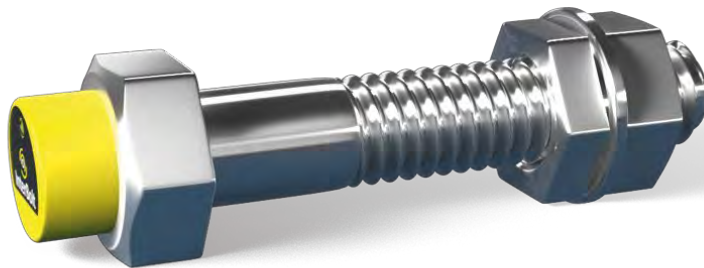




12 Month Report:
Intelligent Bolt Trials for Fishplates & Temporary Clamps



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12 Month Report:

Intelligent Bolt Trials for Fishplates & Temporary Clamps

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Problem Statement:

There are over 500,000 bolted rail joints in the network, which require optimum levels of clamp force to operate safely. There is a current lack of understanding of optimum levels for a joint to fish continuously without the need for constant maintenance. The ability to monitor in track performance hasn't been possible until now. The ability of the Intelligent bolt to provide real time in track data is groundbreaking technology. Using Intelligent Bolt technology allows us to now understand the performance of ALL mechanically jointed connections greater than M10 or ½" diameter bolts / studs in any application.

Customer Statement:

Network Rail was looking for in-track reporting data to challenge the current status quo of maintenance of jointed track which has been in effect for over 50 years. This is a fundamental part of the modernising maintenance Network Rail has been driving through their business over the course of the previous control period. Enabling change to Predict and Prevent Maintenance regimes that make the infrastructure more resilient and reliable for traffic while increasing track worker safety with the removal of boots off ballast.

The budgeted restrictions of CP7 highlight the need to drive change through the Network Rail business that not only increase the safety and reliability of the network but also generate tangible cost benefits such as this project will demonstrate.

Background:

The initial objective was to simply confirm that the Hardlock Nuts performance in track is a superior and a cost-effective solution compared to the current product used in the application of fishplates. As the trials progressed several additional features and benefits became apparent. This report now provides conclusive data for Network Rail to improve the performance of their jointed track with the ability to use Risk Based Maintenance programs to potentially extend the frequency of Basic Visual Inspections.

During the trial, the scope of work has been extended to include intelligent bolts into approved temporary rail clamps.

The trial continues to provide compelling data supporting the transition to metric bolts with zinc coating, Hardlock Nuts and Intelligent Bolts while simultaneously refining training protocols to embody industry best practices.

The trial continues to gather data to provide quantifiable and accurate data which can give confidence and assist to curtail Basic Visual Inspections (BVI's) by up to 75% through the strategic application of Risk Based Maintenance (RBM).

Executive Summary:

The following conclusions can be drawn, which Network Rail should consider for implementation.

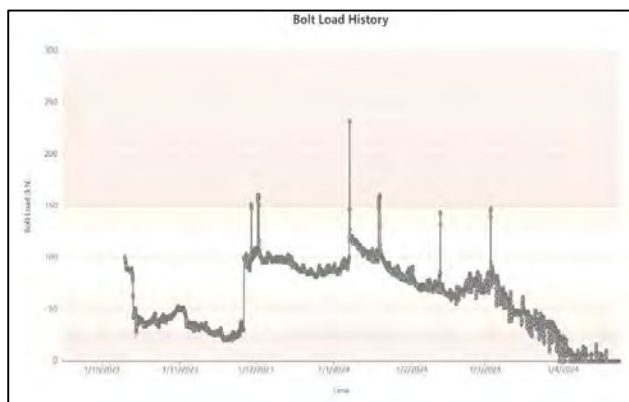
1. Hardlock Nuts have been proven not to loosen under traffic, making this a predictable failure mode, whereas traditional nuts continue to loosen and require continuous maintenance making it impossible to predict failure. This is an important conclusion for the Risk Based Maintenance (RBM) program to remove boots off ballast and improve maintenance efficiency by reducing the Basic Visual Inspection (BVI) frequency.
2. The existing imperial bolt quality doesn't comply with the correct specification. Network Rail should increase quality assurance in this key safety area.
3. Traditional installation method/tools currently overload bolts, taking circa 33% of bolts beyond their yield strength.
4. Installation process (2,3,4,1) needs to be repeated. Initial clamp force in bolts 2&3 reduces by over 30% when 4&1 are tightened thus leaving a potentially failed joint if only one tightening pass is made.
5. Current Network Rail torque values for metric bolts, when installed in track, do not replicate the clamp force recorded in the Network Rail / Tata Steel approval process.
6. The data recorded gives confidence to progress the conversion of all fishplated joints to metric bolts, with Hardlock Nuts and Interflon lubrication, to improve the performance and reliability of jointed track. There is a supporting business case which shows financial benefit. An initial £ [REDACTED] investment is required to convert the entire network, with a payback of approximately 1.6 years. After this, there is an ongoing annual saving of circa £ [REDACTED]
7. There is an upgrade path for fishplate joint conversion, with an option to complete in 1 to 4 years. The maximum efficiency is gained from either 12 or 24 month schedule.
8. Tight Joints, RE/PW/853, was produced 21/01/2020 but not implemented as yet. There is an opportunity to improve tight joints with Hardlock nuts and the trial data gives additional confidence.
9. Defective fishplates cannot be easily identified with RS Clare lubrication. Use of Interflon EP allows clear visibility of fishplates and joints.
10. Uncoated bolts rust resulting in failed bolts in service. An effect of the removal of RS Clare lubrication is that bolts and threads lose the corrosion protection side-effect that the RS Clare provided. Zinc coated bolts have very little price variance against uncoated bolts and so all track bolts should be coated. NB: All bolts that are converted to Intelligent bolts will be supplied with a coating.
11. Heat cycling – a variation in recorded temperature has been recorded between RS Clare/Imperial and Interflon/Metric of $\pm 10\%$.
12. PPE, track worker safety and HAVs. Current Network Rail process of lubrication with RS Clare is a dirty, laborious and arduous task, resulting in a risk to the physical well-being of track maintainers and damage to PPE. Use of heavy, petrol powered machinery increases risk of HAVS.
13. Intelligent Clamps have been successfully trialled and the payback for Network Rail is around 10 days if daily inspections are removed.
14. Existing 'dumb' clamp stock can simply, quickly and cost effectively be converted to Intelligent clamps.
15. Intelligent clamp derogation is required to allow widescale roll out, measuring clamp force every 15 minutes (or other defined time period) whilst moving dip and gap checks to weekly.
16. Opportunity for Network Rail and Network Rail Consulting to share knowledge to their clients worldwide.
17. Interoperability – any bolt or stud above M10 or ½ " diameter can be converted to give intelligence, allowing the technology to be used in all areas of track infrastructure and beyond.

- Hardlock Nuts have been proven not to loosen under traffic, making this a predictable failure mode, whereas traditional nuts continue to loosen and require continuous maintenance making it impossible to predict failure. This is an important conclusion for the Risk Based Maintenance (RBM) program to remove boots off ballast and improve maintenance efficiency by reducing the Basic Visual Inspection (BVI) frequency.**

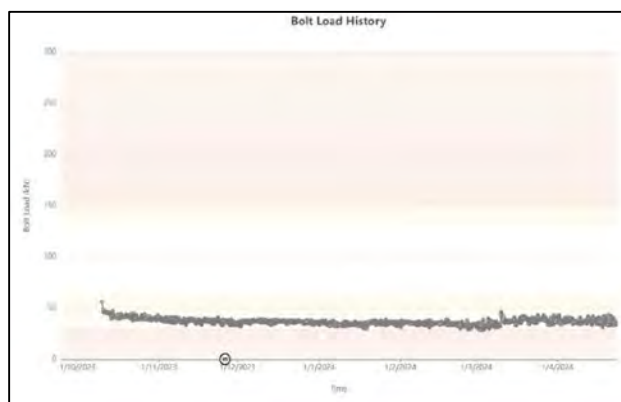
Hardlock Nuts have been installed in multiple railway infrastructures around the world. In the British rail network, they have been installed over 20 years. There are circa 1.5 million Hardlock Nuts installed in the British rail network with no known failures. An important part of the trial was to use technology to unequivocally demonstrate the robustness of the Hardlock Nut in track with scientific data gathered from real world applications to support the laboratory test data. In the graphs below you can see a real-world comparison of the Hardlock Nut and the current nut design used in Fishplates. The graphs clearly highlight the discrepancies in performance when directly comparing the current imperial fasteners to the new metric fasteners. The erratic clamp force achieved during installation, coupled with the inconsistency in the performance of the imperial fasteners, prevents any reliable predictions about failure. This lack of consistency creates uncertainty and makes it difficult to forecast outcomes with confidence.

In contrast, the metric fasteners consistently demonstrate reliable data, which allows for robust failure predictions ahead of time. The stability of the metric fasteners' performance ensures that future failures can be anticipated more accurately, providing a significant advantage over the variability seen with the imperial fasteners.

Further investigations are ongoing to finalise the optimum clamp force to ensure the fishing surfaces perform at their optimum.



Imperial bolt with standard fastener
Large variability in clamp load makes prediction difficult



Metric bolt with Hardlock Nut
 Consistency of clamp load makes prediction possible

Once joints are converted to metric bolts with Hardlock Nuts, data shows that there is now an even distribution of clamp force across the whole joint, which improves joint integrity and eliminate spot loading and / or potential bending forces on the fishplates. This should remove the risk of lateral fatigue cracks and breaks, assuming all other track geometry is within standard.

Evidence from significant lengths of track converted on Wales and Western is that joint gaps self-regulate under traffic.

2. The existing bolt quality doesn't comply with the correct specification. Network Rail should increase quality assurance in this key safety area.

In line with ISO898-1 and ASME A193, the fasteners modified to intelligent bolts undergo a tensile load test on a batch basis. The number of bolts per batch that need to be tested is dependent on the bolt diameter and length but typically this is at least 1 in 100 bolts. Tensile load testing is conducted by an external UKAS approved test house. The results are documented in a tensile load certificate which is then used to update the overall EN10204 3.1 certificate for the batch of bolts.

During the conversion of bolts supplied by either Network Rail or the clamp supplier, significant failures were recorded. There was a failure rate on an average of 20% on fishplate bolts. This increased significantly to a failure rate above 50% when converting bolts for use in temporary clamps.



Images show failed bolts under load test.

3. Traditional installation methods/tools currently overload bolts, taking circa 33% of bolts beyond their yield strength.

During the installation process, using the specified Network Rail tooling of a Bance wrench and breakback torque wrench, a large percentage of bolts yielded due to the uncontrolled power of the Bance and the lack of control/calibration to torque values. This resulted in bolts being installed prone to early failure, exacerbated by the quality of the imperial bolts.

Installing fishplates with metric bolts and Hardlock Nuts using improved, battery-operated, calibrated tooling could remove this failure mode from the application.

The use of the Bance wrench is a major contributor to HAVs in this application. Additionally, the need to transport flammable liquids to site can be removed by changing to battery powered tooling.



4. Installation process (2,3,4,1) needs to be repeated. Initial clamp force in bolts 2&3 reduces by over 30% when 4&1 are tightened thus leaving a potentially failed joint if only one tightening pass is made.

The current Network Rail work instructions for installing and maintaining fishplate joints require the nuts to be tightened in a specific order, this being nut 2, nut 3, nut 4 and then nut 1. All nuts are tightened in a single pass to the full torque value. The use of the intelligent bolt in track has identified a failure in this process. When nuts 4 and 1 are installed, the clamp force already recorded in the initial assembly drops by over 30%. To remove this failure mode, repeating the process of torque checking in the same order of 2,3,4 & 1 will ensure the joint is left in service in the optimum condition. Note that this applies to both metric and imperial bolts and should be adopted as best-practise.



Full Video: <https://vimeo.com/939483991>

5. Current Network Rail torque values for metric bolts, when installed in track, do not replicate the clamp force recorded in the Network Rail / Tata Steel approval process.

The initial installation torque values were based on a trial conducted by Tata Steel on behalf of Network Rail in March 2017. This report aimed to match the clamp force values for each variant of nut tested. The trials were conducted in laboratory conditions, identifying an optimum clamp force of 57kN which suggested an installation torque of 350Nm for the lower Hardlock Nut and 300Nm for the upper Hardlock Nut.

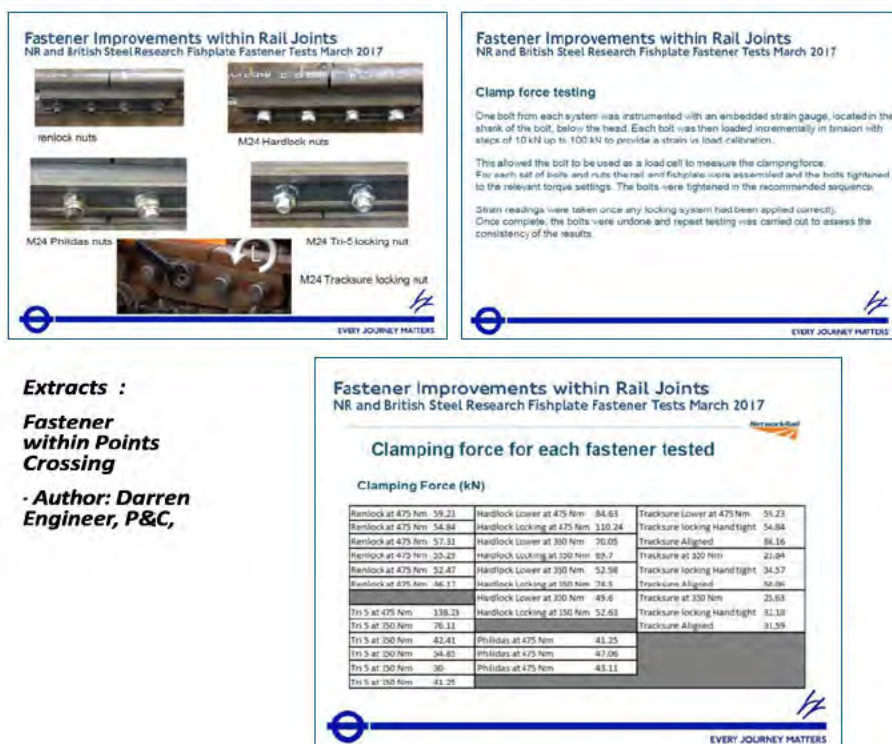
The average installation value for Renlocs installed to the prescribed installation torque of 350lbs/ft was 141kN with the lowest recorded at 72kN and the highest recorded at 230kN.

The data recorded is considerably higher than that of the baseline data from Tata Steel.

When considering the baseline data for the metric fasteners with Hardlock Nut, an average of 64kN was recorded with a lowest of 47kN and the highest recorded of 96kN. No consideration was given for any loss due to settlement/embedment of the fastening. This is an area for improvement that requires further investigation to enable the optimum performance to enable the joint to fish as per its design criteria.

Some bolts are reporting a gradual decline in bolt load over time. This is likely to be a result of low bolt leading to the bolted connection seeing a greater amount of the dynamic loading. This in turn will exacerbate vibration induced loosening. If the bolt has a higher bolt load, it is likely that the severity of this would be significantly reduced. The average bolt load of metric bolts after settling and embedding losses were taken into account was 39kN which is around half that expected for the application.

As part of the trial, the torque value was increased to 375Nm on the lower nut with the upper nut retained at 300Nm, this increase demonstrated our initial report recommendations. The slight increase in clamp force resulted a stronger set of results, providing further support for an RBM process of change to BVI's.



6. The data recorded gives confidence to progress the conversion of all fishplated joints to metric bolts, with Hardlock Nuts and Interflon lubrication, to improve the performance and reliability of jointed track. There is a supporting business case which shows financial benefit and a reduction of boots on ballast.

Upfront Costs:

- **Initial Upgrade Cost:** £ [REDACTED] (for the entire upgrade program over a control period)
 - This is the upfront investment Network Rail must make to purchase materials for the upgrade. This cost is over and above what is spent under the current process.

Ongoing Benefits:

1. Material Purchase Savings:

- **Annual savings:** £ [REDACTED] per year in material purchases after the upgrade is complete.
- This represents a direct, recurring reduction in costs related to material procurement.

2. Man-Hour Savings (Track Access Time / Boots on ballast):

- **Annual savings:** 125,000 man-hours saved per year due to the upgrade.
- At £ [REDACTED] per hour, this translates to £ [REDACTED] in savings annually (£ [REDACTED] * 125,000 hours).

This is a significant saving in terms of labour costs for track access.

3. Additional Costs (Other Departments):

- It's noted that the costs to other departments (involved in track access and coordination) could be 2 to 3 times the figures quoted for direct material and man-hour savings, which suggests a wider ripple effect on cost reduction across the business.

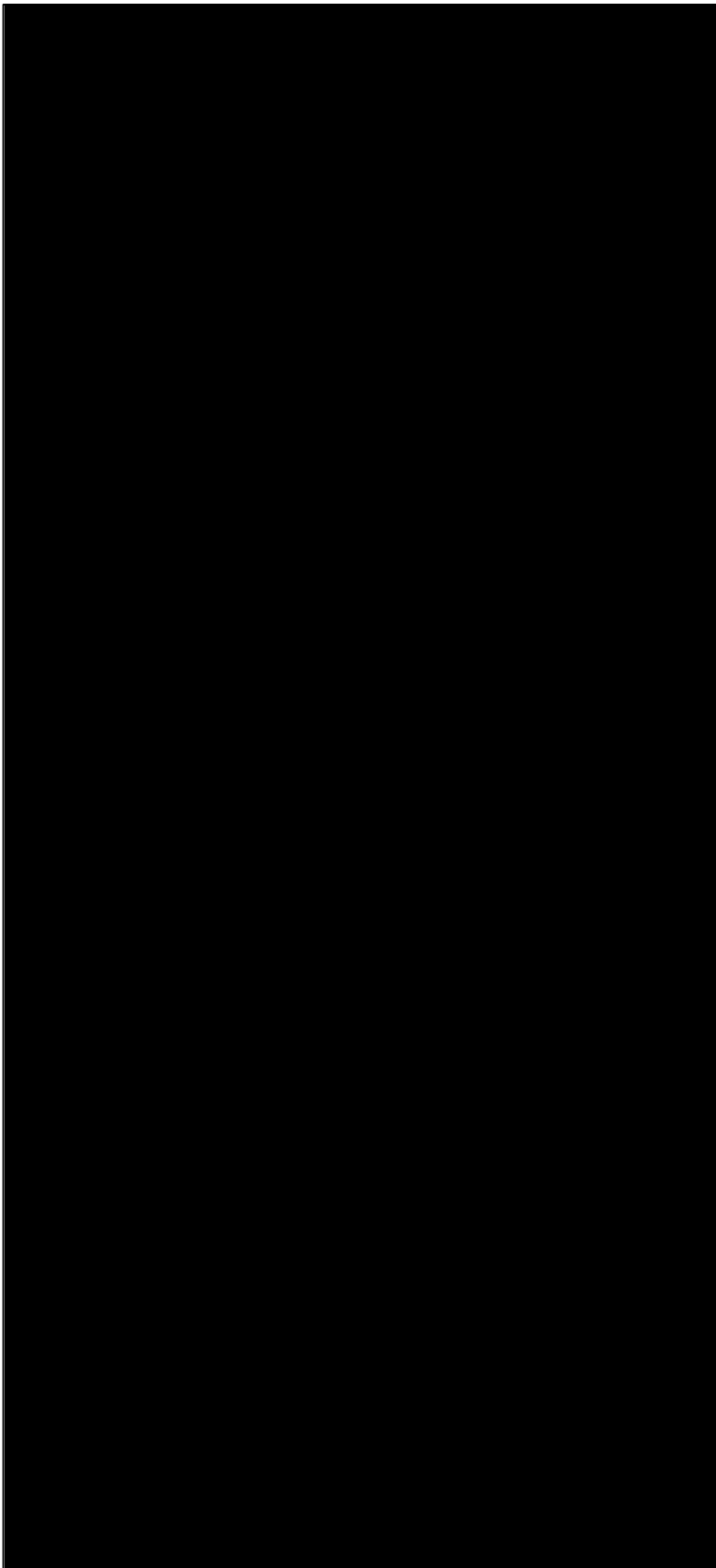
However, since the exact additional costs are not quantified, this would have to be factored in to get a complete picture of savings.

Cost Neutrality:

- The £ [REDACTED] upfront cost for the upgrade is effectively offset by the annual savings of £ [REDACTED] in material purchases and £ [REDACTED] in labour savings, totalling £ [REDACTED] in annual savings.
- Over time, the ongoing savings from reduced material purchases and labour costs will exceed the initial investment. Given that the savings occur annually, the payback period for the initial £ [REDACTED] is roughly **1.6 years** (i.e., £ [REDACTED] / £ [REDACTED] per year).

Conclusion:

Based on this analysis, the upgrade program appears to be **cost neutral** or potentially even financially advantageous in the long term due to the recurring benefits. After the initial investment, Network Rail can expect to see **net annual savings** and reduced operational costs, particularly in material purchases and labour time for track access. This would make it a worthwhile investment for Network Rail, especially considering the indirect benefits for other departments and the potential for further operational improvements.

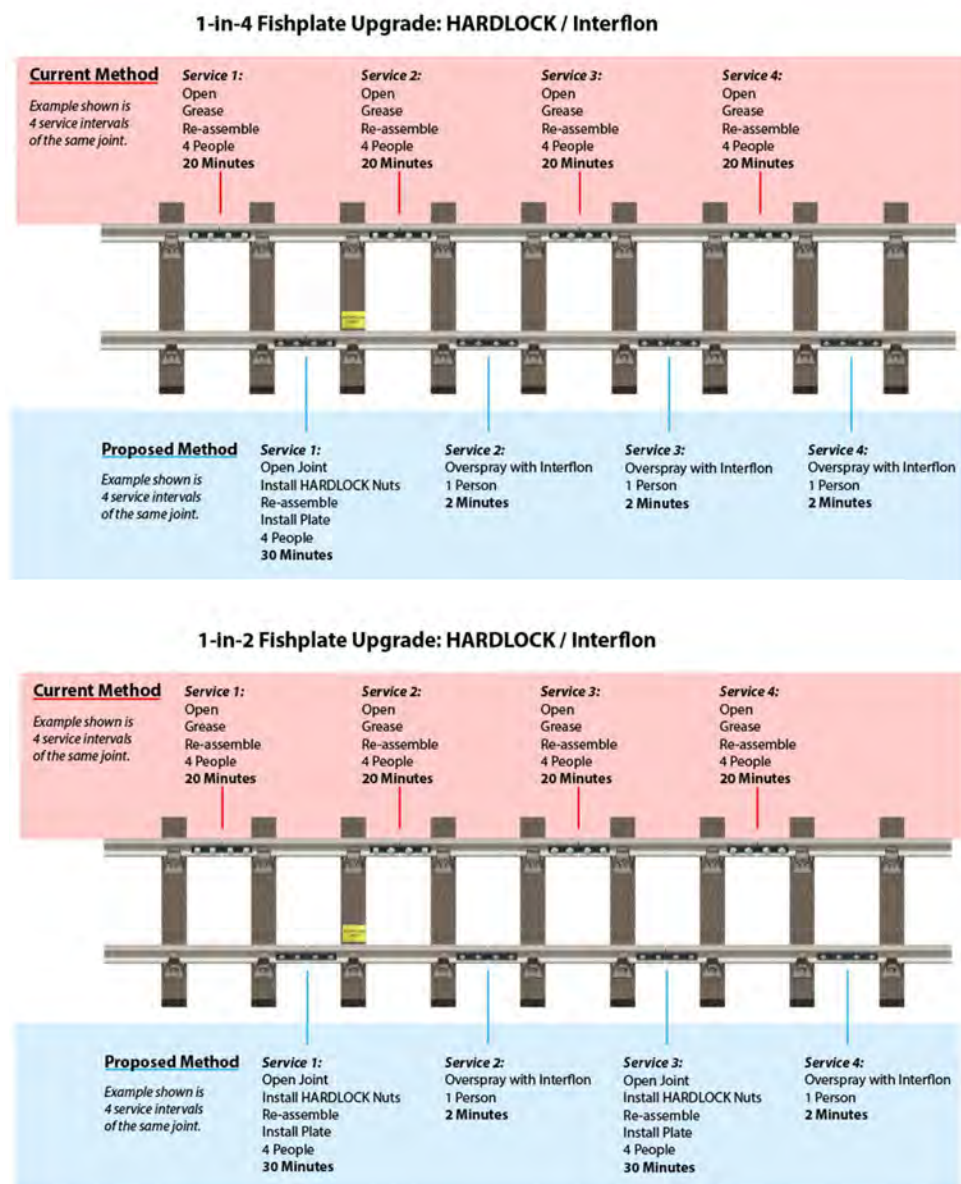


Example data from business case calculator
* Assumptions based on data supplied by Network Rail
March 2023

7. There is an upgrade path for fishplate joint conversion, with an option to complete in 1 to 4 years. The maximum efficiency is gained from either 12 or 24 month schedule.

The original fishplate upgrade program allowed for a 1 in 4 upgrade, with the remaining 3 joints being over-lubricated with Lube EP. One of the early adopters of this program was Dave Deeley from the Wales & Western route. Upon reviewing the 1 in 4 upgrade strategy, he pointed out that the primary benefit of the new maintenance program—the time and cost savings from 'oiling' upgraded fishplates—would not be fully realized by his route until all joints were upgraded.

