EXPERIMENTAL INVESTIGATION ON COMPETITION BETWEEN WEAR AND RCF IN A RAIL STEEL

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ABSTRACT

Wear and RCF were studied by an experimental approach in order to put into evidence their competitive aspects. Particular emphasis was addressed to the investigation of the different mechanisms of RCF crack nucleation and propagation and their interaction with wear, in dry and lubricated working condition, in pure rolling and rolling/sliding regime. Wear was assessed in terms of thickness consumption rate, and compared to the estimated crack propagation rate.

1 INTRODUCTION

Railroads have been one of the most important means of ground transportation of bulk goods and passengers for well over a century. In the last years, because of the steady increase in loads and total traffic that railroads tracks have to carry, accompanied by increased train speeds (Knupp [1], Stone [2]), rails had to sustain service conditions more severe than those considered in their original design. As a consequence, an excessive wear of the rail head and a decrease in the rail life occurred. This problem was faced by increasing the rail head cross section and/or increasing the rail steel strength to obtain higher wear resistance (Knupp [1], Clayton [3]), but in this way Rolling Contact Fatigue (RCF), the other competitive type of rail damage, emerged (Brown [4], Burger [5]).

Research about wear and RCF of rails has progressed very much in recent years: laboratory research work has been carried out to study the occurrence of wear and RCF damage separately by means of rolling/sliding testing machines and to assess the effect of different parameters on these two phenomena (Sato [6], Way [7], Danks [8]).

In particular rail wear has been studied in correspondence of high creepage values to reproduce the worst in-service sliding conditions. Nevertheless, under normal rolling contact conditions, rails spend most of their life under very low creepage; these conditions are therefore of the great interest and deserve to be studied because of the possible concurrent occurrence of wear and RCF.

Indeed, wear is in competition with propagation of RCF surface cracks. Once cracks are formed, as shown by several experimental evidences, they can propagate in the depth or branch towards the contact surface (Chue [9], Flasker [10]). Wear, by uniformly removing material from the surface region, can partially or entirely remove the surface cracks, counteracting therefore crack propagation (Kapoor [11]). In Donzella [12] a predictive model was introduced to assess these phenomena and, in particular, to analyse the competitive role of wear and RCF surface cracks. The scope of the predictive model was to assess the structural integrity of the rail under service conditions. The model was therefore aimed to evaluating which combination of material properties and working conditions can become critical for the component safety and, in particular, to analysing the possibility for RCF cracks to develop in competition with wear, and to overcome wear in leading to serious damage. However, some parameters necessary for the model application are still undetermined, and require an experimental validation. In this paper some experimental RCF results are shown: in particular the effect of different working conditions on RCF and wear are investigated, and a rough estimation of crack propagation rate and wear rate is performed.

2 ROLLING CONTACT TESTS: CONDITIONS AND RESULTS

Rolling contact tests were carried out using a twin-disk machine. Rail steel rollers had a diameter of 60 mm and a width of 10 mm, and were mounted as followers in contact with antagonist wheel steel rollers of identical dimension. The rail steel was 900A and the wheel steel was R7T. All the rollers were machined from real components. The relative sliding speed (creepage) between the two rollers were superimposed through the shafts speed regulation. In dry tests a continuous blast of compressed air was used to cool both rollers; in lubricated tests the contact region was invested by a continuous water/glycol jet.

Wear was measured by removing both rollers periodically and weighting them. These data gave wear curves of mass loss against the number of shaft cycles from which the thickness loss was derived. RCF cracks nucleation was individuated by the first appearance on the contact surface of a naked eye visible crack; the propagation rate was estimated by the observation of crack sections at the test end. Metallurgical examination of wear and RCF damage involved the use of optical and scanning electron microscopy (SEM). In Table 1 the tests conditions are collected.

Table 1: Test conditions.

Test N°	Contact pressure [MPa]	γ[%]	Rolling speed [rpm]	Lubrication
1	900	0.00	500	No
2	1100	0.00	500	No
3	1100	0.06	500	No
4	1100	0.06	770	No
5	1300	0.01	500	No
6	1100	0.06	500	Yes
7	1100	0.00	500	Yes

In dry rolling/sliding tests (tests 3, 4 and 5) wear was very high; moreover, no significant RCF phenomena were observed. On the contact surface periodically some waves appeared (see Figure 1a) due to surface layer plastic deformation; from the waves bottom some surface cracks started propagation (see Figure 1b); however, waves and cracks were both removed by wear in the following work cycles.

