different surface initiated failures were concentrated to the supporting base material (900A), 20–50 mm from the start/stop areas of the coating (in longitudinal direction). After 12–15 loaded trains had passed the test site, it was clearly visible that the Duroc 222 and Duroc 508 materials were unaffected of the traffic, whereas the 900A surface was highly polished and grinding marks from the track installation welding had been worn away. For the coated rails, grinding marks were still

Experiments carried out in the project indicate that the steady-state material behaviour is elastic shakedown [4]. Based on this observation, the contact load distributions applied to the rail model of the FE tool are assumed to follow Hertz assumptions. Also, the results from the separate FE calculations using tangential and normal contact load distributions can be superposed to examine the relationships between contact loads, coating thickness, coating material and friction coefficients, and how they affect the RCF performance of the two-material system.

Three-dimensional wheel–rail shakedown maps have been calculated and they can be used as an aid in coating selection, see Fig. 4 for an example. For the contact modelled here, the 508 coating thickness should be at least 3 mm thick for maximum strength, but contact pressure should not exceed 2500 MPa. The shaded region represents typical operating conditions for dry contact: friction coefficient between 0.3 and 0.4, coating thickness greater than 2 mm. For the 222 coating, the shakedown limit curves will be lower (because the 222 is 370 HV, whereas the harder 508 is 410 HV), but the traction coefficient (and also the friction coefficient) for the 222 is lower also.

5. Application development

The Duroc technology for laser cladding of steel materials was developed more than 10 years ago. However, rail steel materials have not been laser clad before. In order to make this possible and with a successful result, extensive process development have been made.

The process application development started early in the InfraStar project and resulted first in laser clad two-material twin disc samples for laboratory testing. Very positive laboratory test results made it then possible to further laser clad a 6 m prototype rail for field testing. The performance during 2 months in track was also very promising. No cracks and less plastic deformation compared to normal steel grade 900A were found.

Table 1
Railhead profile measurement results at Malmbanan test site

Rail Material	MGT	Max wear		Max deformation	
		Degrees ^a	mm	Degrees ^a	mm
900A	2.5	38–41	1.1	48–53	–1.3
222	2.5	38–41	1.1	49–53	–0.7
508	2.5	37–40	1.0	47–52	–0.4
900A	6.7	38–41	1.9	48–60	–1.7
222 (wide)	6.7	44–46	0.3	51–55	–0.8
222 (narrow)	6.7	36–47	0.6	50–53	–0.5
508 (wide)	6.7	45–49	0.4	51–54	–0.1
508 (narrow)	6.7	36–47	0.3	50–53	–0.1

Degrees are according to the Miniprof system.

^a InfraStar used the “MiniProf—angle A” calculations for location definition; 0° is at the top of rail, 90° at the side of the railhead. The gauge corner is positioned at about 45°.

visible. Initially, the Duroc 508 coating was more resistant to plastic flow than the Duroc 222 coating, and the 900A material had started to develop “tongue lipping” at the start/stop area of the coating.

The Miniprof measurement system was used to evaluate railhead profile changes between the uncoated 900A rail and the two coated rails. The shape of a new standard UIC60 profile was used as reference and it was measured using the Miniprof system. The profiles of uncoated 900A and coated rails were also measured after some time in service. Rail profile residual plots were constructed as the change in rail profile between the reference rail and the three types of rails used in service, respectively. A positive residual value is a profile change dominated by wear, while a negative residual value is mainly due to plastic deformation; note, however, that both options include a combination of wear and plastic deformation. The areas on the railhead where maximum wear and deformation occur are presented in Table 1.

The railhead surface hardness increased from 270 to 320 HV for the 900A during the test period. The Duroc 222 material had a hardness of 480 HV and the Duroc 508 material 560 HV. The old rail that was replaced with this first 6 m test rail had a hardness of 370 HV. This indicates that the hardness for the 900A was not fully developed during this test period. The 2.5 MGT was not enough to develop a full hardness for a 900A grade rail at this test site.

