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Wheel – Rail Contact Fatigue

Sumant Patel*, Dr. A. V. Gohil**
*(Research Scholar, Department of Mechanical Engineering, Ganpat University, Mehsana)
** (HOD, Department of Production Engineering, Gujarat Technical University, Morbi)

ABSTRACT

Contact Condition between the wheel and rail involved a combination of rolling and sliding contact, commonly referred to as mixed rolling/sliding Contact. Material damage modes that develop as a result of these contact conditions involve material loss (wear), and the development of surface initiated cracking (rolling contact fatigue). The inter-relationship between wheel/rail contact conditions and materials response is well understood for steady state condition.

Keywords - Rolling Contact Fatigue, Sliding Contact Fatigue, Wear, Crack, Fatigue

1. INTRODUCTION

The stresses in the metal near the contact exceed its elastic limit, and therefore deform plastically. Even if the material is fully constrained, the material becomes extruded with the surface layers of material progressively shearing relative to the subsurface material in the direction of traction force. This plastic deformation can increase the length of any slanted cracks by moving the position of the crack mouth away from crack tip. Similarly, this process can form 'laps' or 'folds' in the surface material as it becomes extruded over itself and develop features which can becomes cracks.

Figure – 1 without Deformation

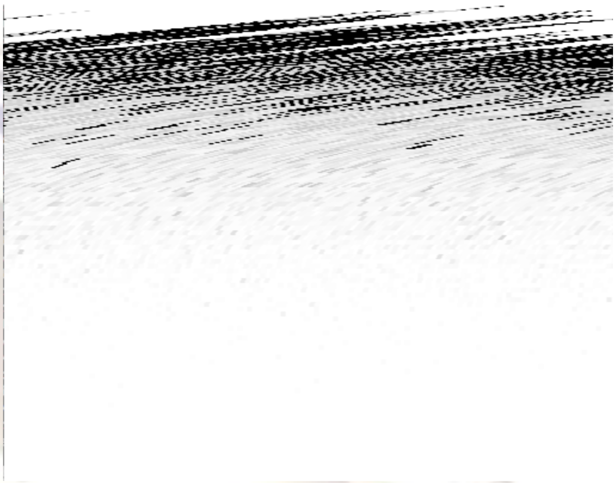


Figure – 2 with Deformation

Two plots of ratchetting (accumulation of plastic deformation) damages are illustrated in figure 1 and 2. Figure 1 shows the accumulation of damage in the undeformed material. This shows the surface appearance of the material as a rough surface. When plotted to show the plastic shear deformation the rough feature of the surface clearly take on the appearance of crack like defect due to folding of rough surface over each other as shown in figure 2.There better understand of wear and crack in wheel rail contact condition.[1]

2. INITIATON OF WEAR AND CRACK

A. Kapoor, D. I Fletcher, F. J. Franklin was carried out modeling of wear and crack. When a rail is first installed it can undergo both wear and crack initiation start without prior damage of rail. These process are grouped together because the same mechanism is the primary driver of both failure mechanism. Both wear and crack initiation are considered on surface based, i.e. wear can only occur at a surface and crack must also lie at the surface of the material. It becomes larger by mechanism. The crack lengths considered from virtually zero up to around 100 microns internal growing into the rail. Wholly internal cracking or cracking at the foot of the rail are not considered.

2.1 Wear Modeling

Wear is modeled as ratchetting process using software develop for rapid assessment of the thousand of cycles over which failure typically take place. Small variations of material properties within the microstructure are measured and included to accurately represent the rail steel. Material which accumulates an experimentally determined critical strain is determined to have "failed". i.e. it can no longer sustain further stress and can not support the material around it. Where this occur at the rail surface the failed material may be removed as wear debris. Modeling rail deterioration in this way has shown good correlation of the predicted wear rates with the field tests. Mechanical properties of the rail steel such as hardness and ductility have variations of the order of a few percent with position within the rail. To represent these properties the rail to be modeled is divided into an array of "bricks" each with mechanical properties slightly different from its neighbors. It should be noted that this array is not a finite element model of the rail as shown in figure-3.

As a simulation is conducted rolling/sliding contact loads are applied to the rail by passing wheels. Bricks in the array represent the rail accumulation damage at slightly different rate from one another because of their different mechanical properties. Ratcheting mechanism of damage accumulation is implemented. Failure by ratchetting of an elements in the array is define as accumulation of critical strain. [2]

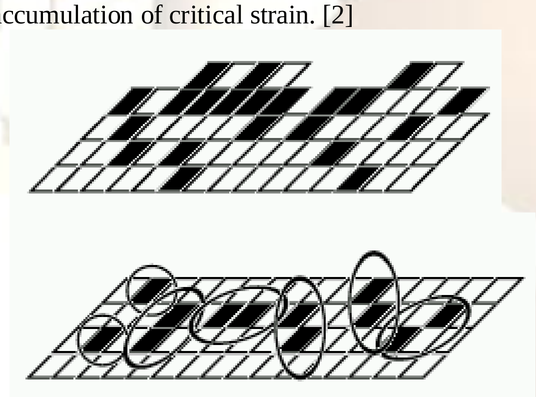


Figure – 3 Failed Elements at the surface are allowed to break away as wear debris

