Article:

Lewis, S. orcid.org/0000-0003-2597-9625, Lewis, R., Goodwin, P.S. et al. (4 more authors) (2017) Full-scale testing of laser clad railway track; case study - testing for wear, bend fatigue and insulated block joint lipping integrity. Wear, 376 (Part B). pp. 1930-1937. ISSN 0043-1648

https://doi.org/10.1016/j.wear.2017.02.023

Full-Scale Testing of Laser Clad Railway Track; Case Study - Testing for Wear, Bend Fatigue and Insulated Block Joint Lipping Integrity

S. R. Lewis[1], R. Lewis[*1], P. S. Goodwin[2], S. Fretwell-Smith[3], D. I. Fletcher[1], K. Murray[4], J. Jaiswal[5]

(1) Department of Mechanical Engineering, University of Sheffield, UK. (2) Laser Cladding Technology Ltd, Worksop, UK.
(3) Tata Steel Rail Technologies, Rotherham, UK. (4) Sandvik Osprey Ltd, Neath, UK.
(5) ARR Rail Solutions LTD, 3m Buckley Innovation Centre, Firth Street, Huddersfield, UK.

Abstract

This paper reports on a series of tests which were carried out on full-scale sections of rail that had been treated by laser cladding aiming to create a layer (~1-2mm) of high performance material on the rail head. Experiments were designed to measure wear, lipping of insulated block joints (IBJs) and bending fatigue of clad samples. The wear rate of the clad samples was between 78- 89% lower than that of the standard R260 reference sample. Cladding of either side of an insulated block joint greatly improves its lipping resistance and allows it to withstand approximately 3 times the energy input into the contact compared to a standard un-clad IBJ. A section of rail clad with martensitic stainless steel was subject to bend fatigue testing and ran out to 5,000,000 cycles at a stress range of 350 MPa matching the performance of an unclad R260 rail. Although there is no standard for the bend testing of laser clad rail this performance exceeds the performance requirements of the NR/SP/TRK111 standard which governs the bend testing of flash but welded rail.

Keywords: Full-Scale, Testing, Laser Cladding, Wear, Insulated Block Joint, Lipping, Bending Fatigue

1 Introduction

Replacement of worn rail, extension of rail life and prevention of rail failure particularly from wear are significant cost contributors to the running of a rail network. The same is true for high value track components such as insulated block joints (IBJ's) or switches and crossings. Network downtime caused by replacement and maintenance can cause significant disruption to passenger and freight traffic having a follow on impact on the wider economy. The treatment of rails and other track components by laser cladding to improve rail durability has been studied before [1 – 4] and shows good potential as a method for reducing wear and increasing the RCF life of rails. Tests which simulated an IBJ [5] have shown that laser cladding of the rail head around the area of the endpost can reduce the tendency for the rail to lip across the joint. These tests, however, were all carried out using small scale twin-disc apparatus. This paper presents an approach to validate laser cladding of rail by performing full-scale tests. In this study three series of tests were carried out on full-scale sections of rail which had been treated by laser cladding aiming to create a layer (~1-2mm) of high performance material on the rail head. In the first series of tests wear experiments was carried out on one metre lengths of clad rail track using The University of Sheffield's full-scale wheel-rail test rig (FSTF). The FSTF is capable of testing under controlled load, speed and slip. In the second full-scale test series, one metre long sections of rail were tested including an insulating "end-post" inserted into the head of the rail halfway along the length. In the field IBJs are used to electrically isolate two adjoining sections of rail for signalling purposes. The primary failure mechanism of standard un-clad IBJ's in the field is by a mechanism referred to as lipping [5] which is the result of plastic flow of the rail material across the insulating polymer endpost and caused by cyclic loading of passing wheels. The electrical connection caused by lipping leads to the failure of the signalling systems. The third test series used a four-point bend fatigue configuration to load clad rail specimens to investigate the integrity of the interfacial clad/substrate bond by subjecting the rail to the bending stresses that it would see in the field.

2 Specimens

R260 rail grade was used as a baseline and as a substrate for the clad samples in these tests. Two cladding materials were applied: (i) Stellite 6, and (ii) a grade of martensitic stainless steel, hereon referred to as MSS. These cladding materials were selected from a larger list of potential candidate materials based on their favourable wear and RCF properties seen during twin-disc tests performed previously [2].

2.1 Specimen Manufacture

An iterative process was followed to develop a set of parameters which led to a satisfactorily bonded clad layer on 60-E2 rail. This development process was performed over a period of 2 years prior to this project. Cladding was performed using a Balliu LCF System Laser Cladding Facility with a 6 kW Diode Laser and 4mm diameter focal spot. Rails were clad over a range of different parameters such as laser power, powder feed and scanning rate. These clad rails were then sectioned and examined for: microstructural developments in the heat-affected zone, porosity in the deposit and the quality of the bond between the clad and parent material. This process was repeated until parameters were found which gave the best quality clad which had a martensite free HAZ, was porosity free and well bonded with the parent material.

2.2 Wear (Series 1)

For test series 1 both types of clad specimen were prepared for FSTF testing starting from a standard R260 grade one metre long section with 60-E2 profile. The crown radius and the gauge corners of the rails were machined away to a depth of 2mm. The profiles of the rails were then restored by cladding the deposit materials in two layers which were then ground to restore the original profile and achieve a good surface finish leaving a 2mm thick layer of clad at the surface as shown in Figure 1. Only part of the rail head comes into contact with the wheel, however, the full profile of the rail head was clad to show that the technology is capable of cladding any area of the railhead.

Figure 1: A section image of a R260 60-E2 rail clad to a depth of 2mm used in series 1 tests

2.3 IBJ (Series 2)

For test series 2 the IBJ specimens consisted of a clad one metre long rail with a 6.4 mm wide groove machined into the railhead approximately halfway along its length. A nylon endpost was glued into the groove which had the same profile as the rail and sat flush with the rail crown as shown in Figure 2. This solution did not fully represent an in-track IBJ, but was chosen as it did not require a fully bolted rail joint which would not have fitted into the FSTF without heavy modifications to the machine. For this test the rail surface contact and plastic flow was of interest, and as the rail could not bend within the FSTF so the lack of a full rail joint was not significant.

