

Removal of severe rolling contact fatigue (RCF) defects by means of a heavy corrective rail grinding intervention: experience gained in practice

Today, in order to keep the rail in a good condition during its entire service life, it is common practice to conduct cyclic grinding as a preventive measure. However, there are cases in which rail defects, such as rolling contact fatigue (RCF), may have become so deep that preventive cyclic grinding cannot provide a remedy and, therefore, a different action has to be undertaken before the defect becomes so severe that a premature rail renewal would be required. Experience gained in practice has shown that severe RCF defects, provided that there is sufficient rail material left before reaching the critical limit, can often be removed very efficiently and effectively by means of a heavy corrective grinding intervention, after which preventive cyclic grinding can be continued.

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Modern preventive rail maintenance strategies are aimed at keeping the rail free of surface defects during its entire service life and avoiding the need for any premature renewal and, thus, achieve an optimum life-cycle cost (LCC) of the rail.

Ideally, during its service life, the rail would only require:

- in the case of new rails: initial re-profiling, in order to remove the decarburised layer formed during production and any surface damage formed during installation, as well as optimise the rail head profile;
- in the case of existing rails: corrective re-profiling, in order to achieve the same condition as that for new rails;
- preventive or cyclic re-profiling, in order to remove small defects and maintain good wheel/rail contact properties until the wear limit is reached.

However, in the case of locally unexpected severe rolling contact fatigue (RCF), preventive cyclic grinding may not suffice, as the prevailing defects may be too pronounced, necessitating a heavy corrective grinding intervention, in order to prevent them from deteriorating to such an extent as to require a premature rail renewal.

SEVERE RCF DEFECTS AND THE INFLUENCE OF RAIL VEHICLE AND TRACK CHARACTERISTICS

Severe RCF defects, and the careful remedying thereof, is a topical matter, as is well illustrated by the fact that, recently, a number of papers, e.g. [1], [2], [3] and [4], have addressed this issue. Severe RCF may manifest itself not only in the form of headchecks on the gauge corner of the rail, but also by surface cracks located towards the centre of the rail head, which could have serious consequences if not remedied. In Figs. 1, 2 and 3, examples of severe rail defects are shown that could merit from heavy corrective grinding.

The formation and development of RCF is a somewhat complex matter, as its occurrence is influenced by a number of wheel/rail interaction parameters and, thus, concerns both:

- *railway vehicle and train operation characteristics, including:*
 - *axle load and running speed:* the trains of today – both passenger and freight – have higher axle loads and are operated at higher running speeds than in former days. This increase in axle load and running speed leads to the exertion of higher dynamic forces onto the track which, in turn, results in an increase in rail wear (abrasive and plastic deformation), as well as more severe rail fatigue;
 - *wheel profile condition:* the condition of the wheel profile has an influence on rail wear. For instance, in the case of uniform railway vehicles, e.g. electric multiple units (with distributed power, including light-weight vehicles), with well-maintained (uniform) wheel profiles, the wheels may contact the rail in a consistent manner, resulting in a narrow wheel/rail contact zone that is subjected to only very little, but constant, slip and creep. Hence, hardly no rail wear occurs and, thus, no wearing away of martensitic particles.



Fig. 1: Advanced centre-line spalling



Fig. 2: Deep spalling in the rail head centre

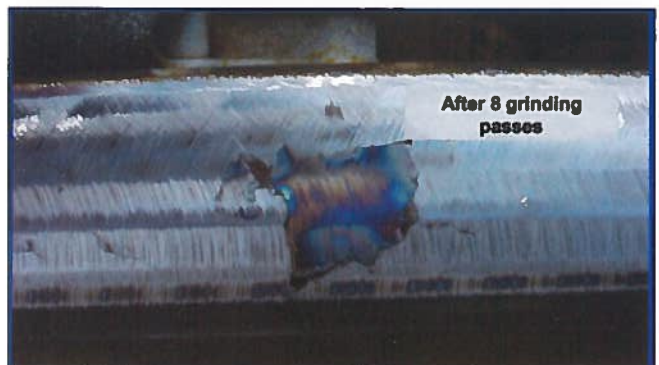


Fig. 3: Appearance of a squat-like defect during grinding

Freight trains, in particular in the case of heavy haul, show a totally different behaviour, as these often have wheels that are characterised by worn and out-of-round profiles, which contact the rail surface at different locations and in wide wheel/rail contact zones. Consequently, a considerable amount of random slip and creep takes place, which provokes rail wear that contributes to the wearing away of martensitic particles;