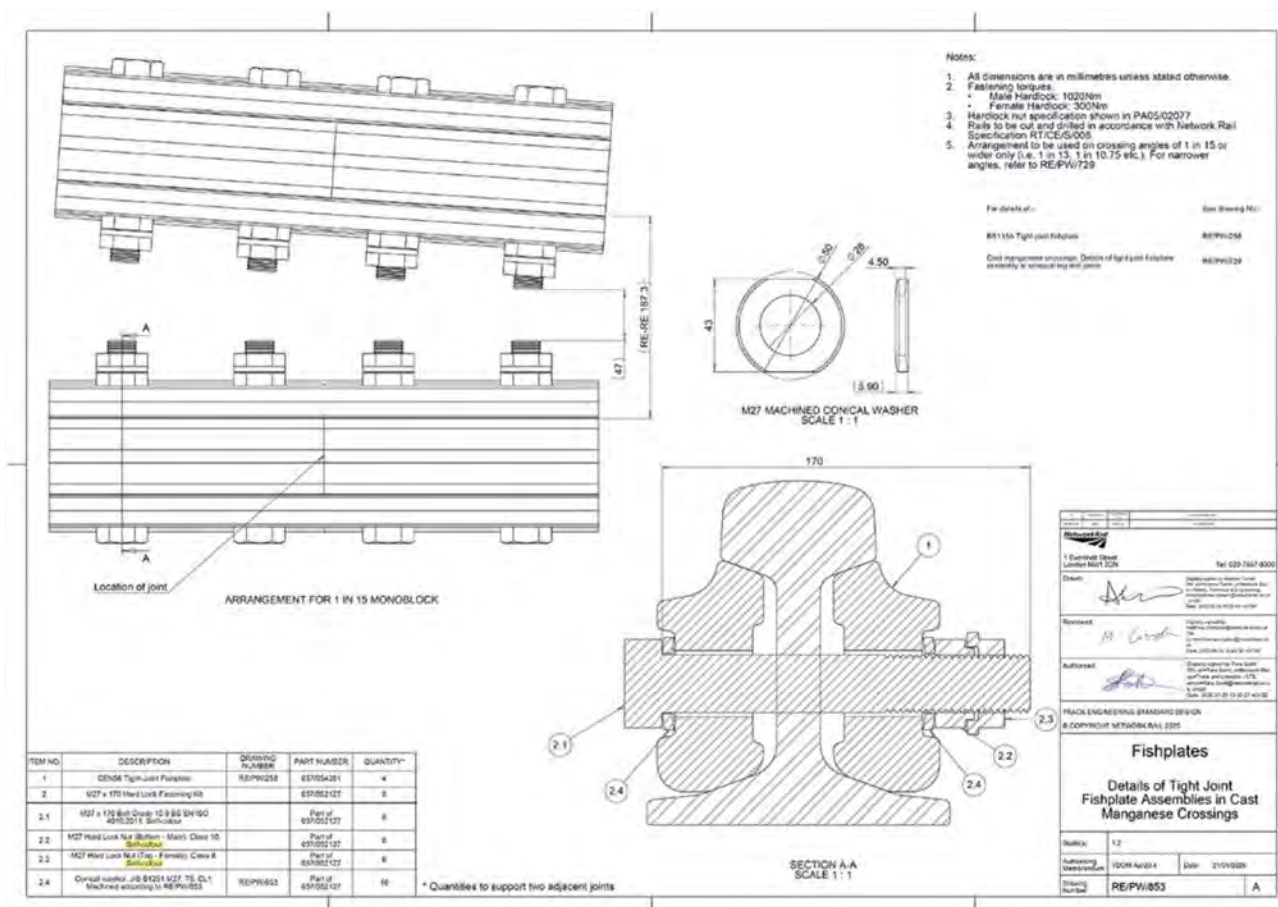
As a result, they adopted the best practice of upgrading 1 in 2 joints instead. The key benefit of this approach is straightforward: by upgrading more joints within the current maintenance cycle, they can begin realising time savings in year 3. This also allows for the redeployment of personnel to other critical aspects of infrastructure maintenance.



8. Tight Joints, RE/PW/853, was produced 21/01/2020 but not implemented as yet. There is an opportunity to improve tight joints with Hardlock nuts and the trial data gives additional confidence.

Tight joints have mostly been replaced with Continuous Welded Rail (CWR), but numerous still remain in the track without being upgraded to include the replacement of imperial fasteners with metric ones, along with the use of Hardlock Nuts. Network Rail drawing RE/PW/853 was produced and released on January 21, 2020. However, there has yet to be a widescale rollout to upgrade these legacy in-track units or the adoption of the updated drawing by first-tier manufacturers.

The data presented in this report strongly supports the need to reignite this rollout. It is clear that the performance of the current imperial fasteners—by design similar to fishplate bolts—could significantly improve with the adoption of the updated fasteners. The torque values specified for this application could be reviewed using data gathered from intelligent bolts to confirm that the appropriate values are being specified.



9. Defective fishplates cannot be easily identified with RS Clare lubrication. Use of Interflon EP allows clear visibility of fishplates and joints.

Although the number of cracked fishplates is not consistently or rigorously reported across the network, it remains a very common issue. The current maintenance method, which involves applying a thick layer of black grease, often conceals cracks of any size or depth. These cracks remain undetected until the fishplate eventually fails and separates into two pieces.

In contrast, Interflon Lube EP is transparent, and while switching lubrication materials will not directly prevent failure, it will allow any potential defects to be identified much earlier. This proactive approach facilitates the early detection of cracks, enabling the timely removal and replacement of failed joints with new plates before further damage occurs.

Traditional grease



Interflon Lube EP



- 10. Uncoated bolts rust resulting in failed bolts in service. An effect of the removal of RS Clare lubrication is that bolts and threads lose the corrosion protection side-effect that the RS Clare provided. Zinc coated bolts have very little price variance against uncoated bolts and so all track bolts should be coated.**

Traditionally black bolts have benefited from layers of black grease smeared across not just the fishing surfaces but also the bolts. The hidden benefit means that the old imperial bolts are not prone to rusting. Moving to the new lubrication process of Lube EP from Interflon removes these layers of grease therefore the bolts are open to the elements and corrode over time, this is now a new failure mode that needs to be addressed. Grit has also contaminated the threads resulting in thread strip of the bolts requiring the use of disc cutting equipment to remove the seized components.

The bolt shown in the photo below failed due to corrosion and not the material quality / specification. The track was also in poor condition where the joint had known dip angle and voiding. This is fully explained in the independent test report included in the Appendices.

To remove this failure mode Network Rail should consider moving to a zinc plated bolt in line with the finish of the Hardlock Nut ie. an already approved coating. It is worth noting that the cost variance between a self-colour bolt and a zinc plated bolt is comparable. Network Rail tends to store products outdoors, in this scenario there is a high probability of self-colour bolts rusting prior to installation.

As a result of the trial, all new Intelligent bolts will be supplied with a zinc coating. Without any form of corrosion protection, the spread of the corrosion from the bolt head where the Cap is secured has the potential to cause the connection to fail. We have noted this in 4 bolts installed during the trial period.



Failed metric bolt due to corrosion

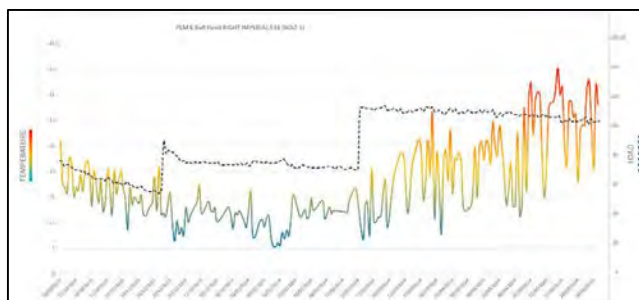


Bolt corrosion leading to seal failure and moisture ingress

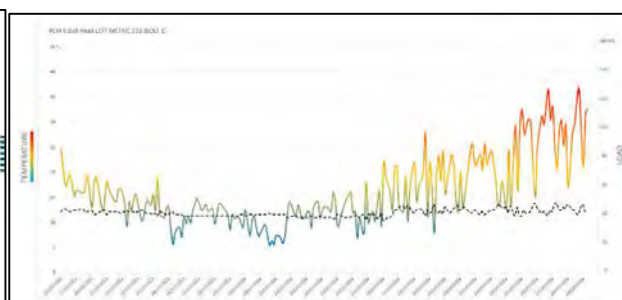
11. Heat cycling – a variation in recorded temperature has been recorded between RS Clare/Imperial and Interflon/Metric of $\pm 10\%$

The intelligent bolt not only records clamp force, but also monitors the internal temperature of the bolt, providing a core temperature rather than just a surface temperature. This offers a more accurate reflection of rail temperature. From the data collected, it has been observed that imperial joints lubricated with RS Clare lubricant generate and retain, on average, approximately 7% more heat.

Imperial



Metric



While it's currently difficult to provide definitive reasons for this heat increase, several factors could contribute. One possibility is that the higher clamp force required for imperial joints generates more heat. Additionally, RS Clare lubricant in this application may create a vacuum effect, which could also necessitate greater force to fish due to seized joints, contributing to the elevated temperatures.

Since heat buildup is a primary risk factor for track buckling this issue should be explored further, if funding from Network Rail can be made available.

Network Rail requested that Tata Steel Rail Technologies (TSRT) conduct laboratory testing (December 2011) on a range of fish plated joint lubricants in order to benchmark their performance and support the creation of a new Network Rail product standard for fishplate lubricants. A copy of this report is attached in the Appendices.

Extracted from this report *'The load on the lubricated fishplate significantly reduced immediately after the Interflon application, thereafter the load remained constant. The dry fishplate resulted in a very low load of only 1.2kN after 258 cumulative cycles. For the dry fishplate, over 80% of the load reduction following Interflon application occurred in the first ten cycles'*. The load reduction will have a significant impact on the forces required for the joints to fish which indirectly will reduce the retained heat within the joint.

12. PPE, track worker safety and HAVs.

Current Network Rail process of lubrication with RS Clare is a dirty, laborious and arduous task, resulting in a risk to the physical well-being of track maintainers and damage to PPE. Use of heavy, petrol powered machinery increases risk of HAVS.

The current methodology places a significant strain on both personal protective equipment (PPE) and the physical well-being of track maintainers. The task of lubricating is not only dirty and labour-intensive but also results in stains on PPE and workers' hands. This compromises the reflective capability of the PPE, which is essential for safety during nighttime operations, raising concerns about the visibility and overall protection of workers.

Additionally, the process requires the transportation of heavy equipment powered by petrol. Network Rail has long been focused on eliminating the need to transport and use petrol, both in vans and on-site. Although Network Rail has begun introducing battery-powered technologies, the current process still involves the use of a Bance, a device that introduces significant hand-arm vibration syndrome (HAVS) risk, limiting its usage to just 8 minutes per hour per operative.

By adopting and rolling out the fishplate upgrade program, the time spent on track at each joint will be reduced by 19 minutes. This will significantly enhance track worker safety and eliminate the need to transport heavy equipment and flammable liquids to the site. Going forward, maintenance will only require a torque wrench and a backpack containing Interflon Lube EP, streamlining the process and improving both safety and efficiency.



13. Intelligent Clamps have been successfully trialled and the payback for Network Rail is around 10 days if daily inspections are removed.

Temporary rail clamps require visual/physical inspection every 24 hours to check that the clamps are still attached, that there is no voiding and that the gap in the rail remains in specification. This inspection regime was introduced following various failures where clamps had fallen off in service presenting a serious derailment risk. The gap and dip measurements are incidental inspections when the daily clamp inspections take place as they do not provide an immediate derailment risk.

Whilst one person is required to 'kick the clamps' there are many others involved in providing track access, safe system of work, permits, safe work pack, line blocks, train management etc.

The intelligent clamps measure and report clamp force every 15 minutes, or any other time period specified, remotely via a portal, meaning that no track access is required to monitor the integrity of the clamps. This in due course will provide the opportunity to remove the requirement for a daily physical check of the clamps, removing boots off ballast whilst significantly reducing costs. If the track is handed back as per NR/L2/TRK/001 mod 13 table 7, the track should be in a compliant and stable condition, which means there should be no voiding, dip angles or wide gaps. The most critical inspection is the integrity of the clamp, which is now remotely monitored on a continuous basis.

Based on the cost involved of clamp inspections along with supporting back-office staff, the cost of the intelligent clamping system will see client payback in approximately 10 days.

Further trials have been completed with use of a self-powered gateway which allows deployment anywhere in the field. The current self-powered gateway uses both battery and solar technology. Further developments continue at pace to provide a full battery only variant with up to 45 days charge capacity.



14. Intelligent clamp derogation is required to allow widescale roll out measuring clamp force every 15 minutes whilst moving dip and gap checks to weekly.

Network Rail currently have a PIN listed for the development and supply of a Smart Rail Clamp, which measures the clamp force, dip and gap in a single device. Discussions with many experienced track engineers conclude that only the clamp force measurement is safety critical. Clamps fitted with the intelligent bolt satisfy this requirement, however a derogation will be required to allow wider scale to roll out. This would see physical inspections changed from daily to weekly. As over 90% of temporary clamps are removed within 1 week this offers a huge opportunity to remove boots off ballast and significantly reduce costs. Measurements are recorded every 15 minutes, but this frequency can be increased if required. This offers a step change in the management of the risk of clamp failure.

The screenshot shows the Network Rail Bravo portal interface. At the top, there's a navigation bar with the Bravo logo and a timestamp of 09:03. Below this, the breadcrumb trail indicates the current page is for 'Project: project_37306 - Instrumented Rail Clamp System Requirements. Wales & Western Region'. The main content area is divided into sections: 'Details', 'Published Opportunity', 'Project Details', and 'Opportunity Details'. Under 'Project Details', the 'Project Code' is 'project_37306' and the 'Project Title' is 'Instrumented Rail Clamp System Requirements. Wales & Western Region'. Under 'Opportunity Details', the 'Project Description' is 'Instrumented Rail Clamp System'. The description text explains the purpose of the rail clamp and the project's aim. The 'Notes' section contains three numbered points providing additional context and instructions. The 'Work Category' is 'Supplies', the 'Listing Deadline' is '12/10/2023 17:00', and the 'Contract Duration' is 'tbc'. The 'Procurement Route' is 'FTS Negotiated', the 'Contract Start Date' is '01/11/2023', and the 'Estimated Value of Contract' is '300000'. The 'Kind Regards' section is signed by Kevin Ritchie, Senior Procurement Manager, Wales & Western Region.

Project Code project_37306	Project Title Instrumented Rail Clamp System Requirements. Wales & Western Region
Project Description Instrumented Rail Clamp System Rail clamps have been widely used in the UK rail network to join unwelded sections of rail for many decades. The purpose of the rail clamp is to temporarily provide a robust joint between two sections of rail, until it is possible to weld the rail sections together. Whilst a rail clamp is in place, it is required to be monitored at 24-hour intervals to ensure the integrity and safety of the joint. The inspection specifically requires assurance that the joint deflection, rail to rail gap and clamping force has not exceeded the limits set in Network Rail track standards. The aim of this project is to deliver a system that meets all standards relating to rail clamps and track mounted components which also can be maintenance free. It must deliver a safe and secure clamped rail joint. If applicable the solution can be integrated into an already product approved clamp. It must be able to reliably transmit data that can be used to aid the application of understanding the condition of the joint, to remove the requirement of physical/manual inspection of the temporary clamp.	
Work Category Supplies	Procurement Route FTS Negotiated
Listing Deadline 12/10/2023 17:00	Contract Start Date 01/11/2023
Contract Duration tbc	Estimated Value of Contract 300000

Notes

1. This PIN is an extension of a PIN previously published. The PIN has been updated to include addition information and instruction to interested parties within the supply chain.
2. The Contract Start Date and the Estimated Contract Value is, at this point in time, indicative. The Procurement events (Pre-Qualification Questionnaire (PQQ) and Invitation to Tender (ITT) which follow this PIN, will provide greater clarity on the Network Rail project. Please note concurrent to this PIN an Expressions of Interest (Eoi) has been published in BravoNR to all suppliers. Eoi reference in BravoNR: pqq_3225. Closing date and time: 13/10/2023 17:00.
3. Please refer to the attached document titled "Instrumented Rail Clamp System Requirements-FINAL" for further technical information.

Kindly email me at the email address given if 1) your organisation has accessed this PIN; and 2) if your organisation is interested in undertaking this activity for Network Rail. To assist Network Rail with this project you are requested to respond to the Eoi if 2) is applicable.

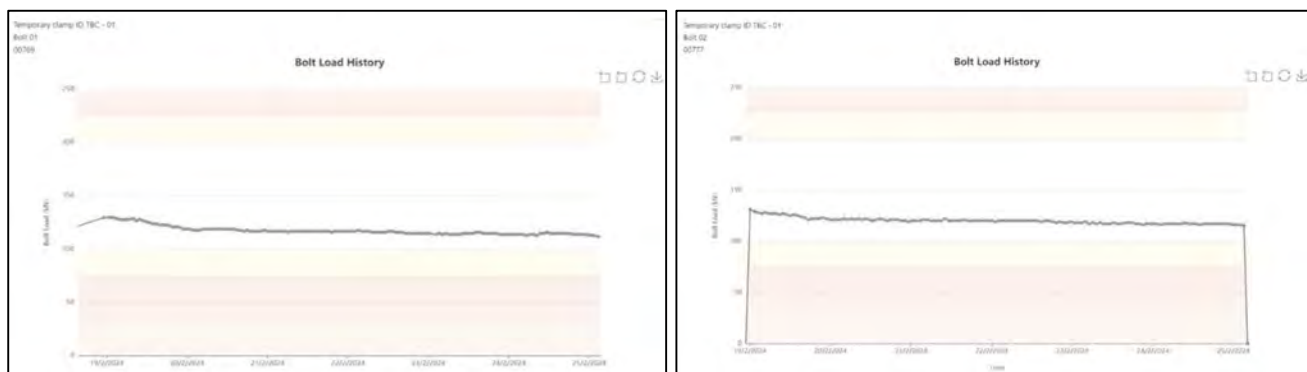
Kind Regards
Kevin Ritchie, Senior Procurement Manager, Wales & Western Region

Extract from Network Rail Bravo

15. Existing 'dumb' clamp stock can simply, quickly and cost effectively be converted to Intelligent clamps.

One of the current suppliers of 'dumb' clamps (Henry Williams) notified Network Rail of their intention to close the forge in Q2 2024. As a result, Network Rail took a business decision to procure 7,200 clamps to ensure continuity of supply whilst a new supplier is identified. These clamps are currently being delivered into the network. These provide a quick and cost-effective opportunity for conversion to Intelligent clamps. In addition to this, extensive discussions have taken place with all Network Rail approved clamp suppliers to convert to Intelligent clamps. So far Codiun, Robel and Geismar clamps have been upgraded.

The images below show a Temporary Intelligent Clamp installed at Park Junction, Newport. Intelligent Temporary Clamps upload telemetry to the cloud every 15 minutes providing 672 data points logged per week. There was no disruption, or any concerns to the clamp and data transmission, under tamping.



Data covering a 7 day installation

16. Opportunity for Network Rail and Network Rail Consulting to share knowledge to their clients worldwide.

The first publication of the intelligent clamp via LinkedIn generated responses from over 35 countries expressing an interest. Network Rail Consulting operates on a global basis providing best practice to rail companies. As an early adopter of this product, they could take first mover advantage and gain significant traction with both new and existing clients. We are working with international suppliers of clamps so the synergies for collaboration are significant.



Steve Featherstone FREng • You
Chair, Non Exec, Senior Advisor
6mo • 

Temporary clamps have a history of sometimes coming loose and falling off. Because of this the **Network Rail** standard requires that they are checked every day.

Many thanks to the **Network Rail** Wales and Borders Maintenance team for working with myself and the **Staytite** team to test new smart clamps.

The smart bolts in the clamps constantly monitor the clamp force within the fastener and then transmit this data to the cloud where it is accessible to engineers via a dashboard on their phone, laptop or other smart device.

Alert and alarm levels can be set such that texts and emails are sent to a pre-agreed group of people in the event that the clamp force goes outside of acceptable limits.



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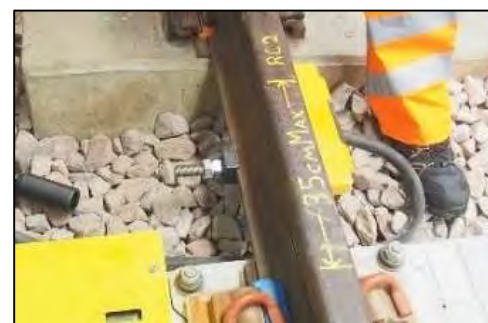
17. Interoperability.

The Intelligent Bolt is fully transferable for use in any application where the bolt or stud diameter is greater than $\frac{1}{2}$ " or M10. It is important to note that any diameter under 1" or M24 will require a special head to allow the fitting of the Interbolt cap. As of the time of writing this report, we have been approached for its use in chair screws, barrier crossings, axle counters, and various applications within Overhead Line Equipment (OLE).

The widescale deployment of the Intelligent Bolt will enable continuous remote condition monitoring of both clamp force and temperature. The frequency of data recording is fully programmable, ranging from every 15 minutes to hourly. This flexibility allows for the collection of extensive data, ensuring that the infrastructure is maintained to the highest standard at all times.

Applications include:

- OLE
- Signalling (eg. Axle counters)
- Temporary rail clamps – (Daily inspections removed)
- G Clamps
- Telecommunications (masts etc)



Appendices:

- E0102 - Trial Report Tenby, Oct '23
- R-Tech report – Examination of a fractured 8.8 bolt, 31/01/2024
- E0102 Bolt Report, Oct'24
- TATA Report – B829 Draft - Fishplate Lubricant, Laboratory Testing, 15/12/2011



E0102

Trial Report Tenby

Oct'23

Confidential

Project:	E0102
Document ref:	Trial Report Oct '23
Revision:	01
Date of last revision:	05/11/23
Prepared:	Jack Bryan Hughleigh
Approved:	N/A



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Summary

InterBolts were installed at Tenby on 10/10/23, fitted to both flat bottom and bull head rail types, using both metric and imperial fasteners.

The purpose of the trial was to:

- Confirm that the InterBolt system operated as expected in an operational rail environment
- Empirical characterise the performance of metric and imperial versions of fishplate bolting

To date, the system has operated as expected with good wireless connectivity between InterBolts, InterBolt Gateway and InterBolt Cloud. There are some dropped data packets between the InterBolts on the far side of the site and this is to be expected as the communication distance is over 500m and there is no clear line of sight communication path. It is recommended to install a second Gateway towards the Whitlands end of the site to mitigate against any wireless black spots.

The generated bolt load data to date has shown the following:

- Imperial bolts are being overtightened at installation. This resulted in 33% of the imperial bolts being yielded at installation. This increased fishplate loading could prevent the fishplate/ rail interface from sliding, increasing the risk of track buckling. The k-factor of imperial bolt is much lower than predicted which indicates that accidental lubrication is likely to be occurring.
- Imperial bolts have a highly variable bolt load at installation, whilst metric bolts are achieving a much more repeatable bolt load.
- Imperial bolts have an unpredictable bolt load over time when compared to metric equivalents. This is likely to be a result of poor under-head surface condition of imperial PEAR headed fasteners.
- Metric bolts are achieving 50% lower bolt load at installation, when compared to imperial equivalents. This is a combination of a different installation torque being used for the two fastener types and a variance in k-factor. For a metric fastener to have the same bolt load as the imperial equivalent, the data suggests that its installation torque needs to be greater than that used for imperial bolts (i.e. greater than 450Nm).
- Metric bolts have an average bolt load of 39kN after embedding and settling losses (72 hrs of operation) have been taken into account. This is a low bolt load for this application and it is likely to exacerbate vibration induced loosening.
- A significant amount of elastic interaction occurs in the fishplate which results in the first bolt being tightened (Bolt 02) having a much lower bolt load after neighbouring bolts have been tightened. A second torque pass was found to help address this.

The data clearly shows significant deficiencies associated with imperial fasteners which supports replacing this legacy technology with metric equivalents.

The data to date has shown minor deficiencies with the installation procedure for metric fishplate bolts which results in a low bolt load being achieved at installation. Improvements to the installation procedure will result in a bolt load closer to the target load and a connection that is more resilient to effects of dynamic loading (vibration induced loosening, fatigue failures, etc.).

System Performance

1.0 InterBolt -> InterBolt Gateway communications

A LoRa wireless network is created between InterBolt and the InterBolt Gateway. The receive signal strength (RSSI) is measured at the receiver (InterBolt Gateway) to estimate the performance of the wireless link. An RSSI greater than -110dBm would result in a very good wireless link with negligible failed wireless transmissions.

For most of the Tenby site, RSSI is averaging -105dBm but there are a few black spots, particularly towards the Whitlands end of the site, where there are frequent failed transmissions. This is to be expected since the communication distance is close to 500m and there is no clear line of sight. To address these black spots, a second Gateway should be installed towards the Whitlands end of the site. Placing the InterBolt Gateway higher on the relay room should also help this issue since the antennas are currently <5cm away from the metal structure of the relay room.

3.0 InterBolt Gateway -> InterBolt Cloud communications

3.1 Cellular survey

During installation, a cellular survey conducted using Siretta cellular analyser. Results show good connectivity for several different networks across 3G and 4G networks.

3.2 Cellular performance of installed Gateway.

The cellular performance of the installation Gateway has been perfect to date with no outages. It is currently using a O2 4G network. The Gateway features an international SIM card so will automatically switch network provider if there are any prolonged outages.

4.0 Installation

4.1 Gateway installation

Gateway installation very straightforward and unit was installed in less than 45 minutes. Important to photograph exact location of Gateway including where it is going to be powered from during pre-installation site survey. This way E&P Engineers can be briefed as to the exact installation requirements and the correct equipment can be brought to site.

4.2 InterBolt installation

Installation of InterBolts straightforward.

To prevent bolts from being yielded, it is thoroughly recommended to use the InterBolt Tablet and embedded LEDs on the InterBolts. This should form part of the toolbox talk prior to installations taking place.

Imperial Bolts - Load Evaluation

1.0 Bolt load at installation

Imperial 15/16" PEAR, 1" PEAR and 15/16" SQUARE – tightened to 450 Nm (350 ftlb)

The bolt load achieved by the imperial fasteners is highly variable and predominately much higher than estimated for the application (estimate from the technical note on bolt load). A summary of the bolt loads achieved at installation are given in Figure 1 below. The red line denotes the load to yield of the bolt (160kN) so all data points above this show bolts that have yielded.