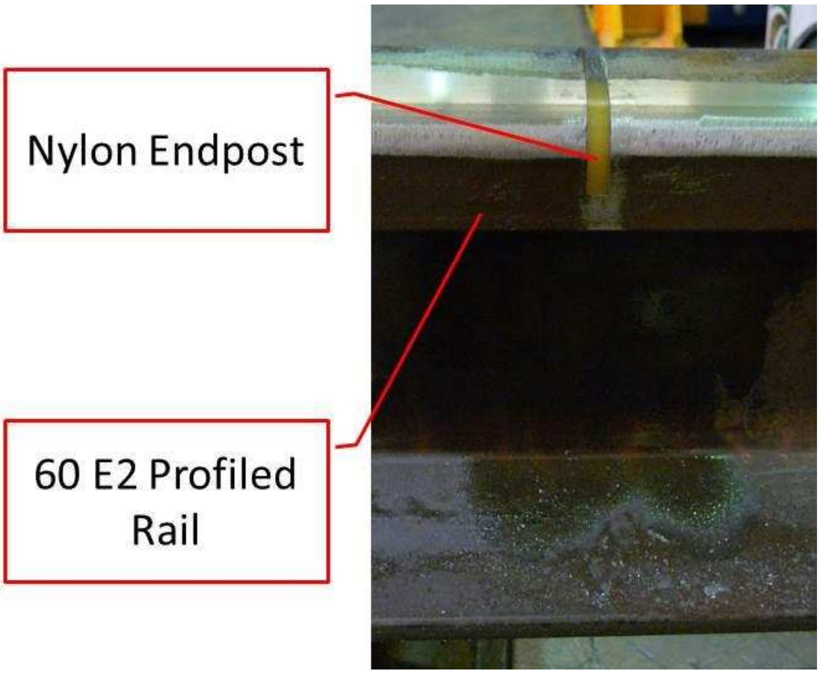


Figure 2: Image of IBJ sample

2.4 Four-Point-Bend Fatigue (Series 3)

The bend fatigue samples were 500mm in length. These samples had the rail web and foot removed to reduce the vertical load required to practical levels to achieve the desired stress range. The need to represent the full rail profile was not deemed to be worth the high cost of profile grinding therefore, after cladding, the bend specimens were machined back to an approximate profile as shown in Figure 3.

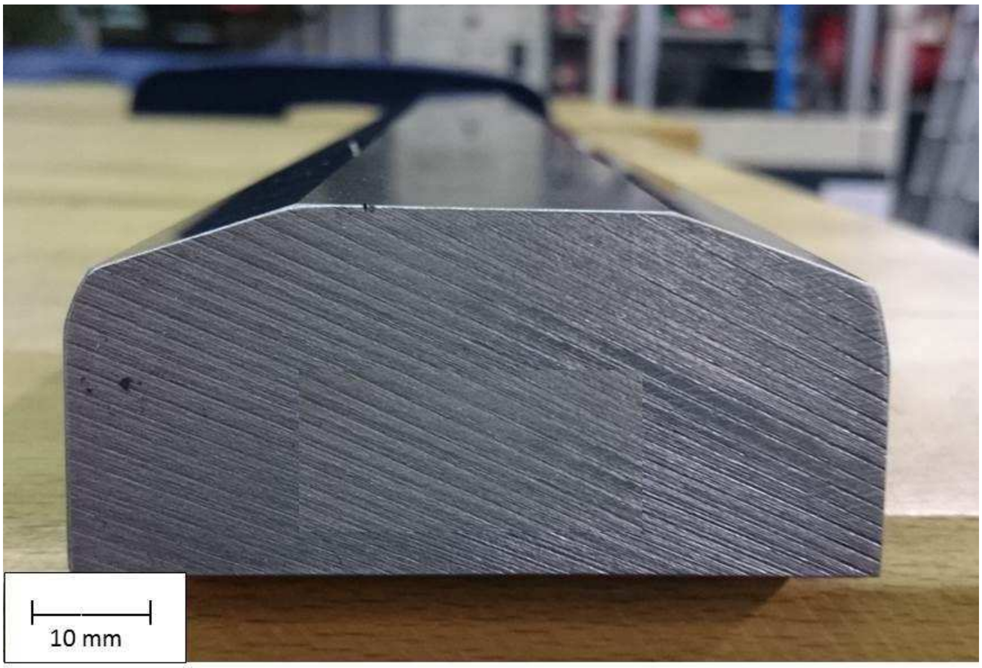


Figure 3: Image of a bend fatigue specimen

3 Apparatus

3.1 Wear and IBJ Tests

For the Wear and IBJ tests (series 1 and 2), clad one metre long rail sections were tested in The University of Sheffield’s Full-Scale Test Facility (FSTF). A schematic of the FSTF is shown in Figure 4. It consists of a locomotive wheel with P8 profile which sits within a pivoted loading frame. The wheel rests on top of the rail specimen under test. Figure 4 shows the operating motion of the FSTF.

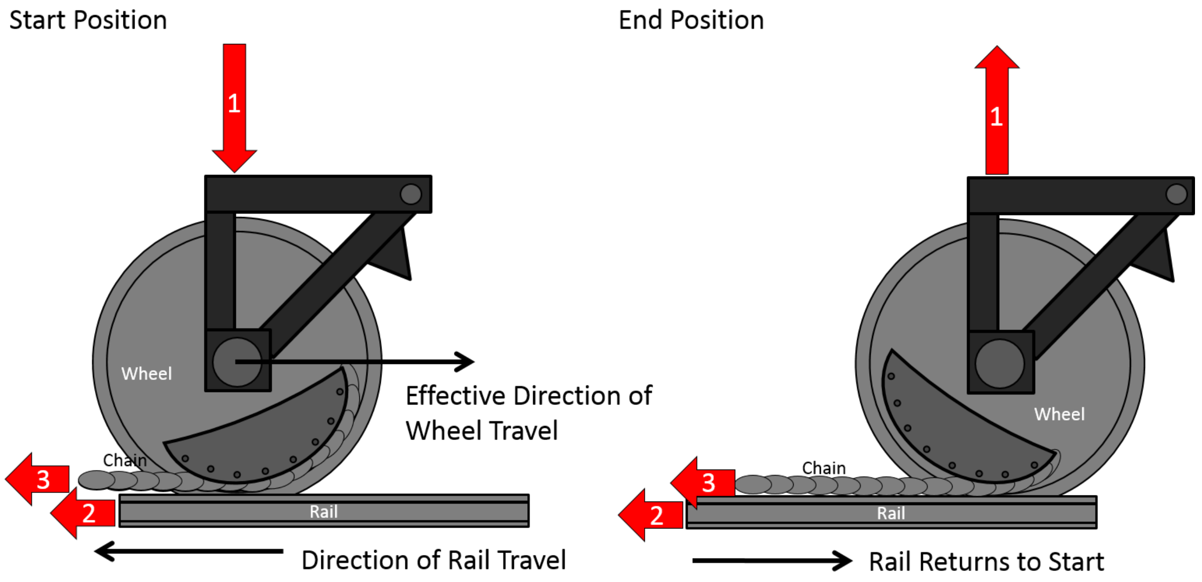


Figure 4: A working schematic of the University of Sheffield Full-Scale Test Facility.

