Assessment of Corrosion on Rail Axles

John Rudlin[1], Dorothee Panggabean[2], Antonietta Loconte[3] and Angelique Raude[4]
TWI Ltd
Cambridge CB1 6AL, UK
Telephone 01223 899000
Fax 01223 890689
E-mail john.rudlin@twi.co.uk
3 Politecnico di Milano

Abstract

Corrosion fatigue has been the reason for failure of rail axles in a number of accidents. This has led to stringent requirements to remove axles from service when corrosion is present. However the assessment of the corrosion is uncertain and mainly limited to a simple visual test which is heavily dependent on the inspector.

Study of the growth of fatigue cracks from corrosion pits has enabled patterns in the development of the corrosion fatigue that gives an idea of the remaining life of an axle. An instrument has been developed that enables these patterns to be determined during inspection and this gives train operators a better method of sentencing the axle.

This paper describes the patterns observed, and results of inspections of various axles demonstrating the feasibility of the instrument.

1. Introduction

The European rail network is targeting a considerable expansion of passenger and freight traffic by 2020. In order to achieve this, increased reliability and availability of rolling stock is necessary whilst maintaining the same or a better level of safety. The axle life is a crucial part of both the safety and economic performance of the vehicles and the axle deteriorates through its lifetime by means of fatigue and corrosion mechanisms. Periodic inspection is used to ensure that these mechanisms have not compromised the axle safety; however inspection which takes a vehicle out of service impacts on the economic aspects of train operation.

1.1 Method of Corrosion Assessment for Axles

The current state of the art for this seems to be only visual inspection, at best supported by a pit depth gauge or similar device. Corrosion can be measured in the laboratory by optical methods to a high degree of accuracy but these measurements tend to be slow, requiring precision scanning of small areas and do not give a suitable output for sentencing. There is no instrument that can be used directly for the quantitative on-site inspection of axles. For corrosion assessment generally there are a number of standards for the measurement and classification of pits, but these are not related to high cycle fatigue.

1.2 Corrosion Fatigue in Rail Axles

Some bibliographic notes report cases of axle failures due to crack propagation from corrosion pits. Hoddinott [(1)] reports that about five mid-span failures of in-service axles occurred in the UK from 1996 to 2003, four of which have been connected to the presence of diffuse axle surface corrosion and corrosion pits. The Transportation Safety Board of Canada [(2)] reported one axle failure to have been caused by corrosion pits under the journal bearing. It also mentions another seven similar failures occurring between 1998 and 2000.

The effects of corrosion on fatigue properties can firstly be observed as a number of surface defects or pits which obviously reduce the fatigue strength of the axle body (this seems to be the effect described by Hoddinott in one case). There is also considerable experimental evidence [(3-6)] showing a detrimental effect of the environment upon the S-N diagram.

Recently, investigations have been carried out to assess the effect of corrosion upon fatigue properties of A1N, a type of steel widely adopted for railway axles [(7), (8)]. Rotating bending corrosion fatigue tests on both smooth and micro-notched specimens machined from axles were performed. The S-N data for complete failure of the specimen have shown that corrosion has a significant influence on the fatigue life especially at high cycles (>107 cycles) where the absence of a fatigue limit seems to be confirmed.

2. Corrosion Assessment

2.1 Corrosion Fatigue Crack Initiation and Growth

A large number of small scale rotating bending fatigue tests using specially designed equipment have been carried out and are providing information for the S/N curves and Paris equations for fatigue crack growth in corrosion conditions in A1N and A4T axle steels. This has enabled classification of the crack growth into 4 stages:
Stage 1: Pitting only (similar to corrosion without fatigue) and crack initiation from pits
Stage 2: formation of microcracks (Figure 1a)
Stage 3: Coalescence of microcracks (when depth exceeds about 0.3mm, Figure 1b)
Stage 4: Growth of macrocrakcs detectable by NDT

