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INNOTRACK

Integrated Project (IP)

Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

D4.1.1 Interim database for actual and new, innovative rail/joints

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Revision [draft 2]

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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Glossary

Head checks	HC
Surface crack length	SCL
High rail	HR
Low rail	LR
Ultra Sonic / Ultra Sonic Testing	US/UT
Eddy Current	EC
White Etching Layer	WEL
Aluminothermic Weld	AT
Flash Butt Weld	FB
Alternating Current Potential Drop	ACPD
Traffic in million gross tonnes	MGT
Cant(super elevation)	The severity that the track is banked in curves

1. Executive Summary

This report describes degradation data from test sites that have been monitored by both rail producers and the Infrastructure Managers (IM's). The parameters that have been monitored and reported are those which have a major influence on rail and joint degradation, including wear and rolling contact fatigue (RCF). This report gives details on the methodology of data collection along with an explanation of what data has been collected; the data is collated in an accompanying spreadsheet. The data reported include information on the track characteristics, loading characteristics and the degradation which has been observed.

Analysis of the data has been and continues to be carried out in parallel with this collation exercise with the initial results on rail degradation mechanisms being reported in the accompanying deliverable D4.1.2.

2. Introduction

This report details a database of the degradation mechanisms of rails and joints from observations of their behaviour in track. This is an interim report with further data being added when it is made available by the other partners, a final database is foreseen as a further deliverable in month 36. Further inputs will come from track trials being carried out as part of the project including those planned in WP4.6 at ProRail. Analysis of the data has been carried out in the accompanying deliverable D4.1.2.

The data reported here have been collected by Corus and VAS from their test sites. The work has been performed in partnership with the different railways represented by the work package members. The data presented are the results from practical track performance tests with different rail steels under various loading conditions for mixed traffic and for passenger traffic only. It gives an overview of the advantages of different rail steel grades tested under various track and loading conditions. Degradation such as wear and RCF are quantitatively recorded while information on squats, corrugations, WEL's, etc is given qualitatively if available. Details on the monitoring of joints and welds are given where available.

A direct link to an individual line is not given to ensure confidentiality of the railways. But the track layout, rail profile, rail grade and the loading of the track site are specified. This information is considered to be sufficient for an initial study of the degradation behaviour of rails and joints. The database contains all information from test sites that was either recorded by the monitoring team or was made available by the IM's at the time of the investigation.

3. Source of Information and Parameters

The database of detailed monitored sites consists of more than 2000 datasets from 211 test sites (design locations). While a design location is defined as one rail grade at one location. The columns contain information on the installation dates, maintenance dates if known, track geometry, traffic type and loading of the site. Wear data has been measured by some of the following parameters: vertical, 45° to the gauge corner and horizontal, for the high rail (HR) and occasionally the low rail (LR)) Rolling contact fatigue damage in the form of head checks has been quantified by the surface crack length (SCL) and crack depth measured by non destructive techniques. From the data obtained it is possible to calculated degradation rates for different grades of rail as a function of track characteristics and loading parameters

Other track faults, including squats, corrugations etc. are recorded where they occurred within the test site, where possible this was made quantitatively if not then qualitatively.

The aim of the majority of site monitoring that has been carried out in the past has been to asses the behaviour of different rail steels in track. Such data collection has concentrated on the continuous rail rather than the joints to reduce the variability in the results. Therefore information on rail joints and welds is limited to a few test sites that have been installed deliberately to look at welds. Further information on joints will be added to the database when the results of the site monitoring at ProRail that is being installed by WP4.6 are available. This test site will also give further detailed degradation recordings on high strength steel grades.

3.1 Data from site monitoring

Both rail manufacturers have carried out site monitoring at a number of locations around Europe; Corus with a focus on the UK and voestalpine with focus on the German and Austrian network.

Corus and voestalpine Schienen want to express their gratitude for an excellent cooperation over many years to the involved railways; namely: DB, NR (and its predecessors), OEBB, ProRail, RFI and SNCF. This partnership is very valuable for all partners in terms of product development and common knowledge building.