In dry pure rolling tests (tests 1 and 2) wear rate was low; on the contact surface, only formation of non – propagating microcracks was observed (see Figure 2).

In lubricated tests (tests 6 and 7) macroscopic RCF damage was observed (see Figure 3), whilst the wear rate was very low. It is also to be underlined that in the wheel steel specimens no RCF phenomena occurred.

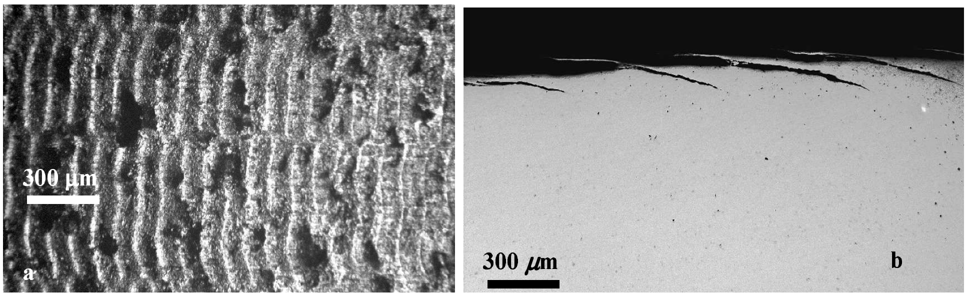

Figure 1: a) contact surface in test 4 (1×10^5 cycles); b) section in test 5 (4×10^5 cycles)

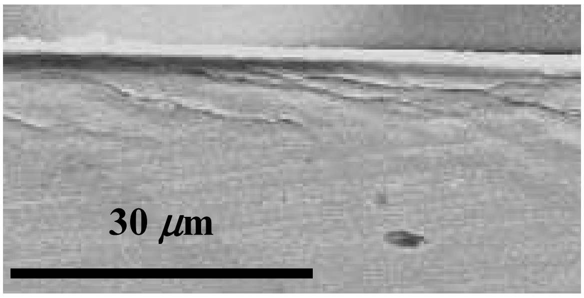

Figure 2: Section of the rail steel specimen in test 1 (1.6×10^6 cycles)

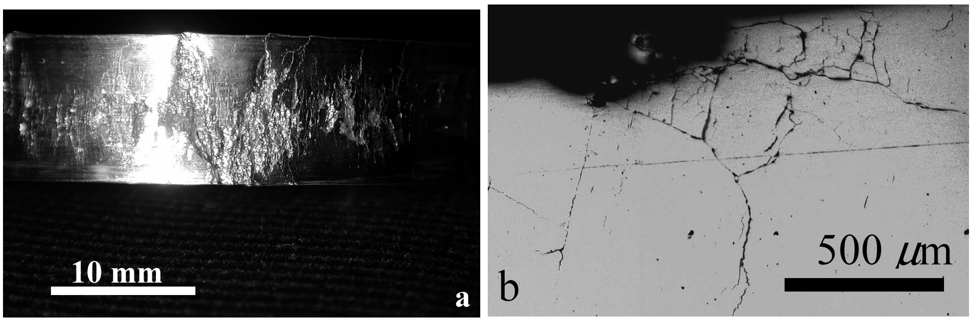

Figure 3: a) contact surface in test 6 (1.25×10^6 cycles); b) section in test 6 (1.25×10^6 cycles)

3 DISCUSSION

The test results gave some information about the prevalent mechanisms under different working conditions. In Figure 4 the wear results are shown in terms of thickness loss vs. cycles number; moreover, an estimation of the crack propagation rate in test 6 is shown. The propagation rate was estimated in terms of ratio of the cracked depth at the test end to the cycles number occurred from the first crack appearance to the test end.

It is evident that in dry rolling/sliding condition (tests 3, 4 and 5) the surface layer is removed by a high wear rate: after 7.5×10^5 cycles (when the first RCF cracks were observed in the lubricated tests) about 0.15 mm in thickness were removed from the surface. As cracks develop in the significant contact stresses region, that in the tests was located within 0.05 mm and 0.15 mm below the contact surface, they were removed before they could cause serious damages. Moreover in test 5 the wear rate was comparable to the propagation rate observed in test 6.

In dry pure rolling condition wear was low, but only surface non – propagating microcracks were observed. This phenomenon was explained by the "quiescent zone" approach (Miller [13]): the quiescent zone is a low stress region included within the asperity – scale contact stress field and the macro – contact scale stress field (see Figure 5); when surface microcracks fall in this region they arrest, if any further factor enhancing their propagation does not occur.

