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ISSUE 01

CHINA
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WELDING 4.0
A new way of aluminothermic welding

ASK THE EXPERT
Oliver Dolder on emission free maintenance

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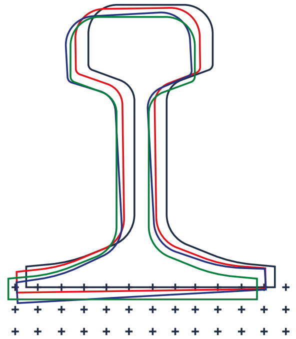
In this issue

This edition of Focus is dedicated to heavy haul. Pandrol shares its stories, its experience and its solutions to drive availability, safety and lifetime value of freight operations.

LEADERSHIP COMMENT



SHOWCASE PROJECTS ACROSS THE GLOBE

PRODUCT INNOVATION

PANDROL

Pandrol rail fastenings have been used on **ALL OF THE MAJOR HEAVY HAUL** railways in the world with a track record covering more than **FOUR DECADES** and extending across **ALL CONTINENTS.**

FOCUS

EDITOR'S LETTER

Pandrol Rail Fastenings are in service on axle loads up to 40 tonnes and performing in climates ranging from the exceptionally dry arid deserts of North West Australia and the Middle East, through the humid tropics of Africa to the extreme cold of Canada and Scandinavia.

All Pandrol heavy haul assemblies incorporate highly engineered technology delivering high quality track and very low maintenance ideally suiting heavy haul rail operations.

Testimony to Pandrol's technology is one of the great dedicated iron ore railways of the world at Hamersley Iron, which operates iron ore trains of up to 35,000 tonnes between Paraburdoo and Dampier in North West Australia, and transports 90 million gross tonnes per year, and which first operated on timber sleepers with Pandrol clips in 1978.

The performance of the Pandrol clips was such that when the original timber sleepers were replaced with concrete sleepers in 1986, the original fastenings were recycled and reused on the new concrete sleepers. All track extensions have been with Pandrol clips and there have been no maintenance or operational problems to date.

The majority of heavy haul operators in North America have used Pandrol fastenings including Union Pacific, BNSF, Canadian National, Norfolk Southern and CSX, VALE (Brazil) and Spoornet (South Africa) also operate heavy haul tracks with Pandrol clips.

In recent years, Pandrol Fastclip has been used increasingly by heavy haul operators, with unprecedented use of high output mechanisation for installation and maintenance that delivers lower installation costs for contractors and repeats those efficiencies in stressing operations, re-railing and rail maintenance activity throughout the life of the fastening system.

Pandrol Fastclip has been installed in Saudi Arabia since 2010 on the world's longest dedicated heavy haul line and continues to be used in current projects. Each 2.8 km long mineral train on the 2000 km, North South Line consists of 5 locomotives and 160 wagons with a payload of up to 16,000 tonnes per train. The Saudi Railway Company (SAR) carry 5.2 million tonnes of phosphate and 4 million tonnes of bauxite per year, although the line has capacity for up to 10.4 million tonnes of phosphate and 13.8 million tonnes of bauxite.

Banff National Park, Canada

Per Pande Rolfsen

In recent years we have seen innovative ideas revolutionise industries at a pace never before experienced. However, long before the invention of the internet, smart phones and colour TV, one Norwegian engineer had an idea that would revolutionise an industry that had already permanently altered how heavy goods were moved and sold around the world.

In 1950 the widespread uptake of continuously welded rail and concrete sleepers was imminent, the then 'Elastic Rail Spike Co.' managed by Stewart Sanson was hunting for the next generation of rail fastening products after recognising that none of their current spikes designs would be suitable for such applications.

Numerous experiments were undertaken to assess other resilient fastenings for concrete sleepers. But ultimately it was in Oslo that Sanson was to find the answer to the conundrum. Having spent many years visiting the Chief Engineer of Norwegian State Railways (NSB), Sanson was approached by a man named Per Pande-Rolfsen, a young NSB permanent way engineer who had invented his own indirect fastening. Sanson immediately saw its potential, untested though it was.

A fully-resilient indirect fastening which did not transmit vibrations from passing trains, the self-tensioning spring clip was far more adaptable than any other product on the market, applicable to timber, steel and newly-developed concrete sleepers.

In May 1958 Elastic Rail Spike Co registered international licensing rights under an agreement with Moller & Ringstad Export Co, which was acting on behalf of Rolfsen. Taking two syllables from the name of its creator, the indirect fastening was rapidly christened 'the Pandrol clip'. The name which was eventually adopted by the Elastic Rail Spike Company following the widespread adoption of the Pandrol clip across the world.

OFOTEN LINE
FROM RIKSGRÄNSEN TO
NARVIK IN NORWAY

1957 Per Pande-Rolfsen, an engineer with the Norwegian State Railway, approaches the Elastic Rail Spike Company with his rail fastening design. This subsequently becomes known as 'the Pandrol clip'.

1959 First production of the Pandrol clip takes place.

1963 Manufacture of the Pandrol clip starts in Australia. The first Pandrol clips with ductile iron shoulders are tested by British Rail near Northampton.

1965 The Pandrol clip is adopted as the standard fastening for wooden sleepers by BR. An agreement is made with S A Robicel for the manufacture and sale of the clip in Belgium, Holland and Luxembourg.

1966 British Rail adopts the Pandrol clip as the standard fastening for concrete sleepers.

1967 South African Railways makes the Pandrol clip its standard fastening.

1969 Pandrol clips penetrate the 'Iron Curtain' with a trial installation in Romania.

1970 The Elastic Rail Spike Company changes its name to become Pandrol.

1971 Pandrol clip production passes the 67 million mark.

1972 Freight railway from Port Augusta to Whyalla steelworks in South Australia opens to traffic. It is the first line to be built in Australia to feature Pandrol fastenings throughout.

1987 Production of Pandrol clips totals 100 million.

2019 Today Pandrol solutions are at the heart of more than 400 railways, in over 100 countries, and with over 3 billion products in service. A truly global business, Pandrol is proud of its historic and intrinsic connection to Norway.

RAIL FASTENINGS FOR HEAVY HAUL APPLICATIONS.

Rail Fastenings

Rail Industry expert, Dr. David Rhodes takes a look back at key issues raised at the International Heavy Haul Association (IHHA) meetings in Calgary and New Delhi.

On the face of it rail fastenings are not required to do anything more in heavy haul applications than they are in any other railway. Heavier rail sections and closer sleeper spacing can compensate for higher axle loads and the loading on the fastenings does not need to be any higher than usual. However, in practice the demands of the specialist heavy haul operators are such that quite different approaches to track component design are usually necessary.

The detail design of rail fastening systems affects parameters such as track gauge, track stiffness and rail inclination, all of which affect, in turn, wheel-rail interface mechanics. Of course that all makes the fastening specification a critical factor in keeping railways running smoothly, but in the case of the heavy haul railways three additional factors are highlighted which combine to make these requirements even more challenging.

HIGH ANNUAL PASSING TONNAGE

Firstly, compared with conventional railways, the annual passing tonnage of heavy haul railways can be very high. In conventional applications 20 million tonnes per annum constitutes quite a busy line. In heavy haul operations 200 million tonnes per annum is not unusual. The obvious effect of that is that if components still require maintenance or replacement after the same accumulated passing tonnage, that maintenance requirement is reached in a much shorter elapsed time. What is less obvious is the effect which that has on life cycle cost analysis. Maintenance activities which would be discounted to negligible net present value on a conventional railway, because they would occur so far in the future, are much more significant on the heavy haul railway.

At the detailed level of the rail fastenings the cost of maintenance and replacement does not lie in the cost of the components themselves but in the cost of labour and track closures. There are considerable economic benefits in replacing small track components only when other maintenance work, such as re-railing, is being carried out. That suggests that considerable savings can be made by ensuring that the life of fastening components exceeds the life of the rail – and that becomes more of a challenge as rail lives are extended, with the major US heavy haul railways now expecting rail to last for 3 billion tonnes of traffic in tangent track.

In the case of a heavy haul line with high annual passing tonnage the net present value of such savings is high enough to justify investment in more durable components.

HIGH TRACTION FORCES

Secondly, the effects of traction forces on longitudinal track stresses can be very significant. For most railways, once track has been designed to cope with forces due to thermal expansion and contraction of the track and the maximum expected braking forces then it will by default be strong enough to withstand the applied traction forces. In heavy haul applications that is not the case. On uphill grades the sustained application of high traction forces, train after train, can induce track failure modes not seen elsewhere. Usually the first sign of failure is uneven movement of sleepers which become skewed and displaced relative to the rails and the ballast.

The solution to the problem lies in the design construction and maintenance of a high quality track bed and in attention to the selection of rail fastenings with appropriate longitudinal shear elasticity. Tests carried out on several railways over a number of years have shown that different types of rail pad which have similar performance in conventional type-approval tests do, nevertheless, give quite different performance in terms of mitigating the effects of high-traction forces.

The solution to the problem lies in the design, construction and maintenance of a high quality track bed.

SPECIFICATIONS AND STANDARDS

Most heavy haul railways which are being planned or built today are proposed not by established railways but by mining companies. The railway becomes a part of the mining project because it is the most economical and reliable way to move bulk commodities from source to consumer and so in most cases the whole job of designing, building and even operating the railway is put out to competitive tender in the same way as any other capital investment. That process requires a specification of technical performance which can be written into a commercial contract. The problem is that no established technical standards take into account the kind of factors which have been discussed above. To make it even more difficult, technical standards which exist within individual railway networks are closely interdependent. For example, the calculation of the loads which are applied to test a sleeper or rail fastening system is based on assumptions about the stiffness and consistency of the track bed. That in turn is based on another assumption, that track maintenance limits specified elsewhere in the system will be observed – and those limits are based on empirical assessment of particular track and traffic conditions.

Simply adopting technical specifications from one railway and applying them to another in a different part of the world is rarely sufficient. The heavy haul railway industry has an enviable record of sharing technical knowledge through organisations such as IHHA. It is through that process that best practice can be "exported" to new and more challenging projects.

EXTREME CLIMATES

Finally the heavy haul railways are unusual in demanding all of these things in some of the most hostile environments our planet has to offer. As deposits of minerals – especially iron ore – are exploited in ever more inaccessible places it becomes necessary to construct railways which can be built, operated and maintained in extreme climatic conditions. For components made from steel and concrete that is not too difficult, but there are two things in particular which function quite differently at extremes of temperature and humidity. The biggest technical problems are those associated with plastics. Within the rail fastenings system plastics are used to provide electrical insulation, resilience and sometimes sacrificial wear elements. Materials such as nylon function well in most climates but are softened in hot, wet conditions and become brittle in dry conditions. A significant amount of work is being undertaken to find additives which can mitigate these effects or to evaluate the use of completely different engineering polymers which may not give the best performance in "average " conditions but which work acceptably well across a wide range of extreme environments.

The other thing which does not function so well in extreme climates is the human body! This may not sound like a technical issue but the fact is that we still expect to use a great deal of manual labour for track construction and maintenance. When heavy haul lines are built in inaccessible and inhospitable places the pressures to introduce more automation and to extend maintenance intervals are increased because of the additional human factors which must be taken into account.

DELIVERING CHINA'S LARGEST HEAVY HAUL RAILWAY

Pandrol's Rosenqvist CD200 facilitates optimised installation

The Menghua Railway will be China's largest heavy haul railway. It will cover a wide geographical area, with two crossings of the Yangtze River and one crossing of the Yellow River, across the Qinling, Zhongtiao and other mountain ranges with complex geological conditions.

The Menghua railway line will connect the coal mining areas in northern China with the industrial hub in the south, starting from Inner Mongolia in the north and ending in the Jiangxi Province. As a dedicated heavy haul line, it has a planned annual capacity of more than 200 million tonnes and is scheduled to open at the end of 2019.

LARGE-SCALE PROJECTS

Pandrol is involved with two projects to supply fastening systems for the Menghua railways. The first, known as Menghua, is with the Mengxi-Huazhong Railway Co, to which Pandrol will supply fastenings for 586,000 sleeper sets that will stretch from the towns of Xiang Yang to Yue Yang – a distance of 370 km. The other contract is known as Jing-Shen, with the Shanxi Jingshen Railway Company Ltd, which connects Jingbian with Shenmu - a distance of 275 km.

For both of these major national infrastructure projects, Pandrol's Fastclip FC-16 fastening system was chosen, to be used on over one million sleeper sets. The rail clips will be manufactured at Pandrol's new factory in Wuhan, China, with the insulators and rail pads for the fastening system also locally produced.

SOLUTION

The Pandrol Fastclip FC-16 fastening is designed for use on ballasted track and is engineered to allow for easy maintenance. With Pandrol Fastclip, all components are delivered to site pre-assembled on the sleeper. This provides huge labour savings, as well as reduced distribution and handling costs during track laying, stressing and rail changing.

The project has involved training and technical support from the Pandrol team in the UK and China. Pandrol's product support team provided training exercises to the track building contractors - familiarising them with hand tools, machinery and other ancillary equipment which complements the Fastclip FC system. The team also worked closely with the sleeper manufacturers to provide technical details on the manufacture of the sleeper and on correct production of the relevant tooling. Technical product support is also being provided on this project.

Onsite training with Pandrol's Rosenqvist CD200 clipping machine

INSTALLATION

Shanxi Jingshen Railway Company Ltd acquired 15 Pandrol CD200 machines for installation of the Fastclip FC systems on site. The CD200 is a walk-behind high-performance clipping installation machine, which can be used to install both Pandrol Fastclip FC and Fastclip FE. Available in two different configurations, it has an in-built sleeper lift with a hydraulic lifting capacity of 50 mm. The CD200 can be utilized by a single operator and can easily be carried off the track. Excellent lighting is a feature of the machine which helps to improve visibility for work at night. Use of the CD200 clipping machine in combination with the Fastclip system provides a quick and effective installation method for fastenings and enables lower installation and maintenance costs.

A WORD FROM ZHOU GANG

Managing Director Pandrol China

These are important contract wins, which demonstrate Pandrol's commitment to expanding its presence in China. We were successful in securing these projects due to our proven technology and global experience in heavy haul fastening systems. Our expertise as an innovative solutions provider means that not only have we supplied high quality products, but were also able to offer pre-assembly, mechanised installation and auto inspection.

A WORD FROM ANDY SLOWE

Product Support Engineer Pandrol

This project is a great example of many different Pandrol divisions working together for the benefit of the customer. It involved technical and manufacturing expertise from our specialists across the globe to provide an innovative solution that met all requirements.

ALUMINOTHERMIC WELDING

NEW WAY OF ALUMINOTHERMIC WELDING AS A SOLUTION FOR HEAVY HAUL 4.0

F. Delcroix, T. Descamps & Dr. L. Winiar
Pandrol SAS, Raismes, France

New developments in the rail's mechanical proprieties, reduction of track maintenance costs, and safety improvements are all major factors which constitute new challenges to address for developing dedicated welding products in alignment with railroad requirements.

For many years, Pandrol has invested in technological solutions related to Industry 4.0 in order to improve the mechanical proprieties of the aluminothermic welds for use in heavy haul applications. Pandrol's welding research and development department has adopted rapid digitization, rapid prototyping and digital simulation solutions. This technology was employed to assist with understanding and reducing weld defects.