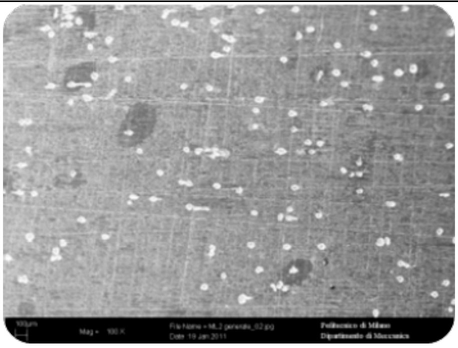
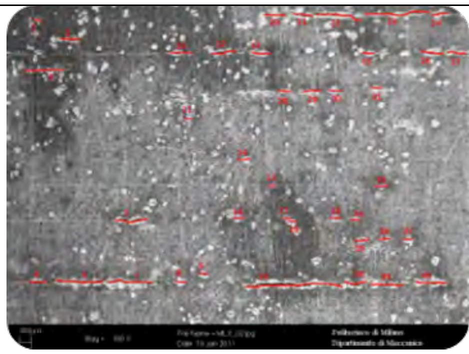
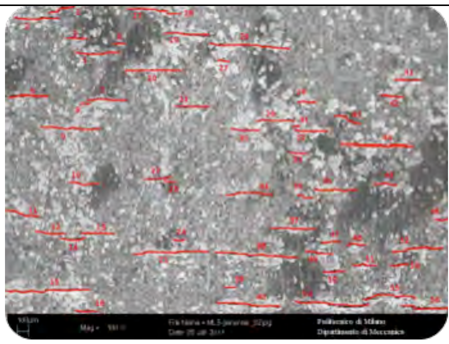
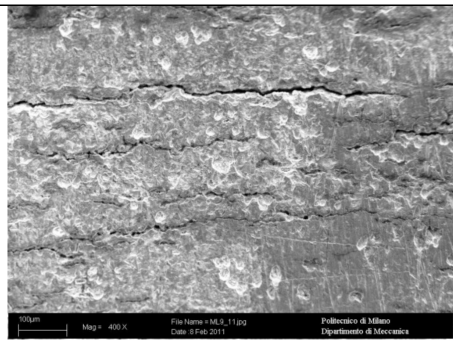
	
(a) Pitting only	(b) Early microcracking
	
(c) Coalesced cracks	(d) Growth of macro-cracks

Figure 1. Different crack formations during corrosion fatigue

Table 1 shows how crack length data builds up in a single specimen as time goes on. The ML numbers refer to tests after each period. The crack length with a probability of occurrence of 50%, L_{50}, (determined by plotting a Weibull Distribution) reaches successively higher peaks when the crack numbers decrease, due to coalescence (at ML5, ML7 and ML9). This picture is more complicated in specimens with different load levels but the effect is clear.

Table 1. Progress in crack numbers and lengths for single sample under corrosion fatigue

Specimen	**ML3**	**ML4**	**ML5**	**ML6**	**ML7**	**ML8**	**ML9**
Cycles (x103)	200	300	400	500	600	700	800
Number of cracks	40	81	56	68	46	50	33
L_{50}(µm)	133	143	257	223	308	372	488

3. Equipment Development

3.1 Introduction

The evidence provided by these experiments shows that if no cracking is present then the life of the sample is less than 10% complete and it is reasonable to say that such an axle could be returned to service without a safety risk.

However in order to establish that no cracks of this size are present, we need to be able to either improve conventional surface NDT to quantify the microcracking status or carry out a microscopic evaluation of the surface (or a combination of methods). Optical and eddy current methods were considered however this paper deals solely with the optical method.

The optical approach requires that surface rust be removed. For the laboratory work the rust was removed from the samples by using a solution at 75° C for 20 minutes. This is not a procedure that can be used on site; Figure 2 shows the equipment deployed to inspect the wheel seat of an axle.

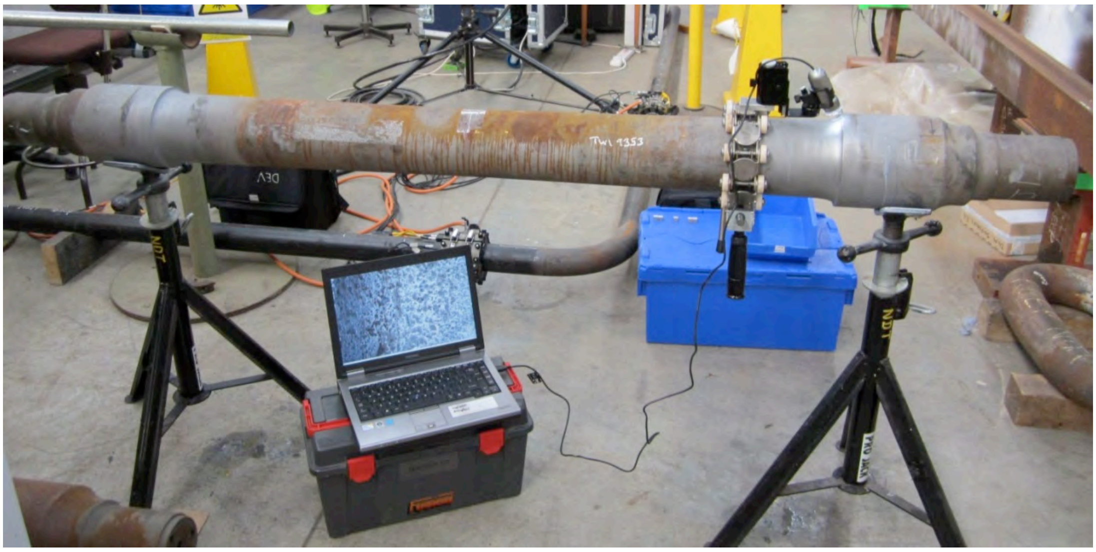


Figure 2. Equipment deployed on axle

3.2 Equipment

The system requirements are:

