Advancing the Railway Industry Through Technology

Source: Institute of Railway Technology

In Australia and throughout Asia, the work of the Institute of Railway Technology (IRT) at Monash University is changing the way that railways operate.

The premier track and vehicle railway research centre in Australia, IRT is one of the main technology service providers to heavy haul railway operations and leading mass transit railway systems, providing a 'one-stop-shop' technology access point for the international railway industry.

IRT evolved from BHP's Melbourne Research Laboratories (MRL) in January 2000 and, together with its predecessor, has been advancing the railway industry through technology for over 45 years.

According to a recent interview in Create (Engineers Australia's magazine), IRT's Director Ravi Ravitharan said, "[Rail] is a growing industry in Australia, and an important industry globally. At IRT we work with industry bodies to help them overcome issues with maintenance and with the management of railway operations. Our group is set up to deal directly with industry, and to link industry to solutions that we have developed over the last 44 years."

The institute has an established track record in solving railway related technical issues, and its solutions have been adopted by railway systems throughout the world. Just some of the institute's international clients include the MTR Corporation in Hong Kong where a team of researchers are assisting to further improve railway operations, as well as SMRT in Singapore, Indian Railways and Jakarta Metro.

Closer to home, IRT has worked with some of Australia's largest general freight and passenger rail corporations, including Queensland Rail, Australian Rail Track Corporation, Metro Trains Melbourne and V/Line. IRT also works alongside some of the world's largest heavy haul companies, such as Rio Tinto, Fortescue, Roy Hill and BHP.

According to Ravitharan, "Over the last 17 years we have worked with over 150 entities around the world on about 450 projects. We are a group of engineers from various specialties including civil, mechanical, electrical, electronics, metallurgy, and industry partners come to us to figure out how they can do things better."

"We focus our efforts towards industry. We have created a rail research atmosphere that has applied research focus as well as brings other academics into the rail industry. The industry benefits from having that connection to academia, as well as having a group like ours that understands their challenges."

Areas of Expertise

The IRT is comprised of highly skilled engineers, scientists and technicians that cover a wide range of mechanical, civil, electrical, metallurgical and general science disciplines.

Primary areas of expertise include vehicle and track structure design and maintenance, vehicle and track performance, asset health condition monitoring, railway component testing, failure analysis, quality control and auditing, wheel-rail interface, rail welding, vehicle and track dynamic modelling, standards development and training.

IRT now offers an expanded capability recognising the need to respond to the changing nature of global railway industry needs. With this in mind building on existing capabilities of the IRT team, internationally recognised researchers and practitioners have joined the IRT team as Rail Research Associates, providing 'whole of industry' solutions to the expanded needs of railway advancement.

IRT and its rail research associates undertake various activities related to materials and their performance, including:

- Mechanical behaviours of advanced materials, biomechanics, fracture, fatigue and wear
- Solid mechanics to deal with the deformation and failure of materials and structures
- Rail/wheel contact mechanics- carried out many three-dimensional -wheel-rail contact simulations
- Plastic ratcheting and rolling contact fatigue of rails
- Plastic deformation and failure of high strength rail steels in heavy haul transportation of mineral products
- Development of a new rail maintenance technology by using laser cladding
- Rail and wheel interface, wear, and rolling contact fatigue
- Physical metallurgy, mechanical metallurgy, modelling and simulation of materials, steel, aluminium alloys, 3D metal printing
- Micro structure, welding (cracking of welds) and corrosion and combined effect of corrosion and mechanical loading (such as fatigue loading)
- Nanomechanics and nanocomposites, smart materials and structures, sensors and actuators, structural health monitoring, hydrodynamics and very large floating structures (VLFS)
- Formation modelling (ballast)
- Subgrade and formation levels (reactive soils) and treatment of reactive soils with additives
- Measurement of formation properties, behaviours (GPR and other sensors)
- Corrosion of metals (buried metal corrosions, concrete structure buried underground)
- Ground Penetration Radar (GPR)

Materials and Performance

IRT and its Rail Research Associates drawn from Monash University leading academics drives key research in materials and material performance, which has a range of applications to varied industry needs. Monash University is developing novel materials for construction including high performance concrete and steels, nanomaterials for reinforcement and for corrosion control. Monash has exceptional facilities for materials characterisation and structural testing, including a wind tunnel, and leading expertise in analysis of fractures and fatigue.