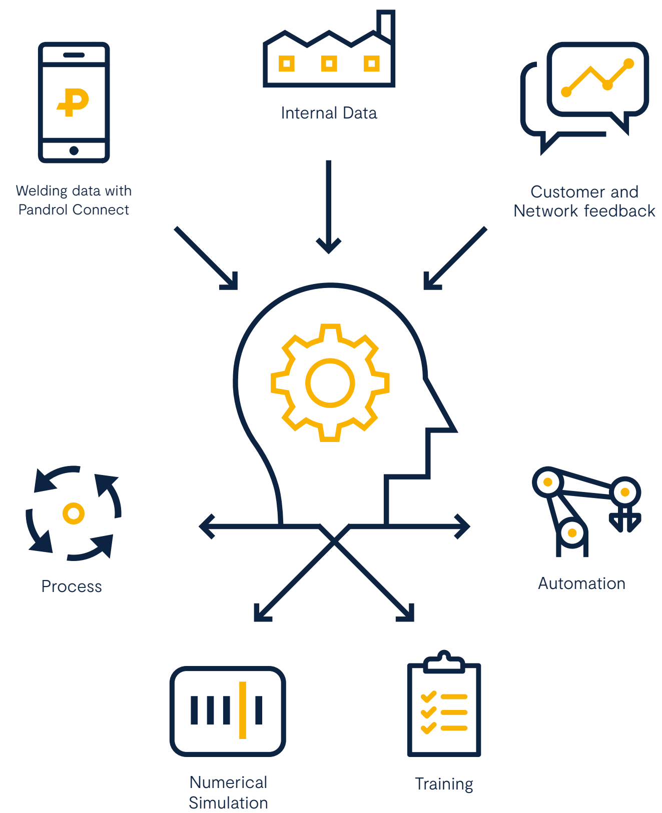


Fig 1. 4.0 Technology in Aluminothermic Welding

INVESTIGATION & ANALYSIS

Figure 2 shows an example defective weld assumed, according to the on-site preliminary findings, to be due to preheating and sandmould geometry issues. Pandrol undertook a large number of test welds in order to confirm the assumption. Testing showed that an overheating of moulds in addition to a shrinkage could have caused the defect.

In addition to test welds, digital simulation was undertaken to develop a better understanding of the aluminothermic welding process – Figure 2. This technology helped the R&D department understand complex physical phenomena that occurred during the weld. The Pandrol Preheating Controller, Figure 3, allowed Pandrol to accurately measure the preheating parameters during the test welds.

Thanks to the use of digital simulation and the precision of the Preheating Controller, the investigation has shown results that accurately confirmed the on-site findings. The preheating and defects were able to be accurately reproduced.

DEVELOPING THE SOLUTION

Based on this results, a geometry improvement, casting slope, and optimization of the weld cast parameters were identified as the necessary interventions to provide a solution.

Digital simulation allowed Pandrol to accelerate prototyping phases and reduce development and laboratory time. Moreover, it offered the possibility to optimise casting parameters: collar shape, temperature, cooling and preheating using the Preheating Controller.

These two innovative tools have been used to define the optimised geometry and the appropriate preheating to get the best weld. Thus, the achieved results associated to the lab ones contributed in improving the weld. All controls – ultrasonic, bending and fatigue tests – have confirmed the weld performance. The optimised process was to keep the same current welding parameters and modify the sandmould geometry.

To ensure ongoing recording of data before, during and after welding, Pandrol has introduced the Pandrol Connect phone app, which ensures tracking and traceability of the weld parameters.

Fig 2. Test welds and digital simulation results

WELDS REMOVED

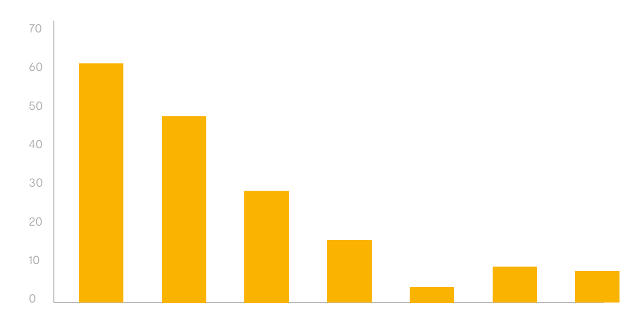


Fig 4. On-track removed welds evolution - 2012 to 2018

PREHEATING CONTROLLER

Pandrol's analysis, Fig. 3 was used to identify the optimum settings for welding preheating, and the Preheating Controller allows the welder to achieve a greater consistency in achieving these settings.

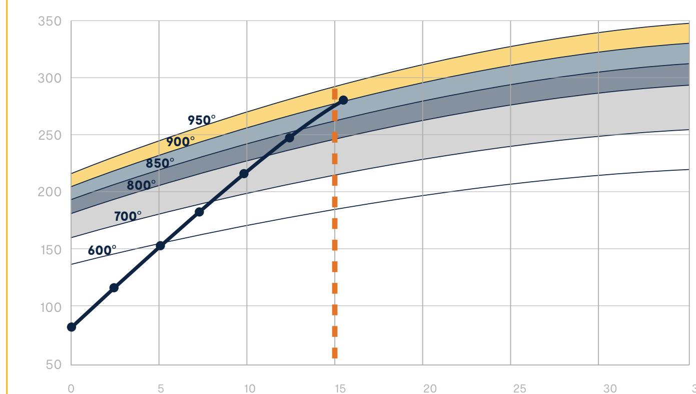


Fig 3. Preheating Innovation

CONCLUSIONS

Figure 4 shows the impact that these improvements have delivered on the number of defective welds in track. Thanks to these continuous improvements, Pandrol remains a world leader in aluminothermic with best-in-class product quality and the lowest failure rate.

A continued investment in new technologies, including digital simulation, the Preheating Controller and the High Flow Preheater, supports Pandrol's market leadership and commitment to adding value for customers. These technological tools allow Pandrol to support customers with bespoke products related to their requirements, utilising Industry 4.0.

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Assessment of the standards for laboratory testing of rail fastening systems used on heavy haul lines.

D. Herron & S.J. Cox
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Abstract

Standards for the laboratory testing of rail fastening systems are now in use in various forms around the world. These standards are used to assess the suitability of a fastening system for use in-track and therefore relate design for safety, reliability and durability. Two of the main standards for testing fastening systems for heavy haul applications are compared here, supported by an analysis of measurement data obtained on a very demanding section of a heavy haul line. The aim of this work is to identify the aspects of these standard tests which are successful, those where there is scope for further improvement and in the case of the latter, to make proposals as to how this can be achieved. It is found that there is a good case for combining key ideas in the two major standards to achieve a test for durability that simulates the load and environmental conditions found in-track appropriately.

1. Introduction

Standards for the laboratory testing of rail fastening systems have now been in use for a number of years, such as those used in North America, Australia, Europe and those introduced more recently in China. These standards are used to assess the suitability of a fastener for use in-track under a given set of operating conditions and represent an important part of the qualification/type approval process by which it is ensured that the track is built using suitable fasteners. These tests therefore relate to design for safety, reliability and durability.

The laboratory test standards for fastening systems can be assessed in several different ways. In this paper, they are assessed by comparing the approach taken by two of the major standards, by referring to measurements made in-track and computer modelling, and also by evaluating the ability of the tests to identify problems that occur in-track.

The in-track measurements presented here were taken on a particularly demanding section of heavy haul track, where the load conditions are expected to be sufficiently harsh to make the measurements suitable for use as a basis for qualification/type approval testing in the laboratory. The experience of problems with rail seat abrasion and high rates of component wear at this site also provides a means to asses the ability of the laboratory test to identify these issues correctly.

2. Comparison between test standards in use around the world

2.1 Overview

Various different standards describe standard laboratory tests for fastening systems intended for use on heavy haul railway tracks. Chapter 30 of the American Railway Engineering and Maintenance-of-Way Association (AREMA) is perhaps the most prominent. The Australian Standard AS 1085.19-2003 is also well-established. The European Standards for testing fastening systems, in the form of the EN 13481 and EN 13146 series, were introduced in 2002, but did not include tests for heavy haul applications initially. These were finalised in 2012, with the introduction of category E (axle loads up to 350kN) in 2012. These standards will be referred to hereafter as 'CEN'. The China Academy of Railway Sciences have also introduced test requirements and procedures for fastenings proposed for use on heavy haul lines in China.

While there is some overlap between these different standards, there are some significant differences between them. A comparison between AREMA chapter 30 and CEN for Category E applications appears to capture a large part of these differences, so this is prioritised here.

2.2 Comparison of AREMA chapter 30 and CEN for category E applications

Table 1 presents a summary of the tests required by AREMA Chapter 30 and CEN for category E applications.

Table 1. Summary of tests required by AREMA Chapter 30 and CEN for category E application.

Fastener property	Standard	
	AREMA	CEN
Clamping force on rail foot	Yes	Yes
Longitudinal rail restraint	Yes	Yes
Durability with repeated load	Yes	Yes
Durability with repeated load/ severe environmental conditions	Yes*	No
Lateral load resistance	Yes	No
Torsional rail restraint	Yes*	Yes*
Electrical impedance	Yes	Yes
Vertical stiffness	Yes	Yes
Pull-out resistance of cast-in components	Yes	Yes
Resistance to corrosion	No	Yes
Attenuation of impact loads	Yes*	Yes

* Indicates tests described by the standard but are not a required part of tests for type approval/qualification.

Table 1 suggests that the two standards have a great deal in common. However, in some of the cases where both standards require a test for a given property, the way the test is performed, or the performance requirements, differ significantly between AREMA and CEN. The longitudinal restraint required by AREMA, 10.7kN is considerably higher than that required by CEN for Category E, 7kN. There are also requirements for maximum rail movement given by AREMA, but not by CEN. The durability test with repeated load is a three million cycle test for both AREMA and CEN, but the loading conditions differ markedly between them. This is discussed further in Section 2.3 and 3 below. The AREMA torsional restraint test is a proof load test, in which no failure/cracking/yielding should occur. The torsion test given by CEN provides information only, there are no performance requirements attached. The vertical stiffness test is another where the AREMA load requirements are much higher than those in CEN. AREMA specifies a secant stiffness found between loads of 107kN and 196kN in a test on the rail pad only, no clip loads present. CEN describes stiffness tests with and without the clip loads present. It is the test without clip loads that is directly comparable with AREMA and the result of this test is a secant stiffness found between 20kN and 95kN. This difference is much larger than can be explained by the higher axle loads found on U.S heavy haul lines than on those in Europe.

Table 1 shows that the only property of the fastening system that is tested according to CEN but is not required for testing to AREMA is the resistance to corrosion. The CEN test for corrosion resistance is a salt spray test over the course of three hundred hours, after which the fastening system must be dis-assembled and then re-assembled using standard tools, without component failure.

Table 1 shows that AREMA includes two tests that are not covered by CEN. One of these is the lateral load resistance test. This is a proof load test in which an inclined static load is applied that has a lateral load component of 90kN. It is performed after the durability with repeated load test. There must be no component failures and there are limits on the rail movement allowed. While CEN does not include a directly comparable test, the relatively high lateral load component in the CEN Category E repeated load test, more than 60kN applied three million times, may be expected to identify fastening systems with inadequate resistance to lateral load.

The second test included by AREMA but not by CEN, can be described as a test for durability with repeated load and severe environmental conditions. However, it is a not a required part of the sequence of tests for AREMA type approval/qualification at present. The severe environmental conditions are sand spread on both sides of the rail seat, water dripping on to the field and gauge sides of the fastening system throughout the test and temperature cycles between 40°C and +57°C degrees (which requires a small chamber to be built around the fastening system). There are maximum permitted values for rail movement during the test and there should be no failed/damaged components. Further, the rail seat is examined for damage and the maximum depth of the wear in the rail seat is measured. This is an example of in-track experience being fed back into the development of the laboratory test standards, with the aim of improving their ability to identify problems in advance of the fastening system being used in-track.

2.3 Load conditions given for the durability with repeated load tests by AREMA and CEN Category E

It was noted in Section 2.2 that both AREMA and CEN require a durability with repeated load test, in which the load is applied three million times. The load conditions applied in these tests is intended to be representative of those on the fastening system in a low-radius curve section of track. This is because it is normally the lateral load component and the over-turning moment (due the lateral load component and the height above the fastening system at which it is applied) that place the greatest demand on the durability of the fastening system. The task of determining what representative load conditions are for a fastening system in a low radius curve section of track is not straight-forward. These loads conditions are affected by many different factors (properties of the fastening system and rolling stock, train speed and details of the track site).

Further, these load conditions are relatively difficult to measure.
Early work on the development of the laboratory test was based on making measurements in-track at various locations and under a range of conditions. Rail deflection measurements were the most common approach, providing a means to adjust the load conditions used in the laboratory test until the rail deflection in the laboratory test matched those measured in-track. The research work done in support of the development of the CEN standards took a different approach to this task than that supporting the development of the AREMA manual, by applying the inclined load at a reduced height above the rail seat than is the case in-track (Rhodes et al., 1989). This was thought necessary to achieve a good match between the rail deflections in the laboratory test and those in-track. The justification given for applying the load at a reduced height in the laboratory test is that in-track, the torsional stiffness of the rail means that a number of fastening systems contribute to the resistance to rail roll, while this is not the case in a laboratory test on a single fastening system. The reduced rail height allows the overturning moment applied in the laboratory test to be reduced to compensate for this independently of the reduction in the vertical and lateral load components that is required to compensate for the effect of the vertical and lateral stiffness of the rail causing the wheel loads to be distributed amongst a number of fastening systems in-track.

An important step in the development of the CEN standards was the use of a computer model called 'Non-linear Response of Track' (NRT) for the behaviour of railway track (J. Turek, 1994). The model was compared to track measurements made at various sites. One such comparison that is relevant to heavy haul applications is given by Cox et al. (1997), where measurements had been made in-track on a 350m radius curve (5o) during the pass-by of heavy axle rolling stock at a range of speeds relative to the balance speed for the curve. The measurement data consisted of rail strains, which were used to determine the vertical and lateral load components applied by the wheel to the rail head, and the rail deflections. The model was shown to predict the rail deflections quite successfully, given the vertical and lateral loads applied at the rail head as input data. The model also gives the vertical load component, lateral load component and the moment per fastener, which is the data required to set-up an appropriate laboratory test. This kind of modelling work and successful comparison against in-track measurements confirmed the need to apply the loads at a reduced height in the laboratory test.

The CEN standards were introduced in 2002 and specified that the inclined load to be applied in the durability with repeated load test to be applied through a point 15mm (for all but light rail applications) below the centre of the gauge corner radius. This distance is referred to hereafter as X. The revised CEN standards introduced in 2012 required that for the new classes test, the loads should be applied at even lower positions on the rail. The test for heavy haul applications, Category E, requires that the load is applied though a point 75mm below the centre of the gauge corner radius (X). This is shown together with the AREMA load line in Figure 1 below.

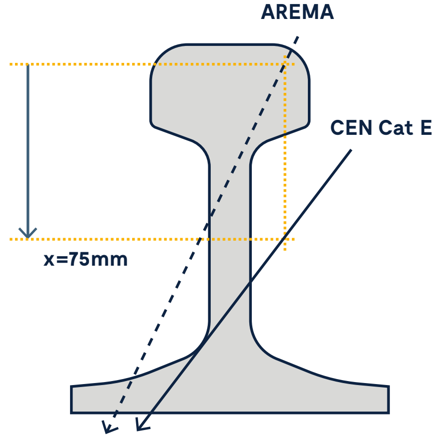

Figure 1. Load line in a CEN Category E and AREMA durability with repeated load test.

Figure 1 shows the difference in the height at which the inclined load is applied in the AREMA and CEN Category E tests. A significant difference in the angle at which the load is applied is also evident, it is 20 degrees in the AREMA case and 40 degrees in CEN for Category E. Table 2 below summarises the load conditions for the two tests.

Table 2. Load conditions used in the durability with repeated load tests given by AREMA Chapter 30 and the CEN for Category E applications.

Fastener property	Standard	
	AREMA	CEN Cat E
Maximum load magnitude (kN)*	133	108
Angle (°)	20	40
Vertical load component (kN)*	125	82.7
Lateral load component (kN)*	45.5	69.4
L/V ratio	0.36	0.84
X (mm)	0	75

* Values given for case of fastening system with dynamic stiffness greater than 200kN/mm. Values for softer rail pads are slightly lower.

The factor of two difference in the angles at which the loads are applied brings about significant differences in the lateral load component and the ratio between lateral and vertical load components (L/V). The scope to increase the load angle in the AREMA test is very limited, unless the height at which the load the fastening system in the laboratory test if the load angle is increased significantly above 20 degrees.

A further important difference between the durability test with repeated load required by AREMA and CEN is the minimum value in each load cycle. CEN specifies that the load is cycled between the maximum load given in Table 2 and a minimum load of 5kN, with the direction shown in Figure 1 at all times. AREMA requires that the load is cycled between the maximum load given in Table 2 and a minimum load that is in the opposite direction, this means lifting the rail rather pushing it down. The maximum lifting force is set at 60% of the clamping force of the assembly and it is applied at the same 20o angle of inclination as the downward load. This is intended to simulate the upward movement of the rail that occurs at some distance away from the wheel load in-track due to the vertical bending stiffness of the rail. In this respect, the AREMA approach may capture the situation expected in-track more fully than does CEN, which appears to omit part of the load and deflection range experienced by the fastening system in-track.