All these test sites were installed to test the performance of different rail grades at special test conditions. Within this report the data of various conditions are collated to enable a more general view on track design, loading, rail grade and the resulting degradation. On the basis of this data, rail degradation algorithms will be developed in deliverable D4.1.2. For comparison of degradation at a single site (with different grades) the knowledge off all possible influencing parameters is not necessary. Hence the information collected here show some significant gaps in the column for track design, maintenance and the loading that the rail carries.

The two rail manufacturers have inserted the data in the joint spreadsheet in different ways; therefore company specific explanations are given as follows.

3.1.1 Corus site data

Corus has stored data for every measurement point they recorded on the spreadsheet. Every test site has several test locations usually three but sometimes more with the same track geometry. A number of site visits have been carried out on different days with timescales ranging from 1-2 years to one site that was monitored over 11 years. Therefore the Corus database contains just under 2000 measurements. The degradation mechanisms monitored were wear for all sites, in the form of profile measurements and for some sites RCF measurements. The gauge and cant were also monitored. This may allow degradation of track geometry to be estimated but no knowledge of maintenance procedures such as tamping is known. To allow traceability of the data each individual measurement has an identification number called a TID, those from Corus are numbered in the range 1 to 10000.

To allow analysis of the data, the measurements have been aggregated together based on route, location, radius, rail grade, direction and project. This gives 85 individual sites with the number of measurements ranging from 3 to 105. The sites from Corus UK are numbered in the series 1-100.

3.1.2 voestalpine Schienen site data

Test sites monitored by voestalpine with the respective railways are setup in a similar way to those of Corus. Each test site consists of at least three measurement points which were monitored on a regular basis twice a year. Since wear or RCF crack measurement was not generally performed by voestalpine employees or the railways themselves, the results have been manually extracted from reports. Preferably the latest available information and sometimes additional information from further measurement intervals, is given in the database. The given data are mean values of the measurements on the individual measurement points. Thus the 206 data sets describe 110 individual sites or design locations.

3.2 Description of Parameters

From discussions with partners of WP4.1 and the simulation group of WP4.2 a comprehensive questionnaire was assembled. The questionnaire covers fields such as general information, track characteristics, loading conditions, wear, RCF, other rail defects and maintenance. Every characteristic listed is considered to be of relevance and thus influences the different types of rail degradation. The needs for computational modelling have been taken into account. The collection makes no claim to be complete, nevertheless including all the parameter and track faults one full dataset would consist of 151 items. This amount of data has not been regularly recorded at previous tests. The table below covers the parameters actually listed in the database which have been filled in where data is available.

Parameter	**Unit**	**Description**	**Comment (Problem)**
General Information			
TID	-	Track Identity No	
Project and objective	-	Not given	Only known by both rail manufacturer
Railway company	-	Not given	Only known by both rail manufacturer
Line	-	Not given	Only known by both rail manufacturer
Start Position	-	Not given	Only known by both rail manufacturer
End Position	-	Not given	Only known by both rail manufacturer
Latitude position	-	Not given	Unknown
Longitudinal Position	-	Not given	Unknown
Relevant Dates			
Date of installation	yyyy-mm-dd		
Date of last grinding	yyyy-mm-dd		
Date of relevant/comparable measurement	yyyy-mm-dd	Date which corresponds to the absolute increment of the degradation value given in the dataset (could be the same like Date of installation or Date of last grinding).	
Date of present measurement	yyyy-mm-dd		

Parameter	Unit	Description	Comment (Problem)
Track Characteristics			
Superstructure			
Sleeper material	-	The mechanical behaviour of the superstructure is assumed to have a major influence on the system related rail faults like corrugations, squats and so on. The data are necessary for detailed modelling.	Since the test sites of the rail manufacturer were installed to compare the isolated material effect these parameters were not collected. For further research this parameter should be considered to make different site results comparable.
Sleeper distance	m		
Pad stiffness	N/m		
Pad damping	Ns/m		
Subsoil stiffness	N/m		
	N/m³		
Subsoil damping	Ns/m		
	Ns/m³		
Rail profile HR (LR)	-	Specific designation e.g. according to UIC	Available for all sites
Rail grade HR (LR)	-	According to EN 13674-1 or precise specified according to UIC	Available for all sites
Hardness HR (LR)	BHN	Hardness by Brinell on the running surface	If given it refers to a specified hardness of rail grade and not the individual hardness of the tested rail
Geometry			
Radius	m	Characteristic radius of segment	For curves the original radius is given and for transition the starting radius is chosen
Radius from	m	Starting radius of segment	For Curves and Tangent track this will be the same as radius and is only of interest for transitions
Radius to	m	Ending radius of segment	
Curve Type	-	Curve or Transition or Tangent	
Longitudinal Gradient	‰	±	Only given for some cases
Cant	mm	Absolute (Cant deficiency e.g. should be calculated for actual speed)	Available for the most sites. Can be either a design value or measured
Loading			
Traffic	-	Freight, High Speed, Mixed or Commuter	
Single line	-	Reversed traffic	Not given, but almost all lines are single lines.
Maximum Speed (Vmax)	-	Nominal line speed	