Monash is also researching emerging technologies for building and managing structures such as 3D printing of concrete, modular construction, sensor networks for infrastructure monitoring, and robots and remotely piloted aircraft systems for asset inspection.

According to Peter Mutton, IRT's Associate Director, "In terms of materials science and engineering, one of the major services we offer is qualification testing, targeted at the improvement of rail weld performance."

"Improvements in the quality and characteristics of rail steels has resulted in the performance of rail welds becoming increasingly important, particularly in the premium rail grades used under heavy haul conditions. Activities undertaken by IRT have been aimed at improving the reliability of flashbutt and aluminothermic welds across all sectors in the rail industry."

"Much of the work we do is concerned with the qualification and testing of welds to AS/NZS 1085, specifically Part 1 - Steel rails (which specifies requirements for as-rolled and hardened steel rails made from continuously cast blooms and profiles for asymmetric switch rails and elevated guardrails for railway purposes) and Part 20 - Welding of steel rail (which covers the joining of rails by flash butt welding and aluminothermic fusion welding and the repair of the railhead by arc welding or aluminothermic fusion welding)."

"IRT's qualification and testing expertise extends across a wide range of rail steels, which is particularly important given that railway network components are primarily being imported from overseas these days. This is particularly true of those components destined for the Pilbara region, which are generally characterised by varying alloy grades that can be more difficult to weld," said Mutton.

"Failure examination of bogies, wheels and couplings is another area in which we specialise. These components, particularly when used in freight and heavy haul operations, are subjected to a combination of mechanical and thermal loads, both of which can contribute to increased rates of deterioration. Inadvertent overheating through the application of friction braking may also alter the residual stress distribution and increase the risk of wheel failure, as well as wheel-rail interface related issues."

Instrumented Revenue Vehicles

The IRT commenced its Instrumented Revenue Vehicle (IRV) program in 2001. An IRV is a fully flexible automated measurement platform that can continuously monitor and provide feedback on both rail condition and train operation.

The data that IRVs capture can be used to inform the condition of the track in real time, identify deterioration of the track condition over a period of time and innovative strategies related to evidence based economical track maintenance planning. It is also used to develop appropriate driving strategies and assess rollingstock performance. The IRV fleet is designed around the customers' specific requirements and operates autonomously.

According to Mutton, "The IRT undertakes a considerable amount of remote railway condition monitoring, using Instrumented Revenue Vehicles. We have instrumented over 80 wagons collecting valuable information on heavy haul and passenger networks."

"The IRV technology utilises existing customer rollingstock, which remains in normal revenue service and provides a platform for instrumentation, data collection and communication."

"As opposed to traditional track recording equipment, an IRV monitors the actual response of the rollingstock in both empty and loaded condition during normal operation and provides more regular feedback on track condition, typically daily. The principal premise is that if the rollingstock is riding poorly, then corrective actions are likely to be required," said Mutton.

In addition, IRVs offer several key advantages over other maintenance inspection methods. According to Ravitharan, "With the objective of increasing production rates, mining operations are often under pressure to reduce railway track downtime. The ramifications of reducing track downtime are that it would minimise traditional track measurements and maintenance activities. This could result in a significant increase in operational risks because of a lack of maintenance and an inability to identify deterioration of track condition in a timely manner."

"IRT's instrumented vehicle technology measures the condition of a railway system during normal rail operations without requiring any track downtime. In addition, IRT's technology measures the dynamic responses of normal vehicles during loaded and empty operating conditions under standard speed profiles. Unlike previous track recording vehicle measurements, IRT technology measurements are a direct indication of the loads being imposed on the rail network in a usual operating environment."