Both of the two differences in approach taken to the durability with repeated load test by AREMA and CEN described above can be assessed by reference to measurement data obtained in-track. Since the work of Cox et al. (1997), more in-track measurement work has been performed and which is also supported by the use of the NRT model to provide further insight into the behaviour of the track in a way that can be used to determine suitable parameter values for laboratory testing. It is the lower curve radius that makes this later measurement work a more suitable basis for the selection of suitable load parameters for qualification/type approval testing in the laboratory than that of Cox et al (1997). This work is described in Section 3 below.

3. Further track measurements and Track modelling work

3.1 Site for In-Track Measurements

The track measurements were made on a curved section of a heavy haul line in North America, where the curve radius is approximately 200m and the rail is 136RE section. The rolling stock had axle loads up to approximately 33 tonnes and travelled through the site at a range of speeds. The majority of trains, and all those for which measurements are given here, travelled through the test site at approximately 40km/h. The combination of very low curve radius and large axle load presents a challenge with regard to durability of the fastening systems. This is reflected in the history of rail seat abrasion and high rates of wear of fastening system components at this site.

3.2 Measurements made in-track

Strain gauge measurements on both rails were used to calculate the vertical and lateral load components applied by the train wheels to rails. Strain gauge displacement transducers were used to measure the vertical deflection of the rail foot at the field and gauge sides and also the lateral deflection of the rail foot. This was done for both rails.

A low pass filter with a cut-off frequency of 30Hz was applied so that the resulting data is that which relates to the quasistatic loading and low frequency dynamic loading.

The rail deflection and rail strain measurements show that, as expected, it is leading axle of each bogie that applies the most severe lateral loading. The data given here is therefore for the leading axle only. Figure 2 shows the undeflected rail positions and example deflected rail positions, where the deflections have been scaled up so that they can be seen clearly.

The low rail shows much greater lateral movement at the rail foot and roll than the high rail. This is consistent with the findings of previous studies and is the basis of the loading conditions used in the CEN repeated load test. Note that the roll of the low rail is sufficient for the gauge side of the rail foot to move upwards when the wheel load is applied to the rail head.

For the purposes of estimating the loads that should be used in laboratory tests for durability, the mean values of rail deflection and load applied at the rail head may not be sufficiently conservative. Peak values of load and deflection may also be inappropriate for this purpose, because wear and fatigue are normally the important failure mechanisms, rather a failure under one or a small number of peak load events. A classic statistical approach was therefore taken to the determination of representative values of load and deflection. This is based on the assumption that the data is normally distributed and the addition of two standard deviations to the mean values to obtain 'representative' values, such that approximately 97% of cycles should fall beneath the values generated by this approach.

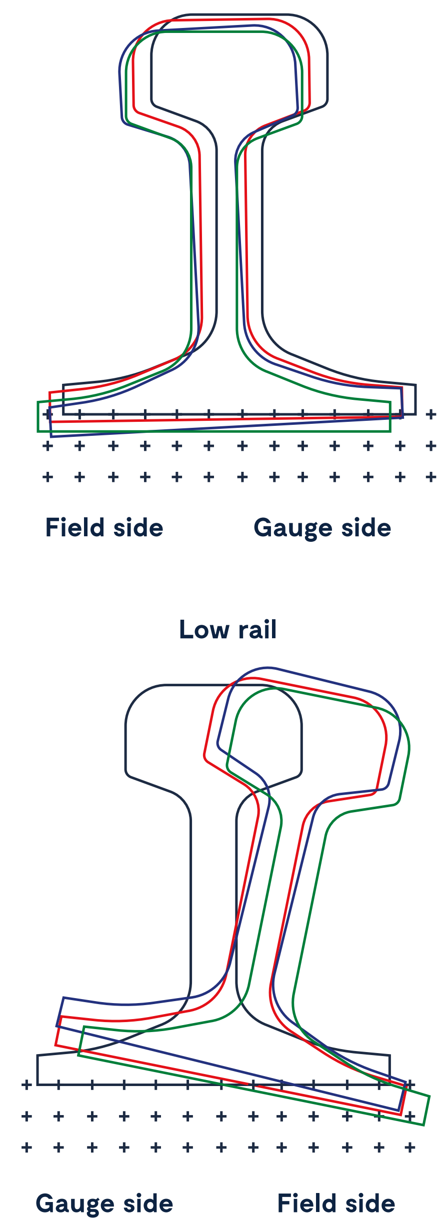

Figure 2. Undeflected and example deflected positions of both rails, with the deflections scaled up for clarity.

Tables 3 and 4 show mean values and these 'representative' values for the vertical and lateral load components applied by the wheels to the rails and the rail deflections respectively.

Table 3. Mean and 'representative' load components applied by the wheels to the high and low rail.

Load type	Load magnitude (kN)	
	Mean	Representative
Lateral, high rail	24.57	64.78
Vertical, high rail	147.14	175.0
Lateral, low rail	51.65	96.95
Vertical, low rail	166.62	196.43

Table 4. Mean and 'representative' deflections for the high and low rail.

Deflection measurement	Rail deflection (mm)	
	Mean	Representative
Lateral, high rail	0.16	0.27
Vertical, field side, high rail	0.39	0.50
Vertical, gauge side, high rail	0.01	0.27
Lateral, low rail	0.13	0.19
Vertical, field side low rail	0.46	0.57
Vertical, gauge side low rail	-1.03	-1.59

Note that the sign convention used for rail deflections here is that positive vertical deflections are for down-ward movement of the rail and positive lateral deflections are for the rail moving away from the track centreline.

3.3 NRT modelling work

The data given in Table 3 for the vertical and lateral load components applied by the wheels to the rail was used as input data to the NRT model. Further input data is required for the position of the wheel contact relative to the rail centreline, approximately 25mm in this case, and the stiffness of the track components. Laboratory measurements were used to provide the stiffness data for the track components.

The NRT model calculates the distribution of loads along the length of the track (and therefore over a number of fastening systems and sleepers) and also the rail deflections from the input data described above. These deflections calculated by the model were compared to the 'representative' values obtained from the in-track measurement work (Section 3.2) to confirm that the model had predicted the response of the track to the input loads at the rail head accurately. This was done for the low rail only, since it is the very challenging load conditions at the low rail that are of interest with regard to the selection of appropriate load conditions to use in laboratory tests for durability. The predicted and measured rail deflections for the low rail are shown in Table 5.

Table 5. Predicted rail deflections and 'representative' measured rail deflections for the low rail.

Deflection	Rail deflection (mm)	
	Predicted	Measured
Lateral, high rail	0.16	0.27
Vertical, field side, high rail	0.39	0.50
Vertical, gauge side, high rail	0.01	0.27
Lateral, low rail	0.19	0.19
Vertical, field side low rail	0.66	0.57
Vertical, gauge side low rail	-1.43	-1.59

There is good agreement between the predicted and measured 'representative' rail deflections, which provides a basis for confidence in the way that the NRT model has captured the behaviour of the track.

In addition to the predicted rail deflections, the NRT model gives the vertical load component, lateral load component and moment applied to a single fastening system as outputs. This represents a full set of the data required to select equivalent load conditions for a laboratory test on a single fastening system. The vertical and lateral load components given by the model are easily converted to a magnitude and angle for the load to be applied in the laboratory test. The moment on a single fastening system given by the NRT model can be compared to simple calculations for the total moment applied to a single fastening system to determine the reduced height at which the load should be applied in order to achieve this same moment in the laboratory test. The load conditions for a single fastening obtained by this means, from the in-track measurement data described in Section 3.2, are shown in Table 6 below.

Table 6. Calculated load conditions for a laboratory test based on the in-track measurements and NRT modelling.

Parameter	Calculated value
Load magnitude (kN)	104
Vertical load (kN)	79.7
Lateral load (kN)	65.5
Moment (kNm)	3.6
Angle (°)	39.4
X (mm)	85

The load conditions given in Table 6 compare quite closely to those given for CEN Category E in Table 2. The comparison becomes even closer when it is considered that the CEN Category E test is written for a typical rail section of 60E1, for which the gauge corner radius is approximately 12mm lower than for the 136RE rail section used at the track site under consideration here. This close comparison is due to the use of this measurement and modelling work in specifying the load conditions for the CEN Category E test.

3.4 Relating the proposed load conditions for durability testing in the laboratory to experience in-track

Laboratory tests performed using the load conditions given in Table 6 result in rail deflections that are com-parable to those found in-track. However, when they are run under clean conditions and at room temperature they do not reproduce the rail seat abrasion and high rates of wear on some components that occur at the track measurement site. This supports the need to include severe environmental conditions in the assessment of fastening system durability. This need has been recognised by AREMA, but it is not currently part of the AREMA test schedule required for qualification/type approval of a fastening system. No such consideration of these environmental factors is included by CEN at present.

A further outcome of the track measurement work and NRT modelling work described in Sections 3.2 and 3.3 is that upward movement at the gauge side of the rail foot occurs due to the moment applied to the rail and consequent rail roll, such that there may not be a need to apply an upward load to the rail in a laboratory test for durability. Note, however, that this would not be the case in a test in which the applied moment and resulting rail roll were significantly lower. The explicit requirement for an upward load to be applied to the rail given by AREMA may therefore be a sensible means to ensure that the durability of the fastening system is assessed for upward movement of the rail in all cases. Upward movement of the rail is expected in-track even where there are no low radius curves, due to the bending stiffness of the rail and resulting uplift wave ahead/behind the wheels.

4. Conclusion

The AREMA and CEN test standards, although similar in many respects, remain quite different in others. The most significant differences relate to the way that the durability of the fastening system is assessed. The load conditions given by CEN for category applications have been developed, in part, by referring to the track measurement data and the output of the NRT model. It is therefore not a surprise that good agreement is shown between the load conditions given by CEN for Category E applications and the measurement data and modelling work presented here. An important conclusion from this is that testing with a reduced height of rail section, even compared to that used in the original CEN standards (introduced in 2002) is necessary to represent the load conditions experienced by a single fastening system on a section of track with a low radius curve, where the demands on the durability of the fastening system are normally greatest.

A second important conclusion from this work is that while the load conditions given by CEN category E were found to reproduce the rail deflections measured in-track, they did not reproduce the rail seat abrasion and high component wear rates found in-track. The severe environmental conditions in the form of water, sand and temperature variations introduced by AREMA would appear to be the means to address this important shortcoming.

5. References

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ASK THE EXPERT

SICUT® COMPOSITE SLEEPERS

Q: What are Sicut composite sleepers?

A: Sicut® Composite Sleepers are an exciting innovation in sleeper technology for all track types, from passenger to heavy haul. They are made from a unique recycled polymer composite developed by Rutgers University and exclusively licensed to Sicut Enterprises Limited, globally. Pandrol is Sicut®'s Exclusive distributor in North America.

Q: What advantages do the offer?

A: Excellent value; safer track; outstanding sustainability. Being made from polymers, they are extremely tough and durable; resisting the physical demands of rail traffic as well as the sustained attack by the environment in which they are placed. Delivering consistent performance over an extremely long life, measured in decades not years, they offer outstanding return on investment. Being made of recycled materials and being fully recyclable, they are a truly sustainable solution, cutting greenhouse gas emissions, keeping waste plastic out of landfill (and the oceans) and reducing the industry's need for timber, including tropical hardwood. Sicut Composite Sleepers "Turn Today's Waste into Tomorrow's Infrastructure". What's not to like?

Q: Where have they been tested?

A: Sicut® Composite Sleepers have undergone the most rigorous and demanding testing of any sleeper product, in both Europe and the USA. In Europe, TU Munich have subjected them to over 10 million load cycles, at loads up to 375kN and temperatures up to 60°C, testing compliance with the most challenging needs of Deutsche Bahn. They have also been tested in accordance with requirements for spike retention, compressive strength, resistance to baseplate cutting and electrical resistivity. All tests have been passed, leading to installation across Europe and around the World. In the US, sleepers made using these technologies were first tested by Transport Technology Center Inc. and installed in the High Tonnage Loop in Pueblo in 1996; over half a million have been installed in track since. Sicut® Composite Sleepers are currently undergoing further testing by Union Pacific, with very promising results.

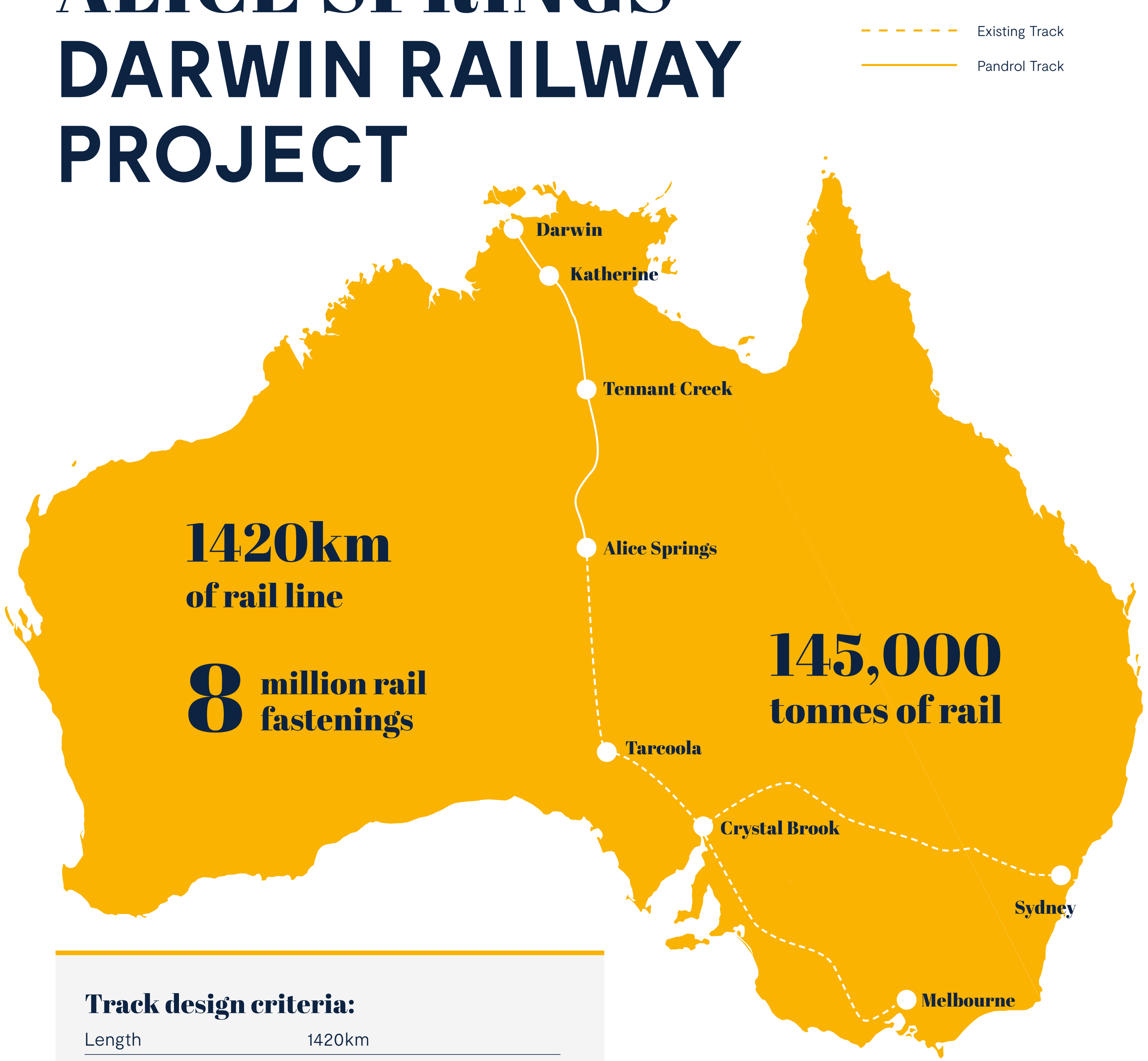
Q: What are you working on next?

A: Sicut® and Pandrol are pursuing a number of innovations that combine their expertise, and that of Rutgers, to offer new and sustainable track solutions to customers. Watch this space...