Results from the metallurgical examination after the first field test showed that the standard rail material 900A had developed RCF damage. The Duroc 508 and Duroc 222 showed no cracks visible to the naked eye, but small cracks were found with the scanning electron microscope (SEM). The Duroc 508 had the same hardness after the test. The Duroc 222 increased in hardness by about 80 HV because of a high degree of deformation hardening during the test.

The main difference between the Duroc 508 and the Duroc 222 coatings is the way they deform with trains running through the curve. Duroc 508 deforms less, which was concluded by observing small “islands” of surface material that had been deformed. Between those islands there was still virgin material present. This gives higher stresses in the con-

tacting areas, which resulted in many very small cracks on the islands. Duroc 222 had no such islands but a smooth running surface. This suggests that Duroc 222 can “adjust” more easily to flatten out the high peak stresses.

6.1.2. Second field test (three pieces of 20 m rails)

In total, three UIC60-900A rails were laser clad. Two 20 m rails were clad with a wider layer (24 mm), one with Duroc 222 and the other one with Duroc 508. The third 20 m rail was clad with a narrower layer (17 mm), half of that rail length with Duroc 222 and the second half with Duroc 508. During the test period, from 27 September 2001 to 2 May 2002, it is predicted that 6.7 MGT and 447,400 axles passed the site. The same measurement intervals and parameters were tested as in the first trial. Due to logistic planning problems in regards to maintenance activities and crack development, one of the 20 m rails (508 coated) was taken out of service in May 2002.

The running-in behaviour of all the three rails was similar to the first trial: the 900A rails were polished, while the coated ones needed more traffic to reach a mirror-finish. Visual inspections showed that different surface initiated failures were still developing in the start/stop areas of the coatings. Some visual observations indicated that the width of the coating is a critical parameter. The narrow coating started to slide towards the gauge corner. This resulted in a longitudinal (in direction of the track) crack development at the interface between the 900A material and the sliding coating. For the wider coating, this plastic separation and sliding was not detected.

Residual plots of profiles were again used to evaluate railhead profile changes due to traffic, see Table 1. The results for 900A indicated that the maximum wear took place in the same area as for the first 6 m test rail (between 38° and 41° according to the Miniprof measurement system). However, because more tonnage had passed as compared to the test with the 6 m rail, the deformation occurred over a wider area (48–60°).

The railhead surface hardness of the 900A material had during the test period increased from 295 to 360 HV. The Duroc 222 material had increased from 390 to about 540 HV, while the Duroc 508 had increased from 530 to about 670 HV.

Metallographical examinations of the rail with the narrow coating show cracks in the heat-affected zone (HAZ) along the border between the coated area and the base material, both on top of the railhead and at the gauge corner. This was due to an incorrect tempering procedure after the laser cladding process. It also showed that the untreated 900A had the largest material lipping and plastic flow at the gauge corner compared to Duroc 222 and Duroc 508 (the Duroc 508 had the least material lipping). Duroc 222 and Duroc 508 also had a higher degree of deformation hardening than the 900A. Duroc 508 is more brittle and has a higher tendency to crack than Duroc 222 and untreated 900A. Also of importance is that no cracks have been detected in the Duroc 222 coating layer. Cracks have been found in the Duroc 508 coating layer, originating at the interface between the coated

area and the base material on top of the railhead due to the incorrect tempering procedure.

6.2. Squeal noise behaviour at the Paris Metro test site

Curve squeal noise is the intense tonal noise that may occur when a railway vehicle traverses a small radius curve. Squeal noise from urban transport trains is considered a major source of annoyance for passengers, service people and people living near metro lines. In the InfraStar project, noise measurements were performed at RATP (Paris Metro) to study the effect of laser clad rails on curve squeal noise.

Although the tested coatings had been selected on grounds of their resistance to RCF, there was reason to believe that these coatings could have a positive effect also on squeal noise occurrence. In laboratory testing, the selected materials have showed a low dry friction coefficient, and this difference in friction characteristics, compared to the steel–steel combination, can have a positive effect. The behaviour of the friction coefficient in relation to slip showed that the selected coatings had a positive slope throughout the full test range (0–3% slip). This indicates that friction will always increase with increasing slip values, thereby avoiding a stick-slip loop, which is believed to be one of the main sources of squeal noise initiation [7].