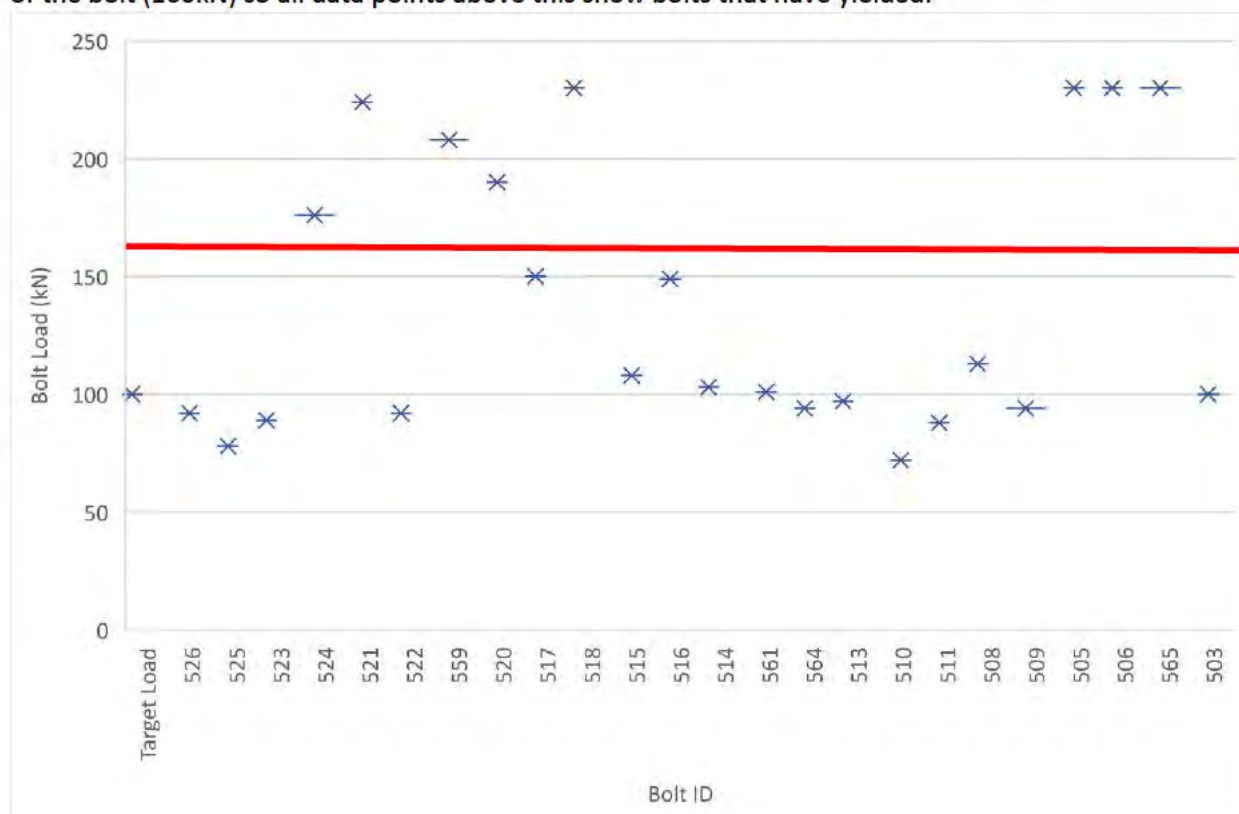


Figure 1. Bolt load achieved at installation IMPERIAL.

Average	141 kN
Min	72 kN
Max	230 kN

Table 1. Average, min and max bolt load achieved at installation IMPERIAL.

The bolt load data at installation is indicating that bolts are being overtightened. Over tightening bolts is not recommended for the following reasons:

- It is leading to the bolts being yielded. 8 of the 24 bolts yielded (33%).
- It is resulting in a high fishplate loading. High fishplate loading will make it more difficult for the fishplate/ rail interface to slide, leading to an increased risk of track buckling.

For future trials it is recommended that the InterBolt tablet and embedded LEDs are utilised to prevent bolts being yielded at installation. The process would be as follows: if InterBolt Tablet or embedded LEDs are showing that bolt load is above proof load (90% of the load to yield), stop applying torque and record torque achieved using digital torque wrench.

2.0 K-factor estimation

From the bolt load achieved at installation, the k-factor can be estimated. Note this is a very course estimate since the torque applied varied by 5-10% and the achieved bolt load was impacted by elastic interaction of the joint (so could have varied when other bolts on the connection were tightened). Bolts that were yielded have been assumed to reach an ultimate tensile load of 230kN.

K factor estimate:

Average	0.15
Min	0.08
Max	0.25

Table 2. K-factor estimate from measured bolt load at installation IMPERIAL.

Since the k-factor is much lower than the estimated value, it is likely that the threads or under-head surfaces have been accidentally lubricated.

3.0 Bolt load over time

The change in bolt load over time of some of the imperial fasteners is highly unpredictable. An example of this is ID 00538 (WHIT 2), see Figure 2 below.

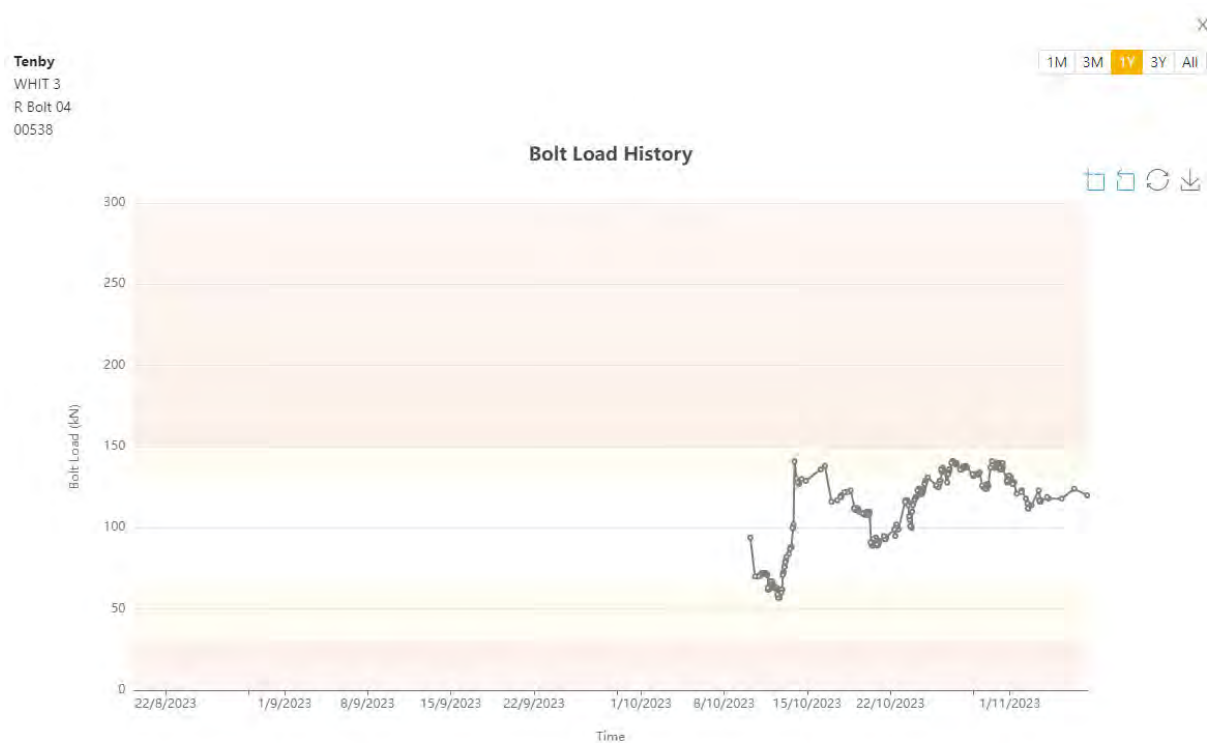


Figure 2. Bolt load over time of imperial bolt 00538.

In Figure 2 it can be seen that the bolt load fluctuates quite significantly over time. This is believed to be a result of the under-head condition of the PEAR headed bolts (see picture of PEAR headed bolt below). Since there are prominent high points on the underside of the bolt head, when the fishplate slides, the load being surface changes so the bolt will see a fluctuation in bolt load (low point = reduce bolt load, high point = increase bolt load).

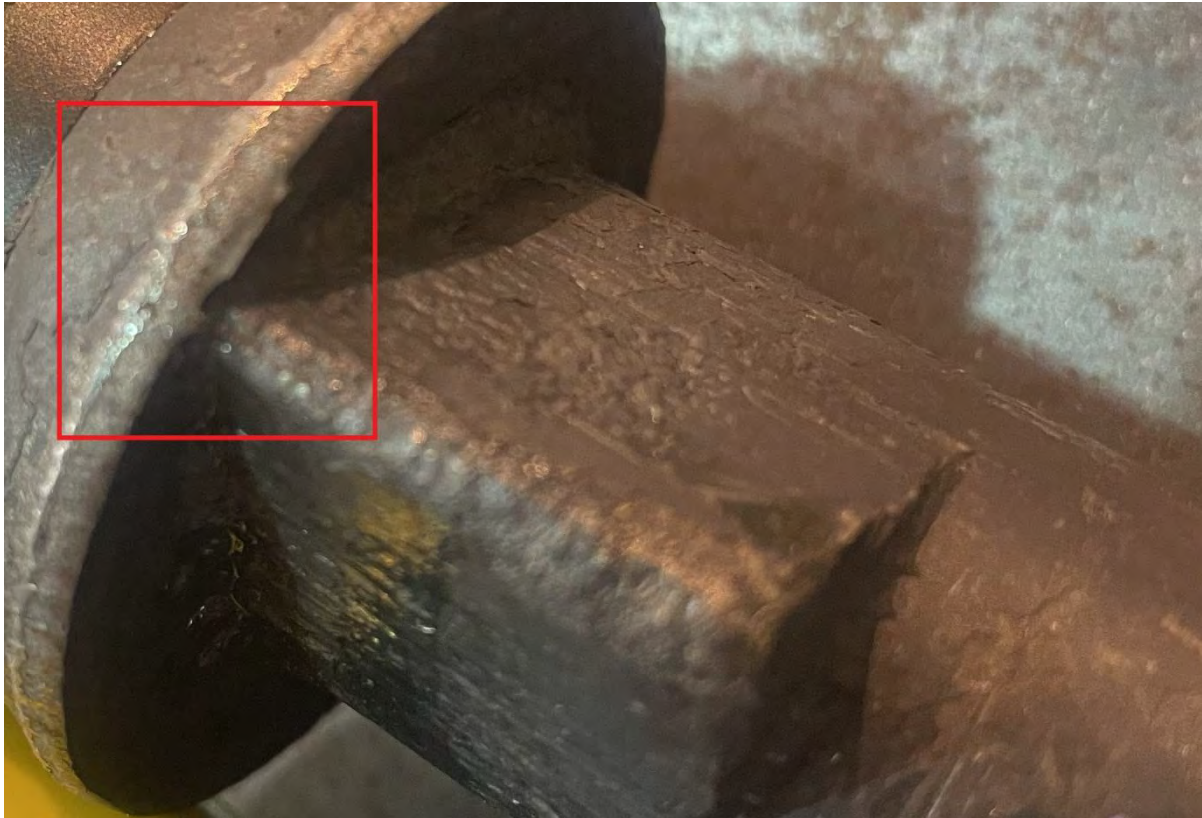


Figure 3. Under-head condition of PEAR headed bolt.

4.0 Key Observations

- 1) K-factor much lower than estimated, highlighting that accidental lubrication of threads or under-head is likely to have occurred.
- 2) A large number of the bolts have yielded (33%) and are applying high loads to the fishplates which may prevent movement.
- 3) Bolt load over time is unpredictable for some of the imperial bolts which is likely to be a result of high points on the underside of the bolt head.

Metric Bolts - Load Evaluation

1.0 Bolt load at installation

Metric HEX head M24 - tightened to 350 Nm (secondary nut tightened to 300 Nm)

The bolt load achieved by the metric fasteners is much more consistent and predictable than imperial fasteners as seen in Figure 4.

The average bolt load achieved at installation for metric fasteners is less than half that of imperial bolts (average 64kN when compared to 141kN). This is combination of using a different installation torque and the k-factor of the imperial bolts being lower.

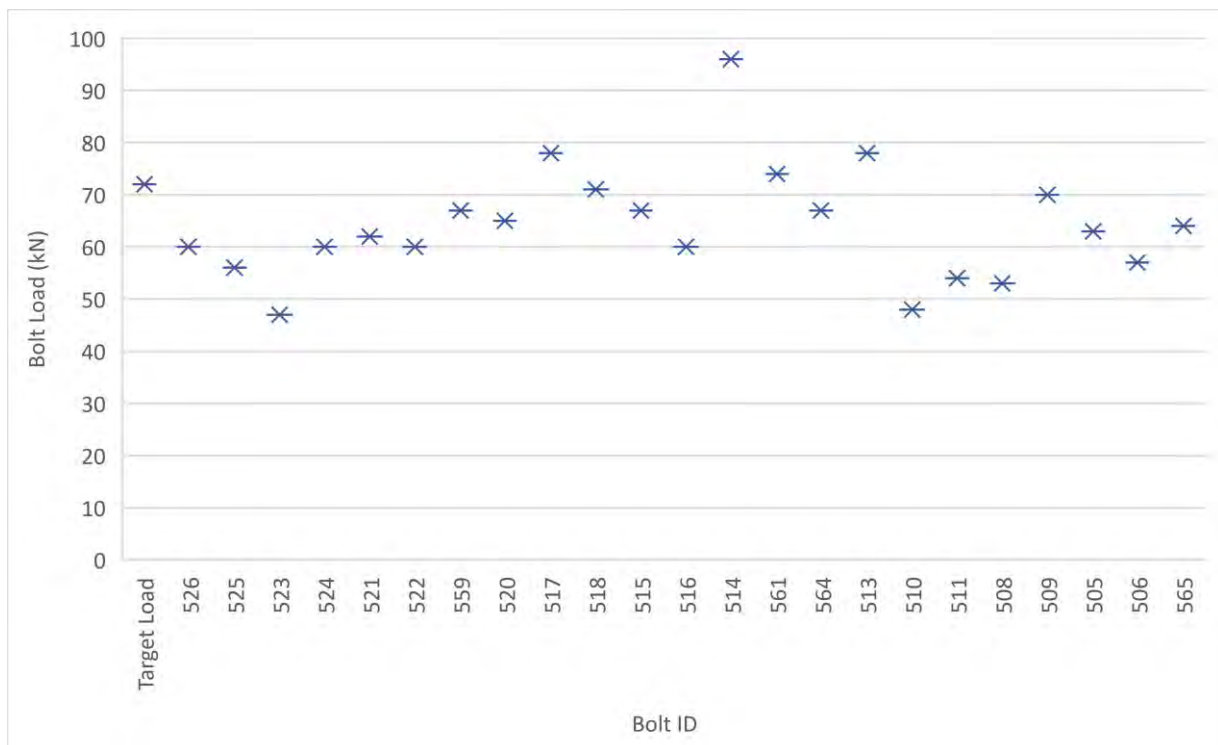


Figure 4. Bolt load achieved at installation METRIC.

Average	64 kN
Min	47 kN
Max	96 kN

Table 3. Average, min and max bolt load achieved at installation METRIC.

A significant amount of elastic iteration in the bolted connection was observed. In particular it was found that bolt position 02 had a consistently low bolt load. Bolt 02 is the first bolt in the joint to be tightened and when neighbouring bolts are tightened, the residual bolt load drops significantly by up to 30%. Performing a second pass (reapplying a torque of 350 Nm to all bolts) was found to help address this issue.

From previous discussions with the TA, we are led to believe that the installation torque for metric fasteners was based on achieving the same bolt load to imperial fasteners, i.e. a 350Nm torque on metric fasteners would result in the same bolt load as a 350 ftlb (450Nm) torque on an imperial

fastener. Since the imperial fasteners have a lower k-factor, the opposite is however true and a larger torque on metric fasteners would be required to get the same bolt load as imperial fasteners.

2.0 K-factor estimation

The k-factor estimation was closer to that estimated for the application (0.18 – 0.20 for dry).

Average	0.23
Min	0.15
Max	0.31

Table 4. K-factor estimate from measured bolt load at installation METRIC.

3.0 Bolt load over time

The change in bolt load over time for metric fasteners is much more predictable than imperial equivalents. An example of this is ID 00506 (WHIT 2), see Figure 2 below.

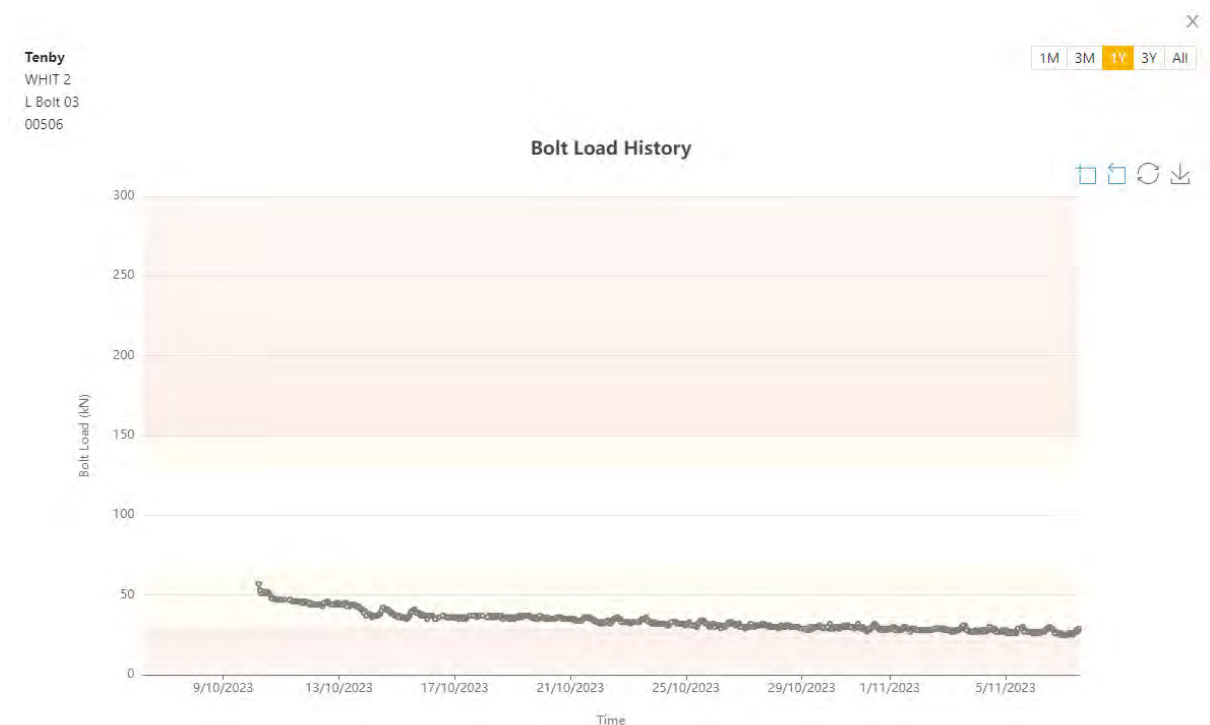


Figure 5. Bolt load over time of metric bolt 00506.

The data is typically characterised by an embedding and settling loss of approximately 15-25kN over the first 72 hrs of operation and then a relatively steady bolt load.

There are a few exceptions to this:

- 1) Both bolts on WHIT 6 reported a complete loss of bolt load after 12 hrs of operation (see Figure 6). An inspection that evening found that the fishplate hadn't been correctly seated. Since the bolts were retightened, no further drop in bolt load has been observed. If the bolts are tightened to a higher bolt load and a second pass is conducted, this may help seat the fishplate and could prevent this from occurring.

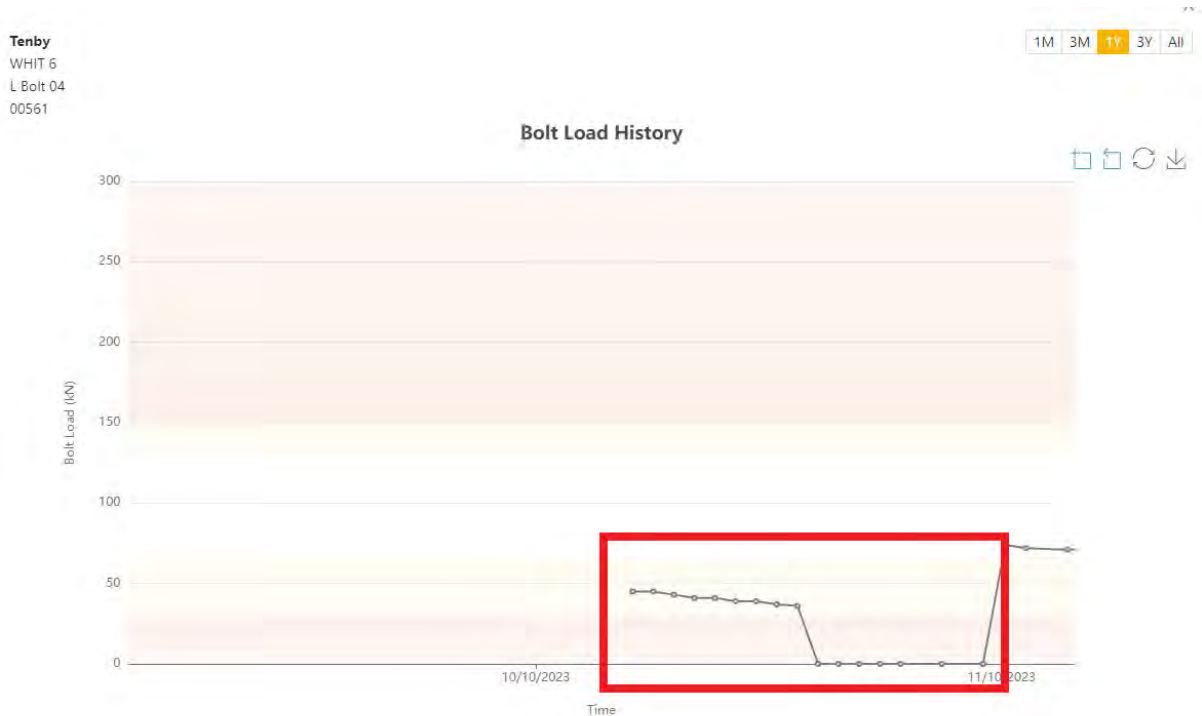


Figure 6. Bolt load over time for metric bolt 00561.

- 2) Some bolts are reporting a gradual decline in bolt load over time (see Figure 7). This is likely to be a result of low bolt leading to the bolted connection seeing a greater amount of the dynamic loading. This in turn will exacerbate vibration induced loosening. If the bolt has a higher bolt load, it is likely that the severity of this would be significantly reduced. The average bolt load of metric bolts after settling and embedding losses were taken into account was 39kN which is around half that expected for the application.



Figure 7. Bolt load over time for metric bolt 00505.

4.0 Key Observations

- 1) A significant amount of elastic interaction in the bolted connection was observed which led to the bolt being tightened first (bolt 02) having a consistently low bolt load when the neighbouring bolts were tightened. A second pass was found to help address this issue.
- 2) Metric bolts have an average bolt load of less than half that of imperial equivalents. It highlights that metric and imperial bolts are not being tightened to the same bolt load.
- 3) One fishplate was found to not be seated correctly resulting in both bolts recording a zero bolt load after 12 hrs of operation. A higher bolt load at installation could potentially help seat the fishplate.
- 4) The bolt load over time of metric bolts is predictable.
- 5) The bolt load after settling and embedding losses (after 72 hrs of operation) have been accounted for is 39kN which is approximately 50% of the estimated bolt load for the application. This is believed to a contributing factor is the gradual decline in bolt load over time.

Examination of a Fractured 8.8 Bolt

Report Number: M23323

Date: 31/01/2024

Purchase order No.: 447585

Customer: Staytite Ltd

Customer Contact: David Cartledge

R-TECH MATERIALS



Report by:

A handwritten signature in black ink, appearing to read 'C. Bartle', is written over a white rectangular background.

Craig Bartle
Welding Specialist

Reviewed by:

A handwritten signature in black ink, appearing to read 'S. Bagnall', is written over a white rectangular background.

Sarah Bagnall C.Eng, MIMMM
Director Consultancy Services

Executive Summary

R-TECH Consultants Ltd received an M24 fish bolt from Staytite Ltd, with a request to determine the cause of failure. The following conclusions arose from this assessment:

- 1) Failure of the bolt is thought to have occurred due to corrosion fatigue. Corrosion fatigue is the result of a cyclic stress operating in an environment that is corrosive to the metal.
- 2) The surface adjacent to the fracture was associated with pitting and a corrosion deposit. The presence of pitting would have acted as a stress concentrator for fatigue crack initiation.
- 3) Multiple secondary cracks were evident behind the fracture surface. The cracks were transgranular in nature with no evidence of any branching. Further, several of the cracks possessed a "spear-like" morphology with many initiating from pits at the surface. A corrosion deposit was also evident within the cracks. These features are characteristic of corrosion fatigue.
- 4) The corrosion deposit was found to consist predominantly of iron and oxygen, with small amounts of phosphorus, barium, potassium, calcium, sulphur, chlorine, and sodium.
- 5) The presence of aggressive corrosive species, such as chlorine and sulphur, increase corrosion and crack growth rates.
- 6) The chemical composition of the bolt conformed with the specified composition for an 8.8 bolt. Similarly, the recorded hardness about the core complied with the hardness range specified by the standard.

Recommendations:

- 1) Application of an appropriate coating to prevent the occurrence of corrosion.
- 2) Regular NDT inspection can determine the presence of any incipient cracking.

