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Rolling contact fatigue in relation to rail grinding

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A R T I C L E I N F O

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A B S T R A C T

Spalling defects of a periodic nature are sometimes observed on heat-treated pearlitic steel rails. Defect properties suggest a relationship between maintenance grinding on a regular basis and the initiation of rolling contact fatigue (RCF). In this work, the effects of maintenance grinding are investigated experimentally for both standard and heat-treated pearlitic rails. Results show essentially different behaviour for both steels. On standard grades, friction-induced martensite (FIM) generated during grinding delaminates when in service. However, grinding induces severe top-layer deformation which coincides with that induced by train operation, thus yielding 'pre-fatigue' of the rail. On heat-treated grades, portions of FIM accumulated at groove edges during grinding are pressed into the deeper pearlitic matrix in combination with severe plastic deformation under tangential wheel–rail contact stresses. That process results in severe and extensive crack initiation. According to quantitative test results reported in the literature, this initial condition yields a reduction of the normal RCF life by roughly a factor nine, which is in accordance with both observations in the field and in the literature on rail spalling defects.

1. Introduction

Recently, an increase in the number of particular rail spalling defects has been noticed on the Dutch rail network. The defects occur typically on heat-treated grades such as MHH (produced by Tata and belonging to the category R370crHT according to the European norm [1]). At first glance, it seems to concern a hybrid defect type with properties of both short-pitch corrugation and rolling contact fatigue (RCF). The defects are characterised by their affected length (with in some cases up to several hundreds of metres of affected rail), by the periodicity in the geometry of the defect, and by the fact that the cracks associated with the defects propagate systematically in the subsurface and do not develop deep into the railhead, leading to transverse defects. Examples are shown in Fig. 1.

On other rail networks, individual spalling defects with similar properties and behaviour have been noticed and called 'studs', a term introduced by Grassie [2] in order to differentiate them from squat defects. 'Studs' were observed to grow relatively much faster than squats and at the same time did not lead to transverse defects [3].

All affected rails perform in the RCF regime (in contrast to the wear regime [4]) and are therefore maintained by cyclic grinding. The defects develop relatively very early in the maintenance cycle of the rail, within the grinding interval of 15 MT of axle loading; however not necessarily on relatively new rail but also on rail that has already been in service for years. Properties of the rail defects will be addressed in more detail and in a wider context in the next section. Several of these properties however are striking, and together with the early development of the defects in the maintenance cycle, they point into the direction of a potential role of the grinding process with respect to damage initiation. This leads to a more general research question: how does rail maintenance grinding (or: the set of operational specifications that control this process) affect the total life cycle of the rail – is rail grinding purely a solution to combat RCF, or has grinding the potential to determine the further degradation of the rail surface by setting the conditions for the further development of RCF? The aim of this paper is to examine the role of the rail grinding process, as it is practised on the Dutch network and many other networks worldwide, with respect to RCF initiation, differentiating between heat-treated and conventional rail grades. Its main novelty consists of an answer to this question, substantiated by experimental results. Because of the number of involved aspects and parameters, such as the speed and other settings of the grinding equipment/train, which determine the specific energy input per surface area unit, and the exact chemical composition and constitutive properties of different rail grades, this first study is at the same time of a preliminary nature. It is limited to two pearlitic rail categories specified in the European norm [1], one standard

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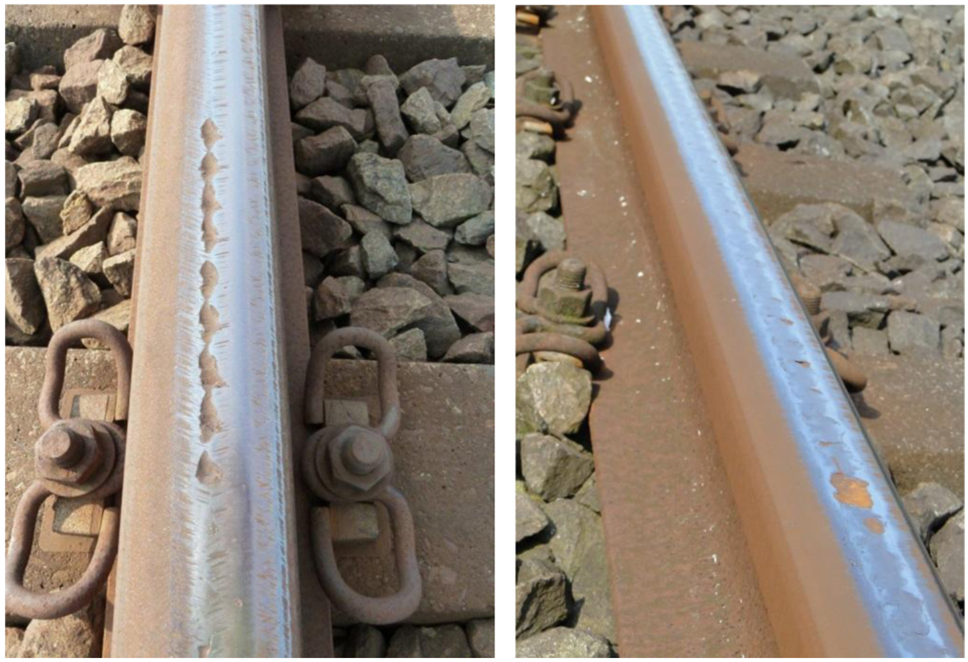