At the start position the specified vertical load (1) is applied representing a half axle load. The rail is then pulled in the direction of travel with the wheel free to rotate as the rail passes underneath it (2). A third actuator connected to the wheel rim via a chain causes creep by pulling the wheel and increasing its surface velocity above that of the rail (3). One cycle is defined as the machine traversing from the start position to the end position and back to the start again.

3.2 Four Point Bend Fatigue Tests

The series 3 four-point bend fatigue tests were performed using a Schenck single axis top loading servo hydraulic machine of 250kN capacity. A two-point loading frame was mounted to the top crosshead of the machine. The bottom two supports were attached to a welded steel frame which sat on the bed of the machine. The top two pivots were 25 mm diameter and the bottom pair were of 60mm diameter. The web and foot of the rails were removed to reduce the load required to achieve a specific maximum stress at the rail head. The samples were 500mm in length. The bottom pivots were set at a distance of 350mm apart equidistant of the force centre giving a sample overhang of 75 mm. The top two pivots were 100mm either side of the force centre as shown in Figure 5.

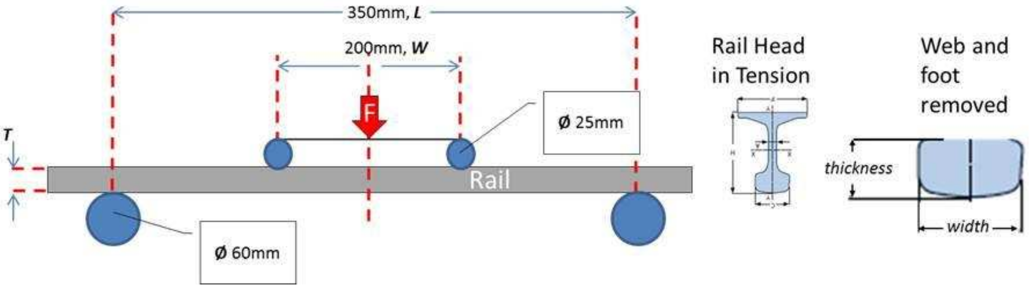


Figure 5: Schematic of the four point bend fatigue test set-up

4 Methodology

4.1 Wear Tests (Series 1)

The original intention was to run the tests until small, nucleated, cracks were visible using a technique developed by Burstow [6]. This technique allowed the measurement of wear and RCF simultaneously. In the wear tests the rail samples were tested in alternating series of 10,000 dry cycles followed by 10,000 wet cycles for a cumulative total of 80,000 cycles. Wear was initially intended to be measured every 10,000 cycles by measuring the rail profile using a Greenwood Engineering Mini-Prof rail profiler. However, it was discovered during the tests that the wear rate of the rail was too low for this technique to capture any wear data. RCF was monitored periodically using magnetic particle inspection, however, no cracks were seen using this method during the entire test regime on any of the specimens. Wear was quantified by measuring the width of the running band on each rail and comparing how much the band tapered along the length of the rail as shown in Figure 6. Tests were performed using a vertical load of 110 kN which gave a contact pressure of approximately 1500 MPa when the wheel and rail profiles were new and unworn. This was measured using ultrasonic measurement of the contact patch [7]. The rail travel distance was 300 mm and a wheel slip of 1% was used.

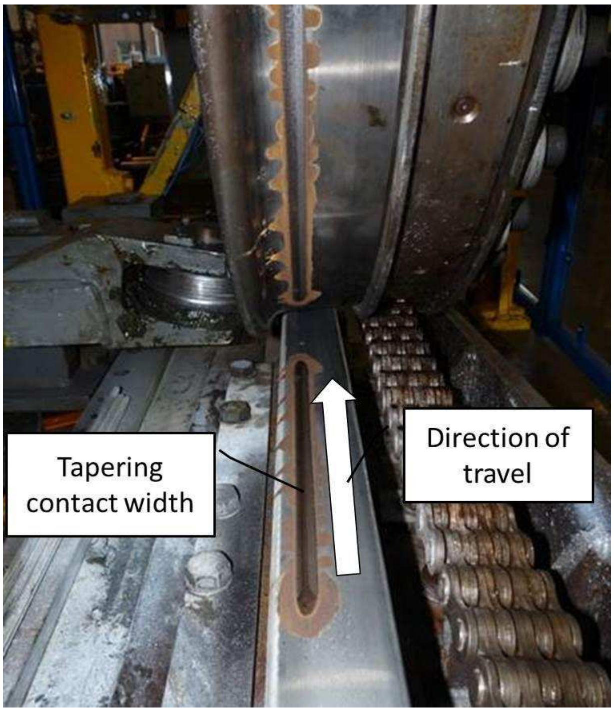


Figure 6: Running band of MSS sample after 50,000 test cycles

4.2 IBJ Lipping Tests (Series 2)

Four IBJ samples were tested including 2 reference un-clad R260 samples and 2 clad R260 samples clad with Stellite 6 and MSS respectively. Lipping of the endpost gap was monitored by measuring the gap every 5,000 cycles. Tests were run in periods of 5,000 cycles until the gap reduction had stopped or stabilised. The IBJ tests were run at 110 kN vertical load, a relatively high slip of 3% and a rail travel of 300 mm. The high slip level was chosen to ensure that lipping of the endpost was seen within a reasonable time frame. A second IBJ reference specimen was run with a reduced slip level of 1% to observe the effect that slip magnitude was having on the lipping rate. All IBJ tests were performed in dry conditions.

4.3 Four Point Bend Fatigue Tests (Series 3)

When a wheel rolls over a section of track which is supported either side of the wheel contact by two equally spaced sleepers the rail head will be subject to a maximum compressive bending stress directly under the wheel. However, either side of the wheel the rail head will be subject to a maximum tensile stress. The tensile region ahead of the wheel will move with the rolling wheel much like “bow wave” [8]. There is currently no standard governing bend fatigue testing of head welded rail. The closest existing standard is NR/SP/TRK111 [9], which governs the bend fatigue testing of flash but welded rail. NR/SP/TRK111 is a Network Rail, UK, standard which specifies that the mean fatigue strength of flash but welded rail should exceed 230 MPa. As the number of samples was limited it was decided to test at a 350 MPa stress range (1.5 times the Network Rail requirement). Should the clad samples still run-out to 5,000,000 cycles then it could still be shown that the samples fatigue strength exceeds 230 MPa. If a sample failed before 5,000,000 cycles, then a new sample of the same material was tested at a reduced stress range until run-out occurred. Table 1 lists the samples tested.