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1. Introduction

R-TECH Consultants Ltd received a failed M24 fish bolt from Staytite Ltd with a request to determine the cause of failure. It was advised that the bolt had been in service for 18 months and had failed under normal operational parameters. The bolt was advised as being M24 class property 8.8 and as such was composed of a medium carbon steel in the quenched and tempered heat treatment condition. R-TECH were informed that the bolt was mechanically fixed through a rail, which was in turn sandwiched between two fish plates. The bolt was received in two halves and identified by R-TECH as 1 and 2, Figure 1.1. For the ease of examination, the fracture surface of section 1 was removed in accordance with the red-dashed line in Figure 1.1.



Figure 1.1. As-received image of the bolt

2. Visual Examination

Visual examination of both halves of the bolt was performed by way of stereomicroscopy. The observations made are detailed below with the associated images, Figures 2.1 – 2.8.

Figure 2.1 shows a general view of the bolt in its entirety. It was clear that failure had occurred within the plain shank region. R-TECH were informed that the fracture location corresponded to where the bolt was engaged with the rail. The bolt displayed evidence of wear about the threaded region, indicated by arrow 1 in the Figure and shown in more detail in Figure 2.2. The wear corresponded to the location of the fish

plate. In addition, a corrosion deposit was observed across the bolt. Areas (1) and (3), indicated in the figure, show an orange/brown deposit at the location of the two fish plates either side of the rail. Area (2) exhibits the same orange/brown deposit at the location of the rail during operation. The remainder of the bolt surface exhibited a darker brown/grey deposit. The nuts evident along the threaded portion of the bolt were found to be tight when checked by hand.

The fracture surface was associated with an orange/brown coloured corrosion deposit, Figure 2.3. The surface was appropriately cleaned with an inhibited hydrochloric acid solution to remove any surface deposits, Figures 2.4 to 2.6.

The fracture appeared to have occurred in two stages i.e. stable cracks were present prior to a final tensile overload. Two areas of ratchet marks were noted which were diametrically opposed. Beach marks were then observed to emanate from these ratchet marks, the surface of which was very flat. These features are indicative of a fatigue fracture mechanism. The presence of ratchet marks diametrically opposed is indicative of a reverse bending fatigue mechanism. The major bending stress was applied to the lower region of the bolt and the minor stress was applied from the top. This is evident from the length of the respective fatigue cracks. An area which exhibited a fibrous surface topography was evident towards the upper region of the fracture surface shown in the figures. This is thought to be attributable to final fracture. The fatigue fracture accounted for approximately 90% of the diameter which is indicative of a high cycle low load fatigue fracture.

The surface adjacent to the fracture was associated with pitting and a corrosion deposit, Figure 2.7. This was analysed by Scanning Electron Microscopy/Energy Dispersive X-ray analysis (SEM/EDX), see later in section 5. Figure 2.8 details the presence of a small secondary crack just behind the fracture surface.



Figure 2.1. Image detailing fish bolt: note damage to threads.



Figure 2.2. Image side 2 of bolt: Not damage to threads where the bolt was fixed through a fish plate. Note also an orange/brown deposit.



Figure 2.3. Image detailing fracture surface of side 2. Note the presence of an orange/brown coloured deposit across the surface.

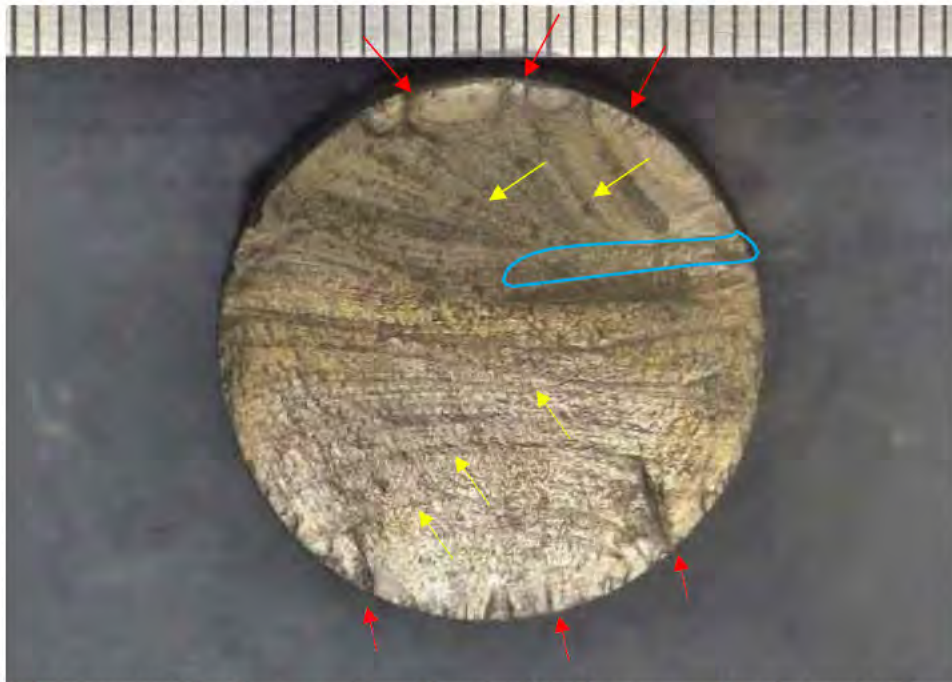


Figure 2.4. Image detailing fracture surface after cleaning. Note areas of ratchet marks diametrically opposed (red arrows), beach marks (yellow arrows) and final fracture (blue line).



Figure 2.5. Image detailing fracture surface after cleaning. Note ratchet marks associated with larger fatigue crack located at the lower region of the fracture surface. Also note the presence of beach marks.

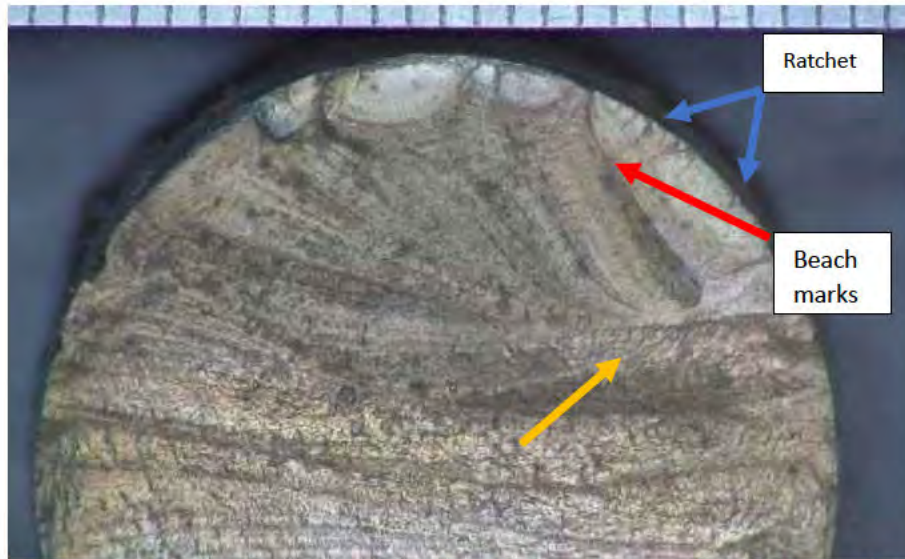


Figure 2.6. Image detailing fracture surface after cleaning. Note ratchet marks associated with smaller fatigue crack located at the upper region of the fracture surface. Also note the presence of beach marks and the final fracture area (yellow arrow)



Figure 2.7. Image detailing surface adjacent to fracture. Note the presence of pitting associated with a corrosion deposit.



Figure 2.8. Image detailing surface adjacent to fracture, after cleaning. Note the presence of a small secondary crack (red circle).

3. Scanning Electron Microscopy

The fracture surface was examined using a Zeiss EVO 60 scanning electron microscope with Oxford INCA EDX microanalysis. The SEM enables supplementary investigation of the facets of damage, providing resolution and magnification many times higher than those achievable using an optical source. The observations made are detailed below, whilst the associated images can be found as per figure 4.1 – 4.6.

The ratchet marks observed are shown in more detail in Figures 4.1 to 4.3. In some instances, pitting was associated with the ratchet marks observed. The main fatigue fracture areas exhibited striations across the surface, Figures 4.4 to 4.8. The final fracture area exhibited micro-void coalescence, which is indicative of a ductile fracture mechanism, Figure 4.9.

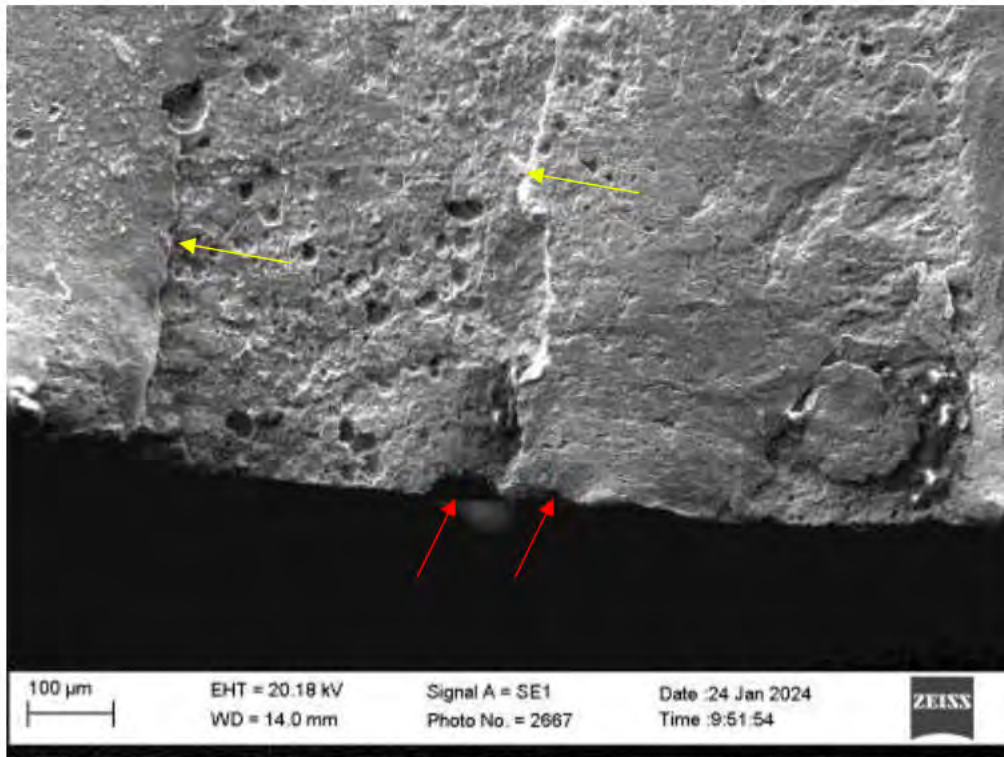


Figure 4.1. SEM image detailing ratchet marks (yellow arrows) associated with major fatigue crack. Note the presence of pits along the surface (red arrows).

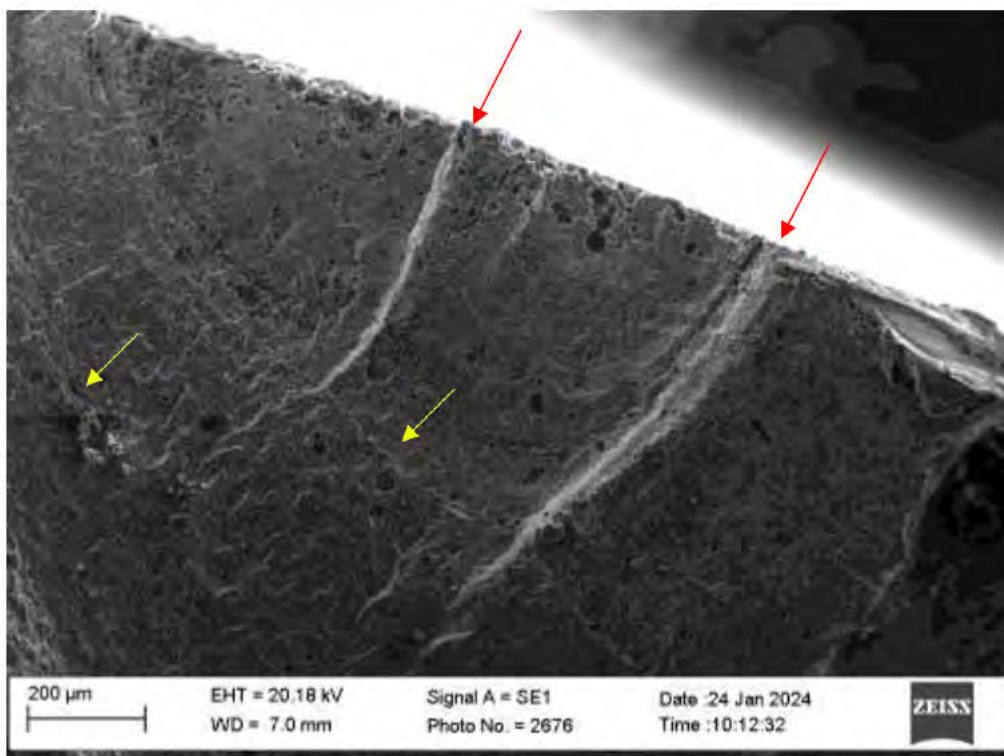


Figure 4.2. SEM image detailing ratchet marks (red arrows) associated with minor fatigue crack and beach marks (yellow arrows).

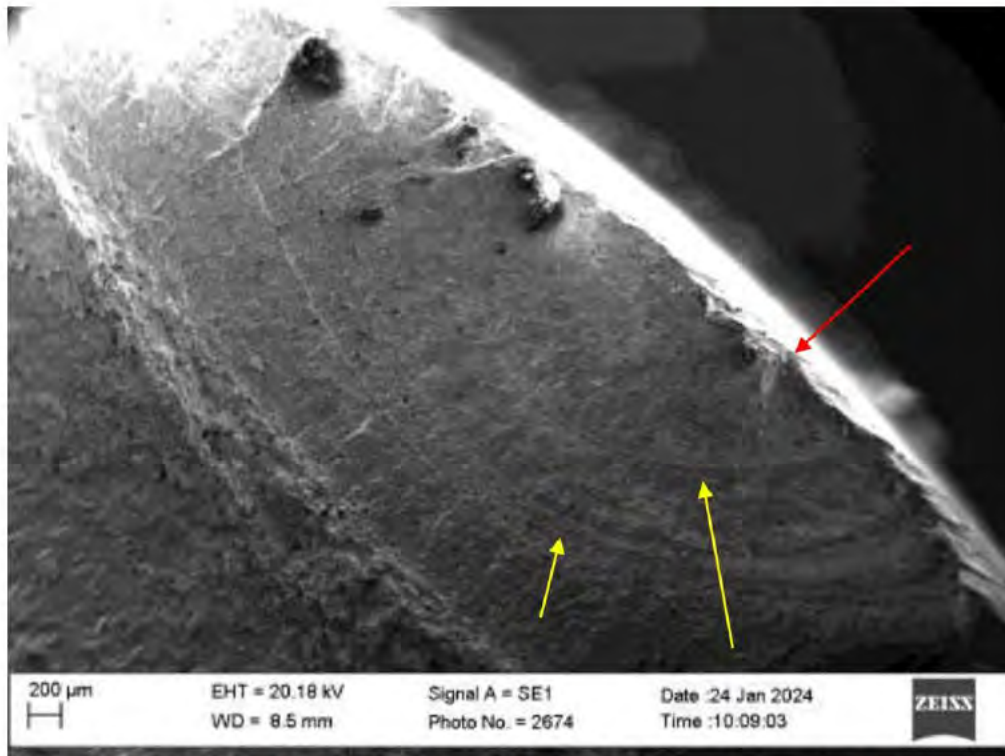


Figure 4.3. SEM image detailing ratchet marks (red arrows) associated with minor fatigue crack and beach marks (yellow arrows).

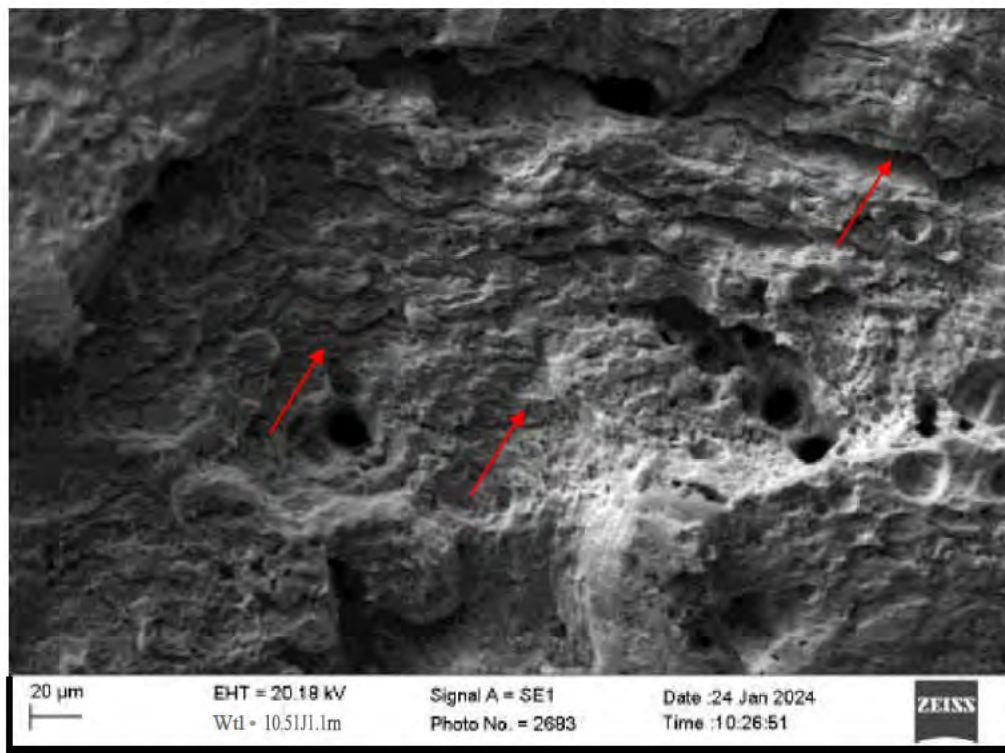


Figure 4.4. SEM image detailing main fracture surface. Note the presence of striations.

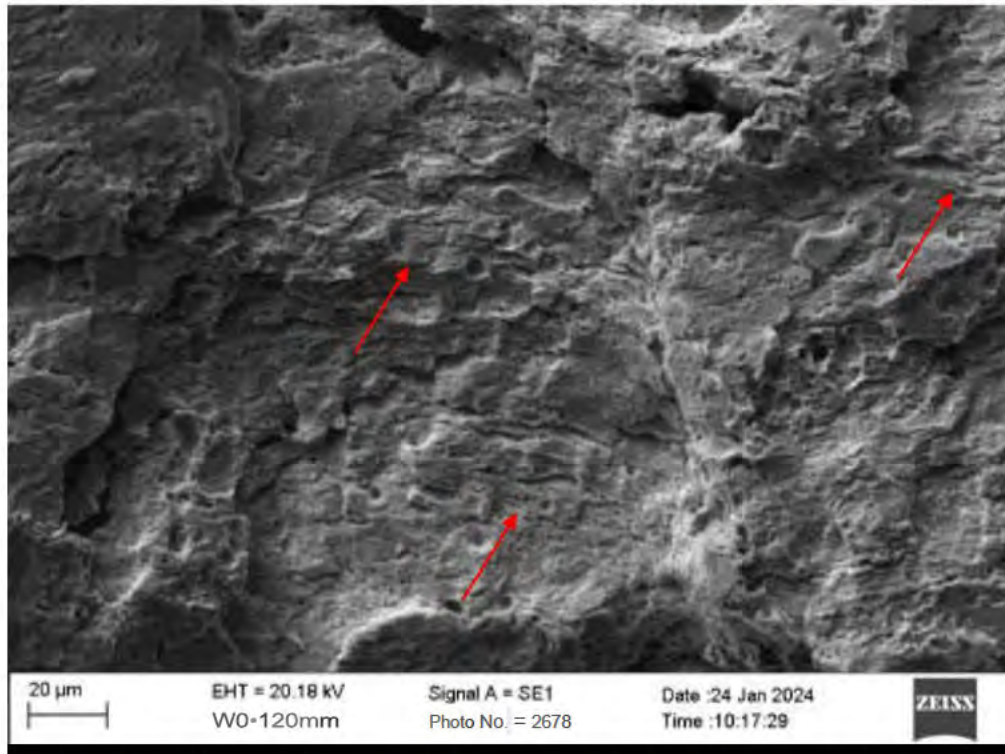


Figure 4.5. SEM image detailing main fracture surface. Note the presence of striations.

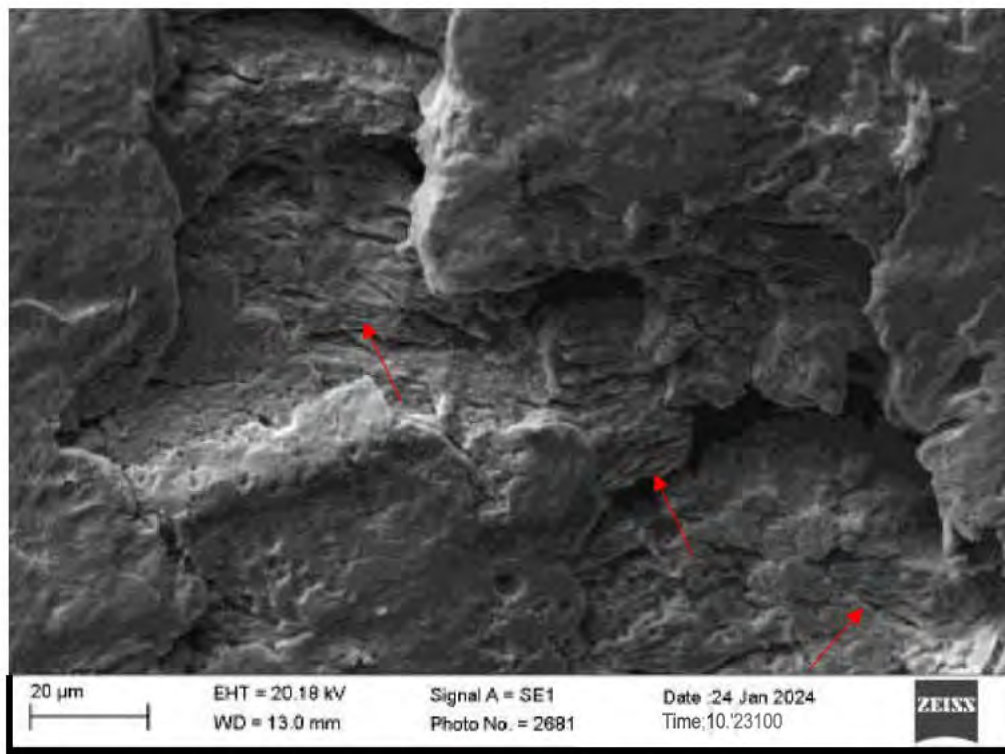


Figure 4.6. SEM image detailing main fracture surface. Note the presence of striations.

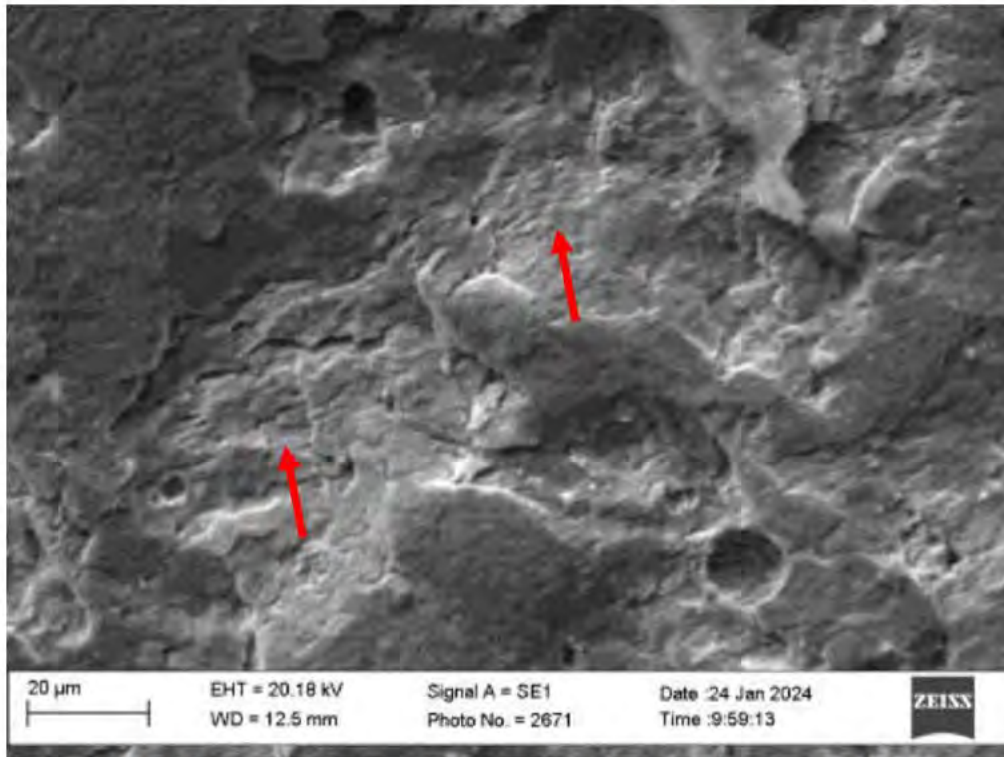


Figure 4.7. SEM image detailing main fracture surface. Note the presence of striations.