Fig. 1. Periodic spalling defects on heat-treated rail grade R370crHT/MHH.

carbon grade (R260Mn) and one heat-treated and alloyed grade (R370crHT, in the form MHH produced by Tata).

The paper focusses explicitly on the 'initial conditions' of the rail surface degradation process as a function of borne tonnage, and not on this degradation process itself and its governing parameters, as these initial conditions may have an influence that may in theory even exceed that of the loading history on the final result in terms of damage. It is further common experience that the degradation process on rails on which not all surface damage, in terms of RCF cracks, has been removed to a sufficient depth (an example is shown in Fig. 2), is only briefly slowed down by the grinding process. In fact, the geometrical irregularity associated to the RCF defect has been removed, but as this irregularity is only a consequence and not the origin of the defect, the presence of surface-breaking cracks continues to affect the local wheel–rail contact stress distribution and therefore the defect continues to grow. This particular aspect of rail grinding is however not within the scope of this paper, which addresses the grinding process (and indirectly its operational specifications) as such.

The formulated research question has received some direct and indirect attention in the scientific literature, but both the research approach and the results are insufficient to answer it adequately. The most relevant work in the literature is a study by Dikshit et al. [5]. This work examined, in the framework of early RCF, samples of heat-treated rail at different moments of the life cycle of the rail, which was ground also upon installation. The analysis included the moment directly prior to maintenance grinding and a moment at 1 MGT after grinding. It was shown that the number of small (smaller than 0.1 mm) cracks was greatest very early in the life of the rail and steadily decreased with born tonnage up to maintenance grinding, whereas the number of long cracks consistently increased. Significant parts of the rail surface were found to be covered with a white etching layer (WEL) at lower tonnage and formed very early in the rail life, decreasing – by a mechanism of spalling wear – with increasing tonnage. However, as the study does not include analyses of the surface conditions shortly after rail grinding but only after 1 MGT of loading, a potential role of the grinding process with respect to the both the generation of WEL and crack initiations was disregarded; their arising early in the rail life was speculatively ascribed to wheel–rail contact conditions. A

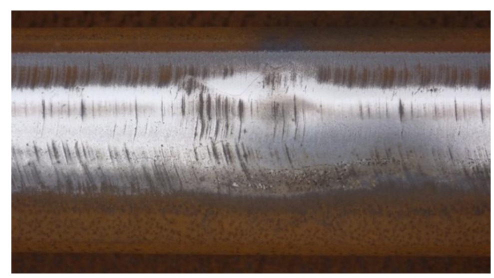

Fig. 2. A squat ground to an insufficient depth.

second study [6] addresses the effect of rail grinding on RCF on standard rail in the Japanese network. This study however deals with the depth to be removed in order to erase all plasticity as a result of accumulated tonnage and does not address the surface quality. Apart from these studies specifically in the rail context, more general work has been reported in the literature on the relationship between surface finishing methods and RCF life [7–10]. These studies will be discussed in more detail, in the framework of a validation of the outcome of the present work, in Section 5.

The structure of the rest of this paper is as follows. Section 2 continues with a more detailed investigation of the properties of the observed spalling defects in the framework of other damage types and of grinding results; Section 3 discusses the set-up of a field experiment with respect to rail grinding; Section 4 presents and discusses experimental results; Section 5 discusses these results in the framework of other/recent scientific work and developments, and Section 6 finishes with conclusions.

2. Properties of rail spalling defects versus rail grinding results

Fig. 3 shows images of rails after cyclic (rotational, with the rotation axis perpendicular to the rail surface) grinding with a grinding train and a relatively short period of short train loading afterwards. In both cases the grinding facets have worn out; in the case at the left a repetitive groove pattern is visible, whereas in the