Test No	Clad	Stress Range, MPa
REF-350	No Clad	350
MSS-350	MSS	350
ST6-350	Stellite 6	350
ST6-275	Stellite 6	275
ST6-200	Stellite 6	200

Table 1: Bend fatigue tests performed

All of the clad samples were clad with 2 layers with a nominal 2mm thick coating. An unclad R260 sample (REF-350) machined to the same profile and dimensions was also tested at 350 MPa to act as a reference. An unclad section of R260 rail was chosen as a suitable reference as this is the type of track which is intended to be replaced with clad track.

It has been shown in [10] that the cladding process can generate inclusions in the clad layer and at the clad/parent material interface. These inclusions can potentially be sites for fatigue crack initiation. The heat affected zone, HAZ, is also another potential area of weakness in clad samples. Equations given in [11] were used to calculate the load required to subject the sample to the specified stress range with stress ratio of $R = 0.1$.

5 Results

5.1 Wear Tests (Series 1)

The amount of wear damage seen on all of the samples tested was too low to be measured using a profilometer. Rail wear was therefore assessed by measuring the width of the contact band. Typically, the contact band would taper from start to finish and it was the amount of taper which was used to gauge the amount of wear/damage caused. It is hypothesised that the change in the contact band width arises from a change in the contact conditions as the wheel rolls/slides down the rail and the creep rate increases from zero to steady state. The taper will not arise solely from wear (i.e. material loss) but will also come about due to plastic flow leading to displacement of material to either side of the contact band. The taper is therefore an indication of the amount of damage that each particular material can withstand for a given input (i.e. rolling/sliding contact) energy.

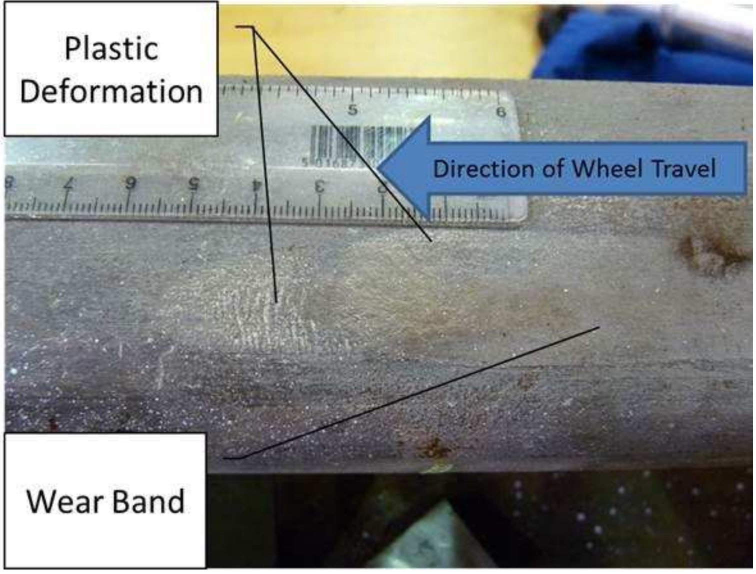


Figure 7: Evidence of plastic deformation on the R260 reference sample after 80,000 alternating dry/wet cycles

Table 2 shows the measurements of the contact bands on the R260, Stellite 6 and MSS rails after 80,000 cycles.

Sample	Width of Wear Band, mm		Taper	
	Start (0 mm)	End (300 mm)	mm	As % of 260-2
R260	13	22	9	-
Stellite 6	12	14	2	22%
MSS	13	14	1	11%

Table 2: Wear band taper results at 80,000 cycles

Figure 8: Illustration of how the wear band taper is measured

5.2 IBJ Lipping Tests (Series 2)

In the IBJ lipping tests the endpost gap was measured every 5,000 cycles up to a total of 40,000 cycles. A machine failure on the FSTF while testing the Stellite sample between 30 – 35,000 cycles meant that only data up to 30,000 cycles could be reported. Figure 9 shows the evolution of the endpost gap for each sample. Three of the samples were tested at 3% slip and a second R260 reference sample was also tested at 1% slip.

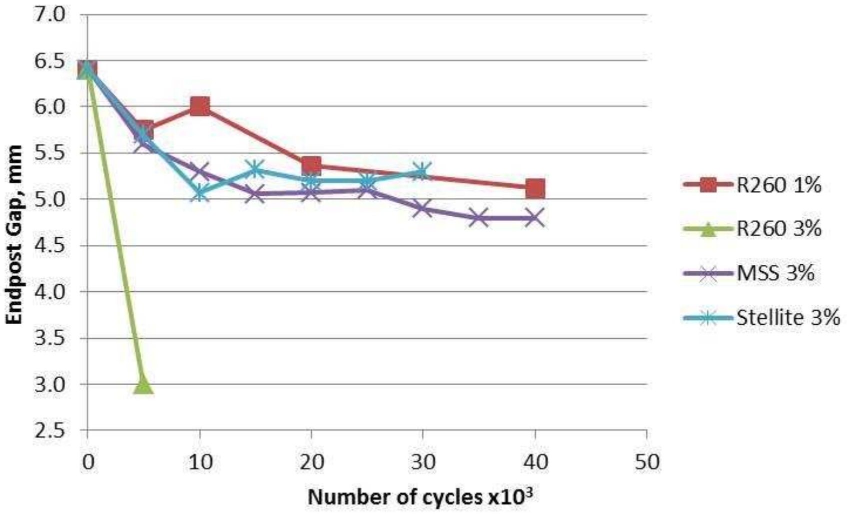


Figure 9: Evolution of the endpost gap with the number of test cycles (R260 3% test stopped early due to large scale deformation)

Figure 10 and Figure 11 show plan view images of the rail head of the R260 and Stellite 6 IBJ specimens tested at 3% slip. The untested IBJ can be seen in each Figure as being straight and un-deformed. After 5,000 cycles for both samples it can be seen how rail material flows across the endpost gap and a lip is formed. The Nylon endpost appears to get crushed by this flowing material.