In lubricated tests significant RCF phenomena were observed. They were due to a twofold effect of the lubricant: first, it reduced wear; second, it penetrated surface microcracks and, when the load passed over them, it pressurised the crack faces enhancing crack tip opening and crack propagation. This phenomenon (known as Hydraulic Pressure Penetration) was widely discussed in Bormetti [14], and is one of the factors that can drive surface cracks across the quiescent zone.

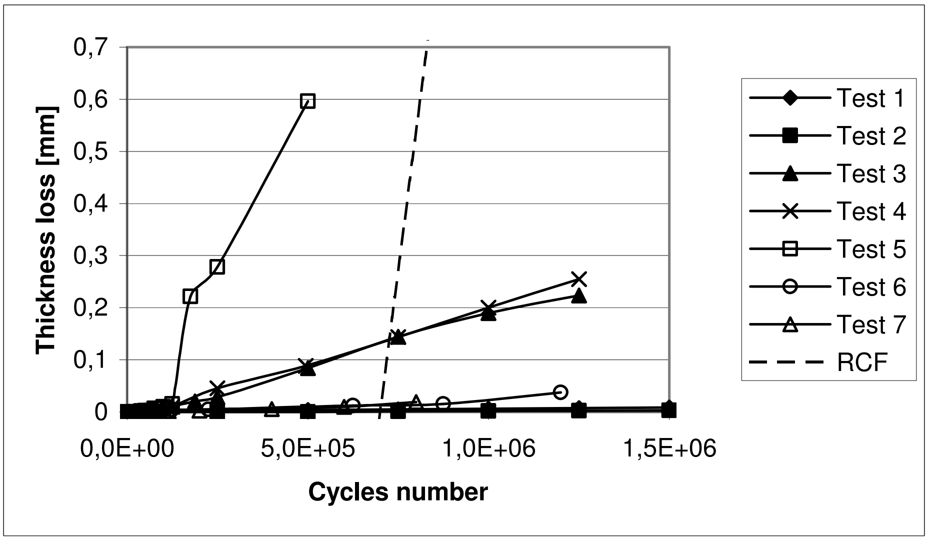

Figure 4: Comparison between wear rate and crack propagation rate

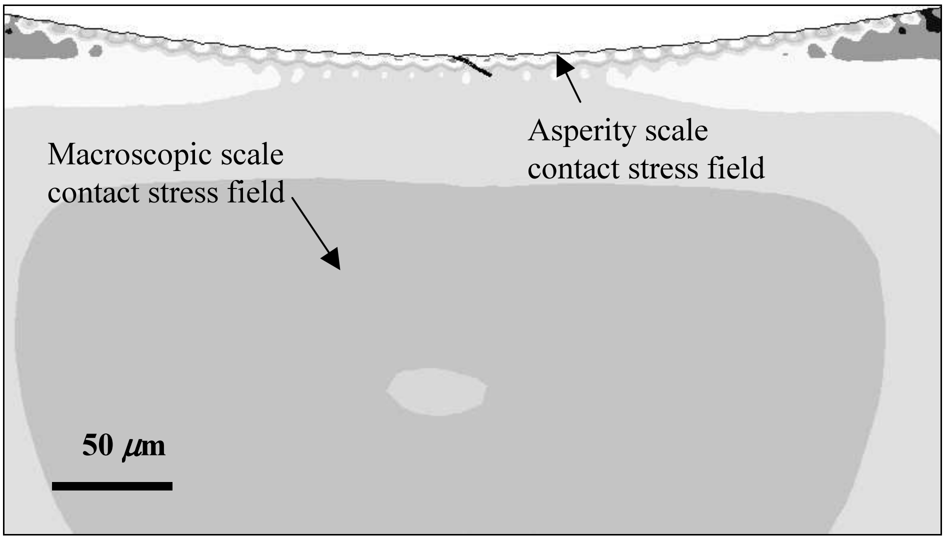

Figure 5: qualitative Von Mises stress distribution in a FEM model of a crack in the quiescent zone

4 CONCLUSIONS

Experimental tests were carried out in order to investigate competition between wear and RCF in different work conditions. It was observed that relative sliding between contact surfaces in dry condition favours wear and inhibit RCF by removing the stressed and cracked material layer. In dry pure rolling condition wear rate is low, but RCF cannot occur because microcracks that nucleate at the contact surface are not able to cross the quiescent zone. Finally, lubricated tests showed that lubricant is a factor enhancing RCF both in rolling and in rolling/sliding condition because of the friction decrease and the Hydraulic Pressure Penetration effect. The experimental results can be a basis for validation of predicting models.

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