Influence of Rail Grade on Flashbutt Welding Requirements

Flashbutt welding conditions for rail grades can vary markedly depending on steel chemistry; this is most commonly apparent in terms of the required post-upset cooling conditions. Reduced cooling rates (sometimes requiring application of post-upset heating cycles) may be necessary to avoid the presence of martensite in more highly alloyed grades, whereas accelerated cooling (achieved by air quenching of the head) is necessary for plain C-Mn heat treated grades such as that covered by AS1085.1-2002.

Two additional aspects of the steel chemistry can also impact on the ability to achieve consistent weld quality during flashbutt welding. The first of these relates to the presence of centerline segregation in the parent rail. These regions typically exhibit higher levels of Mn and P compared to the surrounding rail, which delays the austenite-to-pearlite transformation thereby increasing the risk of martensite formation. In rail grades requiring air quenching, this risk can also be mitigated by restricting any forced air cooling of the web.

The second aspect is the use of higher Si levels (typically >0.5 wt%) in some rail grades. Silicon strengthens the ferrite phase in the pearlitic microstructure, which in turn improves the resistance to cumulative plastic deformation (i.e. ratcheting).

Image Source: Fortescue Metals Group Ltd

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Flashbutt Weld Quality Issues

Heavy haul rail operations such as those in the iron ore industry impose heavy demands on track materials such as rail welds, to the extent that aluminothermic welds, and to a lesser extent flashbutt welds, represent the main risk of broken rails.

These risks can be addressed by eliminating, where possible, the use of aluminothermic welds, and implementing rigorous pre-qualification and quality assurance procedures for both processes. These procedures are generally based on currently-available industry standards, although the experience in heavy haul operations is that such measures may not always be sufficient.

For flashbutt welds, the application of phased array ultrasonic testing (PAUT) procedures has proved to be beneficial in resolving quality issues that were contributing to broken rails in one heavy haul rail network, leading to its more widespread application in acceptance testing of all new flashbutt welds.

Phased Array Ultrasonic Testing Procedure

The phased array ultrasonic testing had previously been developed for the cleanliness assessment of railway wheels, and for the detection of casting defects in draft gear components, and is now routinely used for in-service testing of draft gear in several Pilbara heavy haul systems. Of particular relevance to the flashbutt weld testing requirement was the ability to consistently interrogate a large region of the component (in this case the full height of the rail) at sensitivity levels sufficient to detect and size relatively small discontinuities.

Application of Phased Array Ultrasonic Testing for Enhanced Quality Assurance of Flashbutt Welds

The development of a phased array ultrasonic test (PAUT) procedure for assessment of bond integrity in flashbutt welds was initially directed at addressing major weld quality issues associated with construction of the original Fortescue Metals Group mainline, and expansion of the rail network to achieve a haulage capacity of 155mtpa. These quality issues arose from a combination of rail grade which proved to be more challenging to flashbutt weld, and use of a range of mobile flashbutt welding machines, some of which were not well suited to welding of this grade.

Initial development of the PAUT procedure for the flashbutt welds was aimed at determining the feasibility of detecting and sizing the defects which had resulted in broken rails. This involved correlating the test results for welds in the original mainline with the characteristics of the welds as revealed by more conventional destructive testing, in order to develop acceptance requirements for testing of in-track welds. Tensile tests, using specimens prepared from different regions of individual welds, enables a correlation to be established between the extent of any discontinuities at the bond line and the fracture strength, providing a greater level of confidence that could be obtained by application of the standard bend test as specified in AS 1085 Part 20.

Subsequent application of the PAUT procedure and the associated accept/reject criteria throughout the network, in conjunction with magnetic particle testing, enable preexisting defective welds to be identified and plated in order to mitigate the risks associated with broken rails with minimal disruption to haulage operations, to the extent that these procedures are now also being applied on an ongoing basis for preliminary acceptance testing of all new production welds.