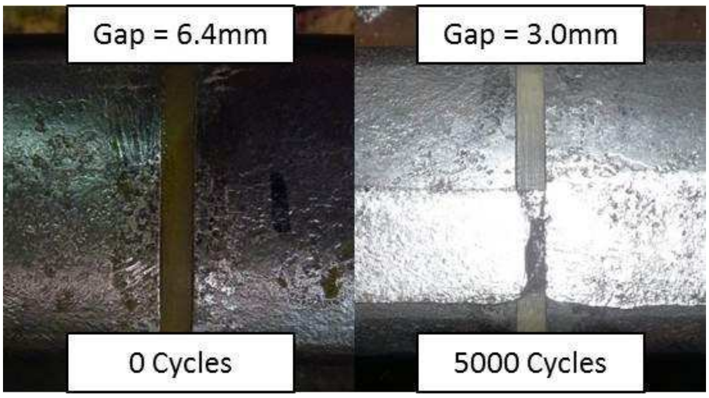


Figure 10: Images of the R260 IBJ specimen before the test and after 5,000 cycles at 3% slip. The rolling direction of the wheel is from left to right

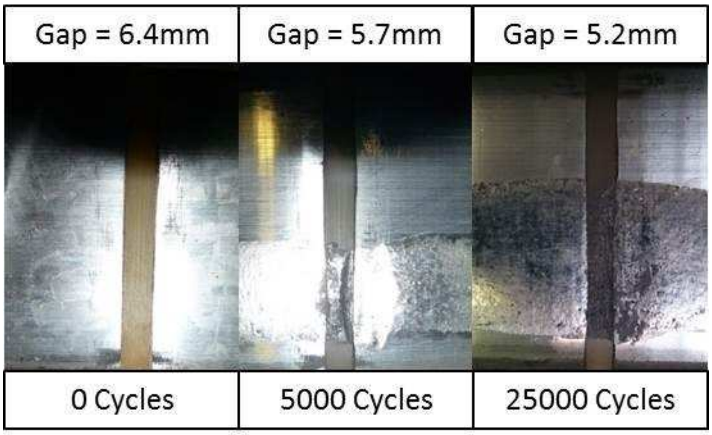
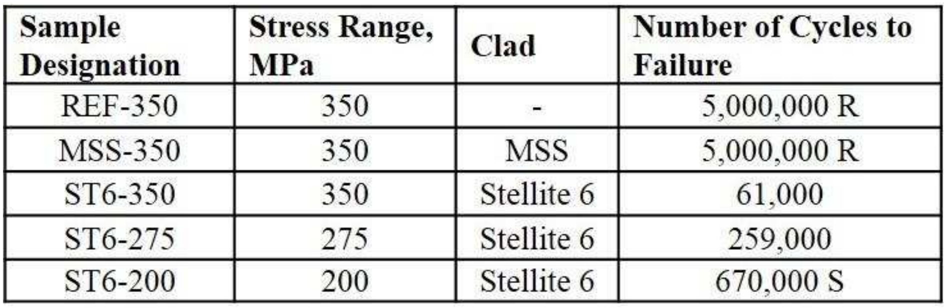


Figure 11: Images of the Stellite 6 IBJ specimen before the test and after 5,000 cycles and 25,000 cycles at 3% slip The rolling direction of the wheel is from left to right. Reflection from the nylon endpost indicates transfer of metal

5.3 Four Point Bend Fatigue Tests (Series 3)

Table 3 shows the results of the 4-point bend fatigue tests. The reference and MSS-350 samples both ran-out when tested at the maximum stress range of 350 MPa. The MSS-350 sample was also tested at 350 MPa and also ran-out to 5,000,000 cycles. The ST6-350 Stellite sample saw complete fracture after only 61,000 cycles. Sample ST6-275 saw complete fracture after 259,000 cycles. Lowering the stress range to 200 MPa on a new Stellite 6 clad sample saw the test run to 670,000 cycles at which point the test was stopped for time constraint reasons.



Sample Designation	Stress Range, MPa	Clad	Number of Cycles to Failure
REF-350	350	-	5,000,000 R
MSS-350	350	MSS	5,000,000 R
ST6-350	350	Stellite 6	61,000
ST6-275	275	Stellite 6	259,000
ST6-200	200	Stellite 6	670,000 S

Table 3. Results of 4-point bend fatigue testing on clad R260 grade rail samples. R indicates run-out, S indicates that the test was stopped with the sample not broken

Figure 12 shows the broken section of the ST6-350 sample which failed at 61,000 cycles.

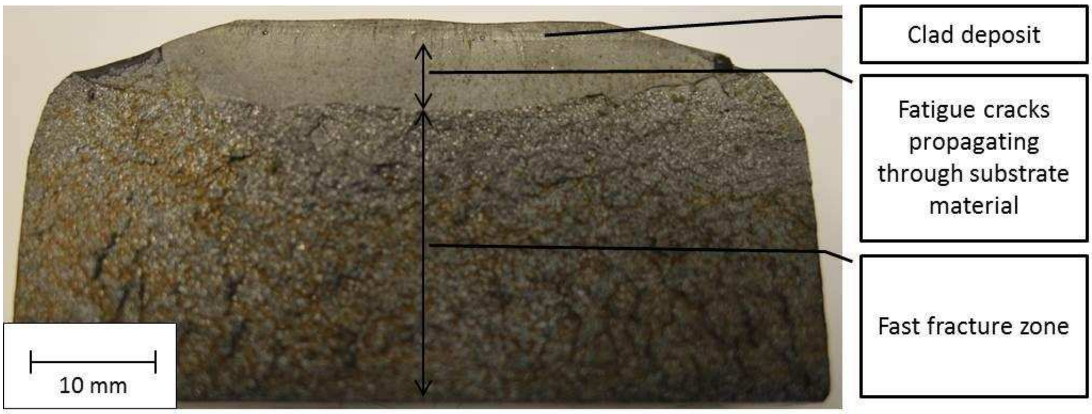


Figure 12: Section view of ST6 – 350 sample after failure at 61,000 cycles

Figure 13 and Figure 14 show close up images of the broken ST6 – 350 sample and show spherical inclusions which were also seen in the Stellite 6 Wear/RCF sample.