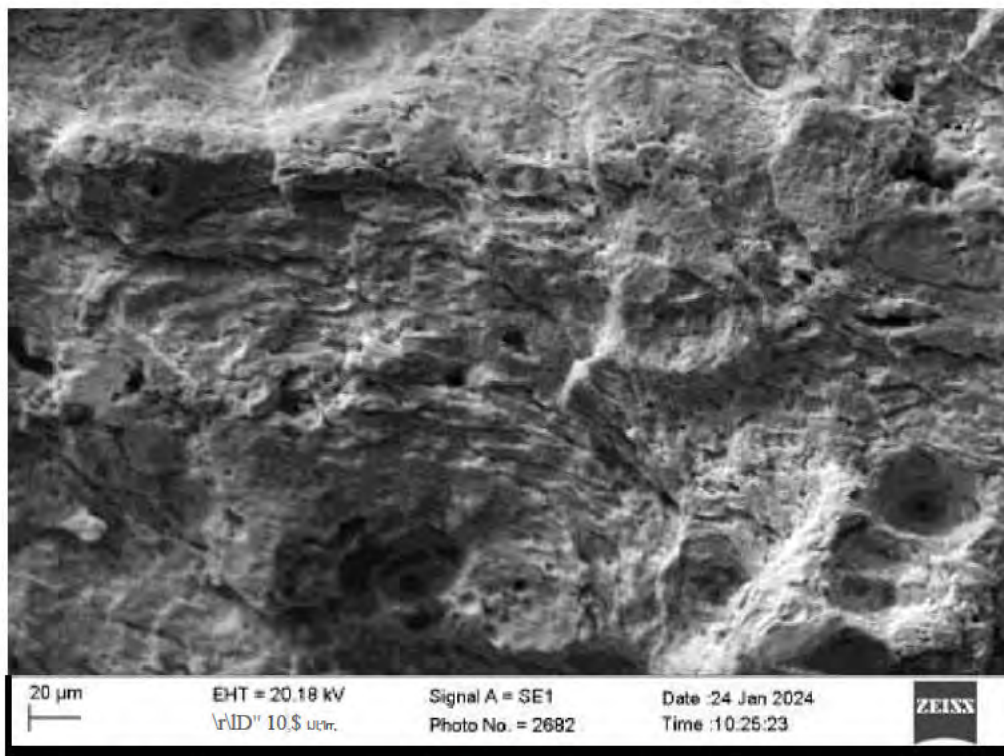


Figure 4.8. SEM image detailing main fracture surface. Note the presence of striations.

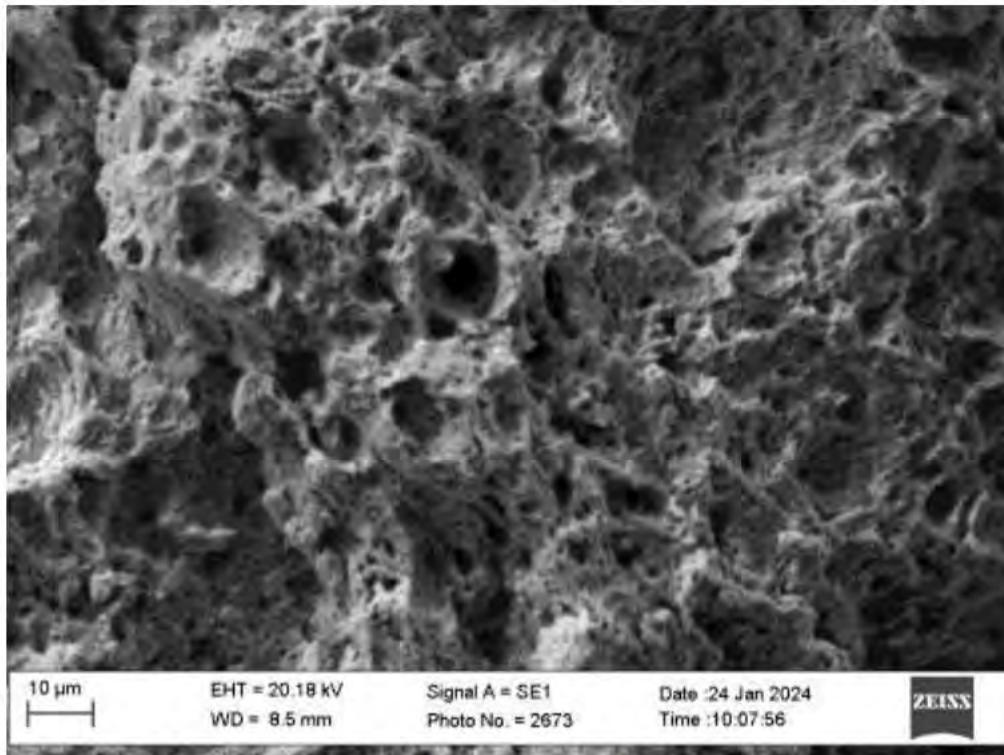


Figure 4.9. SEM image detailing final fracture region with micro-void coalescence evident.

4. Metallographic Examination

Metallographic examination was undertaken as a means of characterising the underlying microstructure about both the fracture surface and the bolt surface, along with any constituent features and defects. To allow this examination, a cross section was produced about the 180° position as per the red-dashed sectioning line in Figure 3.1. The resulting cross-section was mounted in Bakelite, and ground & polished to a one-micron finish. The sample was then observed in the unetched condition, before being etched in a solution of 5% Nital in order to reveal the underlying microstructure, rendering both the grain structure and any resident precipitates visible.

Examination of the bolt surface behind the fracture revealed the presence of multiple cracks which had propagated perpendicular to the surface of the bolt, Figures 3.2 to 3.8. The cracks were transgranular in nature with no evidence of any branching. Further, several of the cracks possessed a “spear-like” morphology with many initiating from pits at the surface. A corrosion deposit was also evident within the cracks.

As per Figures 3.9 and 3.10, the general microstructure of for the bolt comprised of quenched and tempered martensite throughout the section, as expected for a class 8.8 bolt. A thin coating/film was evident in areas across the bolt surface, Figure 3.11.

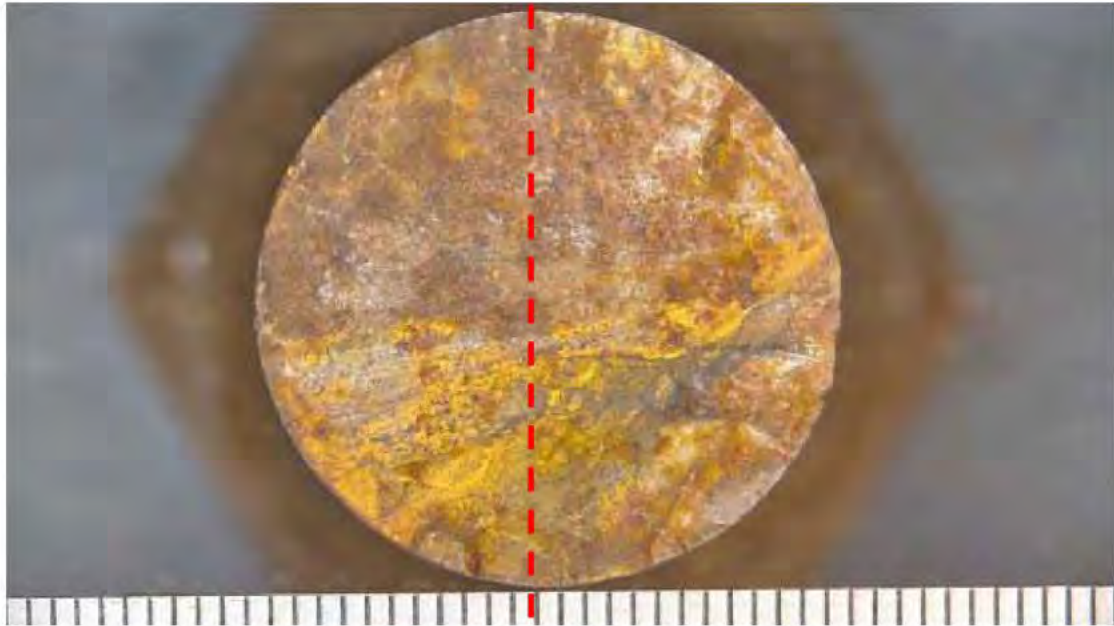


Figure 3.1. Section taken through fracture surface.

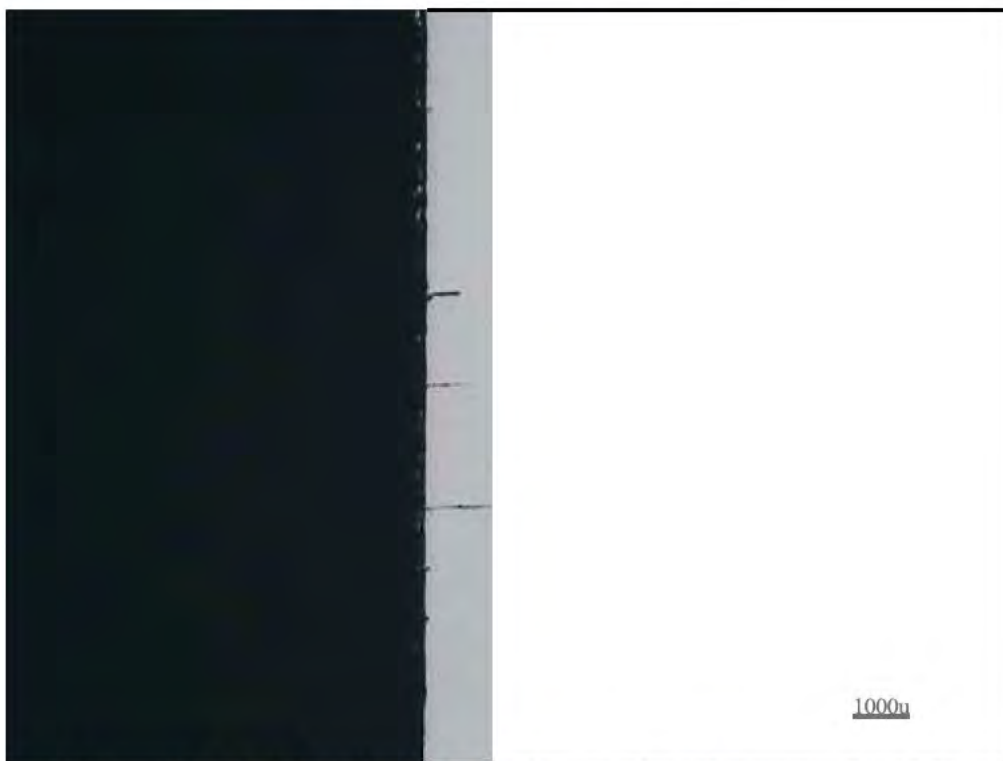


Figure 3.2. Image detailing bolt surface behind the fracture. Note the presence of multiple cracks.

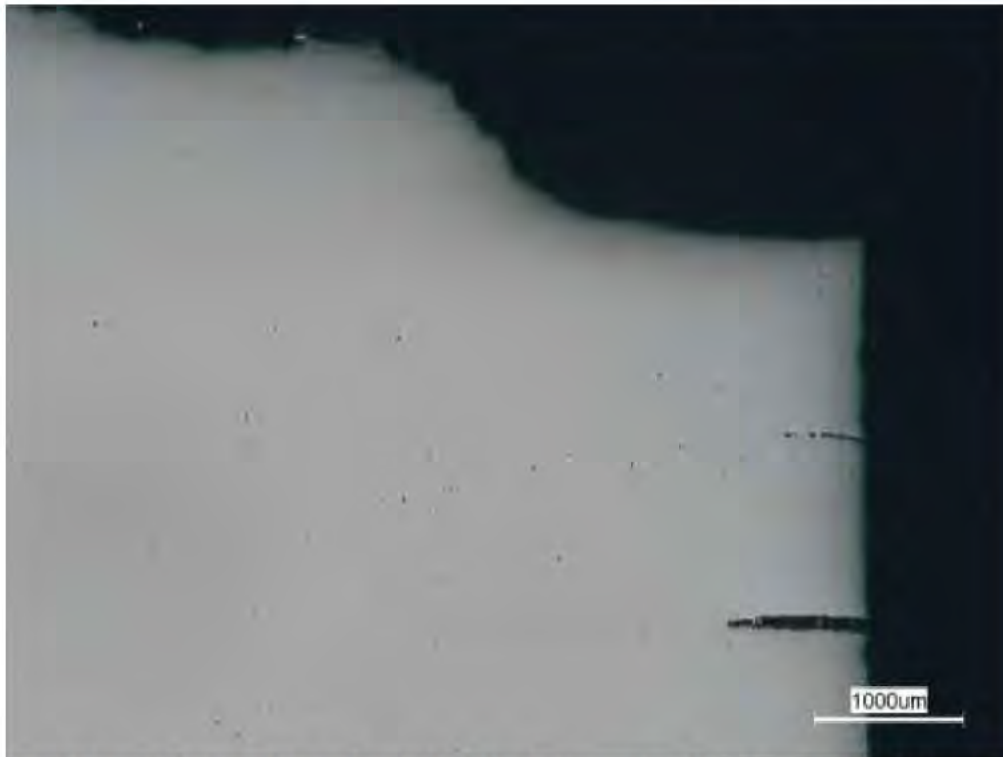


Figure 3.3. Image detailing bolt surface behind the fracture. Note the presence of multiple cracks.



Figure 3.4. Image detailing bolt surface behind the fracture. Note the presence of multiple cracks.

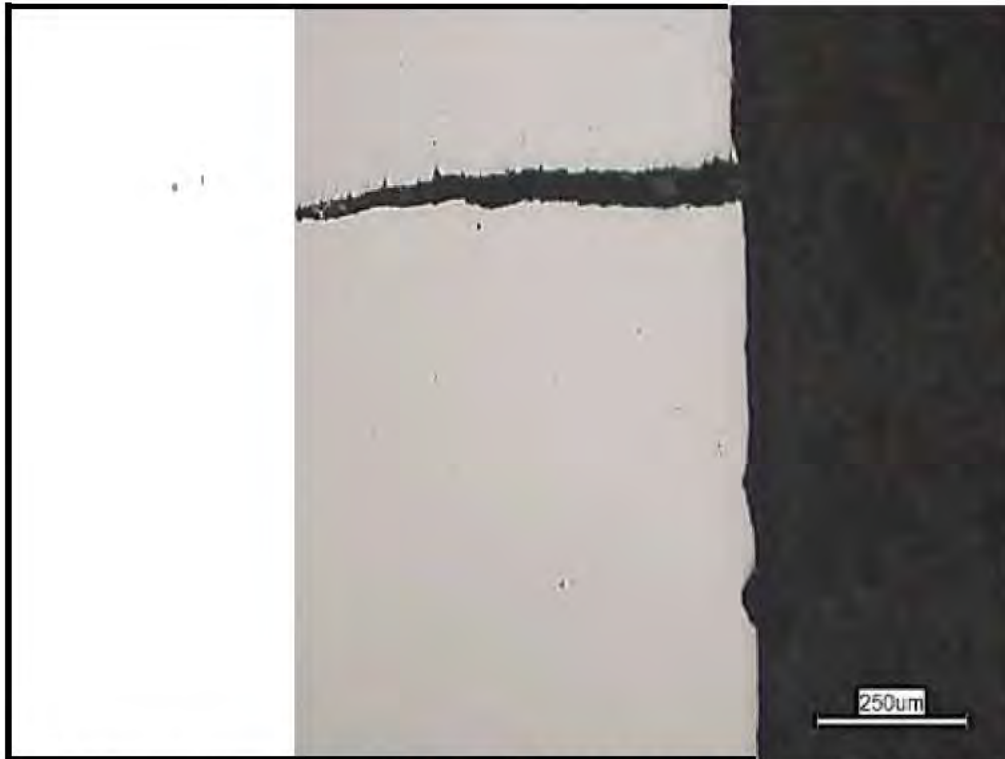


Figure 3.5. Image detailing bolt surface behind the fracture. Note the presence of a “spear-like” crack.



Figure 3.6. Image detailing bolt surface behind the fracture. Note the presence of corrosion deposit within the “spear-like” crack.

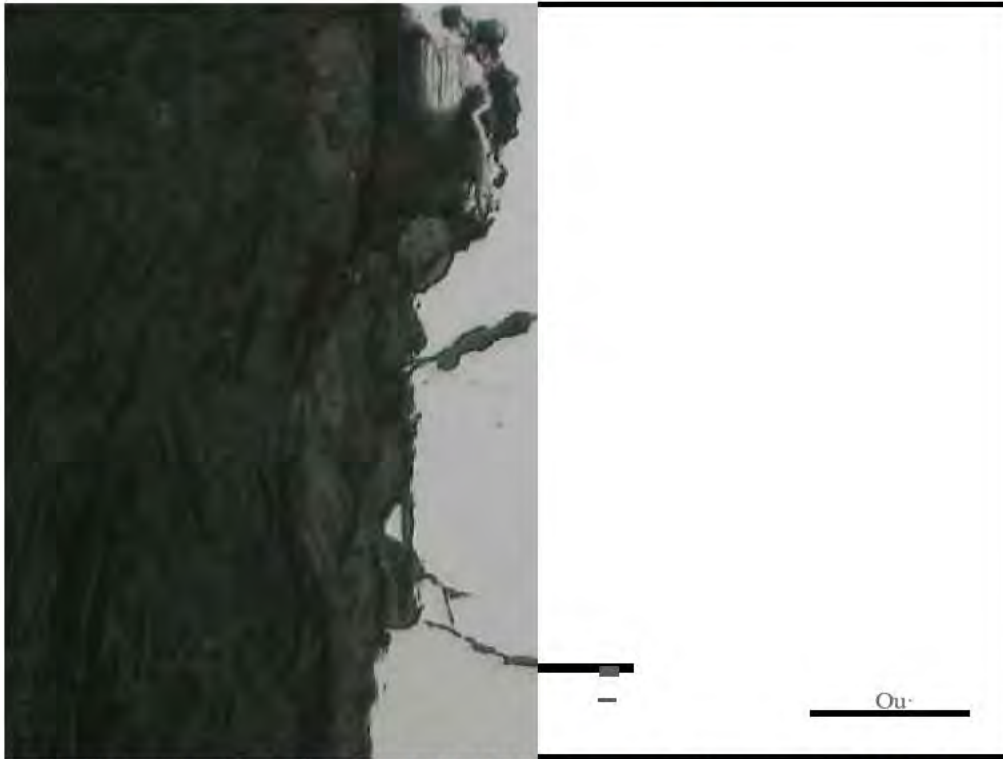


Figure 3.7. Image detailing bolt surface behind the fracture. Note the presence of multiple cracks associated with pitting.



Figure 3.8. Image detailing bolt surface behind the fracture. Note the presence of pitting.

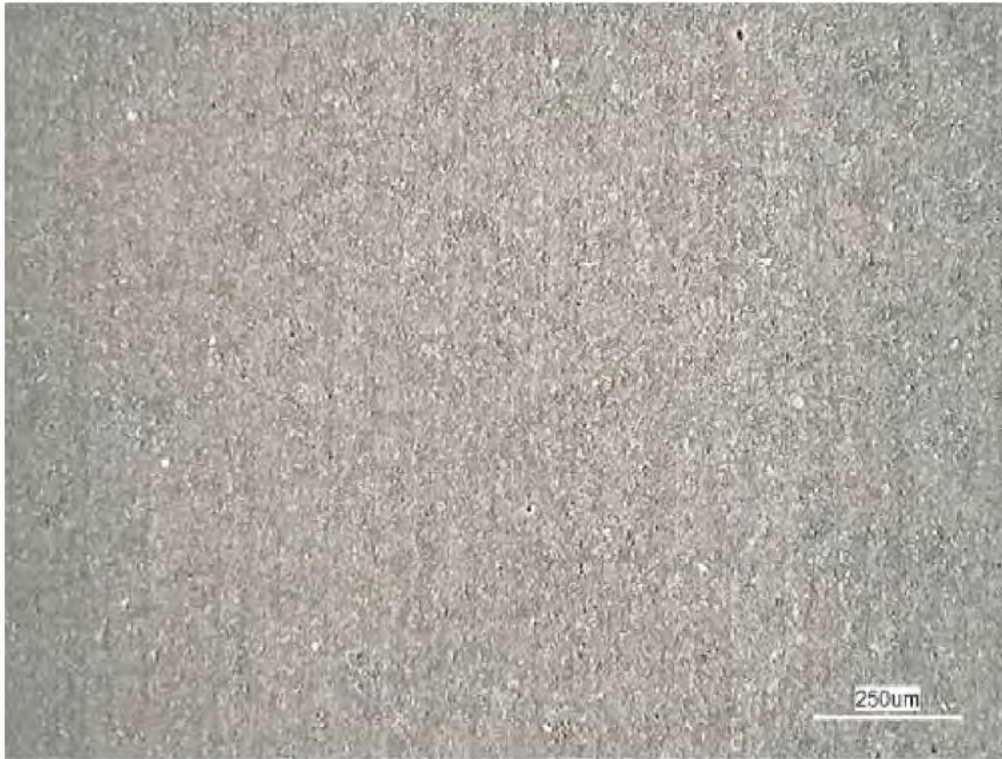


Figure 3.9. General microstructure of bolt x140.

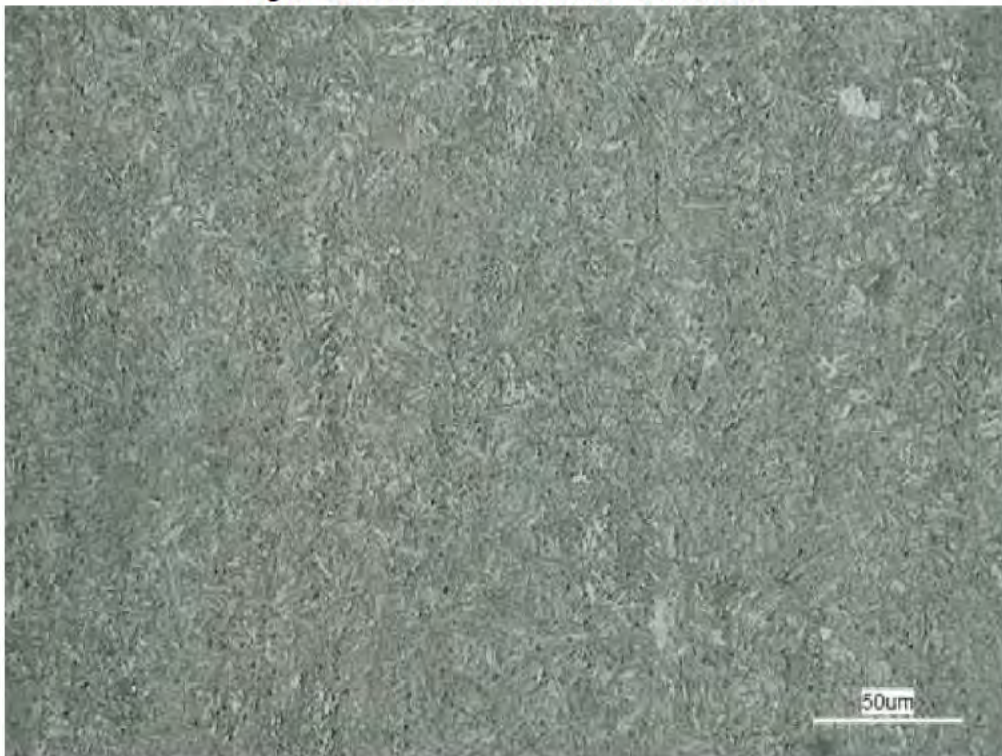


Figure 3.10. General microstructure of the bolt x700.

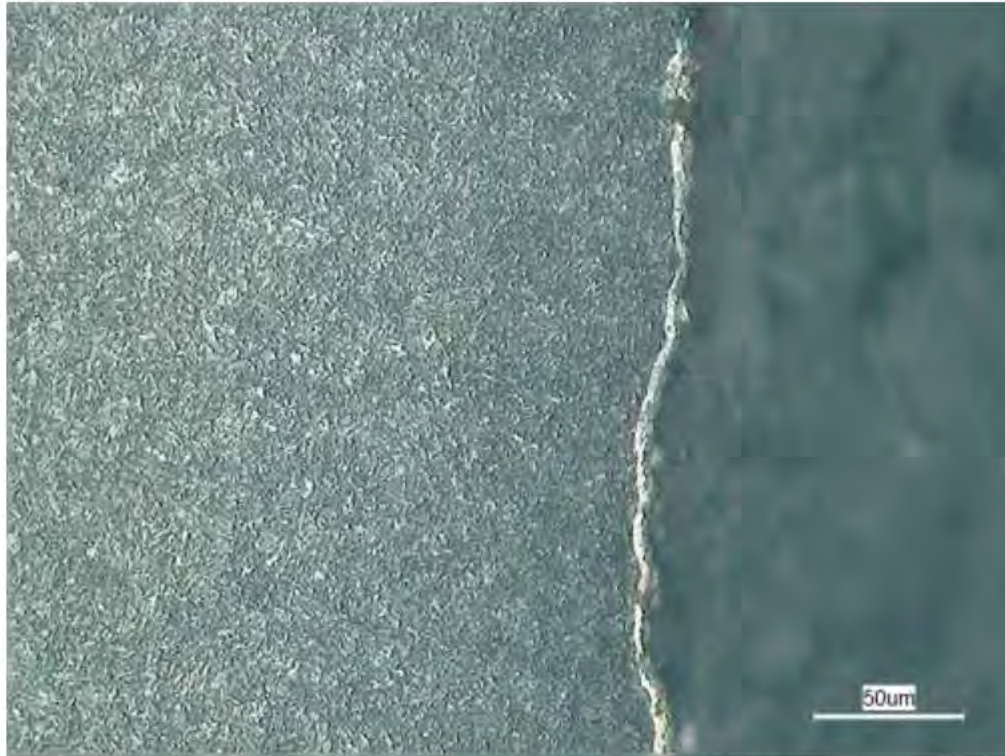


Figure 3.11. Surface of the bolt, detailing a thin coating.