Breen Reardon

President at Pandrol

ALICE SPRINGS DARWIN RAILWAY PROJECT



Track design criteria:

Length	1420km
Rail	50Kg AS 1085.1
Track Gauge	Standard Gauge (1435mm)
Sleeper	Pre-stressed concrete
Sleeper Spacing	720mm
Maximum Design Speed	115km/h
Axle Load	23 tonnes
Maximum Grade	1.2% but generally a ruling grade of0.8% applies

100
Bridges

Scale of the Project:

- 15 million cubic metres of earthworks
- 1,500 culverts
- 100 bridges
- 2 million tonnes of ballast
- 2 million sleepers
- 8 million rail fastenings
- 145,000 tonnes of rail

The Alice Springs – Darwin Railway was constructed to connect the deep water Port of Darwin to the National Railway network, creating a new trade route between the north and the economic centre of South Eastern Australia.

The route length from Alice Springs – Darwin is approximately 1420km. Construction depots were located at Tennant Creek and Katherine, a freight terminal at Berrimah (Darwin) and a siding at the Port of Darwin, 4 passing loops were also provided, at Katherine, Tennant Creek, Newcastle Waters and Illoquara.

TRACK DESIGN

The railway was designed and constructed to the standards appropriate to a modern standardgauge mainline railway in Australia. It is suitable for operation of rail services with 23 tonne axle loads at a speed of up to 80km/h, and allowed for interchange of rolling stock between the new railway and the existing railway and other parts of the national railway network.

ADrail, an unincorporated Joint Venture comprised of Kellogg Brown and Root, John Holland, Barclay Mowlem and Mamahon, has been contracted by the Asia Pacific Transport Pty Limited and Asia Pacific Contracting Pty Ltd for the design and construction of the new railway.

The Joint Venture was responsible for all phases of the works, including the design, earthworks, trackworks and infrastructure, including signalling and communications.

CONSTRUCTION SEQUENCE

Construction began in April 2001, tracklaying began in April 2002, and was completed in early 2004.

Earthworks, bridges and culverts needed to be completed sufficiently in advance to enable uninterrupted tracklaying.

Concrete sleeper manufacturing plants were built at Katherine and Tennant Creek, capable of producing 1600 and 2400 concrete sleepers per day respectively. As earthworks were completed, tracklaying took place north and south of the construction depots at Katherine and Tennant Creek, with work trains leaving the depots each morning with enough material to lay 2.0km of track a day in each direction.

Trackwork is initially heading north of Tennant Creek, and south of Katherine, joining up halfway between the 2 centres late in 2002. The teams then worked north from Katherine to Darwin and south from Tennant Creek to Alice Springs.

15m
cubic metres of earthworks

SLEEPER MANUFACTURE

The Katherine and Tennant Creek sleeper factories, operated by Austrak, produced more than 860,000 and 1.1 million concrete sleepers respectively, all fully equipped with Pandrol Fastclip rail fastenings. Concrete was poured into moulds laid out on long beds, cut by diamond saws, fitted with Fastclip components in the rail ready 'parked' position and inspected to ensure compliance.

1.1 million sleepers

Concrete Sleeper pre-assembled with Fastclip fastenings

RAIL

Rail was loaded onto trains at OneSteel's plant in South Australia for delivery to Roe Creek, which is the transport and logistics centre for the Alice Springs – Darwin Railway, located about 20km south of Alice Springs. From there, it was loaded onto road trains for the trip to either Tennant Creek or Katherine, where the 27.5m lengths were welded into 357.5m lengths.

Once in track, each of these lengths were welded together, creating a continuous rail through from Alice Springs – Darwin. Due to the extreme heat in this region, the rail must be correctly restrained and prestressed, or the steel rails would expand substantially.

Plasser and Theurer SVM1000
Track Laying Machine
Inset: Detail of integral clipping head

RAIL FASTENINGS

The Pandrol Fastclip system was selected as the sole fastening for use on the entire length of the line. As the majority of the line was non-insulated,

Pandrol engineers refined the Fastclip design to dispense with insulators, but still retain the fully captive, rail ready features.

By adapting the standard Fastclip pad, shoulder and clip, a secure non-insulated assembly was developed, which allowed concrete sleepers to be pre-assembled in the factories at Katherine and Tennant Creek, and transported, as required, with no component movement or losses.

Close-up of Integral Clip Application Unit

BALLAST REQUIREMENTS

About 700,000 tonnes of rock was crushed at the Katherine Quarry and 1.3 million tonnes at Tennant Creek to supply ballast for the railway. Ballast wagons transport the 3000 tonnes of ballast required for each shift of tracklaying.

3000 Tonnes of ballast

TRACKLAYING

The Track Laying Machines placed sleepers and rails, and were equipped with integral clipping units, enabling all operations to be undertaken automatically.

Behind the Track Laying Machine a ballast 'rake' dropped ballast over the skeleton track. A tamper then lifted the track 100mm through the ballast and vibrated and squeezed ballast under the sleepers. Next a 2nd ballast drop was followed by a 50mm lift. A ballast regulator and final tamping run completed the operation.

2004

These achievements ensured the successful delivery of the project, with running on the line commencing in 2004.

The Fastclip FC1508 system gave the client significant installation savings during track laying by using the captive Fastclip system. The use of returnable stillages, for the supply of cast shoulders and rail pads direct from Adelaide based manufacturers to the sleeper plants was also a significant cost saving and benefit to the environment. Because of the amount of road traffic on the project, empty semi-trailers were able to backload these stillages to Adelaide for reuse and return to the sleeper plants at Tennant Creek and Katherine NT. Since installation Pandrol has supported Genesee and Wyoming Australia with aluminothermic welding kits and VERSE Rail Stress Measurement units.

The success of the product development on this project lead to the current FC1509 system which has been a key factor in our long term relationship with Australian Rail Track Corporation (ARTC) and their network upgrading in New South Wales on all major freight corridors and Hunter Valley heavy haul coal network. This system has also been selected for the current ARTC Inland Rail project.

Insight

ADVANCES IN WOOD TIE TRACK DESIGN AND MAINTENANCE.

Despite the popularity of concrete ties in other parts of the world, there has always been a preference for the use of wood ties in North America and that trend is on track to continue.

The overall cost of switching from wood to concrete ties is a major factor driving this. Another consideration is the progress made in developing improved wood ties, the rail fasteners used on these ties and the way these locations are maintained utilizing new technology.

The introduction of Borate treatments has also brought about a significant extension to the product life of wood ties. The introduction placed an increased demand on the durability of the rail fastening assembly. The traditional fastener of choice in North America has been the standard AREMA tie plate in conjunction with cut spikes and rail anchors. In severe service territories, plate cutting presented serious challenges in maintaining track gauge as the lateral resistance provided by cut spikes was insufficient on high degree curves.

Significant progress has been made in the development of fasteners for use on wood ties in a series of steps taken since the early 1980's when e-Clip tie plates were introduced to the North American market. While these advancements addressed the lateral and longitudinal restraint issues, there continued to be some baseplate failures. The Victor tie plate was developed to eliminate these failure modes and in doing so unlocked the benefits of an elastic fastening assembly more fully than its predecessor. The result has shown significantly reduced maintenance costs in severe service territories.

In parallel to the advances made in wood ties and fasteners used on them, steps have also been made in the development of new technology to evaluate, maintain and monitor track conditions to ensure ultimate performance and product life of track components. Together, these advances have created a favourable impact in managing the costs of maintaining a wood tie railroad.

NORFOLK SOUTHERN RAILWAYS USA

US railroad operator Norfolk Southern was instrumental in working with Pandrol in the development of the current Victor tie plate used for Heavy Haul applications in North America. In the beginning, Pandrol worked with Norfolk Southern to pioneer the development of a standard asymmetrical 18" AREMA tie plate in locations where reverse rail cant was an issue. The railroad used wood ties, but tie plates equipped with elastic fasteners at the time had a smaller footprint. The challenge for an improved tie plate was driven by locomotives with increasing horsepower, dynamic breaking, more MGTs per year, larger rail and varying tie conditions, which, when combined meant a new tie plate specification was needed for heavy haul applications.

The Victor tie plates features the maximum bearing area available and when combined with resilient fasteners provides the heavy haul railroads with reduced plate cutting, gauge retention, superior holding power and rail rollover protection.

The initial Victor plates were equipped with cut spikes to secure the plate to the tie and were tested on 4-6 degree curves with 1-1.5% grades and 3.5% of super elevation with approximately 40MGT annually. The Victor tests were monitored and found to perform well with respect to reduced tie plate cutting and gauge widening which lowered maintenance requirements and costs for their curve locations.

To date, Norfolk Southern Railways has installed over 3 million Victor plates. These plates have proven to be beneficial in reducing plate cutting, reverse rail cant and gauge widening conditions, as well as providing rail roll-over restraint.
By addressing these factors, the railroad has been able to reduce maintenance costs and increase efficiency. Norfolk Southern has also specified the use of Pandrol Victor plates with screw spikes f or bridge applications.

FASTCLIP FE SYSTEM

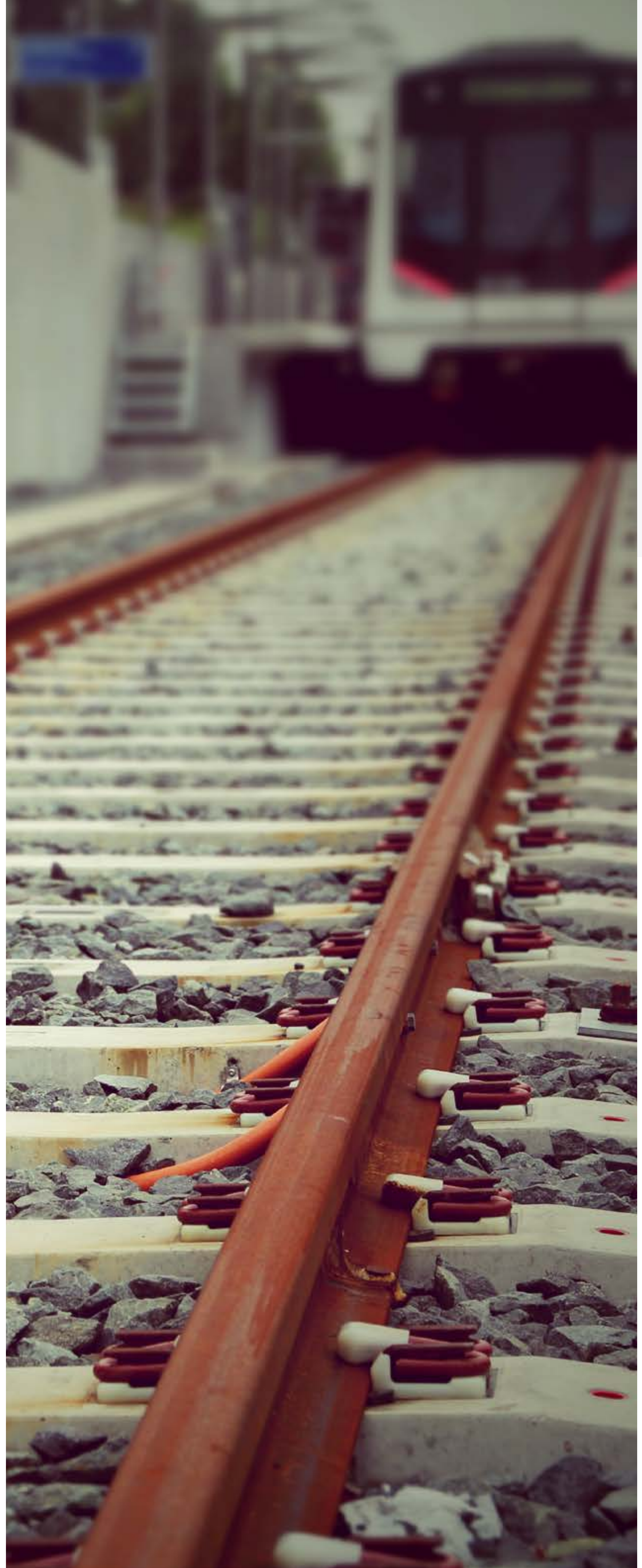
ADDS VALUE IN SCANDINAVIA

Over the last few years the drive towards lower carbon emissions in the production of goods has resulted in increased demand for environmentally-friendly products. To meet this demand, Pandrol has innovated within its range to design products that use less material, whilst delivering equal or better performance and with lower Carbon Dioxide emissions.

Norway has long been an early adopter of Pandrol's innovative fastenings and its national railway, Bane Nor, first switched to the Fastclip FE from Fastclip FC in 2011/12. The FE fastening system is now used on mixed traffic tracks, from high speed, standard passenger trains right through to heavy haul. Norway has now moved completely to using the FE System, in all its new tracks through a combination of engineering integrity, value for money and its environmental benefits.

Since then, Denmark, via BaneDanmark, adopted the patented FE System for its prestigious new high speed line Copenhagen - Ringsted. This was closely followed by Sweden also adopting the patented FE System which offers the same major benefits as a result of being lighter in weight and enabling a quick and straightforward installation and being environmentally sustainable.

In all three countries, Pandrol has worked very closely with the sleeper makers to bring the product to market.



VS.

PANDROL FASTCLIP FC		PANDROL FASTCLIP FE
Ø15 mm clip	Diameter	Ø14 mm clip
0.56 kg	Weight	0.44 kg

LOWER CARBON EMISSIONS

Through careful design, application of new manufacturing techniques and use of green energy sources where possible, Pandrol's new FE System reduces the amount of raw material consumed, the energy required to manufacture them and their associated transportation costs. Use of the FE System means a 30% saving in CO_2 emissions when compared to the FC fastening system.

FE has an innovative design which means it is less prone to damage by on-track equipment, due to the fact that it sits lower on the sleeper. Handling and transportation is improved due to the fact that it is lighter in weight.

The FE System is a value engineered project which has been proven to deliver strong results in life cycle cost analysis.

WORKING TOGETHER

Pandrol held a training day in Sweden in 2017, which was attended by railway maintenance teams and contractors from across Scandinavia, to provide a better insight into the benefits of the clip to facilitate a smoother transition to the Fastclip FE System. The event demonstrated how Pandrol ensure customers achieve the best possible service value from their fastening products.

A WORD FROM ERIKA BERG

Managing Director Pandrol AB

Speed and efficiency is a major factor in the Scandinavian infrastructure market and use of Fastclip FE in combination with Pandrol's Clip Driver(s) means that 2.5 km of track can be covered in one hour. The installation process is therefore speeded up significantly. This is further enhanced by the Fastclip FE being delivered to track pre-assembled on the sleeper.