It can be seen that from figure – 3 that failed elements at the surface of the rail have broken away, generating wear debris and leaving a rough surface. This work has the advantage that the conditions could be more closely controlled than is possible during field trials and the wear rate can be measured more accurately and more frequently. The comparison shows that both the model and the experiments give similar trend in wear rates with a low initial rate followed by high and unstable wear rates, and finally a steady wear rates after around 17500 contact cycle as shown in figure-4.

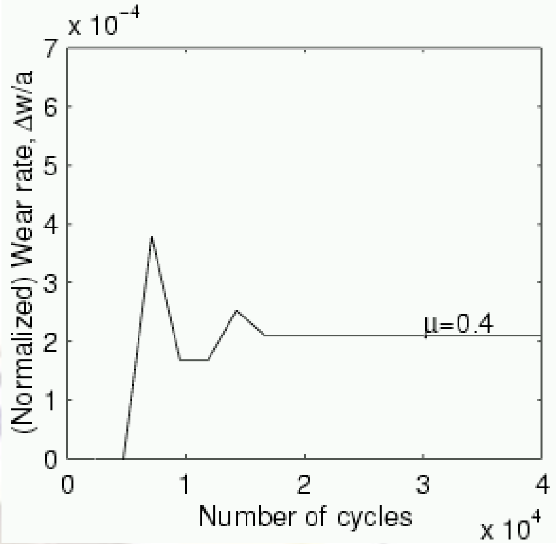


Figure – 4 Wear rate is initially low, followed by an unstable period, and latter a steady state wear rate.

2.2 Crack Initiation Modeling

The development of small cracks in a new or crack free rail begins with accumulation of strain to the point at material fails, just as take place in the generation of wear debris. However while failed material at the rail surface is lost as wear debris, material deeper inside the rail cannot break away \. This weak end material can not sustain further stress and can therefore take to represent the presence of crack. The development of such failed sub surface and surface breaking regions can be analyze using image analysis on the visual representation of result from ratcheting failure models, providing a quantified assessment of crack initiation.

Also shown in figure-3 is a representation of the rail similar to that shown for wear modeling. However, in this case failed elements are below the surface of the rail, and break away. In image such as the failed elements have been identified as cracks using an image analysis technique. This allows cracks initiation through ratcheting to be quantified and the correlates with the rates seem in the field or lab.

3. COMBINATION OF WEAR AND FATIGUE MODEL

The mechanism for surface layer wear is crack propagation. The surface rapidly exhibit Micro cracking. Micrograph of the contacting surface and wear debris for twin disc tests and rail have shown that wear proceeds by removal of flakes from the surface. Some twin disc tests have shown that even in dry contact, RCF (Rolling Contact Fatigue) cracks could eventually initiate. However with a fluid present, the micro cracks typically propagate further into the rail and produce RCF defects.

There are two mechanism by which the presence of fluid can promote crack growth instead of wear. These are alteration to the friction between the cracks faces, allowing them to slide over each other easier and hydraulic pressurization on the crack faces. Due to pressure involved, cracks are more likely to grow under the opening hydraulic loading if they are sufficiently well sealed for pressure to apply load to the crack faces before the fluid escapes. However, finite element modeling has shown that, at normal operating speeds, a crack opening is too rapid for water to be drawn in to the cracks, suggesting that unless water is already present by capillary action during it into the crack, hydraulic pressure could not be generated. Conversely, if there were fluid in the crack prior to passing contact, it would not have sufficient time to flow out. Thus, friction alteration combined with pressurization of fluid already in the crack is likely to be the cause of increased crack growth.

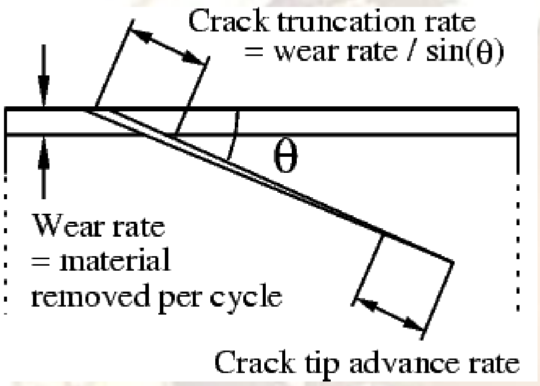


Figure-5, Truncation of a surface breaking crack through wear of the surface.

The commonality between wear and RCF suggest that any RCF theory must incorporate both mechanisms within same frameworks. Figure-5 shows the schematically a cross section of a surface which contains a crack (length a) but which is also wearing.