The phased array procedure provides several advantages over conventional ultrasonic testing, including much higher resolution (and hence the ability to detect smaller discontinuities over the full height of the rail), the ability to determine the width of the heat-affected zone, and improved data capture for post-processing and subsequent analysis (where required).

The Role of Microstructure and its Stability in Performance of Wheels in Heavy Haul Service

Axle loads used in Australian heavy haul operations currently range from 35 to 40 tonnes. Due to the ever-increasing demands of the mining industry that these operations support, axle loads may increase to even higher levels.

On the other hand, tread brakes are still the primary form of train braking, coupled with the widespread introduction of electronically-controlled pneumatic braking systems. The service conditions impose high contact stresses and severe thermal loads on the wheel rim. It is also well known that thermal inputs can be generated from wheel lockup (skid events), friction drag braking, traction forces, curving, hunting oscillation and so on due to slip or creepage from wheel-rail interaction and wheel to brake block friction.

The combination of these thermal and mechanical loading conditions to the wheel rim can result in degradation or failure from one or more of the following modes:

- Thermo-mechanical shelling (TMS)
- Thermal cracking (cumulative heat input)
- Shelling from wheel skids

Each of these degradation modes are strongly affected by the characteristics of the wheel material, the operational conditions, as well as the maintenance regimes in place.

Thermal or thermo-mechanical loading is one of the major causes of wheel surface damage in Australian heavy haul operations. In addition, multi-wear wheels appear to be particularly sensitive to thermo-mechanical damage during their first service life. Such damage can incur heavy machining penalties or even premature scrapping of wheels.

The combination of high contact stresses as well as substantial thermal loading (such as during prolonged periods of tread braking) can lead to severe plastic deformation, thermal fatigue and microstructural deterioration. For some high strength wheel grades, the increased sensitivity to thermo-mechanical damage observed during the first service period may be attributed to the presence of a near-surface region in which the microstructure is more sensitive to these loading conditions than the underlying material.

The standards applicable to wheels used in Australian heavy haul operations are based on AAR specification M-107/M-208, which does not include any requirements for microstructure. The implementation of acceptance criteria for the microstructure, in particular that in the near-surface region of the wheel, may be necessary when new wheels are purchased.

Wheels used in heavy haul operations are subjected to service conditions which involve a combination of mechanical and thermal loads, and it is the combination of these conditions which must be considered when specifying wheel material grades. The wheels should contain homogeneous pearlitic microstructures that are thermally stable and suitable for the intended service conditions.

The presence of mixed pearlite/bainite microstructures in the near-surface region of the rim in multi-wear wheels appears to be the major factor that increases the sensitivity to thermo-mechanical damage during the first service life. Alloy designs and rim quenching conditions should therefore be optimised to avoid the formation of mixed micro-structures. The alloy design should also facilitate the generation of fine pearlite and enhancement of microstructural stability during thermo-mechanical events. The exact alloy levels should be tailored through experiments and verified by on-site trials.

An alloying combination containing chromium and silicon should be used to refine pearlitic structure and increase pearlite stability. Manganese and nickel should be tailored such that embrittlement due to sulphur is removed but not intended to lower eutectoid temperature; additionally, manganese and sulphur contents should be well balanced to ensure proper initial microstructure and machinability. A small amount of vanadium and niobium is also beneficial for rolling contact performance. Suitable concentration of molybdenum could be included to further enhance pearlite stability.

IRT in Action

IRT's comprehensive and systematic approach to problem solving using its team of experienced technical specialists has led to significant savings to its customers' operating and capital costs, surpassing all expectations and providing value added environmental benefits.

The Institute of Railway Technology is continuously developing new technologies to support increasing productivity and safety requirements at the same time as reducing risks and costs, ultimately improving the bottom line for their clients.

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