A HISTORY OF PARTNERSHIP

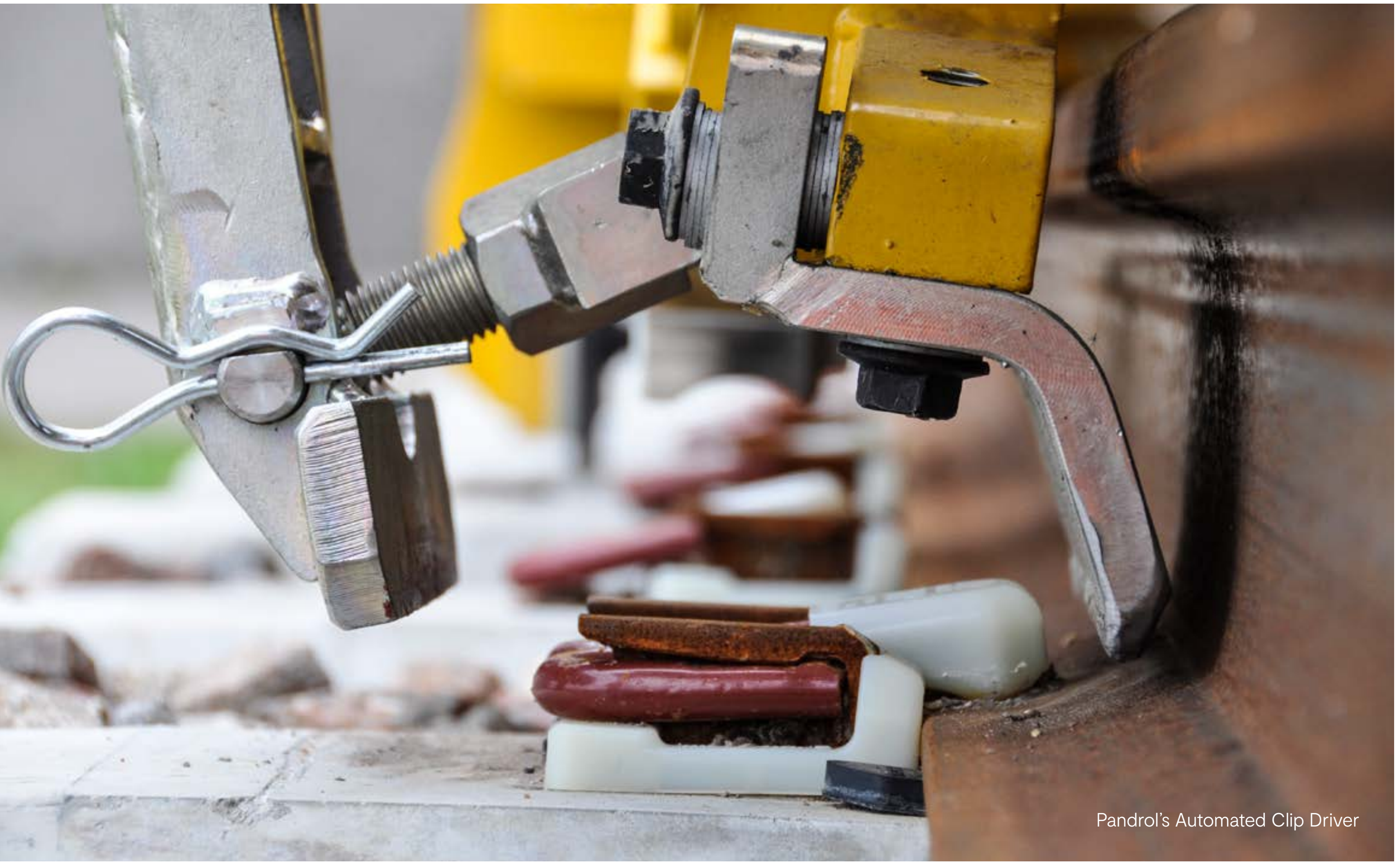
Wayne Peacock
Pandrol's Managing Director for the EMEA region

As market leaders, we want to lead by example in our practices and have a positive footprint for sustainable development. We commit to act as a strong and innovative link in our customers' value chain while controlling the impact of our operations and foster the well-being and development of people – in our teams and in the communities around us.

We have a 50 year history of working with Trafikverket and the Pandrol team placed customer focus at the heart of its efforts engaging positively with the sleeper makers to build alliances. Our bid was built on a recognition of TRV's environmental goals and will deliver value for money, sustained product quality and a high level of product support to the customer.

The FE System has undergone extensive testing in Pandrol's laboratory in accordance with CEN standards. Safety is paramount in the design and manufacture of Pandrol products.

Many other countries across the world are also switching to Fastclip FE. London Underground adopted Fastclip FE and it has introduced major efficiencies, meaning the track can be installed much more quickly and cost effectively.



Pandrol's Automated Clip Driver

Pandrol Fastclip FE System installed in Norway

20 YEAR SWEDEN AGREE-MENT

The Fastclip FE fastening system was recently approved for Trafikverket's 20 year framework agreement with Swedish producers of concrete sleepers Strangbetong Rail AB and Abetong AB. Trafikverket (TRV) carried out a national procurement exercise to source pre-assembled fastening systems and under sleeper pads for Sweden's railways involving around 400,000 sleepers per year over the term of the contract.

The Fastclip FE System is the latest evolution of elastic rail fastening. The development of the FE system responds to commercial pressures to continually drive down costs within the railway industry and achieves significant overall cost savings for railway operators and infrastructure contractors, without any compromise to the performance of the assembly. The design reduces the working profile of the system whilst enhancing performance and functionality.

The Fastclip FE System is designed as a complete system in which all components are delivered to site pre-assembled on the concrete sleeper. Once the sleepers are laid and the rail installed, the clip is simply pushed onto the rail by means of a simple drive action. This switch-on-switch-off capability encourages mechanisation of the installation and extraction processes for both renewals and maintenance. Pandrol's Clip Driver machines, such as the Rosenqvist CD500 provide accelerated installation capability of up to 70 sleepers per minute.

Pandrol has also been successful in being selected as a supplier of under sleeper pads on this tender exercise for 35 tonne axle loads. The under sleeper pads are tailor-made resilient systems designed to reduce track maintenance, increase the quality of the track by fixing elastic elements to the bottom surface of the sleepers. These under sleeper pads are proven to reduce rail corrugation, and ballast degradation, especially in tight radius curves, extending the grinding interval by at least a factor of two.

Pandrol Under Sleeper Pads

SUPPORTING INDIAN RAILWAY'S DRIVE FOR INCREASED CAPACITY

Pandrol is collaborating with Indian Railway's design team RDSO, to develop an aluminothermic welding solution for the specialised Cr-V alloyed High Strength rail which has been developed at Bhilai Steel Plant in India to increase capacity on India's rail network.

According to UN estimates, India will become the most populous country in the world in just 14 years' time, when it will have approx. 1.45 billion inhabitants. This rapid population growth has led to a rise in traffic and freight movement in the Railway which is creating robust demand for additional Rail Infrastructure. Projects such as those proposed by Dedicated Freight Corridor Corporation, the Ahmedabad to Mumbai high speed lines, the doubling and tripling of existing lines, and a host of new metro and light rail projects are all actively gearing up.

The advanced rails are designed to modernise and increase capacity on India's Railway Network, by allowing the track to cope with increased speed and heavier axle loads, and they have specific requirements for the aluminothermic welding process used during rail installation and maintenance.

The Pandrol team has been working closely with Indian Railway to develop a suitable aluminothermic welding process to suit the high strength, 110 Kg/mm2 UTS, rail.

A FOCUSED TEAM

Pandrol continues to invest in the welding operations in India following the acquisition of Harshad Thermic Industries Private Limited in 2015. A range of improvements have been implemented to improve product quality and manufacturing techniques. The facility, which is located in Raipur is constantly moving towards quality through automation of production procedures.

A team of young and dedicated engineers and professionals have been recruited in Raipur to create a local centre of excellence. The engineering team are working together with Pandrol's global aluminothermic welding experts to share knowledge and apply global best practice and know-how to the local Indian market. In addition to the collaboration with Indian Railways, Pandrol's team are working closely with local associates of DFCC such as GMR, L&T and Tata to ensure timely introduction of the latest products and technology, such as the one shot crucible, and also offer full support and training to welding operatives.

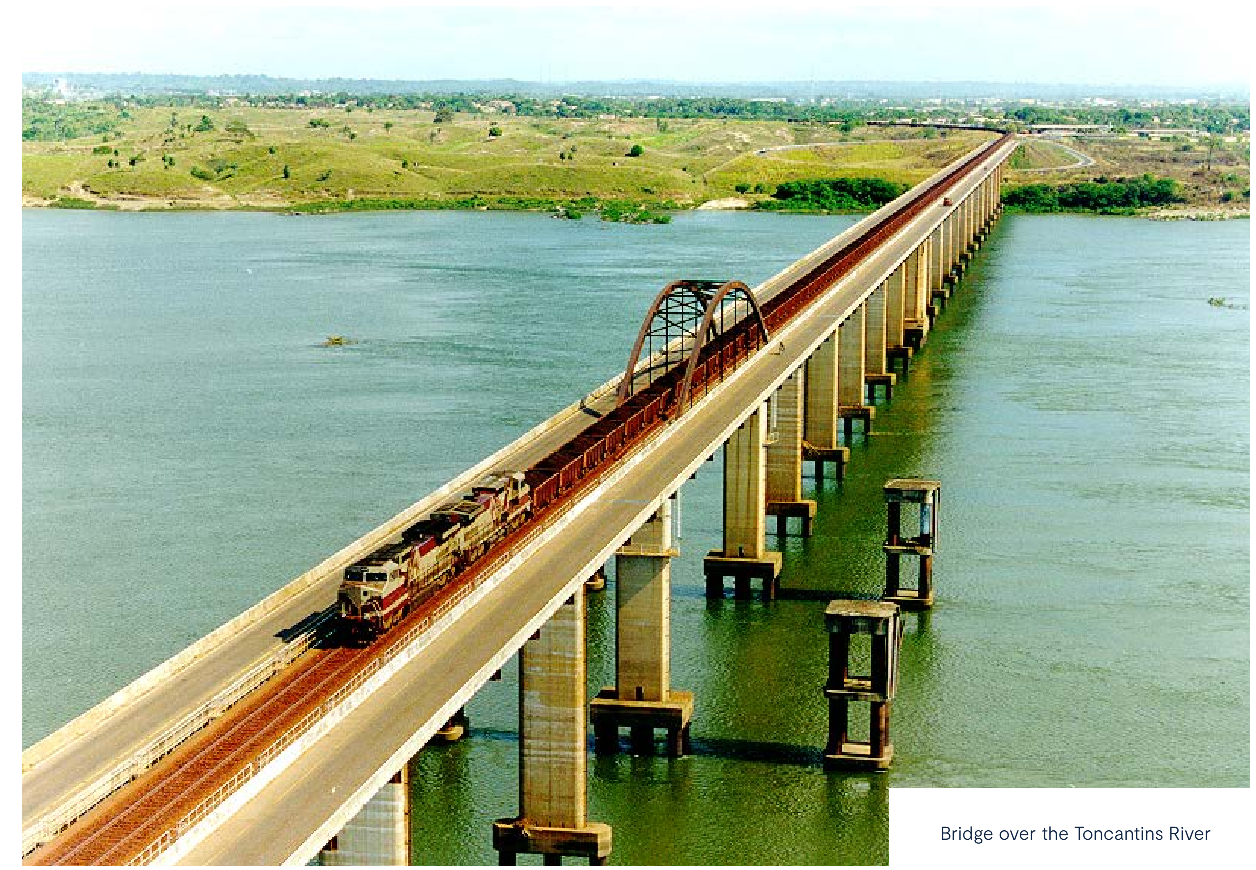
Dinesh Viswanath
Managing Director

"Our partnership with Indian Railways reflects our commitment to developing and strengthening our customer relationships to deliver technical expertise, innovative solutions and in-track services. We see that this approach has delivered a very positive result, with our business in India seeing growth from around 5% of the aluminothermic welding market in India to over 30% by 2018."

Our business in India seeing growth from around 5% of the aluminothermic welding market in India to over 30% by 2018.

A PIONEER EXPERIENCE WITH Pandrol Fastclip IN SOUTH AMERICA

By Henrique da Luz,
Permanent Way Technician,
Carajás Railway, Brazil



Bridge over the Toncantins River

THE CARAJÁS RAILWAY

The Carajás Railway – EFC, is one of two railways belonging to and directly operated by the Vale, the world's largest exporter of iron ore. It is part of a compound integrated mine-line-port implemented for the exploration of the Mineral Province of Carajás, located to the south of the State of Pará, that possesses reserves of iron ore in the order of 18 billion tons, being one of the largest reserves of high grade iron ore (66%) in the world. It is important to consider also the significant presence of other minerals in Carajás, such as manganese, copper, nickel and gold.

All the production of Carajás destined for the export market is channelled through the port of "Ponta da Madeira", located in São Luís, capital of the State of Maranhão, an automated port compound with capacity to receive ore carriers up to 360,000 tons and with a storage yard capacity of up to 3.6 million tons of iron ore.

The Carajás Railway was built as a single line, with 47 passing loops, 1.6 metre gauge, axle load 31.5 t, and approximately 892 km in length. The line runs predominantly in flat country requiring little or no embankment and few tunnels or viaducts. The bridges and viaducts account for only 11.2 km of the total track, the most important being the bridge on Tocantins River, with a length of 2,310m. The track is signalled throughout, with all traffic controlled from the Operation Control Centre, located in São Luis. Three train types operate in the Carajás Railway: ore trains, comprising of 2 locomotives and 206 wagons; cargo trains with about 90 wagons, and passenger trains with approximately 17 cars.

Ore trains transport around 21,630 tons each, reaching more than 2 km in length, characterising the Carajás Railway as a typical heavy haul operator.

EFC is amongst the most modern railways in the world: 73% of its track is tangent, with a minimum radius of curve of 860 metres and a 0.4% gradient for loaded trains.

These are the main characteristics of the Carajás Railway. A modern railway, highly productive, and qualified to carry in the order of 57 million tons of ore per year.

Pandrol Fastclip
APPLICATION IN SOUTH AFRICA

Original article by Arthur Kretzmann,
Manager (Perway), COALlink, South Africa

The Sishen-Saldanha iron ore export line

(860 track kilometres, 1067 mm gauge) carries 40 mgt annually with 30 tonne axle loads.

The Sishen-Saldanha iron ore export line (860 track kilometres, 1067 mm gauge) carries 40 mgt annually with 30 tonne axle loads. Approximately 20,000 sleepers are replaced per year on this line owing to alkalisilica reaction problems on the original concrete sleepers. The Broodsnyersplaas - Richards Bay coal export line (1100 track kilometres, 1067 mm gauge) carries 100 mgt annually with 26 ton axle loads. Approximately 15,000 concrete sleepers are replaced per year on this line, mainly owing to derailment damage.

The Fist type rail fastening system in place on these two lines has been problematic owing to the high level of rail maintenance required, such as gauge adjustment and redemption, rail pad replacement, transposing, destressing and rail replacements. In 2000 a decision, in principle, was taken to move towards the use of a rail fastening system mounted on the surface of the sleepers for all new sleeper requirements for the two heavy haul lines.

In June 2000, test sections of sleepers with Pandrol e-Clip and Fastclip fastenings were installed on the coal line to evaluate the performance of these systems in track, as well as to determine the benefits to be gained during rail maintenance activities. At the same time the estimated life cycle maintenance cost of the systems were compared. The Fastclip system proved to be the most advantageous and the go-ahead for production was given.

Initially HDPE rail pads were used, but the Fastclip design makes allowance for resilient pads to be introduced if required at a later stage. For the ore line, the design is such that gauge adjustments up to +10mm can be made (in 5mm steps) to improve wheel wear

through pummelling. For the coal line, on the other hand, the design is such that gauge redemption of up to 10mm can be achieved (in 5mm steps) to offset gauge widening as a result of side wear on the rails.

The first production sleepers with Fastclip fastenings were installed during 2002. Immediate benefits were seen through the reduced installation cost of the sleepers with all components pre-assembled in the factory. The main benefits are, however, expected in the longer term through improved performance of the fastening system and reduced resources required for rail maintenance activities.

ASK THE EXPERT

EMISSIONS FREE MAINTENANCE

Oliver Dolder

Global Equipment and Control Director at Pandrol

Q: What is meant by emission free?

A: Emission free refers to an engine, motor, process, or other energy source, that emits no waste products that pollute the environment or disrupt the climate.

Q: Is emission free maintenance for railways possible?

A: Although battery technology is not 100% emissions free, it is a solution that drastically reduces emissions; creating a healthier and cleaner working environment for equipment operators.

Q: What are the benefits of using battery powered equipment?

A: Apart from the benefits to the environment that come from lower carbon emissions, battery powered equipment is compact and powerful bringing ergonomic benefits and high-quality performance. Batteries also offer a consistent source of power and require less ongoing maintenance between jobs, making them more reliable and easier to maintain than traditional solutions. From a financial perspective battery operated equipment has a long-life cycle and can offer cost saving opportunities through reduced maintenance requirements and reduced spending on fuel. Track teams can also see a benefit, equipment powered by battery is lighter and easier to carry than traditional railway equipment. Working conditions are also improved as the tools are operated without wires or cables making them less of a trip hazard. Perhaps the most noticeable improvement to track working conditions is the lack of fumes generated by the equipment verses traditional gas-powered solutions.

Q: What are you working on next?