Before installation of the InfraStar two-material rails, a “reference measurement” was performed. After installation of the prototypes, and after allowing them to run in for 3 months, an “effect measurement” was carried out.

6.2.1. Test site specification

The test site is located between Porte Dorée and Porte Michel Bizot on line 8 of the RATP metro in Paris. On this test site, squeal noise is a problem. For measurement reasons, a part of this curve was divided into six 18 m rail sections (S6 up to S1 in the pass-by direction Porte Michel Bizot—Porte Dorée (Fig. 5)). After the reference measurements, three 18 m lengths of 222 coated rail, three 18 m lengths of 508 coated rail and six 18 m lengths of uncoated 260 grade were installed, corresponding to the set-up in Fig. 5.

The nominal track geometry includes curve radius 75 m, curve length 200 m, cant 160 mm and inclination 1:20 with wooden sleepers. The train is braking from 40 km/h to stop at Porte Dorée. Flange lubrication is performed by an oil–graphite mixture (train mounted system). The rail profile is V52, track gauge is 1435 mm, axle load is 6.3 t (empty cars), and the traffic pattern is typically monoculture.

Noise measurements were performed by AEA Technology in close co-operation with RATP. They were set-up according to the measurement protocol for curve squeal noise suggested in [8]. All measurement equipment used during both measurement campaigns was calibrated in accordance with the norm IEC 651 class 1. The location of the microphones placed in each section was as follows. Inner rail: microphones at 1.6 m from the track centre and 0.50 m above the railhead.

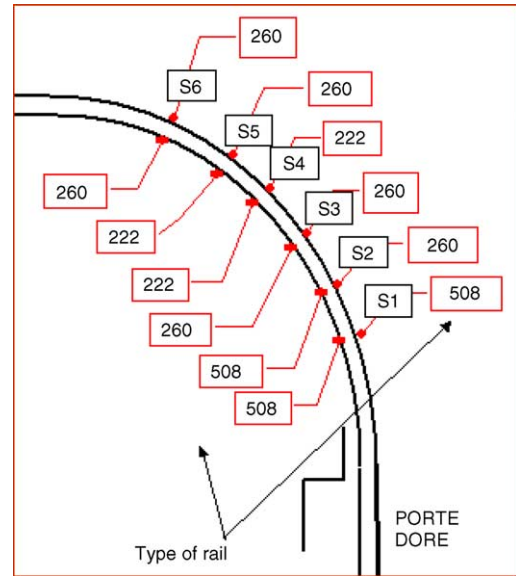


Fig. 5. Test site set-up of the RATP metro in Paris.

Outer rail: microphones at 1.6 m from the track centre and 0.20 m above the railhead (Fig. 6).

Train speed during the pass-by was measured at sections 1 and 6 with an inductive speedometer manufactured by AEA Technology with a precision around 3%. The average speed measured in the curve was 30 km/h. All noise measurements were recorded on tape and were later analysed in 1/3 octave bands (dB(A) levels). For each pass-by, the equivalent noise level (LAeq) and the maximum noise level (LAm_{ax}) were determined. The LAeq calculation is a specific form of evaluation used in connection with pass-by measurements of vehicles and railway trains. The calculation assumes that the noise level as function of time shows an unequivocal maximum, and that a level drop is present before and after the maximum.



Fig. 6. Measuring position at test site (arrow points out microphone).

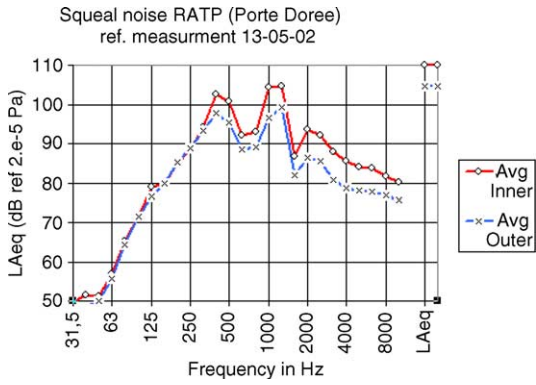


Fig. 7. Averaged LAeq value for inner and outer rails during reference measurements.