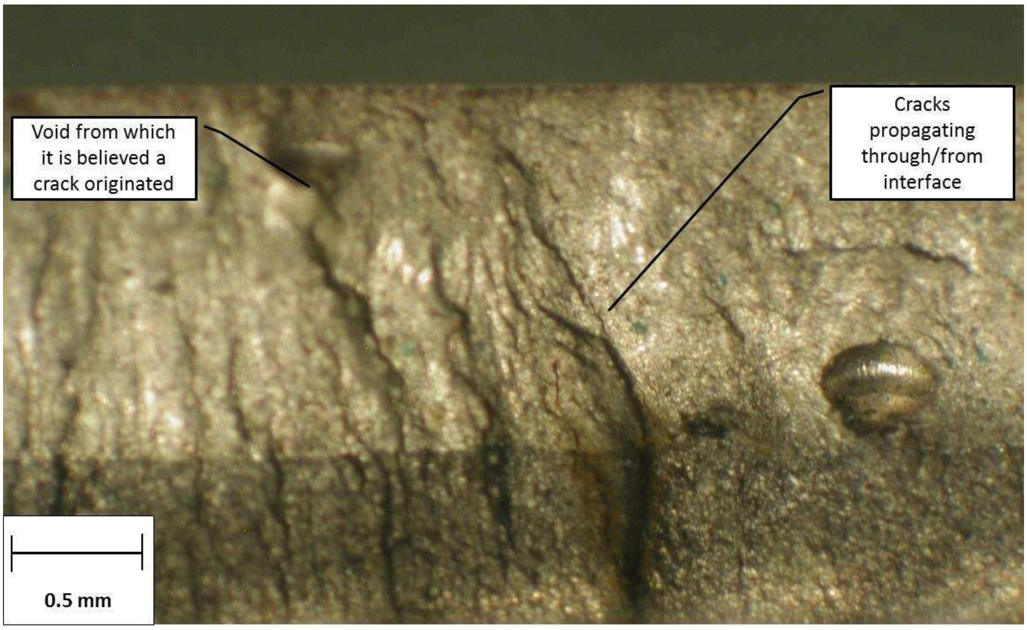


Figure 13: Close up image of broken ST6 – 350 sample section after failure at 61,000 cycles

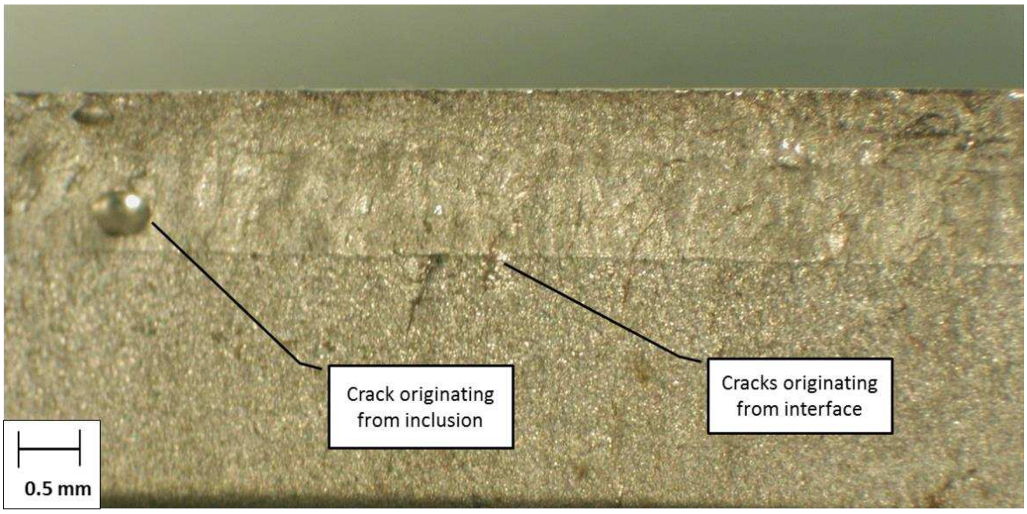


Figure 14: Additional area of close up image of broken ST6 – 350 sample section after failure at 61,000 cycles

It can be seen from Figure 13 and Figure 14 that some of the cracks in the sample appear to originate from the edges of inclusions, some appear to originate from the clad interface and some pass from the clad into the substrate. However, sectioning a sample prior to failure would be required to verify the earlier stays of crack growth.

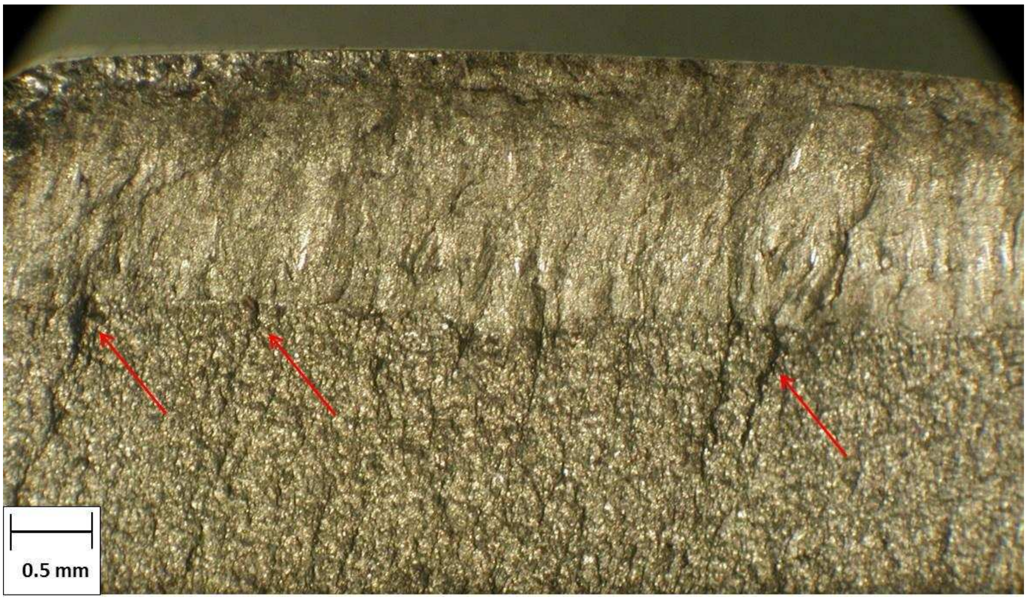


Figure 15: Close up image of broken ST6 – 275 sample section after failure at 259,000 cycles

Figure 15 shows a close up image of the failed section of the ST6 – 275 sample. This sample also had inclusions in the clad layer, however, they were concentrated towards the sample's edges. Cracks were also seen to be growing from the edges of the inclusions downward through the clad/substrate interface. Figure 15 shows cracks growing through the interface between the deposit and the HAZ. It is not clear whether these cracks originate in the clad layer or at the interface. No signs of delamination between the clad and substrate were seen in any of the failed or run-out samples.