Crack tip advance rate per cycle ([da/dN]) may depend on crack length, friction between the crack faces, and the magnitude and direction of externally applied loads. Wear rate similarly depends on a verify of factors, but its sensitivity and dependence on each of input factors is unlikely to match that of the crack tip advance rate. A net crack growth rate can be define as

$$\frac{da}{d\,net} = \frac{da}{dN} - \frac{W}{\sin(\theta)}$$

$$= C(\Delta k)^m - \frac{W}{\mathrm{Sin}\,(\theta)}$$

Net crack growth rate is given by taking the advance rate of crack tip and subtraction from it the truncation rate of crack mouth , which is being worm away. Constant C and m are the Paris Erdogan constants, and Δk is the stress intensity factor range experienced by the crack during the passage of the contact. It can be seen from the equation that the growth rate of the crack and hence its length is depends on the interaction of wear and fatigue processes.

4. PROPAGATON OF CRACK

At Primary stage crack is generated by ratcheting mechanism can grow into larger crack are depends upon pressure of fluid in the crack. This fluid may be rail water or liquid base flange lubricant or other rail contamination. It may act to lubricate the faces of crack, allowing them to slide over each other in a mode of shear failure mechanism as shown in figure – 6.

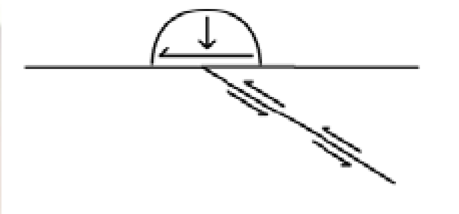


Figure – 6 Shear Mechanism

Alternatively, it may apply internal pressure to the crack through hydraulic transmission of the contact pressure, squeeze film effects, or entrapment within the crack. Internal pressure allows tensile failure mechanism to act even through the crack lies in the compression stress region below the wheel contact as shown in figure – 7. [3]

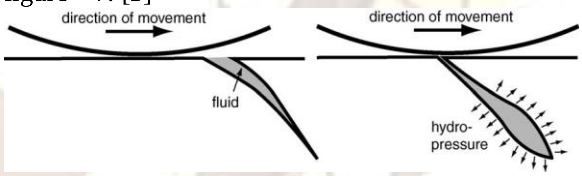
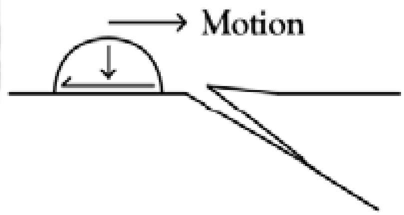
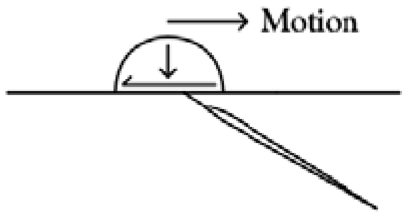


Figure – 7 Hydraulic Pressure Mechanism

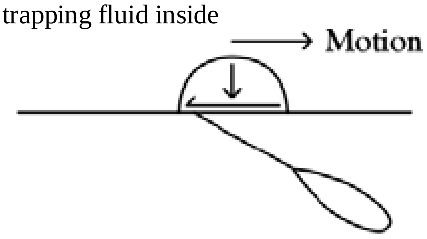
Squeeze film lubrication theory is applied to predict the pressure inside the crack subject to rolling / sliding contact loading. This theory has been developed for situation in which lubricant is alternatively squeezed out and drawn into a gap as shown in figure – 7.



(a) A wheel contact Approach a crack in rail under lubrication conditions



(b) The wheel contact close the crack mouth, trapping fluid inside



(c) The fluid is driven to the crack tip and pressurized until the contact has moved away the crack can open allowing the fluid out

Figure – 8 Fluid Entrapment Mechanism

The result inside high pressures will be generated in a crack filled with fluid when closed by a rolling / sliding contact similar to a rail wheel contact, even if the crack is not sealed, and the fluid is not entrapped. This provides an explanation of why rolling contact fatigue defects can continue grow at a shallow angle when their size is such that complete entrapment is implausible. The presence of fluid and depending on crack orientation and size, the stress intensity factors for surface cracks may be two or more order of magnitude higher than for similar subsurface ones, which are not fluid filled. This is only concern with crack of similar size to the contact patch and these crack growth rate predictions may not apply to the later stage of RCF crack growth in which rail bending becomes important or very large internal cracks such as tache ovales. [1]

5. Conclusion

The conditions could be more closely controlled than is possible during field trials and the wear rate can be measured more accurately and more frequently by wear modeling. By crack modeling crack initiate by ratchetting mechanism can be understand. From the equation of neat crack growth rate, it can be conclude that the growth rate of the crack and hence its length is depends on the interaction of wear and fatigue processes. Finally crack is propagated by squeeze mechanism. Based on this works it clearly understands of crack during wheel rail interaction.

References

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