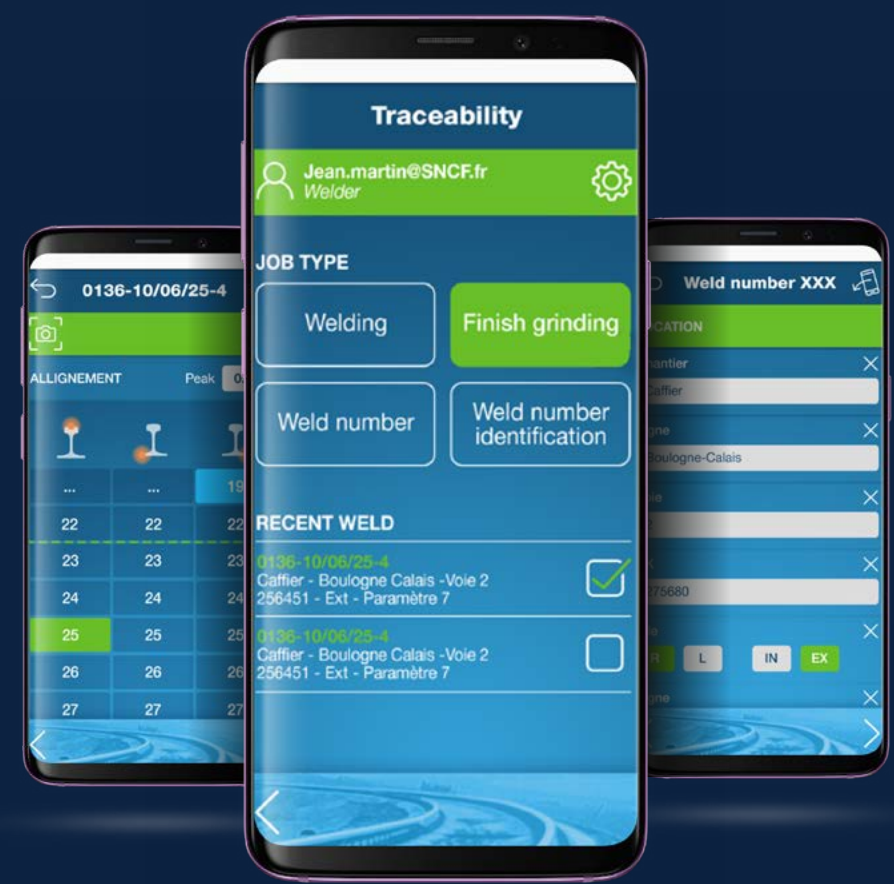
A: We currently have 6 products in our battery-operated tool range and are working on further developments to both increase our offering and improve the products we have.

Q: What do you think the future of railway maintenance looks like?

A: We are seeing a global trend of environmental awareness, some of the largest railways in the world are committing to reducing carbon emissions and setting clear, measurable targets for improvement. Railways have also historically been dangerous places to work, we are seeing more and more countries look to reduce risk to track teams, improve working conditions and invest in safe working. I think these 2 drivers will push the future of railway maintenance to be safer, cleaner and greener than ever before.

PANDROL

CONNECT



Driving greater weld traceability across the rail sector

Pandrol's new Connect app enables complete end-to-end data coverage across the aluminothermic welding sector. The technology reflects Pandrol's core ethos in offering an unrivalled customer experience - maximising rail infrastructure availability, safety and lifetime value.

The app was developed in response to the issues of weld traceability, which can be a major challenge in areas where many different contractors are involved. Efficient traceability is essential to gather, trend and spot anomalies in weld performance data – essential also for optimising costs. The app enables live data capture, a significant time saver for contractor teams.

The app has three modules:

- A mobile version for welders to record on-site data and for welding controllers to review data.
- An online monitoring app to review weld information from the office.
- An online administration tool to apply settings to local standards.

Pandrol Connect, an app with smartphone technologies to share data with multiple networks and companies – in one click– no paper, no emails - just simplified communication and responsibilities.

Pandrol defines the industry standard across the aluminothermic welding sector and has developed the Connect app with alignment to Industry 4.0, as a commitment to visibility and optimisation of the entire value chain.

Pandrol started work on developing the welding app back in 2016, the objective of which was to develop an open platform which would facilitate the recording and transmission of the data between all welding parties, including railway authorities, welding companies and welding kit suppliers. All data is stored in the cloud for easy sharing to contractors and the network, automatically.

Available for Android, the app has already been used, with great success, by Pandrol's welding services teams and contractors across the UK and France.

Feedback has been overwhelmingly positive and has resulted in enhancements to the app, including the latest innovation to include a news function that improves weld documentation opportunities and data sharing overall.


Mobile version

The app is already benefiting Pandrol's quality systems through the automation of the documentation of industrial processes and instantly available information at the touch of a button. Pandrol expects this to have a major impact on welding projects in the future and looks forward to demonstrating the benefits to customers.

Pandrol's research has shown that contractors appreciate the facility to record data before, during and after welding, even with no internet access. Compatible with all welding kit suppliers, data can be downloaded by technicians on location. In line with the product launch, Pandrol has released training videos to support contractors with using the new software, which can be easily located online.

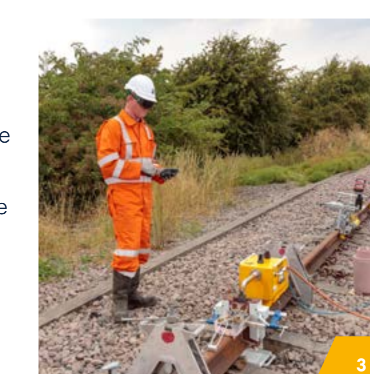
Welders are extremely happy with the ergonomic aspects of the interface, such as immediate access to welding instruction manuals, the use of QR codes, the facility to add voice comments and compatible interface gloves. In addition, welding contractors welcomed the reliability of the report and the fact that data is automatically transmitted from site, with many weld parameters pre-filled (such as the Supplier Job Reference and Job Cost Number), so no need for input. **Data confidentiality is paramount - Pandrol Connect allows only authorised users to view data.**


1


2

BENEFITS

- Enables cost optimisation and enhanced customer service across the supply chain.
- Provides a customisable cost-effective app with no capital outlay.
- Saves time for all users and drastically cuts down paperwork.
- Encourages efficiency and innovation through an incorporated news function.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Under Sleeper Pads

On the up in heavy haul

Recent years have seen a rapid growth in the use of Pandrol's Under Sleeper Pads (USPs) in heavy haul railways. So why are USPs so useful when loads are high?

EXTENDING RAILWAY LIFE

The main benefit of USPs in heavy haul is track protection. Introducing an elastic element to the base of sleepers improves load distribution over the track and its components, both longitudinally and transversely.

Without USPs, ballast is the first elastic track element to consider. Fasteners and ground are also resilient, whereas the wheel, track, and sleepers are all rigid. When heavy loads pass over the track, the ballast is compressed and, with a ballast-sleeper contact area of between 5 to 8% of the total surface, the compacted ballast gets stiffer.

USPs introduce an additional elastic element between the ballast and the sleeper. As a result, the contact surface increases to over 30%, improving load distribution, consistency of track stiffness and overall track quality. Different USP specifications are available to provide the ideal elasticity for specific rail infrastructures. Elastic levels need to be controlled to ensure that while the stiffness of the system is decreased, the elasticity doesn't cause too much track deflection.

In the long term, maintenance costs are reduced and the life of the track superstructure is extended. There is less rail corrugation (especially on curves). The frequency of levelling, lining and tamping (LLT) can be reduced by a minimum factor of two.

ADDITIONAL BENEFITS AND DURABILITY

Whenever is needed, an additional benefit of using USPs is a reduction in structure-borne noise and vibration by up to 15 dBv, by using a specific USP system specifically designed for Noise & Vibration performance. Less rail corrugation, which is a source of noise, also has a positive impact.

USPs have proved particularly useful at transition points, for example at bridges, rail expansion joints and between track construction types. They also help to control elasticity in the case of ballast contamination by sand ingress, reducing stiffness and the risk of damage to sleepers.

The durability of Pandrol USPs has been confirmed through successful performance in SNCF Vibrogir ageing tests – the most demanding on the market.

Pandrol's Micro-Filament Fastening (MFF®) bonding technique is used to fix USP´s onto fresh concrete during sleeper production. Alternatively, USPs can be attached to sleepers at a post-production stage using glue.

USPS IN PRACTICE IN HEAVY HAUL

Heavy haul railways sector is globally reporting significant improvements as a result of introducing USPs.

Improvements in the track with USP includes better track response, greater stability and reduced track maintenance.

One example is Roy Hill, one of the main players in iron-ore mining in Western Australia. An issue with increased compression of ballast at bridges was resulting in frequent track maintenance, including replacing fastenings, repositioning sleepers and ballast tamping, for trains of 420kN Axle Load.

Roy Hill decided to install Pandrol USPs to provide better support beneath the sleepers and mitigate vibrations within the ballast layer. On-site technical training was provided to ensure the correct gluing of USPs to existing concrete sleepers.

With Pandrol USPs already being used by CSX in the United States and Canada, the Rio Tinto mining company in Australia and Trafikverket in Sweden, their growing influence in heavy haul looks assured.

IMPROVING SLEEPER STABILITY IN HEAVY HAUL TRACK WITH RESILIENT TPE RAIL PADS

PHENOMENON SLEEPER SKEWING

The phenomenon of sleeper skewing can be identified, to differing degrees, on many railway tracks around the world. A sleeper is considered as being skewed when it has moved from its original position in the ballast, and is no longer at right angles to the rail.

A novel design of rail pad manufactured primarily from a thermoplastic polyester elastomer (TPE) compound has been optimised to accommodate the extreme axle loads and conditions experienced in the Pilbara heavy haul railways.

This insight article explores behind the scenes of the innovative track trials, lab tests and modelling conducted in relation to the mechanism of operation and effectiveness of these rail pads in the quest to prevent sleeper skewing. In heavy haul rail networks some areas of track, with particular geometry traits and where vehicle dynamic contributions from braking or acceleration are present, have demonstrated a predilection over time towards longitudinal sleeper movement and sleeper lateral rotation ('skewing'). This sleeper movement can lead to track geometry defects and ballast attrition that result in the need for vehicle speed restrictions and require maintenance operations at increased frequency.

UNDERSTANDING PLASTIC MOVEMENT

There are two events that precede a skewed sleeper; i) the sleeper must have moved within the ballast in a non-elastic manner and ii) one end of the sleeper must have moved more than the other. However, the key to prevention of sleeper skewing lies in understanding why any plastic movement occurs in the first place.

The main determinants of sleeper skewing behaviour are the longitudinal forces the rail is subjected to, which are distributed and dispersed by the fasteners, sleepers and ballast. The level of force, the distribution of forces, and the resistance to plastic movement in the fastening and of the sleeper in the ballast determine how much, if any, plastic movement and skewing takes place. The forces may arise from a number of different input conditions, and may include differential forces and stresses acting on the two rails as a result of track geometry (e.g. tight curve radii), the existing stressed state of the rails, and forces arising from the high tractive effort related to acceleration or braking of locomotives. Skewing can occur on tangent and curved track, and on gradients and level track. Because of the high traction forces that apply on heavy haul networks, these railways may be more prone to problems of sleeper skewing.

IDENTIFYING SKEWING BEHAVIOUR

Previous work by Rhodes et.al. (2005) identified a factor that may be important in determining sleeper skewing behaviour, particularly in heavy haul railway track. This is that longitudinal loads are distributed further along the track than are vertical loads, and that the vertical load modifies the longitudinal behaviour. The rail clips provide some vertical loading of the rail / sleeper interface in advance of a train's arrival, even before the train loading has any effect on this interface or the interface between the sleeper and ballast.

Rhodes also identified differences in sleeper skewing performance between two types of rail pads used in South African heavy haul track. A larger scale study was then conducted in Australia, comparing the performance with respect to skewing of two different types of pads on heavy haul track:

- Type A: a standard High-Density Polyethylene (HDPE) type widely used on heavy haul track in Australia
- Type B: a variant developed for use in the extreme heavy haul conditions (40 tonne axle load and above) found in the Pilbara region of Western Australia, manufactured primarily from a thermoplastic polyester elastomer (TPE).

FIELD TRIALS

After an appropriate section of track incorporating steep grades and curves had been identified for the trial on a suitable heavy haul network, approximately 10,000 Type B pads were installed over a distance of approximately 3,000 m during re-railing of the area in August 2016. This area was then monitored closely for a period of 12 months using creep markers to quantify the effectiveness of the pads. After the initial 12 months, monitoring was scaled back to less frequent visual monitoring as part of scheduled track runs by the area track inspectors.

The trial section has shown minimal movement relative to the installed creep monitoring stations since the installation of the Type B pads in August 2016.

Approximately 800 million gross tonnes have travelled over the site during that time (33 months). The sleepers in the trial area have remained in place with only minor visible movement. In contrast, on the same section prior to the trial when standard Type A pads were installed, extensive movement occurred after only 12 months of service.

On reviewing the number of hours of track occupation that were required to rectify skewed sleepers during the trial period, an adjacent section with Type A pads installed required 19 hours of maintenance time to rectify defects associated with skewed sleepers, in comparison with the trial section of type B pads requiring only three hours over the same period.

The field trial work shows a clear difference between the performance of pad types A and B. But it does not provide a means of explaining exactly why that difference occurs. In order to explore this question further, some laboratory testing and modelling work has been carried out.

INSTRUMENTAL BEND

At the Pandrol research laboratory in the United Kingdom, the first obvious difference identified in the tests was in the vertical stiffness of the pads.

Type A pads are a rigid design made from a stiff material with a relatively high modulus of elasticity. Type B pads are also made from a relatively high modulus material, but are designed to have a low vertical stiffness, while still being able to withstand heavy haul axle loads.

The Type B pad is characterised by a central membrane that has vertical studs on either side of it, but which are offset from each other. This means that when the pad is loaded vertically (either by the clamping force of the fastenings alone, or in combination with vehicle loading) the membrane bends, and this provides a level of resilience. As expected, a significant difference was found when these pads were tested.

In short, pad Type B is resilient in the longitudinal direction as well as the vertical direction. This was seen clearly in the test results.

FIELD TEST FINDINGS

A non-linear mathematical model was then developed to identify which of the above performance factors determine the difference in resistance to sleeper skewing, or if more than one factor is involved. This model also helps to identify where exactly slip is most likely to occur relative to the position of the train. The model led to the simple conclusion that there is a significant improvement in resistance to sleeper skewing predicted for pad Type B compared to Type A. In fact, all the pad performance indicators had some effect on the predicted resistance. In all cases, the effect was in favour of the characteristic measured for pad Type B.

RESILIENT PADS DELIVER

The implementation of a trial has proved that it is possible to successfully reduce sleeper skewing to a significant extent in extreme heavy haul track through the application of vertically and longitudinally resilient pads that are effective at mitigating the effects of forces applied to the track. Laboratory testing and numerical modelling explain a mechanism whereby the resilient pad can reduce sleeper skewing.

DEVELOPMENT OF A SIMPLE TO INSTALL, MULTI-ELEMENT RAIL SENSOR AND TECHNIQUES TO MONITOR INFRASTRUCTURE AND VEHICLE PERFORMANCE AND SAFETY RISKS IN REAL TIME.

G.E Curtis C.Eng FIMechE
Technical Consultant, Pandrol (Vortok) Ltd. Derby UK.

ABSTRACT

As manual inspections of track and structures reduce while service intensifies, the state of infrastructure and the effects of vehicles on it needs to be understood (and acted on) on a regular basis.

Aim: To produce a rail-specific sensor system and real-time algorithms to detect problems at source.

A minimum parameter set are needed: Rail temperature, Longitudinal strain, Vertical shear force and rail acceleration Lateral acceleration.

Method: Research determined the possibility of fitting the sensors into a space less than 10mm diameter x 15mm for insertion in the rail web. An interference fit sensor can remain in place for ten years.

Results: The MultiSensor has been trialled globally. Installations monitor, analyse and inform operators on multiple parameters: Stress-Free Temperature changes, Vehicle dynamic loading and Frictional heat.

Implementation: Data from multiple sites combined, producing a coverage better than 'super sites'. Fusing parameters to inform operators makes it possible to set operational risk factors:

- "The rail is tight, we need to reduce the tolerable wheel-flat limit or train speed to reduce the likelihood of rail breaks."
- "A train is creating high lateral accelerations. Rail temperature is high near its SFT - Rail buckling likely."