Parameter	Unit	Description	Comment (Problem)
Fraction of traffic with less than 70% of Vmax	-	Since the nominal line speed gives no information on the deviation of the actual driven speed to Vmax. To divide into a fraction of traffic with reduced speed might be one solution to specify the distribution.	Not known.
Fraction of traffic with less than 80% of Vmax	-		
Fraction of traffic with less than 90% of Vmax	-		
Maximum Longitudinal Acceleration Amax	m/s³	Acceleration and braking forces are assumed to have a major impact on wear, HC, wheel burns or corrugation.	In general not known.
Fraction of traffic with less than 70% of Amax	-	To give an impression on the distribution of the accelerating forces the proportion of traffic with less than the maximum acceleration might be useful.	Not known.
Fraction of traffic with less than 80% of Amax	-		
Fraction of traffic with less than 90% of Amax	-		
Irregularities	-	Irregularities like signals, switches, bridges, crossings may give a hint on singular track faults.	
Maximum Axle load (L_{max})	tonnes		
Fraction of traffic with less than 70% of L_{max}	-	Similar argument as for speed and acceleration.	Not known.
Fraction of traffic with less than 80% of L_{max}	-		
Fraction of traffic with less than 90% of L_{max}	-		
Lubrication	-	Water, oil or solids could be used as lubricants	In general not known. But of significant influence on all surface rail degradation mechanisms.
Maximum traction coefficient	-	Due to lubrication in the range of 0.1 and 0.6	To be included after discussion with IMs.
Daily tonnage	Metric tonnes/day	Number according to the information of the IM.	The actual loading may differ significantly since the values usually are calculated from the timetabled trains that are due to run each day. Only some lines have load checkpoints.

Parameter	Unit	Description	Comment (Problem)
Wear (high rail and low rail listed separately)			
Vertical W1 HR	mm	Vertical wear on the middle of the rail head	At all VAS attended test sites wear is measured with MiniProf (Greenwood Engineering). Since 1997 Corus have use a MiniProf device previously a Unisteel Contourgraph was used
Horizontal W2 HR	mm	AT OEBB, NR and DB W2 is measured 14 mm down the rail crown	
45deg W3 HR	mm	W3 is generally measured radial to a 45° tangent at the gauge corner	
Worn area HR	mm²	Calculated by the difference from reference and actual profile	
Rail defects, according to numbering in UIC Codex 712 E, release 4; detailed description of the faults can be found there. (high rail and low rail listed separately)			
1xxx – defects (high rail and low rail)			
100 Transverse break without apparent origin	Simple occurrence, mm, or % of rail head	Defect size, damage depth or longitudinal extension	Not collected.
111 Kidney shaped fracture			
121 Surface defects			Not collected.
122 Shelling of running surface			
124 Local batter of running surface			
125 Wheel burns			
134 Corrosion			
135 Star-cracking of fishbolt holes			
2xxx - defects			
2201 Short pitch Corrugation (2202 Long pitch Corrugation)			
Average depth HR	mm	These characteristics can easily obtained by a longitudinal measurement of at least 1m.	Not yet included.
Maximum depth HR	mm		
Average wavelength HR	mm		
2222 Shelling of the gauge corner			
Depth HR	mm		
Longitudinal extension HR	mm	Could be obtained by visual inspection, photographs or eddy current measurement.	Actual included in two categories, 0.5mm and 2mm. The information is an assumption from individual characterisation of the occurrence. 0.5mm can be interpreted as black spots on the surface with slight