5. Energy Dispersive X-ray Spectroscopy (EDX) Analysis

EDX analysis was performed about both the eternal fracture surface and spear like crack. Examination was performed using a Zeiss EVO 60 scanning electron microscope equipped with Oxford INCA Energy Dispersive (EDX) microanalysis. EDX results for each sample are detailed in table 5.1 and for all accompanying imagery see figure 5.1 – 5.2.

* **Note:** The quantification procedure strictly applies to polished surfaces and therefore the results on rough surfaces such as particulates, may only be considered semi-quantitative. Carbon can be detected but not quantified i.e. d = detected and D = detected in significant amounts. For other elements:- blank cell = element not detected. The results indicate only the relative proportions of each element.

Table 5.1. EDX analysis results of corrosion deposit.

Location	Spec.	Element (Wt.%)*																		
		C	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Cr	Mn	Fe	Zn	Ba	Co	W
Bolt surface	1	D	15.4	0.8	-	-	0.2	2.6	-	0.1	0.1	2.4	-	0.3	0.9	28.3	-	-	-	-
	2	D	10.3	0.3	-	-	0.2	0.6	0.1	-	-	0.8	-	0.4	0.4	38.5	-	-	-	-
	3	D	12.2	0.4	-	-	0.2	1.7	0.3	0.2	0.2	2.3	-	1.6	1.2	16.5	-	1.1	-	-
	4	D	18.7	0.4	0.2	0.4	0.7	1.6	0.2	0.6	0.2	1.5	0.3	0.5	0.8	24.1	0.3	-	-	-
	5	D	17.4	0.3	-	0.2	0.8	0.5	0.2	0.2	0.1	1.2	-	0.8	0.7	24.2	-	0.5	-	-
	6	D	7.3	-	-	-	0.6	3.1	0.7	0.5	-	5.9	-	3.4	1.0	33.7	-	1.8	-	-
Crack	1	d	33.4	-	-	0.2	0.2	0.6	-	-	-	0.2	-	-	0.3	58.2	-	-	10.3	5.2
	2	d	38.0	-	-	-	0.3	0.6	-	-	-	0.2	-	-	-	54.1	-	-	-	-
	3	d	9.4	-	-	0.2	0.7	-	-	-	-	-	-	10.6	0.6	57.4	-	-	-	-
	4	d	20.6	-	-	-	-	0.4	-	-	-	0.2	-	-	0.4	73.3	-	-	-	-

EDX analysis for all locations revealed a composition predominantly comprised of iron and oxygen, with small amounts of phosphorus, barium, potassium, calcium, sulphur, chlorine and sodium. Isolated areas contained significant amounts of cobalt and tungsten, the origin of which is not clear.

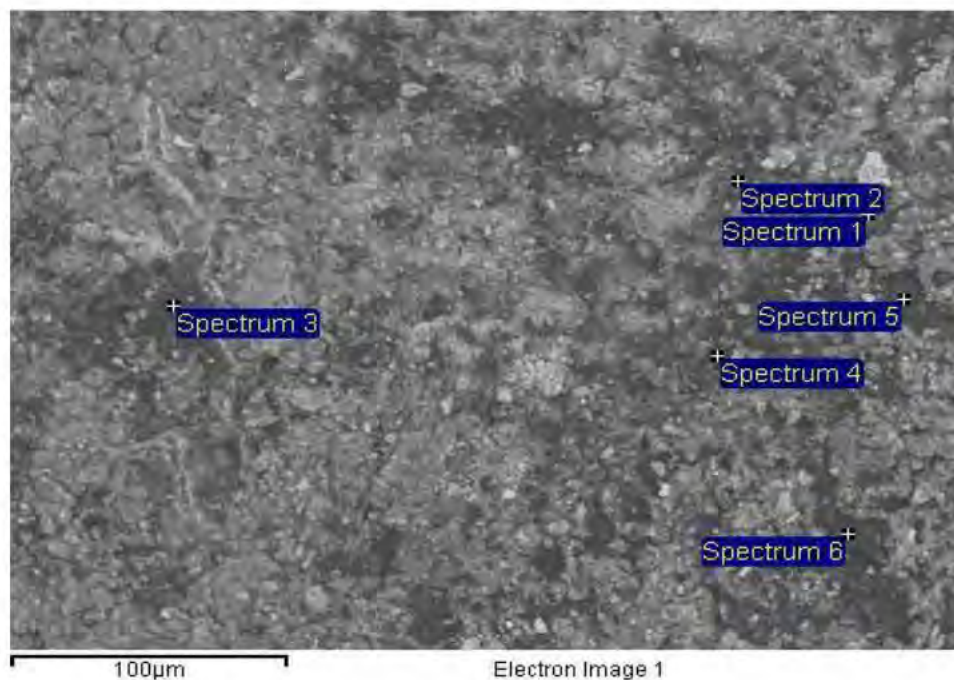


Figure 5.1. Image detailing bolt surface: showing areas analysed.

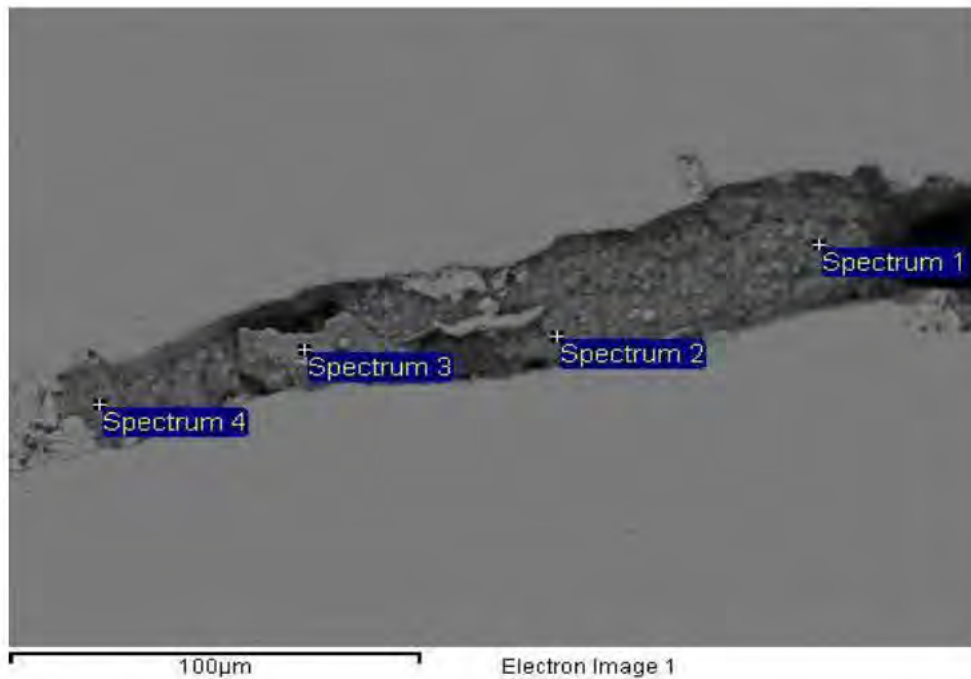


Figure 5.2. Image detailing spear like crack corrosion: showing areas analysed.

6. Chemical Analysis

The bolt was analysed by way of optical emission spectroscopy. The recorded chemical composition is detailed in Table 6.1.

Table 6.1. Chemical analysis results.

Sample	Wt.% Element								
	C	Si	Mn	P	S	Cr	Mo	Ni	Al
Bolt	0.35	0.13	0.75	0.015	0.01	0.143	0.006	0.042	0.038
	Cu	Co	Sn	V	N	B	Nb	Ti	-
	0.082	0.003	0.005	0.004	0.007	0.003	Nd	0.033	-

Table 6.2. Chemical composition for a class 8.8 grade bolt.^[1]

Grade	Element*				
	Wt.%	C	P	S	B
8.8	Min.	0.25	-	-	-
	Max.	0.55	0.025	0.025	0.003

* **Note:** Single values are maximum, unless stated otherwise.

The chemical composition of grade 8.8 is detailed in table 6.2.^[1] Accordingly, the chemical composition for the bolt was found to comply with the ranges specified.

7. Vickers Hardness Testing

Vickers hardness testing was undertaken for the fractured bolt. Testing was performed as per a three-point line interval through the central region of the bolt, using a 10kg load in accordance with BS EN 6507-1:2005. The results are shown in table 7.1.

Table 7.1. Vickers hardness testing results.

Bolt	Vickers Hardness HV10			HV _{AVG}
	1	2	3	
	318	320	280	306

The bolt was understood to comply with a medium carbon steel 8.8 class. The typical average hardness range for this grade is 255 – 335HV.^[1] Accordingly, the recorded average hardness value complied with this range.

8. Discussion

R-TECH Consultants Ltd received a fish bolt from Staytite Ltd, with a request to determine the cause of failure. It was clear that failure of the bolt had occurred within the plain shank region. R-TECH were informed that this location corresponded to where the bolt was engaged with the rail.

The fracture appeared to have occurred in two stages i.e. stable cracks were present prior to a final tensile overload. Two areas of ratchet marks were noted which were diametrically opposed. Beach marks were then observed to emanate from these ratchet marks, the surface of which was very flat. Further, striations were prevalent on a micro scale. These features are indicative of a fatigue fracture mechanism which occurs upon the application of a cyclic loading. The presence of ratchet marks diametrically opposed is indicative of a reverse bending fatigue mechanism. The major bending stress was applied to the lower region of the bolt and the minor stress was applied from the top. This is evident from the length of the respective fatigue cracks. An area which exhibited a fibrous surface topography was evident towards the upper region of the fracture surface shown in the figures. This is thought to be attributable to final fracture. The fatigue fracture accounted for approximately 90% of the diameter which is indicative of a high cycle low load fatigue fracture.

The surface adjacent to the fracture was associated with pitting and a corrosion deposit. A number of the ratchet marks were also associated with pitting. Fatigue cracks will generally initiate in areas of highest stress concentration. Sharp cracks, defects, grooves, and changes in section can often act as stress concentrators which can increase the probability of fatigue crack initiation. In the immediate area of these

stress concentrators, the effective stress is greatly increased. The presence of pitting would have acted as a stress concentrator for fatigue crack initiation.

Multiple secondary cracks were evident behind the fracture surface. The cracks were transgranular in nature with no evidence of any branching. Further, several of the cracks possessed a “spear-like” morphology with many initiating from pits at the surface. A corrosion deposit was also evident within the cracks. This deposit was found to consist predominantly of iron and oxygen, with small amounts of phosphorus, barium, potassium, calcium, sulphur, chlorine and sodium.

The evidence suggests that failure had occurred due to the occurrence of corrosion fatigue. Propagation by corrosion fatigue had occurred to such an extent that the bolt could no longer withstand the applied load which led to the complete fracture observed. Corrosion fatigue is the result of cyclic stresses operating in an environment that is corrosive to the metal.^{[3][4]} The level of stress to initiate corrosion fatigue is generally much less than the yield strength of the material, hence fatigue was able to initiate within a region of increased fatigue resistance.^{[3][4]} It is well known that for steels there is a fatigue endurance limit of stress, below which fatigue failure will not occur, regardless of the number of cycles. However, in a corrosive environment, no true endurance or safe working stress may exist.^{[3][4]} Crack growth rates can therefore be substantially higher in a corrosive environment than those obtained in a benign environment.^{[3][4]} However, it is not possible to establish a simple correlation between the extent to which different environments provoke different amounts of corrosion upon a given material and their relative influence upon the fatigue lifetime.

Environmental factors dictate the advent and efficacy of corrosion fatigue, with corrosion being a particular problem in any environment exposed to the elements or aqueous drip zones where moisture can readily collect. Moreover, corrosion fatigue increases almost proportionately with an increase in the general aggressiveness of the corrodent.^[5] Hence, in the presence of aggressive corrosive species (EDX analysis detected the presence of both sulphur and chlorine) both corrosion and crack growth rates would have increased. For carbon steels, the minimum corrosion rate required is approximately 1mpy.^[4] Furthermore, corrosion rates can be accelerated by the fatigue process itself, which is understood to rupture any associated protective films. The resultant products of corrosion can further contribute to crack growth by way of preventing the cracks from closing, and therein intensifying the stress concentration at the crack tip during tensile cycles.

A thin coating was evident along the surface of the bolt. The presence of phosphorus is indicative of a phosphate type coating/lubricant. The chemical composition of the bolt conformed with the specified composition for an 8.8 bolt. Similarly, the recorded hardness about the core complied with the hardness range specified by the standard.

9. Conclusions

- 9.1 Failure of the bolt is thought to have occurred due to corrosion fatigue. Corrosion fatigue is the result of cyclic stresses operating in an environment that is corrosive to the metal.
- 9.2 The surface adjacent to the fracture was associated with pitting and a corrosion deposit. The presence of pitting would have acted as a stress concentrator for fatigue crack initiation.
- 9.3 Multiple secondary cracks were evident behind the fracture surface. The cracks were transgranular in nature with no evidence of any branching. Further, several of the cracks possessed a “spear-like” morphology with many initiating from pits at the surface. A corrosion deposit was also evident within the cracks. These features are characteristic of corrosion fatigue.
- 9.4 The corrosion deposit was found to consist predominantly of iron and oxygen, with small amounts of phosphorus, barium, potassium, calcium, sulphur, chlorine, and sodium.
- 9.5 The presence of aggressive corrosive species, such as chlorine and sulphur, increase corrosion and crack growth rates.
- 9.6 The chemical composition of the bolt conformed with the specified composition for an 8.8 bolt. Similarly, the recorded hardness about the core complied with the hardness range specified by the standard.

10. Recommendations

- 10.1 Application of an appropriate coating to prevent the occurrence of corrosion.
- 10.2 Regular NDT inspection can determine the presence of any incipient cracking.

11. References

- 1) ISO 898-1:2013, *Mechanical properties of fasteners made carbon steel and alloy steel – Part 1: Bolts, screws, and studs with specified property classes – Coarse thread and fine pitch thread and fine pitch thread*. SWI: ISO.2013.
- 2) Mittermeijer, E. J., Somers, M. A., *Thermochemical Surface Engineering of Steels; Improving Materials Performance*. NL: Elsevier.2015.
- 3) Campbell, F.C., *Fatigue and Fracture; Understanding the Basics*. US: ASM International. 2012.

- 4) Schweitzer, P., A., *Fundamentals of Corrosion; mechanisms, causes, and preventative methods*. US: CRC Press.2010.

---End of report---



InterBolt

E0102

Bolt Report

Oct'24

Confidential

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Prepared:	Jack Bryan Hughleigh
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Background

InterBolts were installed at Tenby on 10/10/23, fitted to both flat bottom and bull head rail types, using both metric and imperial fasteners.

On 29/09/24 several bolts were replaced due to them either being yielded or showing as offline. This report details the condition of the bolts that were replaced.

Observations

- 1) All imperial bolts **yielded** so not showing 0kN when bolts are loose.

InterBolt output when no load applied varies between 32 to 3600kN. This shows all imperial bolts have been overtightened for their bolt specification and have been permanently elongated. With bolts showing up to 3600kN with no load applied, it shows the huge magnitude to which these bolts are yielding.

Yielding bolts will elongate the threads and will make them brittle, reducing their operational life. For this specific application, applying a high load will also mean that the fishplates don't slide as intended.

This highlights that the existing installation and maintenance regime for imperial bolts is incorrect for the bolt specification.

ID	Load at 0kN	Size
566	199	15/16
550	262	15/16
547	184	15/16
549	180	15/16
548	262	15/16
545	43	15/16
540	265	1"
543	40	1"
541	3463	1"
544	30	1"
570	1259	1"
542	3600	1"
533	225	1"
539	32	1"

- 2) Load bearing surface on imperial bolts very small.

Due to the method in which the head of the imperial pear bolts are forged, a ridge is formed around the outside diameter on the underside of the bolt head. This results in a very small amount of the bolt head area being in contact with the fishplate. Small contact areas will cause point loading, high settling and embedding losses, and large changes in bolt load as the surfaces move due to the fishing action of the plates.



Figure 1. Underhead condition of imperial bolt.



Figure 2. Underhead condition of imperial bolt.



Figure 3. Underhead condition of imperial bolt.

- 3) Threads damaged on imperial bolts. Threads damaged on several of the returned imperial bolts. The damage is still clean indicating it is a recent damage. Either caused by the nut, damage during removal or wear due to plate movement during service. No damage identified on metric bolts.



Figure 4. Damaged threads on imperial bolt.



Figure 5. Damaged threads on imperial bolt.



Figure 6. Damaged threads on imperial bolt.

- 4) **M24 bolt 00523 damaged due to use of incorrect tools for device removal.**
Bolt 00523 still operated correctly but was showing offline from the Tenby site because it was outside the wireless range of the existing mains powered Gateway.
A ring spanner was wedged against the bolt head and it damaged the end cap during disassembly. A deep socket should be used over the bolt head or a head retaining plate should be fitted.
- 5) **Moisture ingress to end cap.** Four imperial bolts and one metric bolts failed and were showing as 'offline' due to moisture ingress into the end cap. This is caused by corrosion to the bolt and/or the collar (same material and not coated like the bolts). These components should be coated going forwards.



Figure 7. Bolt corrosion leading to seal failure and moisture ingress.

Summary

The following recommendations are made:

- Improve the method statement and training to ensure the correct tools are taken to site and used (do not use a ring spanner). Better still use a head retaining plate so that a reaction spanner is not required.
- Coat bolts so they have a minimum of 700hr of salt spray resistance. This means that the end cap can be properly sealed against a known and repeatable bolt surface.
- Imperial pear headed bolts have issues with both the threads and underhead condition which leads to inconsistent bolt load.
- The existing installation and maintenance of imperial bolts results in them being significantly yielded and resulted in tight joints which will prevent the fishing surfaces from sliding freely.

Tata Steel Rail Technologies

B829 Draft - Fishplate Lubricant, Laboratory Testing



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Revision No.	0
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1 Introduction

Network Rail requested that Tata Steel Rail Technologies (TSRT) conduct laboratory testing on a range of fishplated joint lubricants in order to benchmark their performance and support the creation of a new Network Rail product standard for fishplate lubricants.

Currently Network Rail has two approved products to lubricate fishplated joints as part of the hot weather preparations, which require reapplication every two years. To apply the product the fishplates have to be loosened such that the lubricant can be reapplied to the fishing surfaces and centre portion of the fishbolt thread. The fishbolts are then retightened to a set torque. This manual process is time consuming and therefore costly especially when long lengths of jointed track have to be maintained.

A new lubricant product has been recommended by a supplier who claims that this particular lubricant can be applied without needing to loosen the fishplate and bolts. In addition, more modern products have been developed than those currently approved by Network Rail. These may offer better protection against the risk of track buckles by providing improved lubrication for longer periods of time or under greater compressive loads (e.g. if fishbolts are over-tightened).

There is currently no product standard for fishplate lubricants so a programme of laboratory tests is required to benchmark the performance of the current products against those available from other suppliers. This report summarises the work undertaken in Phase 1 of proposal B829 “Proposal for fishplate lubricant laboratory testing” [1] which comprises two work packages:

- Work Package 1 (WP1): Trial set-up and comparison testing of a dry and lubricated joint
- Work Package 2 (WP2): Surface corrosion testing

The objectives of WP1 are as follows:

- To confirm that the test technique is suitable;
- To confirm that the load vs. gap displacement can be used to differentiate between dry and lubricated joints;
- To determine whether cyclic frequency affects the behaviour;

- To investigate how the “Interflon” lubricant affects the load vs. gap displacement behaviour post corrosion.

The objectives of WP2 are as follows:

- To ascertain the level of corrosion resistance for each lubricant.
- To compare the corrosion resistance of each lubricant
- To assess the affect of an unlubricated sample in a corrosive environment.

2 Methodology

In WP1, two fishplate specimens were tested: a dry and a lubricated joint. The methodology used to test each of the two specimens is summarised as follows:

- Preparation of specimens for testing (Section 2.1);
- Installation in test rig and application of 180 load cycles (Section 2.2);
- Transfer to corrosion chamber for 150 hours (Section 2.3);
- Re-installation in test rig and application of 4 load cycles (Section 2.4);
- Removal from test rig to spray with Interflon lubricant (Section 2.5);
- Reinstallation in test rig and application of 4 to 10 load cycles (Section 2.6).

All load cycles were applied over a 15 minute period. In order to investigate whether loading frequency affects results, one load cycle was also applied over a 24 hour period.

2.1 Specimen preparation and test set-up

Two specimens were prepared and tested as part of WP1. Each test specimen comprised a standard four-hole fishplated joint prepared from two pre-drilled and machined 375mm lengths of 56E1 Grade 260 rail. TSRT sourced, machined and drilled all rail material. The bolts and fishplates were provided by Network Rail. Bolt holes were not cold bolt expanded (CBX) as it was assumed this would not affect the performance of the joint during testing.

Both specimens were degreased to clean the fishing surfaces of the rail and fishplates. The fishing surfaces of one specimen (11TR205) were lubricated with RS Clare All-Seasons P-Way Lubricant whereas the fishing surfaces of the other specimen (11TR204) were kept dry. The fishbolts were then tightened to a fixed torque of 475Nm. The gap between the rails was set at 6mm using a spacer block as per Network Rail standard NR/L2/TRK/2102, "Track construction standards for rail temperatures between 10 and 23°C" [2]. The ends of each fishplate specimen were machined flat to enable gripping in the test machine, as shown in Figure 1.

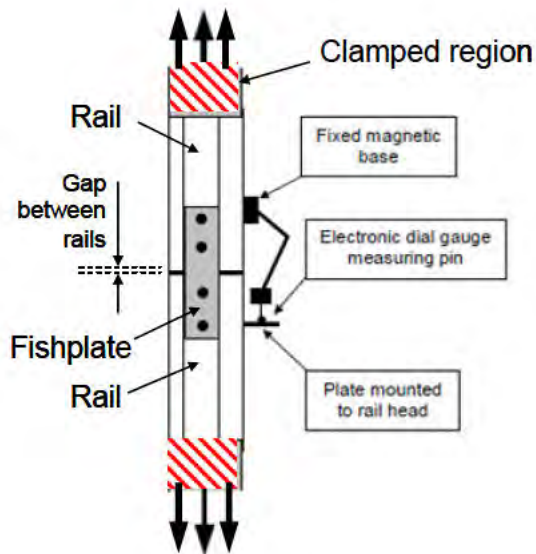


Figure 1: Test specimen comprising two rails joined by a pair of fishplates

In order to measure the displacement across the initial rail gap of 6mm, a linear variable displacement transducer (LVDT) was attached to the specimen using a fixed magnetic base on one rail and a plate mounted to the rail head on the other rail (Figure 1).

The Dartek servo hydraulic 2000kN capacity test machine (machine number FF115) in the Fracture and Fatigue laboratory at Swinden Technology Centre (STC) was used to test each specimen (Figure 2). The tests were performed in the vertical orientation with the two flat ends of each fishplate specimen clamped in the machine. Throughout each test, load and LVDT displacement were continually recorded at a frequency of 1Hz. Testing was performed at room temperature.

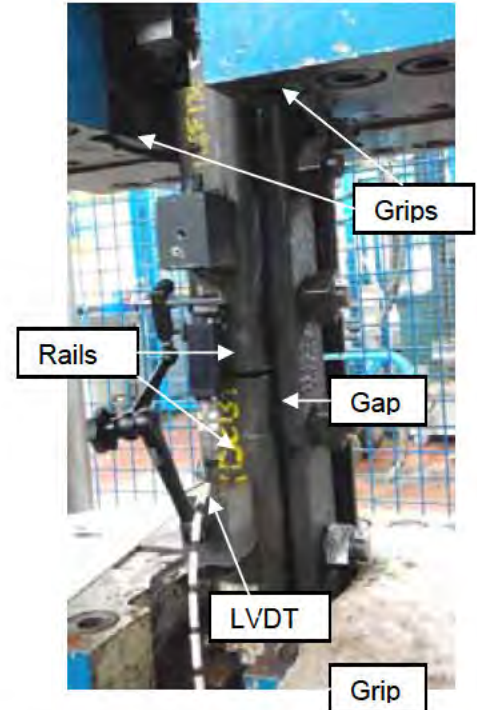


Figure 2: Servo hydraulic test rig – overall view (left) and with test specimen (right)

2.2 First set of loading cycles

All loading cycles were applied using displacement control with loads required to open and close rail end gap measured. The loading cycle used throughout the tests is shown in Figure 3. The first part of the loading cycle was applied in tension to open up the gap from the initial 6mm to 9mm. This was followed by a compressive part of the cycle to close the gap down to 1mm. The final part of the loading cycle was applied in tension to open the gap back to the original 6mm. For both specimens, 180 cycles were applied.

All tests were performed using a total cycle time of 15 minutes with the exception of one cycle on the lubricated sample with duration of 24 hours. The aim of the test with a 24 hour cycle was to establish whether there was an effect of cycle duration on the results.

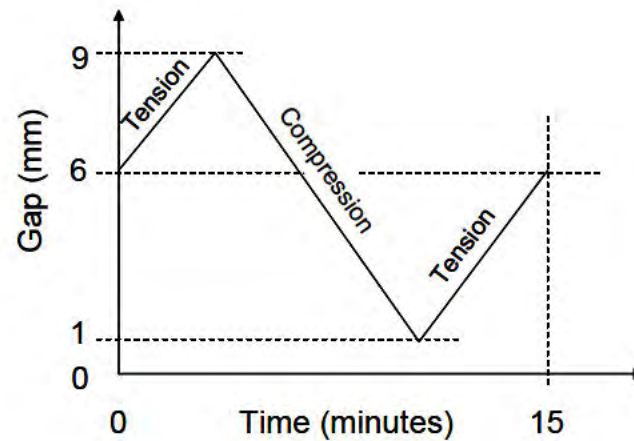


Figure 3: Schematic showing 15 minute loading cycle

2.3 Corrosion

After the first 180 cycles were completed, the specimen was removed from the test rig and supplied to the corrosion laboratory where it was placed in a corrosive salt spray environment for 150 hours. Each specimen was then returned to the Fracture and Fatigue laboratory for further testing. The condition of the two fishplates after corrosion is shown in Figure 4.