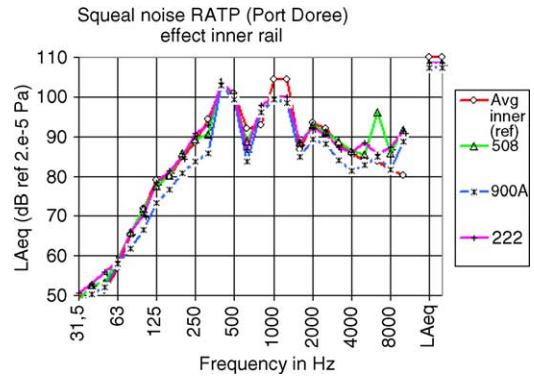


Fig. 8. Results from effect measurement on the inner rail. Spectra for the newly installed standard rail 900A (uncoated) and the 222 and 508 coated rails are compared to the reference measurement.

6.2.2. Reference measurements

During the reference measurements carried out on 13 May 2002, only three sections were monitored: sections 1, 3 and 5 (Fig. 5). 37 pass-bys were recorded and analysed. All metro vehicles generated a high-level squeal noise in each monitored section. Measured noise levels were up to 117 dB(A). The maximum and equivalent noise levels measured in the curve during pass-by was always around 5 dB(A) higher at the inner rail than at the outer rail. The maximum noise levels measured were 7 dB(A) higher than the equivalent noise levels.

Because of the small differences in results between the different locations S1, S3 and S5, the results were averaged for the three sections. The spectra of these LAeq values are shown in Fig. 7.

All analysed measurements (average train speed 30 km/h), showed that the squeal noise appeared in the frequency domain 250–2000 Hz with two peaks, at 450 and 1200 Hz. This spectral signature was also observed during the test carried out in November 2000 by INRETS and RATP [9].

6.2.3. Effect measurements

During the effect measurements, carried out on 30 October 2002, all sections were monitored. For this effect measurements campaign, the track was treated as shown in Fig. 5. A total of 32 pass-bys were recorded and analysed. As for the reference measurements, all metro vehicles generated a squeal noise in each monitored section.

Fig. 8 presents the averaged spectra for the inner rails (outer rail spectra strongly resembles the inner rail spectra). In this figure, the results from the reference measurements (Avg inner ref in Fig. 8) are compared with the results from the effect measurements.

These spectral signatures of squeal noise are similar to the ones found in the reference measurements, with two emerging frequencies at 450 and 1200 Hz. The noise reduction due to the different measures appears in the frequency range 800–1500 Hz. For both inner and outer rails, the noise level

at the peak around 1200 Hz for the new 900A rail and both coatings is 5–8 dB(A) lower than the average level measured during the reference measurement.

6.2.4. RATP track inspection

Directly prior to the squeal noise effect measurements, 3 months after installation of the two-material prototypes, the running surface of the rail was examined. Visual track inspection and hardness (Equo-tip) measurements were performed in track.

The width of the coatings was 40 mm for both inner and outer rails. However, the location of the coating was changed. For the inner rail prototypes, the coating was positioned at the crown of the rail, while for the outer rail prototypes it was positioned on rail shoulder and gauge. From the observed highly polished running band, it was clear that the wheel/rail contact on both inner and outer rails reached beyond the coating. The coating was thus not wide enough to cover the complete running band.

Hardness values for both inner and outer rails indicated nearly full work hardening for this type of traffic (see Table 2). The hardness values of the standard rail material areas next to the coatings, which were also included in the running band, were in the order of 270 HV indicating a normal level of work hardening and contact pressure.