1. INTRODUCTION

One of the largest cost areas for railroads is wheels and their interaction with components on the vehicle, such as brakes or suspension and with the railroad itself. It is not possible to consider the wheel in isolation and much like our scientific forefathers discovered with the earth, the wheel is part of a much larger world in which it revolves.

In order to manage the lifecycle cost of such a system, technology is needed to automatically measure and differentiate between damage and wear so that the effects of both can be understood. Only when the mechanisms are properly understood can educated decisions can be made to guide appropriate maintenance and or replacements.
The MultiSensor development is aimed at the development of a rugged, simple sensor set built into a rugged housing that can sense high-speed inputs into the rail as trains pass and monitor temperature induced forces as environmental conditions change.

Often deployed in remote areas, any installation must be able to operate standalone whilst being able to communicate with rail operators and maintainers. As well as the development of the sensor itself, this project required the development of a low-power realtime processing unit with wireless communication and web-based display systems.

Figure 1. MultiSensor & Printed Circuit Board.

2. DEVELOPMENT

2.1. SENSOR DEVELOPMENT

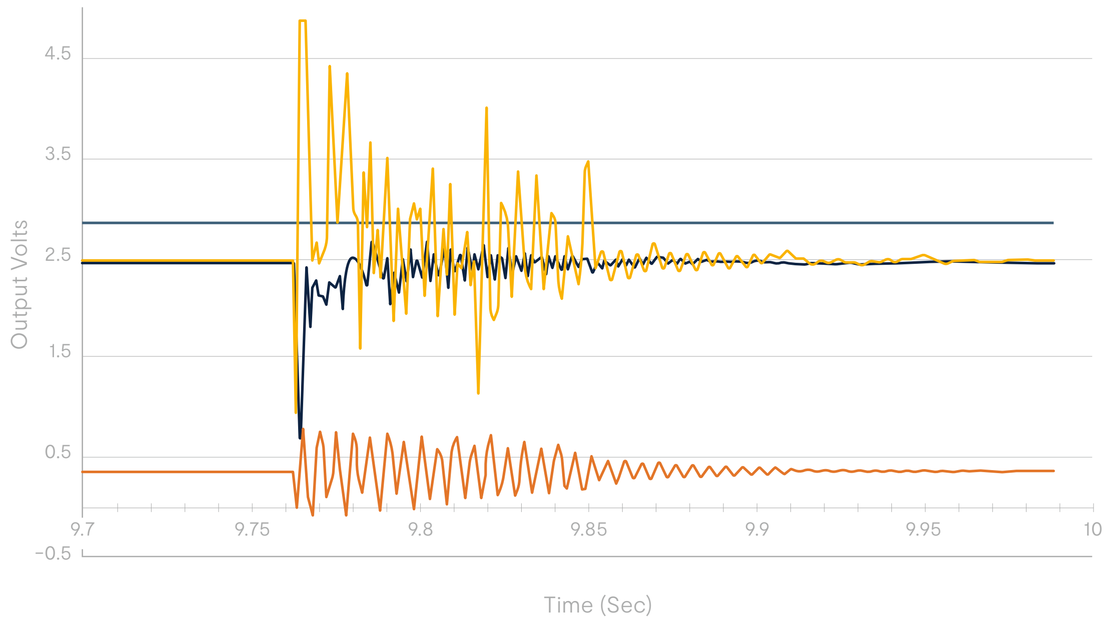
The original work was done at British Rail Research, in conjunction with Roger West Laboratories for a simple embedded load sensor using a novel strain gauge placed at the bottom of a tube. The strain sensor could be applied in laboratory conditions and then the unit could be inserted into the rail web using simple mechanical tools without requiring special tools or environmental protection.

This approach was helpful in the development of the MultiSensor and, by enlarging the sensor barrel to 10mm and casting the sensor body instead of machining from solid, extra sensing elements could be added with supporting channels cast into the body. The new elements were, a solid-state temperature sensor and a two-axis MEMS 70/35g accelerometer.

The printed circuit board is designed such that all sensing elements fit inside the hollow barrel of the sensor and are, consequently, positioned in the web of the rail. The temperature sensor is close to the strain gauge so that temperature is measured at the core of the rail with 2mm or so of the strain measurement.

2.2. INITIAL SENSOR TESTING

A small batch of sensors was made for initial testing to determine performance in both high-speed and low-speed conditions. Dynamic testing was performed with a simple drop test with a steel weight.



2.3. IMPACT REPSONSE

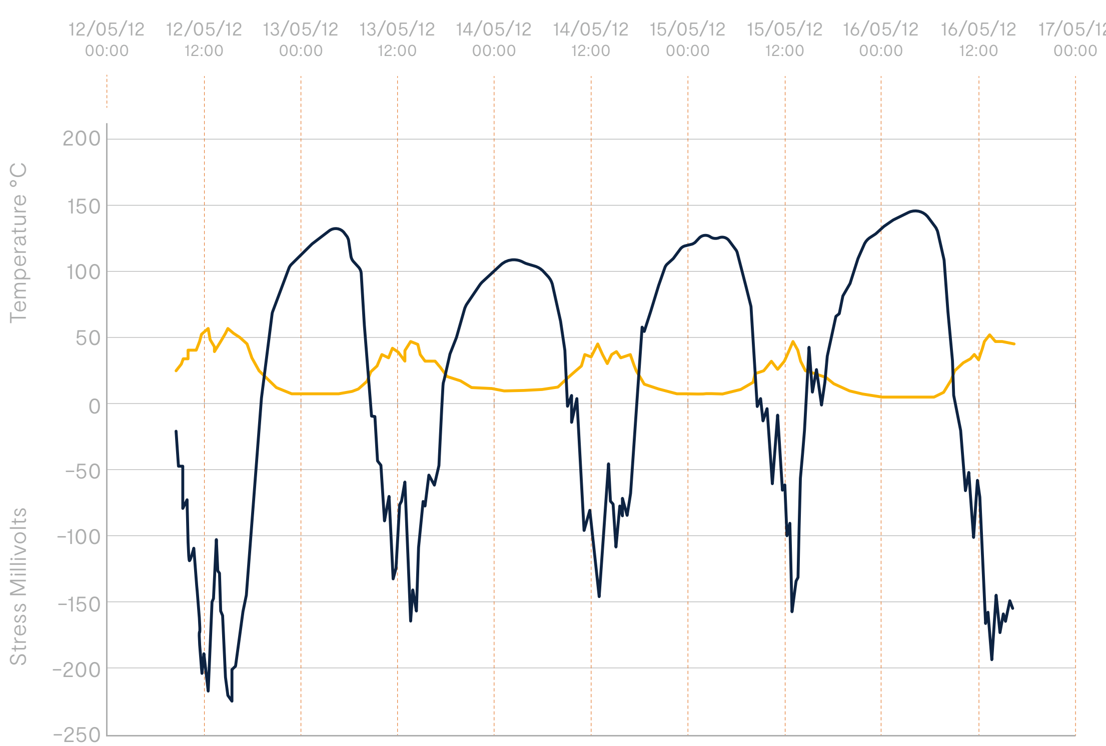
SINGLE IMPACT FREE RAIL ON BLOCKS

Figure 2. Impact response of all sensor elements.

Temp
Strain
Lateral Accn.
Vertical Accn.

2.4. STRAIN – TEMPERATURE LINEARITY

Temperature and strain linearity was checked using a composite test bar built up from alternate bars of copper and steel. This unit acted like a piece of railway track in that it would create longitudinal strain in the steel bar (in which the sensor was inserted) as the temperature changed.

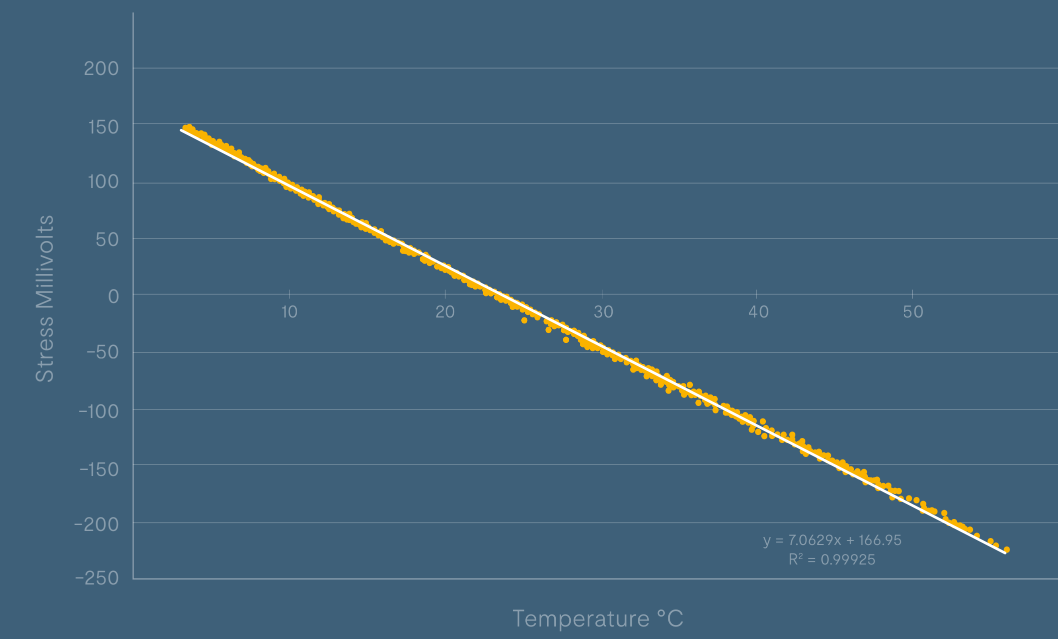


STRESS & TEMP FOR BIMETAL TEST PIECES

Figure 3. Temperature & Strain cycles over four day period.

S0 Millivolts
S0 Temp

Left can be seen the tension change with temperature which clearly mirror each other. If the two parameters are plotted against each other we can see the linearity of both temperature and strain measurements.



STRESS VS. TEMP

Figure 4. Linear relationship between temperature & strain.

Linear S0 Millivolts
S0 Millivolts

3. FIELD TESTING

3.1. SENSORS IN TRACK

The results from laboratory tests were encouraging so several track tests were set up in different locations in the UK, Australia and the USA.

Sensors were installed at the Great Central Rail-way in Leicestershire where data was obtained with a prototype high-speed data logger.

Two tests were planned in Australia to prove the MultiSensor in a horizontal rail stress situation. The first at Douglas Park, NSW was installed and commissioned on 23rd March and data is being collected at 5 minute intervals from three sensors. Two are fed into Vortok's own logger and a third is connected to a system operated by Lynton Surveys for their own evaluation.

Holes were drilled using a Cembre rail drill, then reamed using a simple C-clamp style alignment tool.

Some non-linearities in stress-strain were seen at this site and were traced to poor drilling/sizing or the hole as well as poor dimensional control of the rail sensor barrel.

Lessons learned were that a better set of tooling was needed to drill more accurate and repeatable holes in the field.

MultiSensor had reached pre-production phase with a batch of 100 sensors manufactured to the latest design. Each sensor was individually serial numbered for traceability of its components and performance against specifications.

3.2. FURTHER IMPROVEMENTS

For accurate hole drilling, a better system of tooling was developed for the Cembre rail drill. This split the power unit from the rail clamp so that the clamp could stay in place on the rail after drilling so that perfect alignment was ensured.

During the Australia tests it was discovered that the sensor, oriented in a particular way, was sensitive to both vertical shear force and tension in the rail at the same time.

Figure 5. Cembre drill / ream fixture.

From then on each Measure & Detect system was able to report both wheel flats and track rail stress and temperature concurrently and it was necessary to develop a data logger which could operate on low power and achieve the sample rates required for realtime processing of wheel flat data.

4. HIGH SPEED DATA LOGGER

4.1. MEASURE & DETECT LOGGER

The M&D logger needed to be a very low-power device to provide service in remote areas with minimal power availability. Using an ARM processor in combination with a Telit communications/GPS module it was possible to design a very capable unit with extensive power management facilities to reduce power consumption to around 1watt average power consumption.

Figure 6. Data logger for four MultiSensors.

The unit works in conjunction with a pair of 50 kilo sample per second data acquisition boards which are isolated from the data logger, giving 3 kV isolation from rail to rail when the sensors are installed correctly. Power comes from a 20w solar panel and 24 Ah back up battery. The logger will run continuously for around 7 days without sun in typical UK latitude. The Vortok logger provides data in the form of email attachments or messages to a central server which can be loaded directly into Microsoft Excel for analysis and viewing data.

Each logger accepts up to four MultiSensors and is configurable for logging rate, file sending frequency and recipient.

5. TOOLING & INSTALLATION

5.1. DRILLING SUITABLE HOLES

During testing it was apparent that the quality of output from the sensors (particularly strain) was highly dependent on the fit of the sensor in the hole. When fitting the sensors in hardened rail in Brazil and the USA it was apparent that sensors were being damaged during installation, even with a high-quality, precise hole.

A system of bushing was developed where the sensor was fitted into a bronze bush fitted into the rail. This allowed for a more durable installation as the bush took up imperfections in the rail and gave the sensor a more consistent fit into the rail. No deterioration in sensor output was noted and the new method had the advantage that, if the sensor, needed to be replaced, a low-cost bush would provide a fresh 'hole' for the sensor to mount in to.

Figure 7. Sensor being inserted into bushed hole.

5.2. TRACKSIDE INSTALLATION

The working setup is suitable for pole or ground mounting at trackside and can be installed in around ½ day.

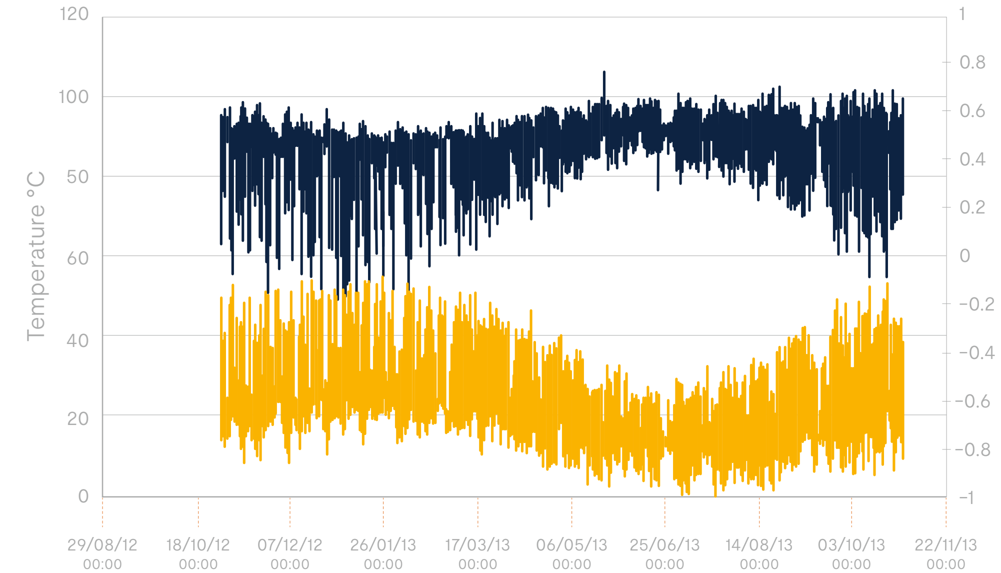
Figure 8. Trackside installation.

6. DATA COLLECTION & EVALUATION

6.1. RAW DATA

Two applications form the main part of the output from the MultiSensor Stress-Free Temperature monitoring (also known as neutral temperature monitoring) and Wheel Flat detection. The first application requires only a data sample every five minutes or so, while the second requires data logging at several thousand samples per second. The raw data from the SFT monitoring application can be handled using conventional wireless communication but the raw wheel flat data must be analysed at trackside and reduced to critical parameters on an axle by axle basis before transmitting to a data store.

Right is a full year of strain and temperature data from Douglas Park, NSW.



STRESS VS. TEMP

Figure 9. A year in the life of rail strain & temperature.

6.2. TRAIN DATA

As well as the low-rate data, the logger must process high speed data. For research investigations the logger has internal storage for collecting waveforms for subsequent analysis.

Below is data showing three locomotives pulling empty wagons near Townsville in Queensland. The trace shows simple strain data as each axle passes over the sensors.