6 Discussion

6.1 Wear Tests (Series 1)

The level of wear was too low for it to be measured using a rail profilometer. It can be seen that the width of the contact band at the start is similar for all three specimens (Table 2). As the wheel starts from rest at the beginning of each cycle the slip is zero. The slip increases to the desired level as the wheel starts to roll along the rail. Any other effects such as lateral and spin creep will similarly increase as the wheel begins moving and reaches the desired longitudinal slip rate. Therefore, is it hypothesised that the width of the wear band at its beginning is similar for all samples as the mechanical work which is being put into the rail at this location is the same for all samples tested i.e. pure rolling. It can be seen from Table 2 that by the end of the contact travel the R260 sample has tapered to a greater extent than the Stellite 6 or MSS samples (9mm compared to 1 – 2mm). It is suggested that as the starting contact width is similar for all samples, then the amount of taper can be directly compared between the samples and used as an indicator of the wear/damage resistance of the rail samples. This is because the amount of taper seen on a particular sample will be a reflection of that particular materials ability to resist the shear forces generated within the rolling/sliding contact. A material which is more prone to plastic flow (a precursor to wear and RCF) will experience more material loss or displacement leading to an increased wear band thickness. This larger area is visible in the increased contact width at the end of the rail travel. By this hypothesis it can be said that the Stellite sample wears at a rate of 22% and the MSS sample at a rate of 11% of that of the reference sample respectively. During small scale tests in [2] the Stellite 6 samples wore at an average rate which was 61% of the reference and the MSS samples wore at 19% of the reference wear rate. This difference in relative wear is to be expected due to the different contact conditions between twin-disc and full-scale tests. For example, side flow displacement of material is possible in a full size 3D contact but not in the 2D line contact of a twin-disc test. It also needs to be noted that in these full-scale tests alternating dry and wet cycles were used whereas the twin-disc tests in [2] were fully dry. Burstow [6] performed fully dry and alternating wet/dry tests and states that "the tests run with intermittent lubrication exhibited a wear rate of approximately half that of the dry material".

These tests were intended to test the specimens for their RCF resistance. MPI of all the samples showed no evidence of RCF cracks. Destructive testing of the samples will be carried out at a later date to investigate the sub-surface state of the samples.

The aim of these full-scale tests was to confirm findings from small-scale tests carried out in [2] and assess the integrity of the layer using the real contact situation. Only one of each of the full-scale samples was manufactured due to their high production cost. The relatively long test duration also meant that repeat tests could not be carried out. The full-scale results do, however, reflect those of the small-scale [2] where the MSS sample was seen to wear at a lower rate than the Stellite 6 sample giving confidence in the results seen here.

6.2 IBJ Lipping Tests (Series 2)

It can be seen from Figure 9 that the gap on the R260 sample tested at 3% slip more than halves in 5,000 cycles reducing to 3.4mm. For the same number of cycles, the MSS sample only sees a reduction of 0.8mm and the Stellite only 0.7mm. A second R260 sample tested at a reduced slip of only 1% showed a reduction of 0.6mm. This is quite a significant result as it shows that an endpost between two clad rails can resist almost 3 times the energy input into the contact (i.e. 3% slip compared to 1% slip) as a standard unclad IBJ. This is reinforced by the fact that the R260 sample tested at 1% tends to follow the same trend as the two clad specimens tested at 3% slip throughout the whole 40,000 cycle duration as seen in Figure 9.

Beyond 5,000 cycles of testing the endpost gaps in the Stellite and MSS samples continue to reduce until they reach approximately 5.3 and 5.1mm at 10,000 and 15,000 cycles respectively.

It can be noted from Figure 9 that the R260-1% and the Stellite-3% samples exhibit fluctuating behaviour where the gap reduces, increases and is then reduced again. This phenomenon is caused when metal flows across the endpost gap initially reducing it. Then a part of the deformed metal breaks away increasing the gap again. With more test cycles the material flows across the gap reducing it once more. This is quite clearly seen for the Stellite sample between 10,000 and 20,000 cycles. It is also quite possible that this is what is happening when the gap appears to increase for this sample at 30,000 cycles. A similar variation is seen in rail wear rate during twin – disc testing [13]. It is attributed to the accumulation of strain varying with depth, (driven by varying contact stress with depth) and the strain history of the material wearing away and reaching the rail surface. It is possible a similar mechanism is behind the fluctuation in gap size observed here.

6.3 Four Point Bend Fatigue Tests (Series 3)

Both the reference and the MSS samples both ran-out to 5,000,000 cycles when subject to the highest stress range of 350 MPa. This result shows that a rail clad with MSS meets the NR/SP/TRK111 requirement of a fatigue strength exceeding 230 MPa. However, the Stellite 6 clad rail failed after only 60,717 cycles at the same stress range. At the lower stress range of 200 MPa the rail did not fail before the test was switched off at 670,000 for time constraint reasons. This premature failure of the Stellite samples was initially thought to be solely due to inclusions in the deposit as described in section 5.3. However, residual stress was measured in the specimens after testing using Incremental Centre-Hole Drilling (ICHD) performed 20mm from their cut edge. The ICHD tests revealed compressive stresses in both the longitudinal and transverse directions in the MSS clad at a maximum of approximately 500 MPa at a depth of 0.65mm with a negligible shear stress component through the depth of the clad. The Stellite 6 clad showed tensile stresses in both directions with a maximum value of approximately 870 MPa at a depth of 0.1mm and had a considerable shear stress component through the tested thickness of the clad. This contrast on the residual stress states in the clad layer of the two fatigue specimens will have massively influenced their fatigue strength. The combination of strong tensile stresses and inclusions in the Stellite specimen will have led to the low fatigue strength of this specimen compared to the reference and MSS specimens.

In service rail is typically subject to a maximum stress range of 35 MPa [14] close to the surface of the rail head, based on a 25t axle load. The MSS sample therefore can be said to easily withstand this level of operational loading and has been seen to far exceed the requirements of NR/SP/TRK111. The reference sample (REF-350) also ran-out at 350 MPa. This is believed to be because the rail was free of any weld/potential weak points. An unclad section of R260 rail was used as a suitable reference as this is the type of track which would ultimately be replaced by clad track.

One of the aims of the bend fatigue tests was to investigate the integrity of the clad/substrate interface. Previous work in a number of locations around the world had resulted in delamination of the clad layers under service conditions and this has resulted in a significant degree of scepticism in the rail industry regarding clad surface layers. It has been found that careful control of the microstructure developed in the heat affected zone (HAZ) can avoid substrate cracking and clad layer delamination [10]. Investigation of the failed Stellite 6 samples showed that the clad/parent interface was still in-tact and there was no bulk delamination present see Figures 12, 13, 14 and 15.