Parameter	Unit	Description	Comment (Problem)
			blowouts. 2mm describe more severe shelling.
2223 Head checks			
Surface Crack length High Rail	mm	Measured with the aid of magnetic particle inspection/photographs etc.	
crack depth (by EC-measurement) HR	mm		Crack depth in track can not be measured directly therefore various NDT techniques have been used. VAS have used an eddy current device. Direction, position, distance between cracks strongly influence the signal. The final EC results have always been compared with micrographs with the result being comparable with good correlation. In contrast Corus have used an ACPD device which has shown good correlation with measured cracks too.
crack depth (micrograph) HR	mm		
227 squat			
crack depth (by EC-measurement) HR	mm		Crack depth could not be measured directly; it is an interpretation of the EC-signal strength. Not yet included.
crack depth (micrograph) HR	mm		Crack depth of squats was not of primary interest of past test sites. The occurrence is marked with an "x" for the VAS sites. Corus monitored crack depth and length using the same techniques as head checks where squats were observed.
Defects at welded Joints 41x – 43x			
411 Transverse cracking of the profile (Flash-but welding) HR	% of rail cross-section	To be obtained by US-testing or metallographic after removal.	Not yet included.
412 Horizontal cracking (Flash-but welding) HR	Yes/No	Occurrence by visual inspection	
421 Transverse cracking of the profile (Aluminothermic welding) HR	% of rail cross-section	See: UIC Codex 712 E, release 4	
422 Horizontal cracking (Aluminothermic welding) HR	Yes/No	See: UIC Codex 712 E, release 4	
431 Transverse cracking of the profile (Electric arc welding) HR	% of rail cross-section	See: UIC Codex 712 E, release 4	

Parameter	Unit	Description	Comment (Problem)
432 Horizontal cracking (Electric arc welding) HR	Yes/No	See: UIC Codex 712 E, release 4	
47 Resurfacing			
471 Transverse cracking of the rail head HR	% of rail cross-section	See: UIC Codex 712 E, release 4	Not yet included.
472 Detachment of shelling of the resurfaced portion HR	% of resurfaced portion	See: UIC Codex 712 E, release 4	
48 Other welding methods / Others (not numbered)			
481 Transverse cracking under electrical connection HR	Yes/No	See: UIC Codex 712 E, release 4	Not yet included.
Joint dip HR	mm		See detailed measurement of weld geometry and hardness – separate section “Welds”
Detached insulation HR	Yes/No		Not yet included.
Maintenance			
Reprofiling	-	Information on the date, the technique and the scale of reprofiling are important to study degradation and develop maintenance strategies.	The test sites studied by VAS have generally not been ground during the monitoring period. In some cases grinding was done without previous information. For the intervals mentioned at “General Information” it can be ensured that the observed degradation listed in the table arises from a period without grinding, reprofiling or rerailing. In contrast the sites monitored by Corus have been ground on a regular basis with some also being rerailed, therefore the date of grinding is recorded where known, if not an assumption is made of the date of grinding or rerailing.
Tamping	-	Date	
Rerailing	-	Date, Profile, rail grade	
Change of pads	-	Date, Pad stiffness, Pad damping	
Welds			
Type of weld (HR/LR)	-	AT – Aluminothermic or FB – Flash Butt	Measurements have been made on pairs of welds but results are reported in spreadsheet individually
Weld alignment	mm	Vertical alignment of rail measured from a straight edge measured at set distances (every 100mm from –800mm to +800mm) from centre of weld.	
Surface Hardness	HBN	P – Parent, HAZ – Heat affected Zone, FL – fusion line	Hardness of surface of rail measured using a portable hardness tester (Equotip). Results are given in direction of traffic.