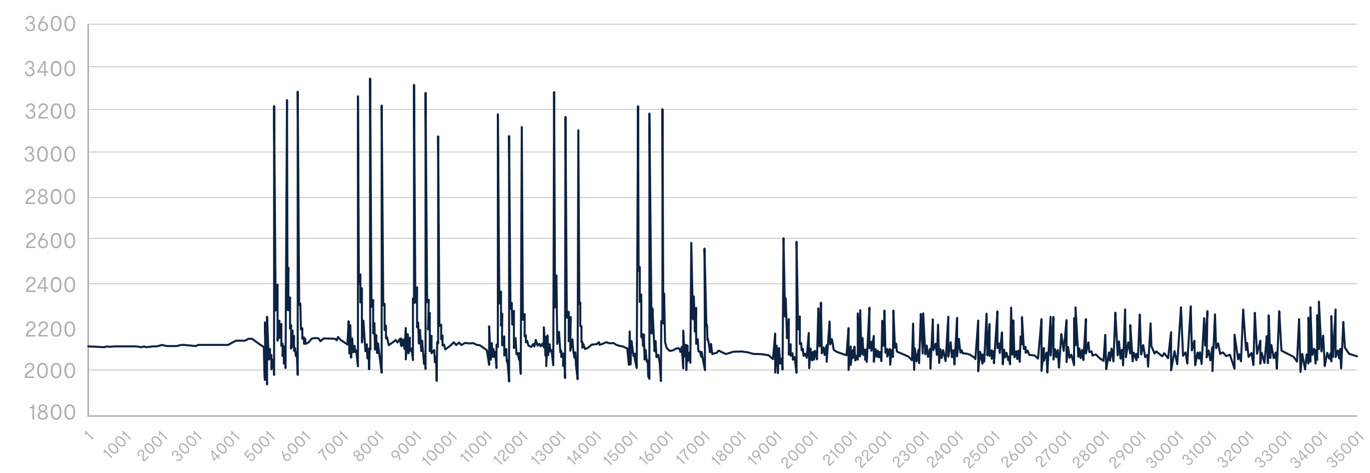


Figure 10. Multiple locomotives & wagons.

7. ANALYSIS

7.1. WHEEL DATA

Although the graph in Fig 10 clearly shows the difference between the different axle weights between locomotives and empty wagons, it is much harder to determine whether a particular part of the trace represents a wheel, a track fault or an example of wheel damage. Our real-time data analysis combines both mechanical properties of rail and sensor with software to detect the passage of a wheel and any damage that exists on that wheel.

In each rail, the sensors are fitted in pairs slightly inboard of the sleeper. Each sensor measures vertical strain. Because the wheel moves from one side of a sleeper bay (crib) to the other, each sensor output is a mirror of the other. At each sensor, the load rises as the wheel is present above the sensor, then decays linearly as the wheel approaches the next sleeper. The 'sister' sensor sees an opposite pulse where the load rises linearly from zero up to the peak.

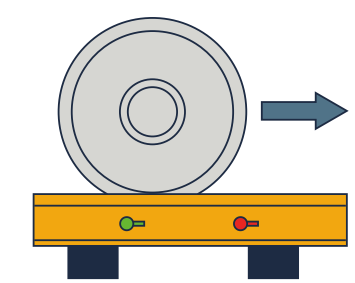


Figure 11. Relationship of wheel with sensors.

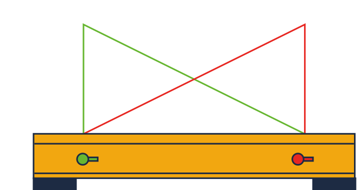


Figure 12. Shear force trace related to Fig 11.

7.2. WHEEL ANALYSIS

In Fig 13 below, the top trace shows the output of sensor 1 (red) and sensor 2 (blue) in the same rail as four axles pass by. Adding those two traces provides the third trace which shows a single pulse for each wheel that passes.

If the wheel is smooth and round, the trace has a smooth plateau. If there is any damage on the wheel surface as it traverses the two sensors, the 'roughness' will be seen on the plateau. Fourth 'wheel' on Fig 13.

The data above is from a real vehicle on track and shows two 'good' wheels on the left, followed by a slightly damaged wheel and a very rough wheel on the right of the graph.

The bottom trace shows the 'effective' load of each wheel. The damaged wheel presents almost twice the effect of the other two on the track, illustrating how important it is to remove damaged wheels from the train fleet.

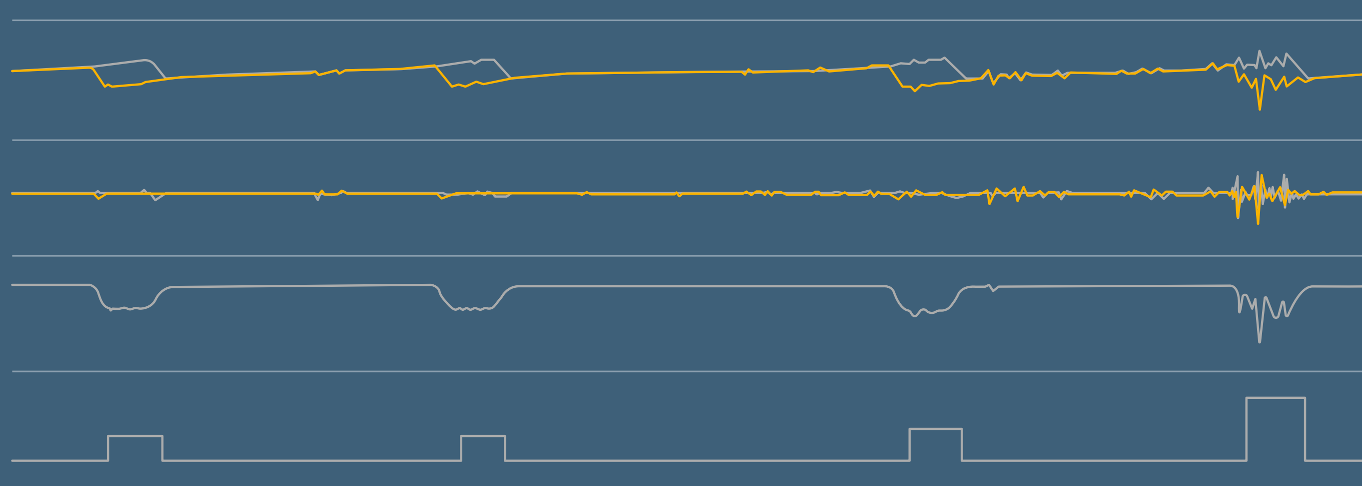


Figure 13. Relationship of wheel with sensors.

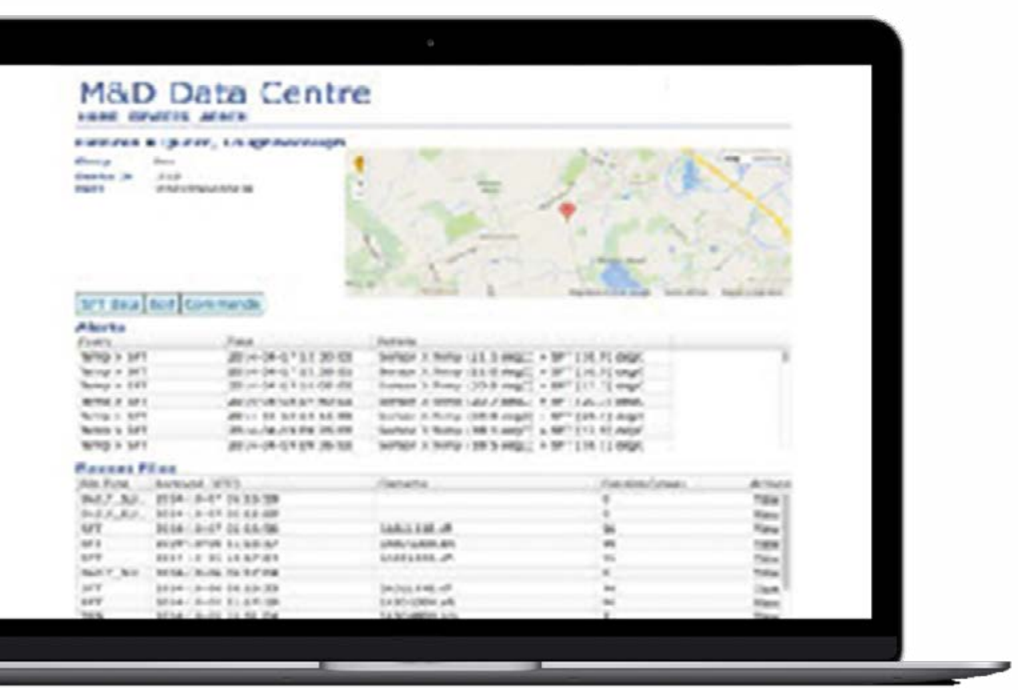


Figure 14. Web screen. Pages are displayed for train loads in graphical and tabular form.

8. INFORMATION VISUALISATION

8.1. WEB BASED INFORMATION

For simplicity, the standard way of using Measure & Detect is via a dedicated web site, but information can be provided in a number of other ways, if required.

Figure 15. Train wheel loads.

And for rail strain / temperature...

Figure 16. Rail strain / temperature.

Data may be downloaded from these pages for further analysis in software, such as, Microsoft Excel. Customer-specific analyses can be written and displayed on additional pages if required. Notifications can be generated and sent via email or text message to responsible individuals.

8.2. TRAIN FAULT DETECTOR

Pandrol won a contract to supply three train fault detectors for Metro-North and Long Island Railways and these will have an advanced information network using special algorithms to amalgamate data from multiple sources and deliver it to operators and maintainers.

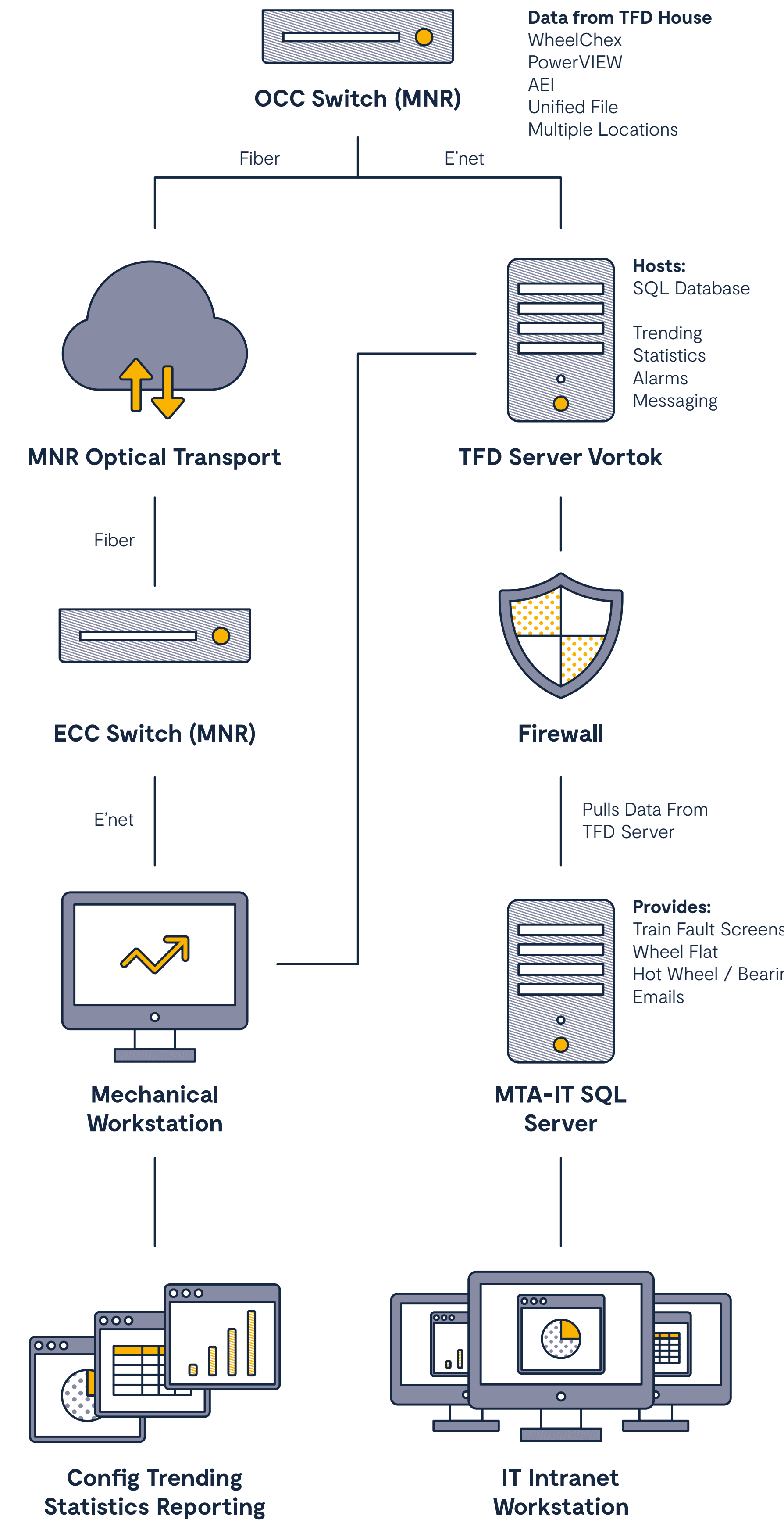


Figure 17. Train Fault Detector for MNR / LIRR.

9. SCALING

9.1. PROBABILITY OF WHEEL DAMAGE DETECTION

Strain-based systems using discrete sensors have an active measuring area between the sleepers. The piece of rail at the sleeper pays no part in the measurement. Fig 11 above.

The detection probability for a single pass over a single bay is typically 16% (500 mm sensor separation and 1000 mm wheel diameter).

If greater probability is required over a single pass then systems with 8 or greater measurement bays will provide a greater than 90% chance.

Three WheelChex systems are being installed by Pandrol for Metro-North Railroad and Long Island Rail Road in the New York area and each consists of four tracks with 8 measurement bays per track using 128 sensors in total.

Where trains pass more frequently over the site, NYCT has a simple Measure & Detect system with just one bay of sensors.

9.2. SUPER SITE OR DISTRIBUTED?

Traditional wheel flat detection sites are large for high detection probability and require extensive services laid on for communication and power.

With the small footprint of the Measure & Detect system the possibility exists to populate the railway with self-contained distributed systems which can create greater coverage and overall detection rate of the larger systems.

The information will be contained and can be amalgamated and analysed as if all the data from each train/wagon came from one site.

If, for instance, a simple site is placed every 10 Km instead of one every 100 km, the wheel flat detection rate is similar but the chance of catching a damaging wheel flat quickly is increased. In addition, other parameters such as rail stress are better monitored throughout the network.

10. MAKING THE MOST OF INFORMATION

10.1.MANAGING RISK

By incorporating a number of measurements in one site it is possible to provide comprehensive risk information to railway operators for improved decision making:

i.e. If track temperatures are high AND I have a train with high lateral accelerations, I need to reduce line speed to avoid increasing the risk of rail buckles.

If rail temperatures are very low and I have a train that is creating big vertical forces I need to restrict my speeds or remove that train from service. This kind of wheel damage may be acceptable on warmer days...

Are other operators increasing my risks through poor wheel-rail dynamics (more heat and lateral forces) and do I need to put restrictions on how / where they operate...

11. CONCLUSIONS

The development has shown that it is possible to produce a rugged sensor which can be easily installed in a rail environment using familiar tools and practices.

The MultiSensor has proved itself suitable for environments around the world and maintains linearity and stability for long-term installations.

The endurance and performance has been tested by a major Class 1 railroad in the USA over a simulated 160 Million Gross Tonne test.

Three four-track WheelChex™ systems are being installed in the USA for Metro-North Railroad and Long Island Rail Roads in the USA in combination with Hot Axlebox Detectors to form a comprehensive wheel management system. These sites use 128 MultiSensors across four tracks, combined with advanced Hot Axlebox/Hot Wheel Detectors. Special software is being created to manage the integrated information for improved maintenance planning.

Because of its integration of multiple sensing elements aimed specifically at railway condition monitoring the MultiSensor and Measure & Detect systems can provide useful data for rail operators & maintainers.

12. ACKNOWLEDGEMENTS

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