From the samples which failed (ST6 – 350, ST6 – 275) (see Figures 12, 13, 14 and 15) it can be seen that cracking appears to start in the clad layer or at the deposit/HAZ boundary and protrude into the substrate material. The MSS clad sample ran-out at the higher stress range it is hypothesised that the stress range in the upper most layer of the substrate material is either insufficient to nucleate cracks or MSS is sufficiently tolerant of small defects which may exist in the deposit and hence the sample does not fail within the 5,000,000 cycle limit. Calculations show that for a sample tested under the 350 MPa range the outer fibre of the sample (clad layer) is subject to a stress of around 389 MPa. Assuming that the clad layer is 2mm deep as designed then the maximum stress seen at the clad/substrate interface is approximately 339 MPa. The outcomes will depend on the presence of fatigue initiators i.e. inclusions and will also depend on the properties of the HAZ. A brittle HAZ will not have a high fatigue strength and this depends on the heat input and subsequent cooling rate during the cladding process. For the Stellite 6 samples it is a combination of inclusions in the clad deposit and a weakness in the interface/HAZ which leads to cracking and ultimately sample breakage but not delamination.

7 Conclusions

7.1 Wear Tests (Series 1)

Full-scale rolling sliding tests have been carried out on sections of rail which were treated with laser cladding. The following conclusions can be made:

- No visible RCF was generated in any of the full-scale test specimens
- Some plastic deformation was seen in the baseline R260 grade sample this being a precursor to RCF formation
- Bulk plastic flow through the depth of the rail was not seen in either of the clad full-scale specimens
- No delamination of the clad layer was seen for either of the clad full-scale specimens
- The Stellite 6 full-scale specimen wears at a rate approximately 22% of the wear rate of the R260 Grade baseline specimen
- The MSS full-scale specimen wears at a rate of approximately 11% of the wear rate of the R260 Grade baseline specimen

7.2 IBJ Lipping Tests (Series 2)

Full-scale rolling sliding tests have been carried out on sections of rail which were treated with laser cladding and had a nylon endpost inserted halfway along their length. It was found that:

- Cladding either side of an IBJ endpost greatly improves its lipping resistance compared to a non-clad standard R260 IBJ
- Cladding of an IBJ allows it to resist approximately 3 times the energy input into the contact as a standard unclad IBJ
- MSS and Stellite clads have approximately equal performance in terms of resisting plastic flow at the simulated IBJ

7.3 Four Point Bend Fatigue Tests (Series 3)

Four point-bend fatigue tests have been carried out on clad sections of rail. Results show that:

- The MSS bend samples did not fail within the 5,000,000 cycle limit while tested at the highest stress range of 350 MPa thus exceeding the NR/SP/TRK111 standard requirement for in service rail to have a bend fatigue strength exceeding 230 MPa
- The Stellite 6 bend samples were stopped at 670,000 cycles at a stress range of 200 MPa, but did fail at higher stress ranges
- Failure of the Stellite 6 bend was linked to inclusions in the deposit. Some cracks in the Stellite 6 bend sample also appear to originate at the clad/substrate interface
- The deposition of a good quality clad with no internal inclusions thus seems to be important to maintaining rail integrity
- MSS therefore shows greater fatigue resistance compared to Stellite 6 when used as a cladding material on R260 grade rail and has a fatigue resistance at least the same as R260 rail
- R260 rail also ran out to 5,000,000 cycles at a stress range of 350 MPa

- When clad onto full-scale sections of representative railhead the MSS material settles with residual stresses of a compressive nature whereas Stellite 6 deposits with residual stresses of a tensile nature
- No delamination of the clad deposited layers was seen in any of the broken Stellite 6 fatigue samples. None of the MSS samples showed delamination within the test time

The MSS clad sample wore at a rate of at least half that of R260 grade rail tested under the same conditions assessed based on running band width development. MSS also shows favourable bend fatigue resistance compared to Stellite 6, and good lipping resistance when used to treat an IBJ.

References

[1] S. R. Lewis, R. Lewis, D. I. Fletcher, 2015. Assessment of laser cladding as an option for repairing/enhancing rails. Wear, Vol. 330-331, pp 581 - 591

[2] S. R. Lewis, S. Fretwell-Smith, P. S. Goodwin, L. Smith, R. Lewis, M. Aslam, D. I. Fletcher, K. Murray, R. Lambert, 2016. Improving rail wear and RCF performance using laser cladding. Wear, Vol. 366–367, pp 268–278

[3] Z. K. Fu, H. H. Ding, W. J. Wang, Q. Y. Liu, J. Guo, M. H. Zhu, 2015. Investigation on microstructure and wear characteristic of laser cladding Fe-based alloy on wheel/rail materials. Wear, Vol. 330-331, pp 592 – 599

[4] W. J. Wang, J. Hu, J. Guo, Q. Y. Liu, M. H. Zhu, 2014. Effect of laser cladding on wear and damage behaviors of heavy-haul wheel/rail materials, Wear, 311, pp 130–136

[5] Beaty, P., Temple, B., Marshall, M.B., Lewis, R., 2015. Experimental Modelling of Lipping in Insulated Rail Joints and Investigation of Rail Head Material Improvements, in press, Journal of Rail and Rapid Transit, Proceedings of the IMechE Part F.

[6] Whole Life Rail Model Application and Development for RSSB (T115) – Rolling Contact Fatigue Testing, Rail Safety and Standards Board Research Program Report, M. C. Burstow, February 2006. http://p.sparkrail.org/record.asp?q=PB009375

[7] Zhou, L., Brunskill, H.P., Lewis, R., Marshall, M.B., Dwyer-Joyce, R.S., 2014. Dynamic Characterisation of the Wheel/Rail Contact using Ultrasonic Reflectometry, Proceedings of Railways 2014, The Second International Conference on Railway Technology: Research, Development and Maintenance, 8-11 April, Corsica, France.

[8] Dukkipati, R.V., Dong, R., 1999. Idealized steady state interaction between railway vehicle and track, Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit Vol. 213 (2), pp 15 – 29

[9] NR/SP/TRK111 issue 3, Flash-weld rails: depot welded strings, 2003

[10] RailClad Project Deliverable D4, Metallographic Characterisation of Laser Clad Rail Samples, Sandra Fretwel-Smith, Tata Steel Rail Technologies., 18th February 2014.

[11] Hearn, E. J., 1977. Mechanics of Materials: an introduction to the mechanics of elastic and plastic deformation of solids and structural components. Vol.2. Oxford: Pergamon

[12] Niederhauser, S., Karlsson, B., 2003. Mechanical properties of laser cladded steel. Materials Science and Technology, Vol. 19, pp 1611-1616

[13] Tyfour, W.R., Beynon, J.H., Kapoor, A., The steady state wear behaviour of pearlitic rail steel under dry rolling-sliding contact conditions. Wear, Vol. 180, 1995, pp 79-89

[14] Jerath, V., Fretwell-Smith, S., YF188_WP5 Discrete Defect Repair 13th February 2008 Science & Manufacturing Technology for Premium Grade Rails A Novel and Cost Effective Semi-automatic Weld Repair Technique for Discrete Rail Defects Corus Rail 13th Februay 2008