4. Example Analysis

Gauge corner wear, which shows a higher wear rate than the vertical wear has been chosen to demonstrate problems encountered in analysing the data. After installation of a new rail and initial grinding, a certain accumulated load is necessary to produce a continuous running band by wearing away the residual grinding marks. The wheel/rail contact tends to develop conformal conditions. In the early stages the wear rate shows a large amount of scatter. For this reason only measurements from site locations which have carried at least 45 million gross tonnes (MGT) have been selected to compare the wear behaviour of R260 with R350HT in figure 1. The general trend of a higher wear resistance of the head hardened rail steel grade R350HT compared with the standard carbon grade R260 is obvious (The behaviour can be described by a power function given in the diagram). For sharp curves with greater wear the enhancement in wear resistance is greater than three. But the wear rate for the same radius may vary about two times, as shown for the grade R260 installed in the 400m curve. The reason for this variable behaviour is the difference in the time since installation with the longer period leading to a higher wear rate. This is not a general conclusion and is only relevant for this site. For curves with radius greater than 3000m it can be observed that there is no economic advantage of high strength pearlitic steels since grade R260 displays similar results with the variation lying within the accuracy of measurement and wear would not limit the rail life. Nevertheless the wear rate for R350HT in this curvature range is approximately half compared with grade R260.

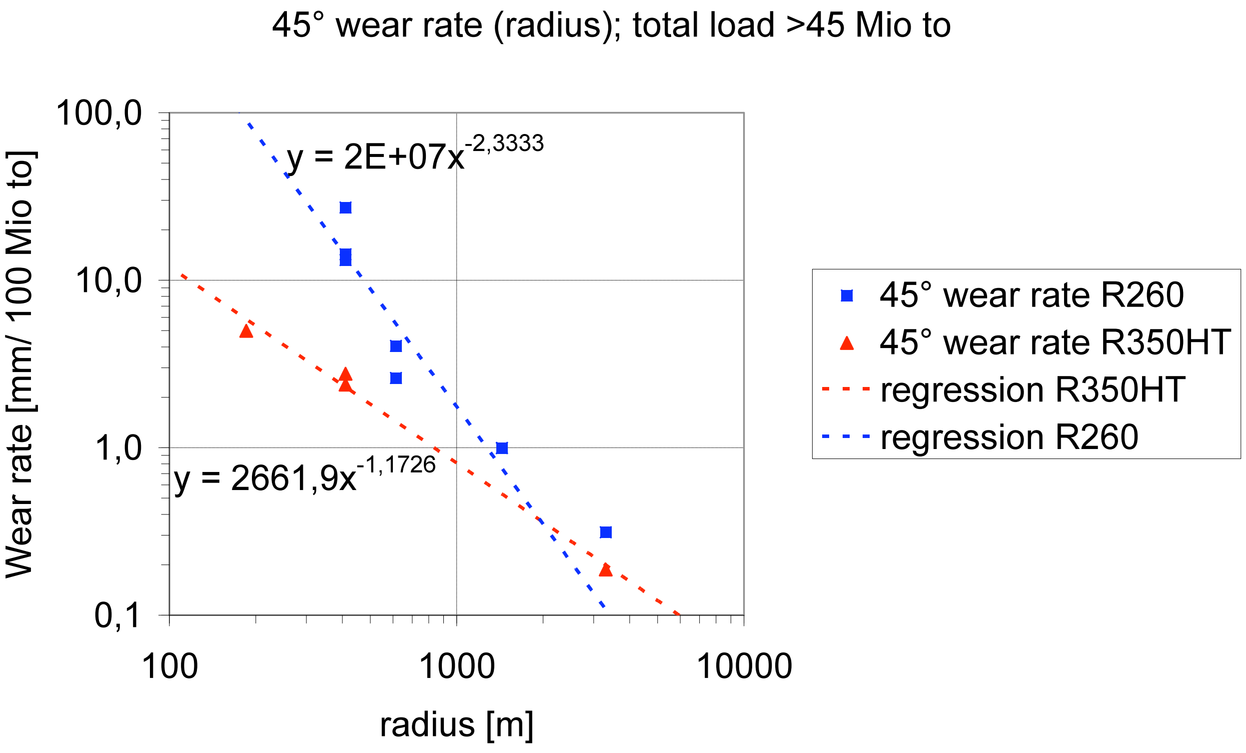

Figure 1

This is just one case of the problems encountered with analysing the data. Further analysis of the data has been carried out and is reported in the accompanying deliverable D4.1.2: Interim Rail Degradation Analysis

5. Statistical Analysis

The monitored sites include many parameters with a range of variables relating to track geometry and loading conditions. The monitoring has been on an ad-hoc basis and not as a single planned project that would ensure comprehensive coverage of all possible track and loading characteristics. In a planned experiment, sites would have been chosen to include full coverage of a range of different parameters so that their effect on degradation can be assessed; a well-known form of experimental design is Taguchi that reduces the number of experiments required but ensures statistical coverage of all variables. Therefore to ensure that the range of sites that have been monitored is representative of all possible variations in track and loading characteristics a statistical analysis has been carried out looking at the distribution of the monitored sites. An aim of this work was to look for gaps in the data that may be filled by the installation of new monitoring sites.