Figure 4: The two fishplate joints after corrosion for 150 hours

2.4 Second set of loading cycles

After the surface condition of the two fishplates was photographed, the specimens were reloaded in the test rig. Four load cycles were applied to each fishplate using the same loading cycle shown in Figure 3 with a cycle duration of 15 minutes.

2.5 Interflon spray

Each specimen was again removed from the test rig and sprayed with Interflon on each side without any loosening or tightening of the bolts. The amount of Interflon sprayed was estimated by timing how long each spray lasted, then spraying for the same length of time into a measuring container. Using this method it was estimated that approximately 22ml was sprayed on each side of the specimens, resulting in 44ml in total for one full application. Two applications were conducted in total for each specimen, resulting in 44ml for each side, or 88ml in total for each specimen. A member of the interflon staff applied the product for testing.

2.6 Third set of loading cycles

After spraying with Interflon, each fishplate specimen was reloaded into the test rig. The same loading cycle was used as before, Figure 3. It had previously been agreed to subject the specimens to between 4 and 10 load cycles, but due to machine availability it was possible to leave each test running longer than originally agreed resulting in over 70 load cycles being applied.

3 Results

3.1 First set of loading cycles

Selected results from the first set of 180 loading cycles are shown in Figure 5. Each cycle began at a gap displacement of 6mm (blue circle in Figure 5). As the gap was increased towards 9mm, the tensile load increased. Once 9mm was reached, the cycle reversed: the load rapidly dropped and became negative indicating that a compressive load was required to reduce the gap displacement and move the rails closer together. When the gap displacement had reduced to around 4mm, the load required increased. This is likely to be due to contact being established between one of the bolts and the edge of the hole in which it was located. As the rail gap was reduced closer to the minimum target value of 1mm, additional step changes in the load were sometimes apparent, for example in cycle 2. These are likely to be due to other bolts making contact with the edge of the hole in which they were located.

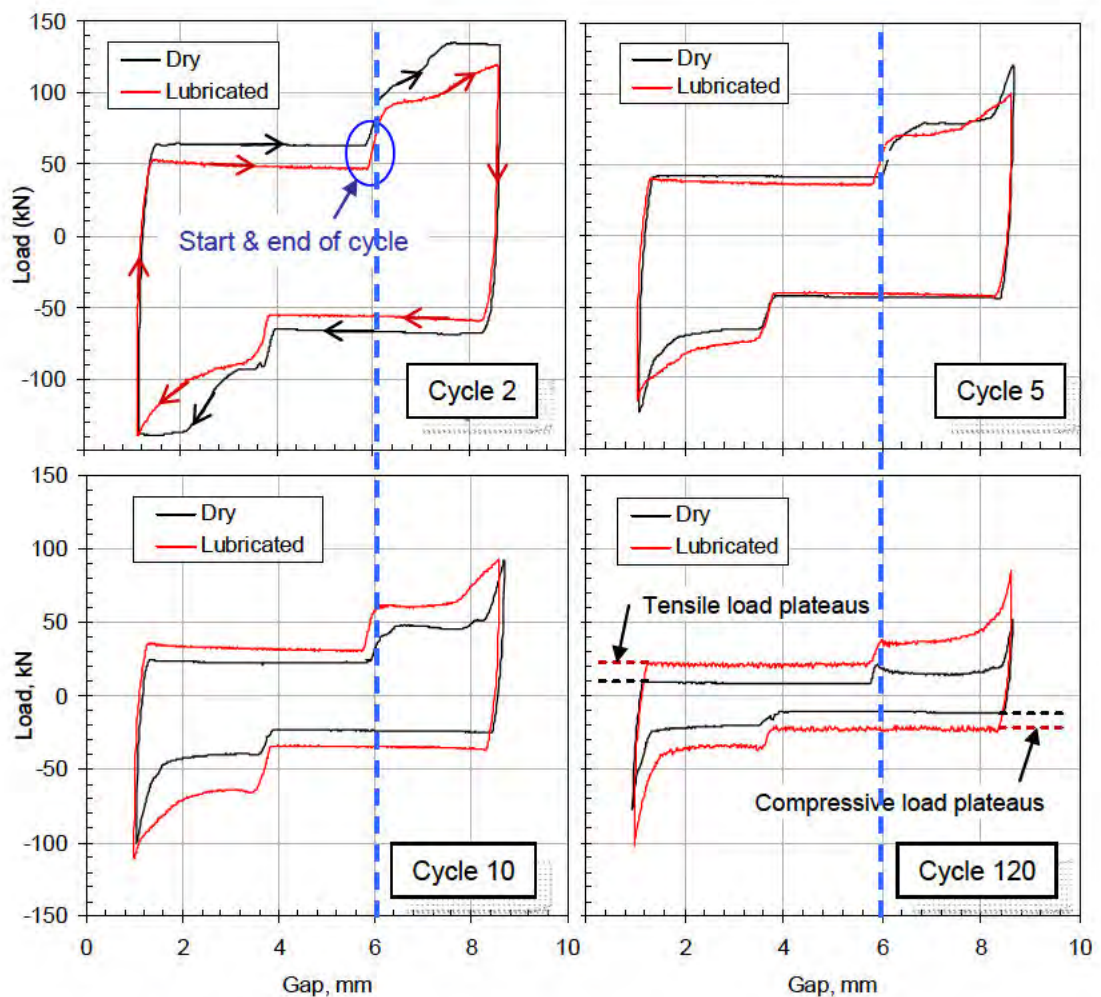


Figure 5: Selected results of the first set of 180 loading cycles

After the minimum rail gap distance of 1mm was reached, the load rapidly increased and became tensile again in order to start increasing the gap distance. The load levelled out at a constant value until the first bolt made contact with the edge of its hole at around 6mm gap displacement, resulting in an increase in applied load. At 6mm displacement, the next cycle was defined as having started and the process was repeated.

The load plateau is a measure of how easily the rail moves with respect to the fishplate, so it is logical that attempts to characterise lubrication effects should concentrate on this region of the test data. Only the first attainment of a load plateau in either a tensile or compressive part of the cycle was considered; other plateaus following step-changes in the load additionally become a function of contact between the bolt and bolt hole edge rather than a unique measure of the rail-fishplate interface.

The values of load plateau are plotted as a function of the number of cycles in Figure 6 and Figure 7.

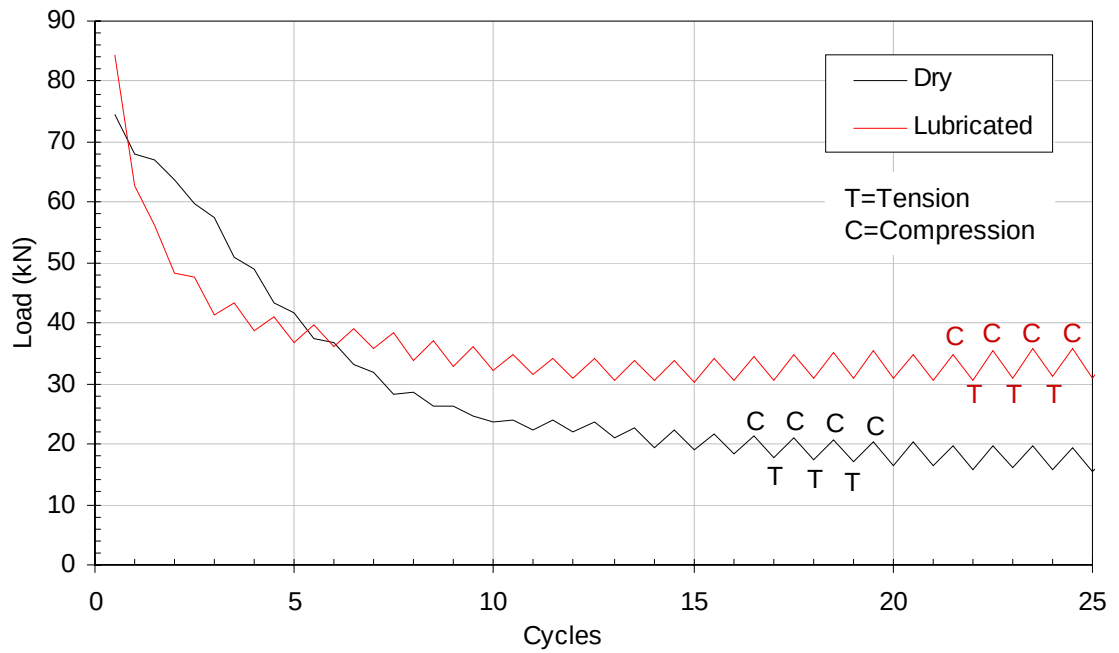


Figure 6: Load plateau values plotted as a function of no. of cycles (first 25 cycles)

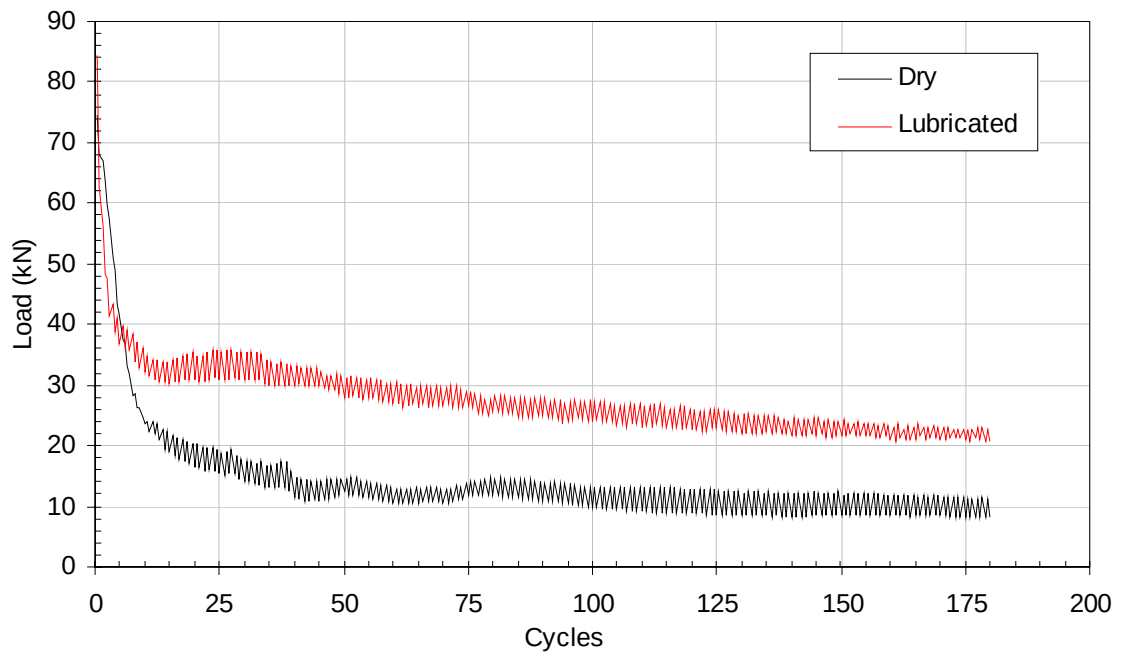


Figure 7: Load plateau values plotted as a function of no. of cycles (first 180 cycles)

Plotting the test data in this way allows several observations to be made:

- Initially the lubricated joint required a lower load to move the rails than the dry joint, but after five cycles this effect was reversed and for the majority of cycles the dry fishplate required a lower load than the lubricated fishplate;
- The loads reduced with increasing numbers of cycles for both fishplates;
- After the first few cycles, a difference in load became apparent between the compression and tension parts of the cycle, with a slightly higher load being required in compression than tension.

3.2 Effect of cycle time

After 180 cycles, the lubricated specimen was subjected to one cycle of 24 hours to investigate whether there is a significant effect of cycle time. The results are shown in Figure 8. The load plateau values in the 15-minute and 24-hour cycles are very similar indicating that there was no significant effect on the load plateau due to the two cycle times. The average load values for each load plateau varied by less than 3% between the 24 hour cycle and 15 minute cycle.

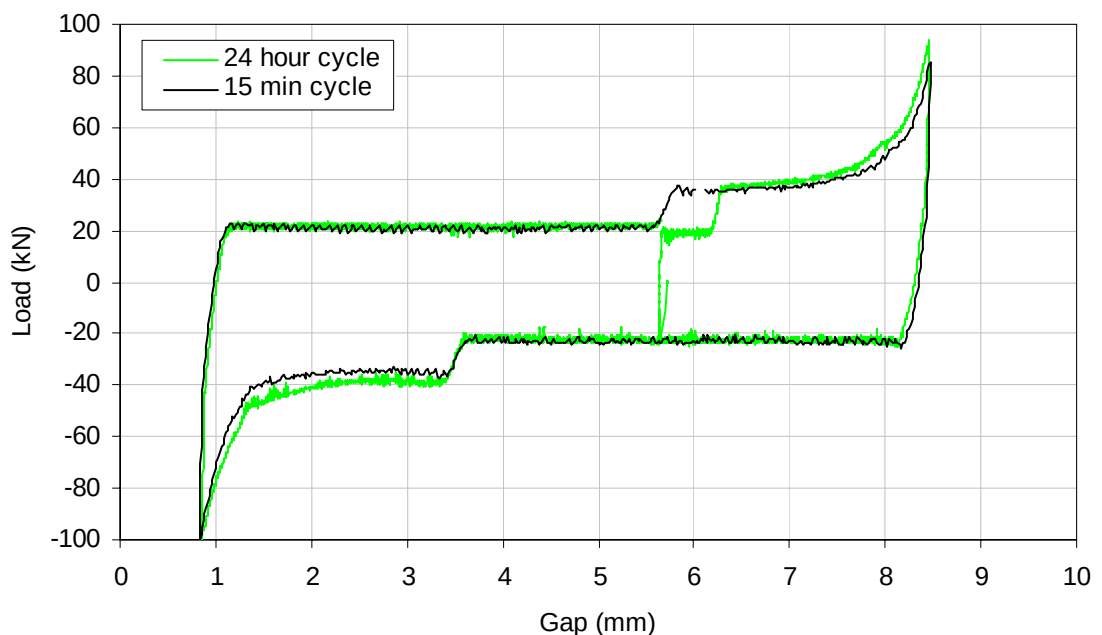


Figure 8: Comparison of load vs. displacement behaviour for 15 minute and 24 hour cycles for the lubricated specimen.

3.3 Loading cycles following corrosion

After both fishplates had been subjected to 150 hours in a corrosive environment, they were reloaded into the test rig for a further 4 cycles (cumulative cycle numbers 181-184). The load vs. displacement graph corresponding to the second cycle after corrosion is shown in Figure 9. The lubricated fishplate joint exhibited a clear 'serrated' load vs. displacement trace with the load oscillating over a range of approximately 10-15kN. This effect was also evident, but to a lesser extent, prior to corrosion where the oscillations in load were of the order of 2kN (bottom right of Figure 5). For the purposes of calculating the value of the load plateau, an averaged load was calculated through these oscillations.

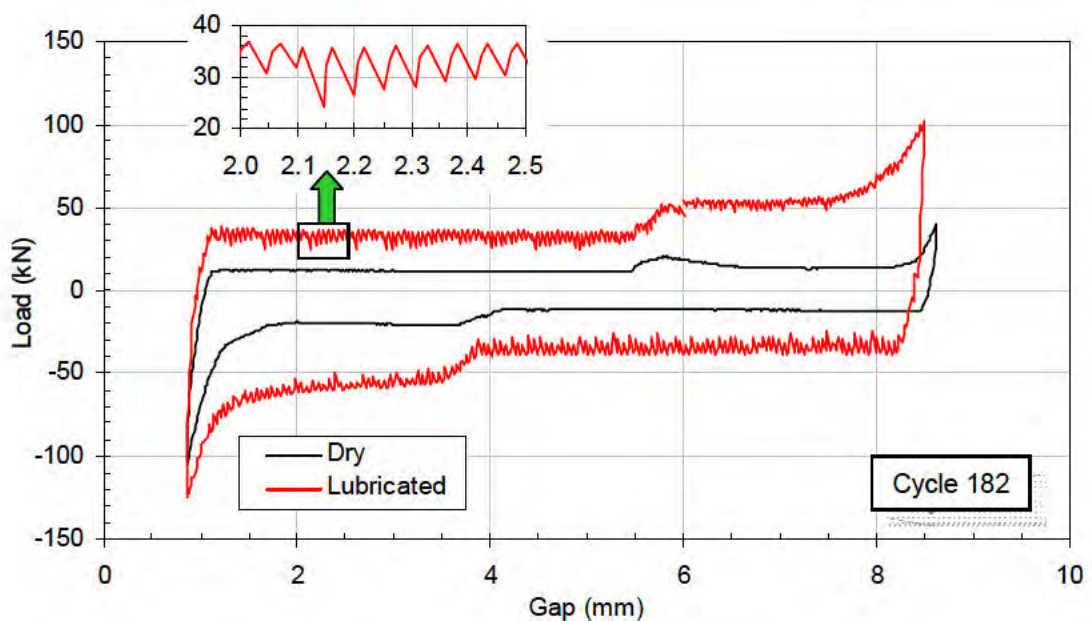


Figure 9: Load vs. displacement behaviour on the 2nd cycle after corrosion (cumulative cycle 182)

Figure 10 shows the value of the averaged load plateau plotted as a function of cumulative cycle number. There is a clear effect of corrosion on the load required to move the rails in the lubricated fishplate specimen: the required load increased by around 60% when comparing tension-to-tension (or compression-to-compression) parts of the cycle.

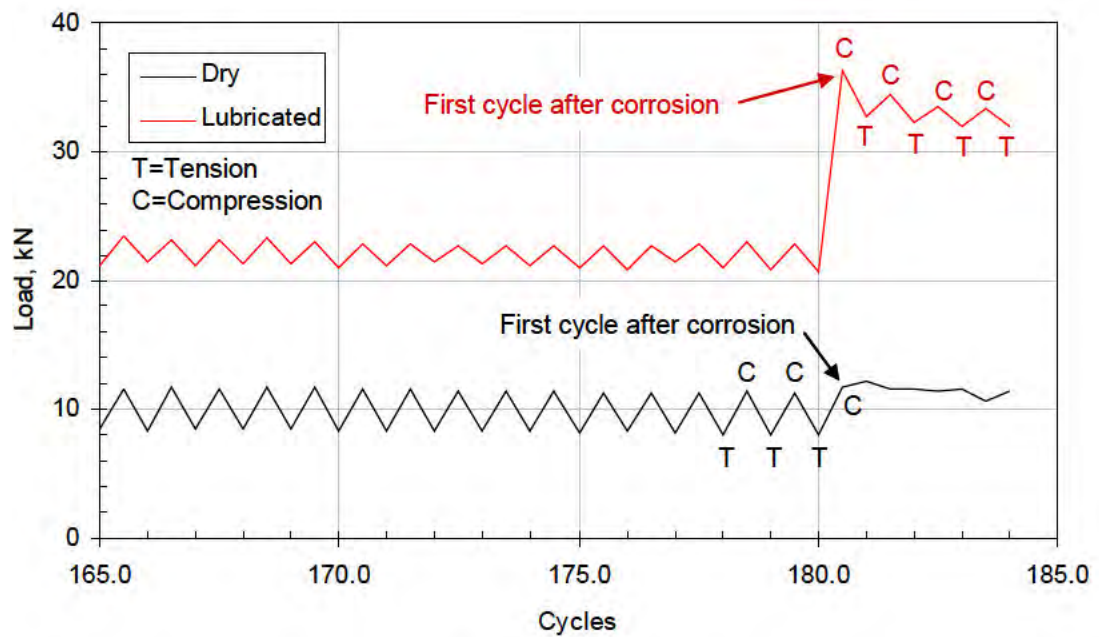


Figure 10: Load vs. cycle number following corrosion

The effect of corrosion on the dry specimen was less significant. The compressive loads required to move the rails were very similar after corrosion to the loads required prior to corrosion. The difference between the tension and compression cycles was reduced following corrosion, with no clear zig-zag pattern visible in Figure 10.

3.4 Loading cycles following application of Interflon

After both fishplates were sprayed with approximately 88ml Interflon each (44ml on each side), they were reloaded into the test rig and subjected to additional loading cycles. It had previously been agreed to test between 4 and 10 cycles but the availability of the machine was such that it was possible to test each specimen for 70-90 cycles. The load vs. displacement graphs corresponding to the second and 72nd cycle after Interflon (i.e. the 186th and 256th cumulative cycle) are shown in Figure 11. The lubricated fishplate continued to exhibit the 'serrated' load vs. displacement trace but at a much lower level, (2-4kN load range) than before the Interflon was applied (10-15kN load range). The dry and corroded fishplate exhibited a much smoother load vs. displacement trace, consistent with its behaviour before Interflon and before corrosion.

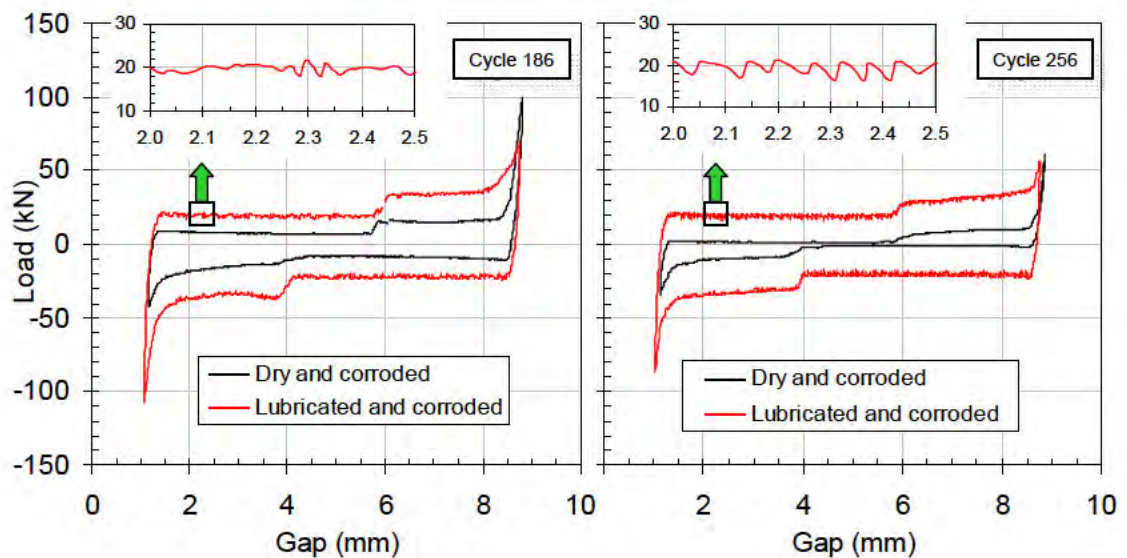


Figure 11: Selected results after application of Interflon

Figure 12 shows the value of the averaged load plateau plotted as a function of cumulative cycle number. The Interflon spray had a significant effect on the loads measured on both the lubricated and dry fishplate. The loads required to move the rails in the lubricated fishplate reduced significantly immediately after spraying, returning back to pre-corrosion levels. However, additional cycles had no further significant effect on the load which remained around 20kN. For the dry fishplate there was a more gradual effect and the load reduced by around 75% in the first 10 cycles after application. After 256 cumulative cycles the load was just 1kN.

The results indicate that Interflon did not have a significant effect on the difference between tension and compressive loads. The dry fishplate showed no clear difference between the tension and compression cycles both before and after spraying with Interflon. The lubricated specimen, which did show a clear difference between the tension and compression cycles, did so both before and after spraying with Interflon.

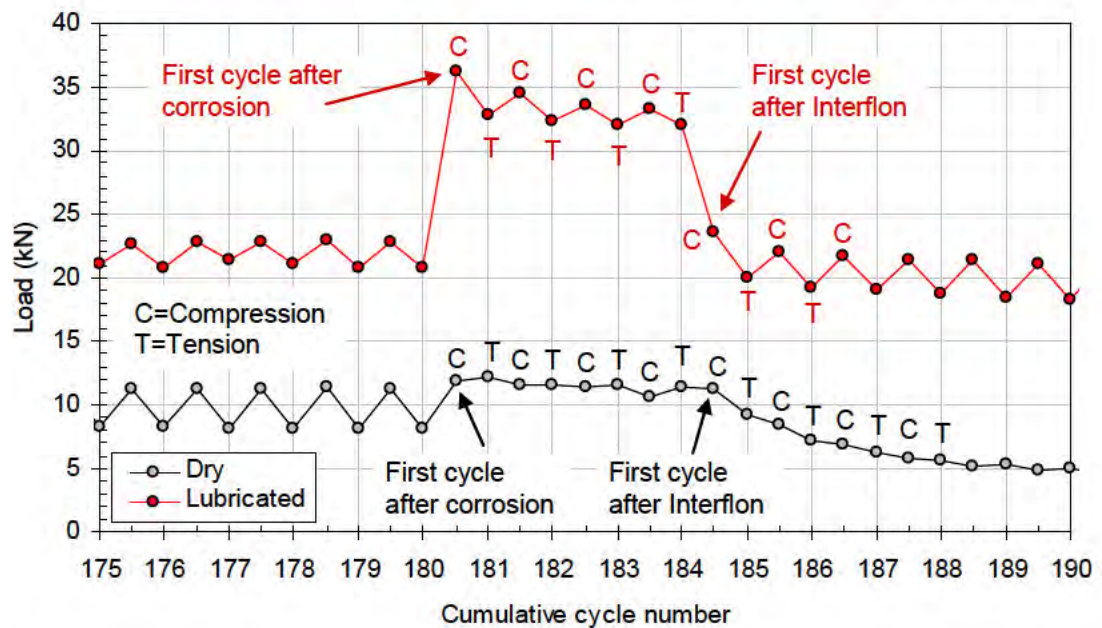


Figure 12: Load vs. cycle number immediately after application of Interflon

Figure 13 shows the load vs. cycle number for the 70-90 cycles applied after Interflon (cumulative cycle numbers 185-260). The load on the lubricated fishplate significantly reduced in immediately after the Interflon application, thereafter the load remained constant. The dry fishplate resulted in a very low load of only 1.2kN after 258 cumulative cycles. For the dry fishplate, over 80% of the load reduction following Interflon application occurred in the first ten cycles (i.e. by cumulative cycle no. 195).