- Site operable rust removal
- Portable microscope to obtain images
- Adjustable and stable on the surface of the specimens
- Automatic sentencing
- Site deployable

3.2.1 Rust removal

A series of tests were carried out on a heavily rusted plate to establish an optimum mechanical and chemical procedure for rust removal. Figure 3 displays the plate on which several rust removal technique were tried to establish the most convenient method to use with the microscope.

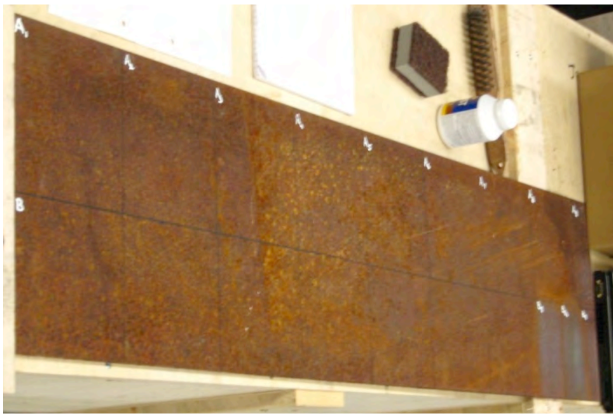


Figure 3. Heavily rusted plate

The mechanical procedure requires that a minimum of scratching occurs since scratches would be picked up clearly by the microscope and the cracks would not be visible. And the chemical removal must leave no residue in order to have a better image of the specimen's surface and a better image of potential cracks. The tests established a suitable procedure for this purposes.

3.2.2 Microscope and image acquisition

A range of portable electronic microscopes were investigated for the inspection and a suitable one was chosen. The requirement to detect such small cracks in images of corrosion cannot be underestimated. Such images are complex and the cracks are small. The lighting system magnification and focussing of the system have been specified and software for automatic crack recognition is in progress.

3.2.3. System Stability

The positioning of the microscope above the sample needs to be assured and this was achieved using a belt system as shown in Figure 4. In order to acquire clear and exploitable images, the microscope needs to be normal to the specimen's surface. The cracks or other objects should be located at the centre of the image as to have the microscope focus on those features.

The belt allows as well the rotation of the microscope all around the axle whilst maintaining stability and height.

Figure 4. Support system of microscope on train axle

4. SENTENCING - Statistical Analysis of Images

Three images taken from the samples have been used in an initial analysis (Figure 5). Different rust removal methods were used for each sample so the colour is slightly different.

Sample 1 is from a heavily rusted plate which has been processed using the site procedure.
Sample 2 is a sample from the edge of a corroded area with additional corrosion in salt water.
Sample 3 is from the centre of a corroded area using the laboratory rust removal method.

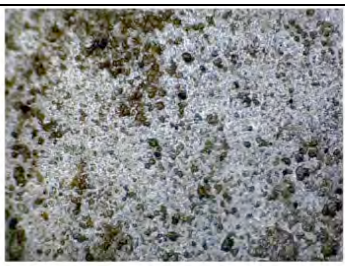
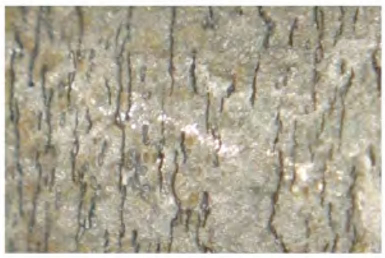
		
Sample 1	**Sample 2**	**Sample 3**

Figure 5. Examples of surface images

Table 2 shows image analysis was able to identify and grade the three images, although this does need further development. For example, using this method if the percentage of objects filtered is greater than say 8%, then it is likely that cracks are developing; if less than 6% the corrosion is relatively benign at the time of testing.

Table 2. Results of image analysis

	Image 1	Image 2	Image 3	Image 1	Image 2	Image 3
	No	No	No	%	%	%
No of objects	1487	147	253			
Example analysis(filter) result	90	15	36	6	10	14

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