Project Title An investigation of residual stresses in insulated rail joints

Brief Description of Project

Insulated rail joints (IRJs) are an integral part of the rail track signalling system. IRJs in heavy haul corridors around the world are periodically replaced due to accumulated damage in their railhead; in Australia it is estimated that the IRJs are often replaced within 10% of the useful life of other rail components. This proposal is for the first ever neutron diffraction investigation of stress accumulation in the vicinity of the rail endposts which abut the insulated gap in IRJs. The investigation will provide fundamental information about residual stress accumulation at and below the rail surfaces, and how this might change during degradation of IRJs. Results will be used by researchers trying to gain deeper understanding of the stages of track degradation prior to IRJ failures, by finite element modellers attempting to simulate progressive damage in the railhead, and by engineers attempting to design of improved longer life IRJs.

Scientific Background to Proposed Investigation

Rail track fracture can result from progressive defects, the propagation of which is influenced by residual stresses in the rail, which occur in the as-supplied track and then change significantly with track use. For IRJs, failure can occur well before the initiation of cracks or surface voids, when metal flow over the insulated rail gap (typically 6-8 mm width) breaks the electrically isolated section of track and results in malfunction of the track signalling system. For this reason a significant amount of track maintenance work is dedicated to inspection of rail ends and replacement of rail sections containing IRJs judged to be approaching an unsafe condition. In heavy haul rail systems IRJ replacement can occur after only 2-3 years of service. Apart from track ballast work, IRJ replacement represents the most significant track maintenance expense in the rail network.

Although failure of IRJs usually occurs via metal flow in the vicinity of the rail ends, other forms of damage include fracture of the side fishplates used to support the IRJ and metal fracture at the rail surface. Many mechanisms of rail failure are related to relationships between defects and the residual stress fields at and below the rail surface. Residual stresses are generated in rails first as a result of manufacturing processes, which includes hot-rolling, and head-hardening. In service, the running surfaces are subjected to repeated rolling contact stresses through contact with the train wheels, and the rail itself is subject to a variety of complex stresses and strains. Stresses are usually high and can cause plastic deformation around the contact surface and modify the stress field near the running line and internally in the railhead. There will also be surface wear, caused by sliding friction near the running band and at the gauge corner side of the head when contact is made by the flange. These effects can change in near IRJs, which represent a different support structure to standard track and where additional forces, such as wheel impact, arise due to the combination of rail gap and rail ends.

Justification for choice of instrument (Kowari)

Diffraction techniques are particularly suited to the non-destructive mapping of complex stress fields. Traditionally, neutron diffraction has been used to determine residual stresses internally in denser materials such as steel, where penetration depths are orders of magnitude greater than those of X-rays. There are a handful of examples in the literature of use of neutron diffraction to investigate residual stresses in rail, including [1-2].

Although most of the cited studies have been performed of rail slices, one investigation, [2], demonstrated that it is possible to employ neutron diffraction techniques to determine the triaxial stress distribution inside of an intact piece of rail. There are no known reports of neutron investigations of damaged rail ends. So the Kowari is chosen because it is specifically designed for the measurement of residual stresses, the goal of this work.

Samples

The samples selected for this investigation are 400 mm length rail ends from square ended insulated rail joints made from the same steel type (Australian standard A1085.1; 60 kg head hardened grade; 0.65-0.92C, 0.15-0.58Si, 0.95-1.07Mn) and same manufacturer. Rail ends from IRJs described as „partly damaged‟ and „badly damaged‟ will be compared with a rail end in the "not damaged" condition, as-manufactured state.

Proposed Experimental Research, Description of Experiment

Residual stresses are expected to be found in the subsurface region of the rail head [8] which are induced due to manufacturing process and due to regular service of train movement over the selected IRJ rail endposts. The distributions of stresses away from the endposts and below the surfaces of the rail are in the focus of the experimental program. Measurements with gauge volume 3x3x3 mm3 are suggested to be done in the central vertical plane of the rails. The range of the first 30 mm under the top surface of the rail will be scanned with this gauge volume. Taken at several (5) selected distances from the endpost, the measurements will produce 2D mesh with approximate number of point 10x5=50. The same measurement strategy will be applied to all three rail pieces enabling to make comparison between them. By doing measurements in the central line we assume symmetry of the stress and only 3 principle directions can be measured for the full characterisation of the stress tensor. The best sample orientation is to be found to minimise neutron flight path in materials to reduce measurement time. The measurements done on the line most close the endpost surface can be used for d0 evaluation using condition that the stress component normal to the surface equals to zero. Alternatively, after experiment completion, rails are to be sectioned to produce d0 samples for the experimental determination of the d0 values. The target accuracy of strain (or d-spacing) determination is 0.7-0.9x10-4 should be sufficient for determining stress values with accuracy ±30 MPa. Iron (211) reflection is to be used since this is the strongest reflection and instrument is optimized for using this reflection.

Expected results

The stress distributions determined experimentally can be used to validate finite element simulations done to assess progressive damage accumulation in IRJ rail endposts through elastic-plastic deformation history and residual stress evolution [3]. Our experimental results, detailed 2-D and 3-D maps, will allow us to narrow selection of the correct FEM model. The combined experimental and modelling efforts should enable railway engineers to understand better how residual stress fields evolve in service. Also this project will contribute to the development of longer life insulated rail joints and to determination the most appropriate rail maintenance and replacement schedules for safe and economic operation.

Time required

Residual stresses are to be measured at different locations inside the rail and under very different neutron flightpath conditions. This makes almost every measurement point to be individual in terms of necessary measurement time. We expect measurement time to change between just portion of the minute (for the most surface point) up to several hours (for the deepest points). Because of that exact time estimate is almost impossible. However,

judging from the previous experience and previous measurements on Kowari involving thick samples, we expect one rail (out of three) to be measured within one week. The average measurement time (1h) gives approximately the same estimate taking setup time into account. Other factors which are difficult to account for are:
(a) Microstresses which lead to peak broadening. This affect necessitate longer measurements in order to achieve the same counting statistics.
(b) Required counting statistics (and consequently the resultant stress value errors). These depend highly on the magnitude of strain variation, which is yet to be determined experimentally.

However, in case of requested time unavailability, without varying the number of rail pieces to be tested, a shortened version of the proposal can be carried out with some losses employing several possible strategies:
(a) reduction of the measurement point (losing stress map details)
(b) reduction of the measurement time (accepting increased errors)
(c) increasing of the gauge volume (reducing resolution).

REFERENCES

[1] P.J. Webster, K.S. Low, G. Mills, and G.A. Webster, 1990, Mat. Res. Soc Symp. Proc., **166**, pp. 311-316.
[2] V. Luzin, J.E. Gordon, T. Gnaupel-Herold and H.J. Prask, Proc. IMECE04, 2004 ASME Int Mech Eng Congr. & Expn, Nov 13-20 (2004), Anaheim, CA, USA, pp 1-25.
[3] N.K.Mandal, m. Dhanasekar and P. Boyd, 8th Int Conf on Contact Mechanics and Wear of Rail/Wheel Systems (CM2009) Firenze, Italy, Sept 15-18 (2009) pp. 783-793.