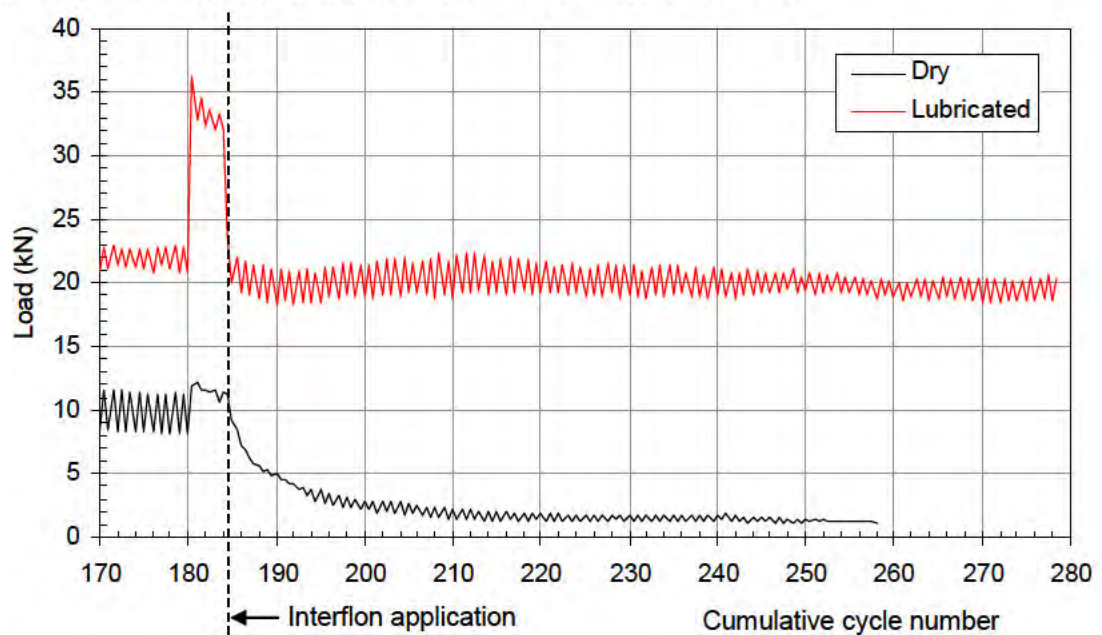


Figure 13: Load vs. cycle after the application of Interflon

4 Surface corrosion tests

4.1 Surface corrosion preparation

The original B829-P1 submitted to NR proposed that a template be used to apply a rectangle area of lubricant measuring 50mm high x 100mm long and x 0.5mm deep to a 120mm long sections of 56E1 rail web, however separate lengths of rail will have varying amounts of mill scale present which, may effect the results of the test. After speaking with the corrosion experts within RD&T it was suggested that a simpler more accurate method which is generally used to test coatings, this method involves applying lubricants to a Q plate which is a 100 x 150mm mild steel plate with a ground finish, a draw bar system will then be used to apply the lubricant evenly over the Q plate.

During sample preparation it was discovered that the differing viscosities between lubricant samples means that a 0.5mm thick layer could not be guaranteed as the lubricants were running over the edges of the Q plate. The only way to test all the lubricants was to use a draw bar and measure the thickness using a wet gauge.

A note was made of the thickness of lubricant applied to each Q plate as show in Table 1 below.

Number	Lubricant	Thickness	Viscosity
1	Bio Naturail	400-450micron	Low
2	Graco AGU plus	350-400 micron	High
3	Fuchs SSM	350-400 micron	High
4	Fuchs WSP540	350-400 micron	High
5	XL Fishplate oil	350-400 micron	Low
6	Finlube Interflon	400-450 micron	Low
7	Condant Bio SP	400-450 micron	Low
8	RS Clare All seasons	450-500 micron	Medium
9	RS Clare Enhanced Pway	450-500 micron	Medium
10	Kluber Stablags (spray)	300 micron	Low

Table 1. Lubricant thickness

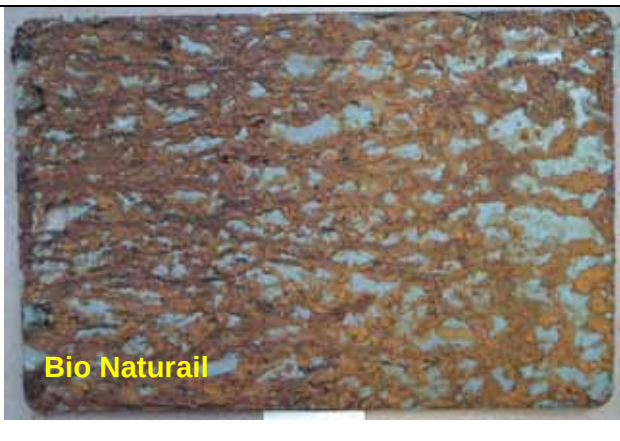
Duplicates Q plates of each lubricant were made to allow for the variability of the assessment technique.

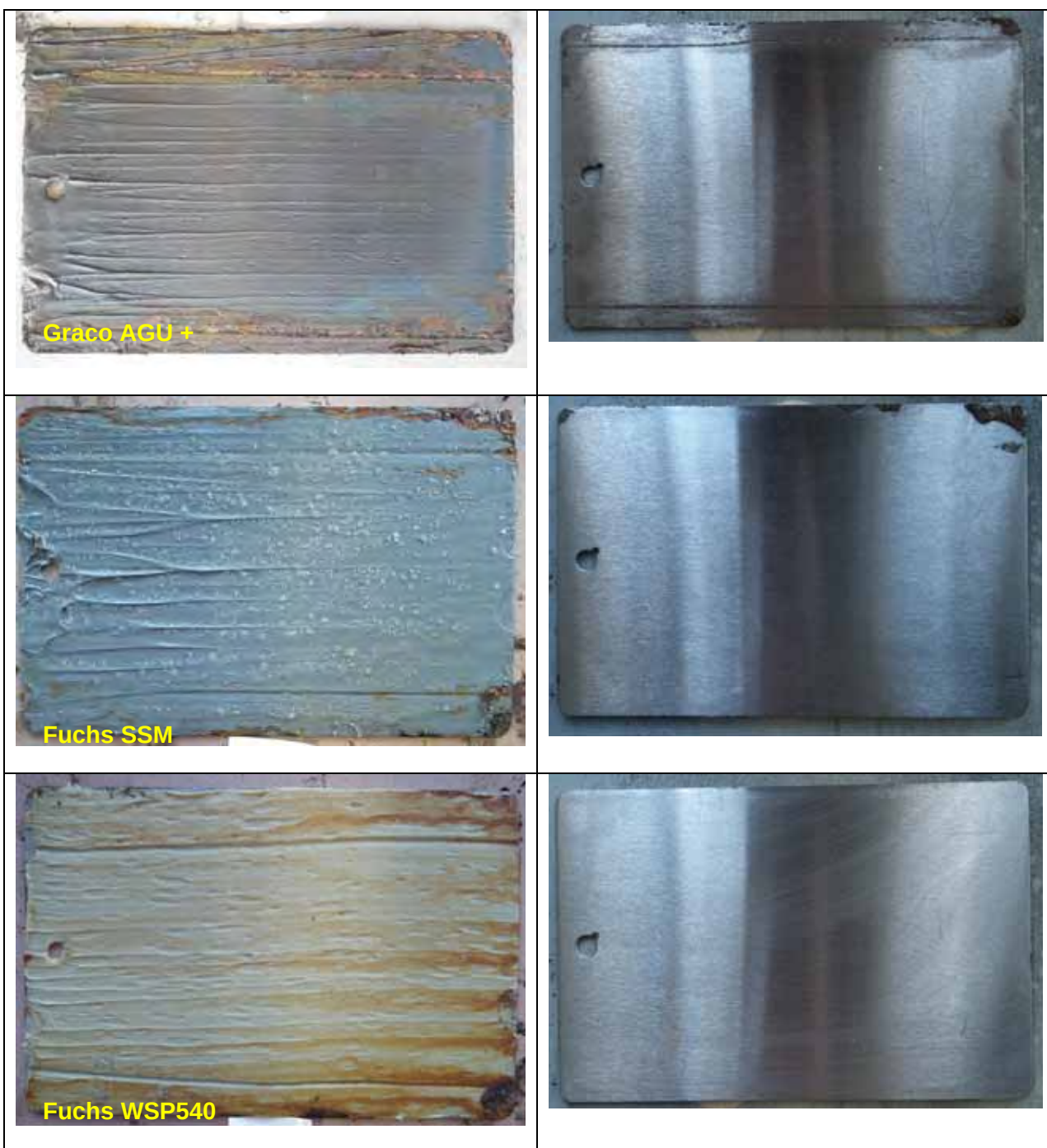
It was noted that in a few cases where the product is more viscous, compared to a high viscous thick grease, that the lubricant was began to 'sag' this is a term used to describe

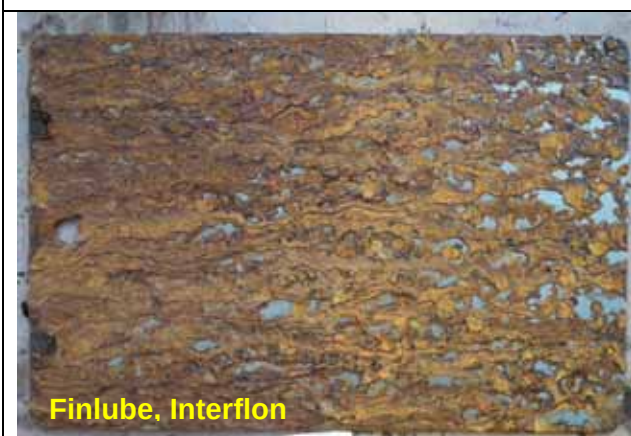
the running effect seen over the Q plate, this may result in the final thickness of the lubricant in these cases being less than originally measured in Table 14 above.

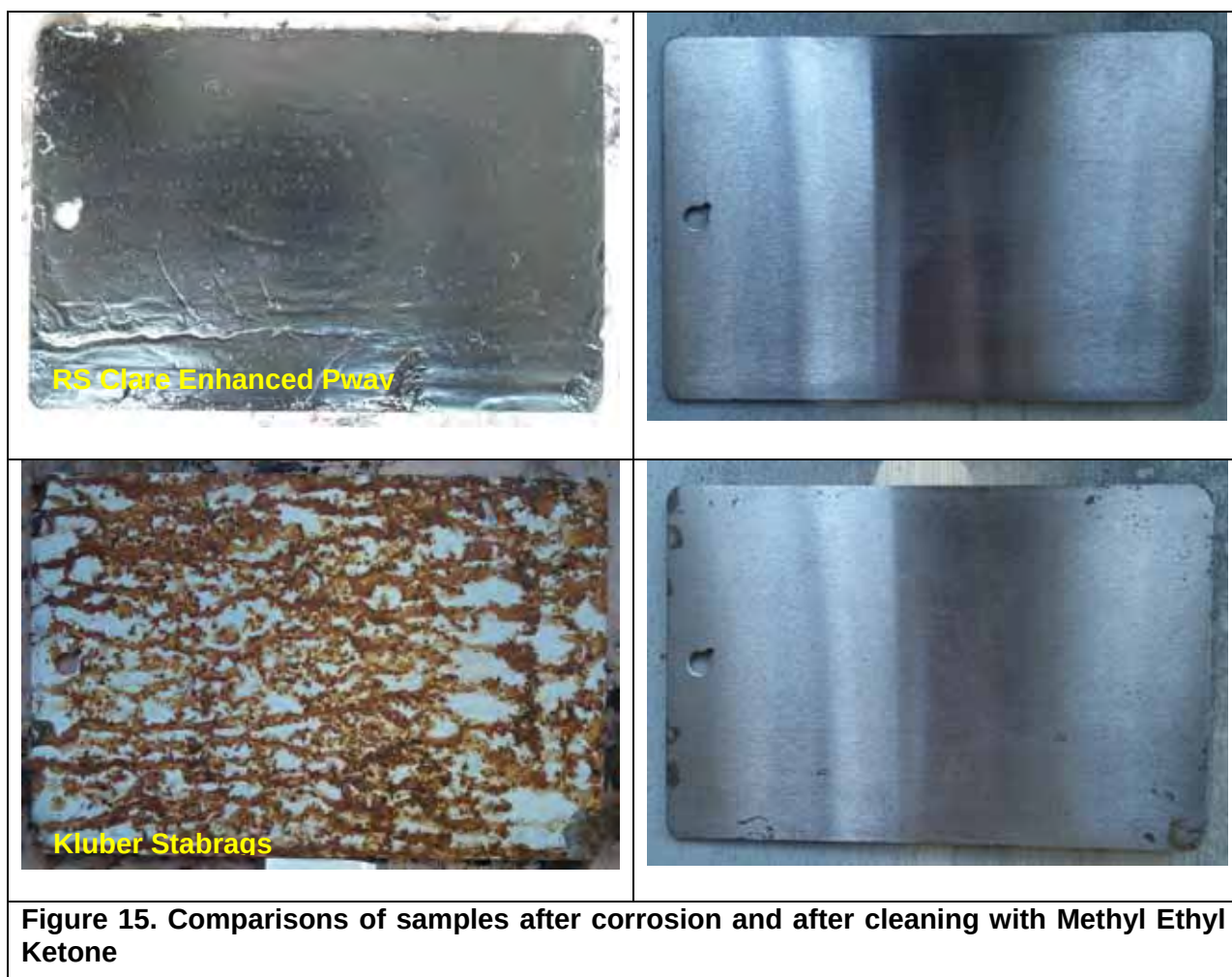
4.2 Surface Corrosion test results

The prepared samples along with two dry control samples were then place in a corrosion chamber where a neutral salt spray was applied to the test piece in a controlled environment according to ISO 9227 for approximately 150 hours. The test piece was then removed from the salt spray and the condition of the sample photographed to record its condition, the lubricant was then removed and the condition of the cleaned Q plate photographed for comparison as shown in figure 15 below.

Photographs after exposure to corrosive salt spray environment.	Photographs after cleaning with Methyl Ethyl Ketone.
 Control sample	
 Bio Naturail	







As show in the images above all the lubricants are generally performing well in all but two cases, Finlube (interflon) and XL fishplate oil where it is shown that after cleaning with Methyl Ethyl Ketone the corrosion has worked through on to the surface of the metal. In both cases, the lubricant used was low viscosity, which could mean that during the preparation of the samples the lubricant may have run off to leave a layer of lubricant too thin to offer a sufficient protection against corrosion.

This also means there is variability in the thickness of lubricant applied, which may have a dramatic effect on results and the ability to accurately compare one product against the other, although this does however show the true nature of each product and how it will perform in track on application to the fishplated joints.

4.3 Results from surface corrosion

To ascertain the severity of corrosion on each lubricated sample Standard ASTM D610-08 Standard Practice for Evaluating Degree of Rusting on Painted steel surfaces^[3] has been used to give an estimation of rust grade for each cleaned sample.

The grading is explained in table 2 below.

Rust grade	Percentage of surface rusted (%)
10	≤ 0.01
9	>0.01 up to 0.03
8	> 0.03 up to 0.1
7	> 0.1 up to 0.3
6	> 0.3 up to 1.0
5	> 1.0 up to 3.0
4	> 3.0 up to 10.0
3	> 10 up to 16.0
2	> 16 up to 33.0
1	> 33.0 up to 50.0
0	> 50.0

Table 2. Scale of rust rating

From the grading table shown above each lubricant has been given a grade to establish the level of corrosion present and provides an indication of the corrosion protection they provide.

Table 3 below shows the results of each sample.

Lubricant	Rust grade	Comments
1	10	Small areas of rust at edges
2	10	Small areas of rust at edges
3	8	Small areas of rust at edges
4	10	Clear
5	0	Approximately 95% corroded
6	0	Approximately 85%corroded
7	10	Small areas of rust at edges
8	10	Small areas of rust at edges
9	10	Clear
10	6	Approximately 1% corroded

Table 3. Lubricant sample rust grade

In the majority of cases the lubricants have performed extremely well with only small areas around the edges having any corrosion present, this is most likely due to area not being as well covered as the rest of the sample.

These lubricants all scored 10 on the rust grade assessment and include the following:

Bio Naturail

Graco AGU plus

Fuchs WSP540

Codant Bio

RS .Clares All Seasons Pway

RS Clares Enhanced Pway

Two samples, which performed slightly less well, are the Fuchs SSM and Kluber Starbrag which exhibited rust on the outer edges of the Q plates of between 0.03 and 1% of the surface.

The two poorest scoring lubricants both scored 0 as the level of rust was above 50% these were XL Fishplate oil and Finlube (Interflon). This is most likely due to the very thin layer of lubricant left on the Q plates after preparation, as they were low in viscosity and dripped off easily.

It was thought that the better performing lubricants would be the ones that offered the most coverage against the corrosive environment, this would make the thicker products the better lubricants for corrosion resistance. This, however, is not always the case, as although this maybe a true relationship in the majority of the products there are a few exceptions. Kluber Stabrag, which despite being an aerosol spray and quite low in viscosity it was one of the better performing products in terms of its rust grade, In contrast

to the Fuchs SSM which although was quite a thick grease, Did not perform as well as similar high viscous lubricant.

5 Conclusions/Recommendations

5.1 First set of loading cycles

The important part of the load vs. gap displacement graphs shown in Figure 5, in terms of measuring the lubrication between the rail and fishplate surfaces, is the first attainment of a load plateau. The load peaks that occur at the gap displacements of 9mm and 1mm are not used to characterise the lubrication of the fishing surfaces. Further testing in Phase 2 has been proposed with maximum and minimum gap displacements of 8mm and 2mm respectively, with the aim of avoiding the load peaks that occur at high and low gap displacements and reduce the risk of overload.

The overall results shown in Figure 6 and Figure 7 may appear counter intuitive at first. Although the lubricated fishplate required a lower load than the dry fishplate at low cycle numbers, after only five cycles the two specimens swapped over. For the remainder of the test the dry fishplate required much lower loads than the lubricated fishplate. A possible explanation is that the close contact between the rail and fishplate in the dry specimen enabled the two surfaces to rub against each other, leading to a polishing effect and a reduction in friction as the number of cycles increased. This effect may not have been able to occur to the same extent in the lubricated specimen due to the presence of RS Clare All-Seasons P-Way Lubricant preventing the two surfaces from rubbing against each other directly.

Another effect seen throughout most of the tests is a difference between the load plateaus in tension and compression. Where a difference is observed, the compressive load is always slightly higher than the tensile load. A potential cause of this difference may be some form of misalignment within the fishplate. Figure 14 is a schematic showing how tension and compression may lead to differences in measured load via this mechanism: tensile loading would tend to straighten out a misaligned joint by creating a turning moment, which tends to reduce the load (top right of Figure 14). The same misaligned joint loaded in compression would be subjected to a turning moment in the opposite direction, which would tend to increase the measured load (bottom right of Figure 14). For a perfectly aligned joint no difference would be expected between tension and compression.

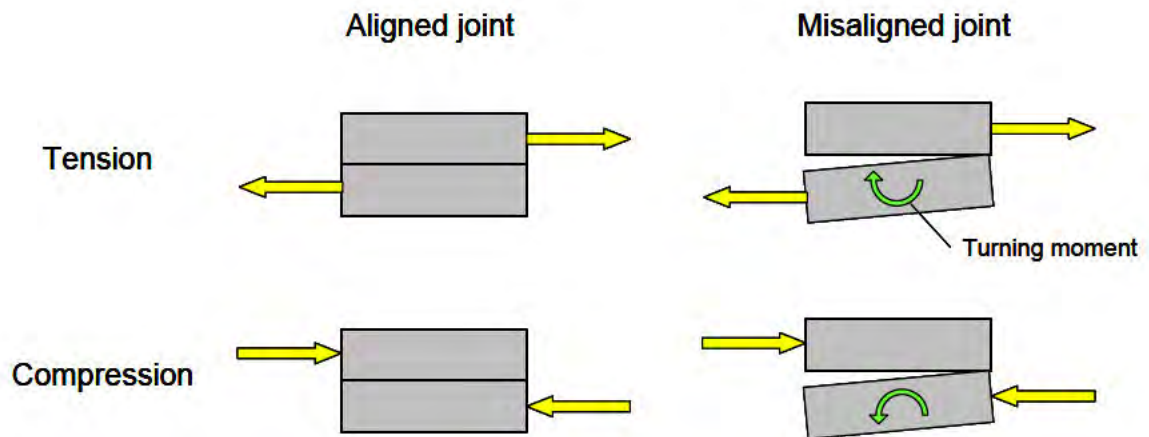


Figure 14: Schematic showing how a misaligned joint could produce differences in load between tension and compression

When attempting to measure the load relevant for track buckling, the higher compressive load would be the relevant load to consider. However, a test designed to differentiate between different lubricants may be more effective if only the tensile load were considered, assuming the idea in Figure 14 is correct. This is because the compressive load plateau in the test is a function of both misalignment and friction, whereas the tensile load plateau is a function of friction only. It is recommended further consideration is given to the differences between the tension and compression loads in the proposed Phase 2 test programme.

5.2 Loading cycles following corrosion

The results in Figure 10 indicate that corrosion has a bigger effect on the lubricated fishplate specimen than the dry specimen. Although it is difficult to draw firm conclusions on the basis of two tests, a potential explanation could be that the effects of corrosion were able to penetrate more deeply into the lubricated fishplate specimen if the two fishing surfaces were slightly apart from each other due to the presence of RS Clare All-Seasons P-Way Lubricant. Some evidence to support this is in the corrosion tests for sample RS Clare All Seasons Pway Lurbicant seeing some corrosion at edges.

The dry fishplate specimen with surfaces in closer contact may have provided a greater resistance to the effects of corrosion. The additional tests proposed in Phase 2 will help to confirm whether this behaviour is repeatable.

The results in Figure 12 suggest that after corrosion the differences between tensile and compressive load almost disappear for the dry fishplate specimen. It is important to note,

however, that the fishplates had been removed from the test rig and moved to a separate laboratory for exposure to a corrosive atmosphere before being returned and reinstalled in the test rig. The observed change of behaviour in Figure 12 before and after corrosion may not necessarily be due to corrosion and may be due to changes in internal alignment that occurred during handling and transport of the specimen. However, it is difficult to draw firm conclusions on the basis of this result alone. Further repeat testing in phase 2 may clarify the role of corrosion and misalignment on the differences between tensile and compressive loads.

5.3 Loading cycles following application of Interflon

Figure 12 and Figure 13 indicate that Interflon had a significant effect on both the lubricated and the dry corroded fishplate specimen. The lubricated specimen that had seen a significant increase in load following corrosion showed a significant reduction in load on the very first cycle after Interflon had been sprayed, back to pre-corrosion levels of around 20kN. However, additional cycles had very little effect. Conversely, the dry corroded specimen showed a gradual but sustained reduction in load after Interflon had been sprayed, eventually resulting in very low values just above 1kN which is even below that seen pre corrosion. The lubricated sample was also moved but does not show this feature

The results indicate that the Interflon does penetrate and provide significant lubrication to the dry joint without any loosening of the bolts being required. Although the Interflon also penetrates the pre-lubricated joint, providing a reduction in load on the very first loading cycle, its beneficial effect is more limited than for the dry joint.

The work undertaken in WP1 has achieved the initial objectives as follows:

- The test technique has been broadly demonstrated as being suitable, although further development is recommended to optimise the interpretation of test results (e.g. to recommend whether tension or compression load is the most appropriate to report) and to check repeatability of the tests.
- The load vs. gap displacement has been confirmed as being suitable for differentiating between dry and lubricated joints.

- The effect of cyclic frequency (24 hours vs. 15 minutes) has been shown to not have a significant effect on the load vs. gap displacement behaviour in laboratory environment.
- When applied in a large quantity, Interflon has been shown to have a significant but slightly different load reduction effect on the behaviour of both dry and lubricated corroded joints.

Further work is recommended as per the Phase 2 proposal to optimise the test conditions (e.g. applied displacements), optimise interpretation of the test results (e.g. tensile vs. compressive loads) and check repeatability of the tests.

5.4 WP2 Surface corrosion testing

Surface corrosion resistance testing, was conducted to establish the level of corrosion resistance each lubricant provided. It was predicted that the more viscous the lubricant the more corrosion resistance it would provide. Although this is true in most cases there are a few exceptions such as Kluber Stabtags, which despite being a low viscosity aerosol was one of the better performing products in terms of corrosion resistance, scoring a rust grade of 6. In contrast the Fuchs SSM lubricant which although was quite a viscous grease didn't perform as well as similar high viscous lubricant.

The most interesting point to acknowledge is the performance of Interflon in the corrosion test. Interflon does appear to lubricate without loosening the fishplate bolts. However corrosion results show that Interflon does not provide the same protection against corrosion compared to the similar low viscous lubricant Condant Bio SP or Kluber Stabtags. If it can be shown that this product also achieves lubrication without the need to loosen the fishplate bolts it may have an add advantage of also providing more corrosion resistance over the Interflon product.

6 References

1. Leonard, L., "P829 Proposal for Fishplate Lubricant Testing", Tata Steel Rail Technologies, 20th July 2011
2. Network Rail Standard NR/L2/TRK/2102 "Track construction standards for rail temperatures between 10 and 23°C"

3. Standard ASTM D610-08 Standard Practice for Evaluating Degree of Rusting on Painted steel surfaces

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