The 222 coating did not show any cracks. The surface was highly polished and small pores from the production process were visible. The 508 coatings showed clear signs of cracks, both on the high and low rails. Cracks had a transverse orientation with 20 mm spacing. The uncoated 900A rail showed

Table 2
Hardness values measured at test track

Material	Hardness inner rail (HV)	Hardness outer rail (HV)	Hardness fully work-hardened (HV)
222	440	410	~450
508	570	550	~570
900A	300	270	~330

no cracks, and the inner rail had developed first signs of corrugation.

7. Main achievements and further objectives

In the first 2 years of the InfraStar project, two materials have been selected with very promising RCF resistance during laboratory testing. Wheel–rail operating conditions, contact forces and contact positions have been calculated using a dynamic train–track interaction model. Shakedown maps for two-dimensional contact for twin-disc experiments, and for three-dimensional contact for field trials, have been produced. There is good agreement between the test results and the expectations from the shakedown calculations. Surface coating application techniques have been optimised and prototypes of two-material rails (field test samples) have been produced and installed in track.

The InfraStar project has focussed on the “invention” of a RCF resistant two-material rail. The project now has proven this new technology, and it has built a high level of wheel–rail interface expertise. This knowledge can be used to optimise the two-material rail for different applications.

This creates the possibility of designing a cost-effective rail in relation to specific demands/functionality by use of superior alloys only where superior properties are required. This will give a “Step Change” in whole life performance. The reduction it brings in required maintenance and (possibly after a further optimisation of the surface material) relief in noise pollution will result in an increase in the system capacity.

Introduction of the two-material rail is believed to be most valuable in areas where further increase of railway productivity, and thus the system capacity, can be addressed. Known bottlenecks are switches and crossings (S&C), which tend to suffer from RCF, wear and damage from corrugation. Also squeal noise is a productivity-restraining factor in S&C. Dealing with problems related to S&C will not only improve productivity but also have a big impact on punctuality.

8. Conclusions

The results and observations from the investigation of the InfraStar two-material rail system can be summarised as follows.

- Rolling contact fatigue—Malmaban tests: During field testing at Malmaban, the two coatings have shown improved resistance to RCF damage, wear and deformation compared to the 900A material. After 10 months of testing, no cracks have developed in the 222 coating, whereas the 900A rail has developed RCF damage. The 508 materials has also developed cracks, originating in the interface between the coated area and the base material on the top of

the railhead, but it is believed that this is due to an incorrect tempering procedure after the laser cladding process.

- Rolling contact fatigue—agreement between laboratory and Malmaban tests results: The metallurgical analyses results and first field test results were in full agreement. Twin disc testing performed in the InfraStar project to judge the RCF resistance and rank the selected materials, have shown good agreement with the field test results. It has so far proven to be a reliable selection tool.
- Noise measurement results from RATP tests: From the noise measurements, it can be concluded that the selected coatings do not reduce or prevent squeal noise occurrence at the RATP test site. Squeal noise is often described as an “on–off system”. This means that one should not aim at a reduction in squeal noise level, but at a reduction in squeal noise occurrence. The tested train–track system has clearly shown a very high squealing instability. The tested coatings could not deliver the necessary reduction of this instability [10]. The coating for both inner and outer rails was too narrow to support the complete running band. This can have a negative effect on squeal behaviour.
- General metallurgical conclusions about the two coatings: From the metallurgical investigation it can be concluded that both selected coatings display a strongly improved resistance to RCF damage compared to the untreated 900A (standard 260 grade) rail material. Bonding quality was also proven to be excellent for both coatings.
- Development of the Duroc laser cladding process: During the first 2 years of the InfraStar project, laser cladding application development has made important progress. The technology has successfully produced samples and prototypes for both laboratory and field testing. The work has created further understanding and knowledge needed to achieve the final objectives with the design of a cost-effective RCF resistant two-material rail.
- Gained knowledge and future work: For RCF problems the InfraStar project has delivered a surface material solution, together with valuable understanding concerning two-material rail behaviour and surface material application development. The InfraStar partners believe that the two-material rail concept presents a high potential solution concerning related problem areas like wear and squeal noise. Delivering a complete solution to the interfacial problems encountered at bottleneck areas like S&C will strongly contribute to the value, and thus introduction, of the two-material solution. Consequently, future work should involve this area.