The variables studied are radius, rail grade, rail profile, cant deficiency, traffic and line speed. The results have demonstrated that many of the variables are not independent but are related to others, for example the majority of the 56E1 profile rail that has been monitored is grade 220 rail whereas their is little data for grade 220 with a UIC60 profile. The reason for this is that the railways of Europe historically have different design standards and use rail grade and profiles that are suited to them and the vehicles that run on them. Similarly, cant deficiency is a function of line speed, radius and the design parameters of individual railways and is therefore not an independent variable.

Therefore the sites that have been monitored do not display homogenous and independent parameters that are required for a designed experiment due to the nature of the site monitoring and the railways. Even so the analysis has shown that monitoring has given a good coverage of different rail grades on curves of different radii. The majority of curves that have been investigated have radii between 700m and 3000m, maximum speeds of 130-170km and consequently cant deficiencies of 80-130mm, curves with lower and higer radii have also been monitored to a lesser extent. The reason for this skew in the spread of sites is that curves of this type have been found in the past to experience the most severe rail degradation mechanisms, in particular rolling contact fatigue and therefore have been targeted for monitoring. Tangent track and transition curves are locations, which have rarely been monitored, because tangent track is regarded as having low degradation rates and transition curves have constantly changing radius and cant making interpretation of the results difficult. Where transitions have been measured this is usually in conjunction with the neighbouring curve. The lack of data on transitions is one area that requires further investigation as the change in the radius and cant produces higher track forces that result in increased degradation compared to a curve with constant radius. When considering site monitoring of transitions the rate of change of radii and cant needs to be taken into account as they are thought to be influential on the behaviour of the vehicle and consequently the resulting wheel/rail forces.

The statistical analysis carried out here and the analysis on rail degradation in D4.1.2 has shown that even where the track geometry parameters are similar the degradation mechanisms and rates can vary widely. Therefore any recommendation for the installation of new test sites would be better after further investigation and analysis of the present data and also with any further data that will be incorporated into the database. To further understand the degradation of rail and understand where gaps in the data may be, modelling of selected test site will be carried out to understand the stresses that arise in the rail as a results of wheel/rail contact. An idealised matrix of test sites is being constructed that will also help to define where data is missing.

6. Conclusions

The database enables analysis to be carried out on the degradation mechanisms over a wide variation of track design and loading conditions within the European network (The analyses are reported in D4.1.2). Nevertheless the database has revealed many gaps in the current data, which, if filled, would be valuable in producing improved accuracy of the rail degradation algorithms. Important information that is missing includes:

- Mechanical behaviour of the superstructure – a significant influence on corrugation, squats and other singular defects.
- Traffic
  - Distribution of different types of trains and vehicles
  - Axle load and speed of vehicles
  - Total accumulated load within a measurement interval
  - Typical acceleration behaviour in the area of a test site, included is the gradient of the test sites.
- Lubrication – very important to find a way to quantify the actual lubrication status. Lubrication influences probably all surface initiated degradation mechanisms including wear, RCF, corrugations, WEL etc.
- Joint/weld defect information – this information cannot be comprehensively studied on separate test sites; statistical information over a longer lifetime is necessary.
- Maintenance – to analyse the degradation over the whole lifecycle, the maintenance history must be known; since degradation does not behave linearly the effect of different maintenance strategies on degradation of the rail can only be assumed.

Those responsible for test sites in the future, either within Innotrack or externally, should take into account the lessons learned from the collation exercise, which has resulted in reexamination of the data and demonstrated where information is lacking. Therefore to allow a deeper understanding of rail degradation as much information should be attained from the site monitoring as possible. This includes completing as many fields or parameters in the spreadsheet as possible with special emphasise placed on the data that will have an impact on the wheel/rail contact stresses such as those mentioned above.

7. Annexes

The complete data collection:

int-sp4.1-ot-05-080219-F1-spreadsheet.pdf

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