Acknowledgements

The InfraStar project is funded by the EU 5th Framework. Partners are AEA Technology Rail BV (NL), the University of Sheffield (UK), Chalmers University of Technology (SWE), Banverket (SWE), Duroc Rail (SWE), Corus (FRA) and Paris Metro RATP (FRA). More details can be found at

598 the project's website: <http://infraSTAR.shf.ac.uk/>. Additional
599 funding was supplied by the National Centre of Excellence
600 in Railway Mechanics Research, CHARMEC, at Chalmers
601 University of Technology in Gothenburg, Sweden. Yanis Ker-
602 ouani of RATP and Bernard Lefranc and Gerrit van Keulen of
603 AEA Technology performed the squeal noise measurements
604 at RATP. Thomas Ramstedt of Banverket performed the field
605 measurements at Malmbanan.

606 References

- 607 [1] E.J.M. Hiensch, A. Kapoor, B.L. Josefson, J.W. Ringsberg, J.C.O.
608 Nielsen, F.J. Franklin, Two-material rail development to prevent
609 rolling contact fatigue and reduce noise emissions in curved
610 rail track, in: Proceedings of the World Congress on Rail-
611 way Research (WCRR 2001), Cologne, Germany, November 25–
612 29, 2001, p. 16.
- 613 [2] J.W. Ringsberg, B.L. Josefson, Finite element analyses of rolling
614 contact fatigue crack initiation in railheads, Proceedings of the
615 IMechE, Part F, J. Rail Rapid Transit. 215 (2001) 243–259.
- 616 [3] A. Kapoor, A re-evaluation of the life to rupture of ductile metals
617 by cyclic plastic strain, Fatigue Fract. Eng. Mater. Struct. 17 (1994)
219–221.
- [4] F.J. Franklin, G.J. Weeda, A. Kapoor, E.J.M. Hiensch, Rolling contact
618 fatigue and wear behaviour of the InfraStar two-material rail,
619 in: A. Ekberg, J.W. Ringsberg (Eds.), Proceedings 6th International
620 Conference on Contact Mechanics and Wear of Rail/Wheel Systems,
621 Vasastadens Bokbinderi, Göteborg, Sweden, 2003, pp. 39–47.
622
- [5] E.J.M. Hiensch, F.J. Franklin, J.C.O. Nielsen, J.W. Ringsberg, G.J.
623 Weeda, A. Kapoor, B.L. Josefson, Prevention of RCF damage in
624 curved track through development of the INFRA-STAR two-material
625 rail, Fatigue & Fracture of Engineering Materials & Structures, in
626 press.
627
- [6] A. Kapoor, J.W. Ringsberg, F.J. Franklin, B.L. Josefson, Shakedown
628 limits in three-dimensional wheel–rail rolling-sliding contacts, in:
629 A.F. Blom (Ed.), Proceedings of the Eighth International Fatigue
630 Congress (Fatigue 2002), Engineering Materials Advisory Services
631 Ltd. (EMAS), West Midlands, UK, 2002, pp. 1365–1372.
632
- [7] F. de Beer, Evaluatie van Maatregelen tegen booggeluid door laterale
633 slip (in Dutch), TNO-TPD Report, HAG-RPT-010600, 1 May 2001.
634
- [8] E. Verheijen, R. van Haaren, J. van den Brink, A measurement pro-
635 tocol for curve squeal noise, in: Proceedings of the Internoise 2000,
636 Nice, France, 2000.
637
- [9] Rapport d'étude, No DEE E 01-5005, Caractérisation acoustique du
638 bruit de crissement dans la courbe Porte Dorée/Michel Bizot, Essai
639 No. 00–92.
640
- [10] E.J.M. Hiensch, B. LeFranc, Development of a two-material rail
641 allows for engineering squeal noise behavior, in: Proceedings Eu-
642 roNoise 2003, Napels.
643