- *type of rolling stock*: the type of rolling stock operated on a given route has its specific influence on the extent of RCF that may occur, as each type has a different ratio of powered to trailing axles, resulting in a varying extent of wheel slip. For instance, in the case of heavy-haul freight trains, two 6-axled locomotives may haul some 60 (often many more) 4-axled wagons, whereby the ratio of powered axles (locomotives) to trailing axles (wagons) is very low. Whereas in the case of high-speed passenger trains, which deploy a high rapid acceleration that requires a constant high tractive force to achieve running speeds of 200 km/h and more on both tangent and plain track, the ratio of powered to trailing axles is high. One locomotive (4-axled) usually hauls less than 14 coaches (4-axled). Acceleration always provokes some form of slip at the wheel/rail interface. If a high number of powered axles with wheel slip follow each other in a very short time interval (high-speed), the resulting higher contact temperature may easier lead to the creation of martensite. When superimposed by an unfavourable wheel profile condition, this may accelerate the formation of RCF (wheel slip and/or high flash temperatures may generate martensite);
- *track characteristics, including*:
 - the rigidity and stiffness of the track and its components (fastenings, pads, sleepers, ballast and subgrade) and, thus, its capacity to mitigate the dynamic forces exerted onto it;
 - the design, gauge width and superelevation of the track, as these three have an important effect on vehicle/track interaction and resulting forces;
 - the rail steel grade adopted;
 - the target profile that is selected for preventive cyclic grinding.

The rail steel grade adopted

A logic answer to combat an increase in forces and, therefore, any resulting RCF defects, has been the use of high-strength, heat-treated rail steel grades. Initially, these were used in the more critical locations that provoke rail wear (e.g. in curves with small radii). Later, following positive results as for instance reported in [5], high-strength, heat-treated rail steel grades were also introduced in curves with large radii that suffer from RCF.

It should be noted that, as standard carbon rail steel grades wear quicker than heat-treated ones, they adapt easier to prevailing wheel profiles on a given route; also, their resistance to wear and fatigue is comparatively low. Heat-treated rail steel grades, which have a much higher wear and fatigue resistance, are much more sensitive to unfavourable wheel/rail contact conditions.

With respect to the latter, particular attention should be paid to the fact that:

- new rail profiles and not appropriately designed (and/or executed) special profiles (e.g. anti-headcheck – “AHC”) may not optimally correspond to prevailing wheel profiles on a given route and, therefore, result in narrow wheel/rail contact zones with high contact stresses – provoking an accelerated growth of rail fatigue cracks;
- rail fatigue development is very much influenced by wheel slip, as the resulting shear stress provokes rail surface cracks;
- crack formation is triggered by hard and brittle martensite that results from wheel/rail contact; also, too aggressive rail grinding is considered to have a negative effect.

The target profile selected for preventive cyclic grinding

The rail is characterised by having a sort of internal memory. If subjected to a high internal stress (in particular shear stress) then gradually, over the course of time, the metallurgical structure of the rail reacts accordingly. Any subsequent rail surface treatment by means of re-profiling has a certain impact (removal of surface irregularities). As it usually addresses only the top surface, the sub-surface may remain untreated and, thus, still be affected – at least locally – and continue to develop cracks.

Therefore, it is important that, from the start, an appropriate rail maintenance strategy is adopted as regards metal (defect) removal rate and correct target profile selection. In the case of gauge corner fatigue (usually headchecks), special anti-headcheck (AHC) profiles reduce gauge corner stresses and positively influence headcheck development. However, it has to be noted that gauge corner relief does not follow the idea of “the more the better”. Too pronounced AHC-profiles or large negative production tolerances may be counterproductive, in particular when used in combination. Changing from 1:40 to 1:20 inclined standard profiles (or, for instance, from 60E1 to 60E2) may be sufficient and provide similar results as introducing AHC-profiles.

HEAVY CORRECTIVE GRINDING FOR SEVERE RCF DEFECT REMOVAL: EXPERIENCE GAINED IN PRACTICE

Whatever the causes of severe RCF defects, before any (further) preventive cyclic grinding may be undertaken, remedial action has to be taken to remove the existing defects and, thus, prevent the need for a premature rail renewal.

Usually believed to be the domain of milling, such work can often also be carried out effectively and efficiently by means of heavy corrective grinding using heavy-duty machines, as alluded to in the following.

Heavy-corrective grinding using a 64-stone grinding machine

A heavy corrective grinding intervention was conducted to remove severe rail surface defects by using a 64-stone grinding machine, which has confirmed its positive effect. In Fig. 4, an example of a severe rail defect that was found in the track section concerned is shown.



Fig. 4: Severe status of rail defect prior to grinding

Preparatory work

Ultrasonic measurements of the rail concerned yielded that the amount of metal that had to be removed would be 6 mm, as measured from top of rail. The machine used for the grinding intervention was a Speno RR 64 M-2, a heavy-duty 64-stone grinding machine. By using the grinding simulation model developed by Speno International SA, it was calculated that the grinding work would require 12 passes at a speed of 5 km/h, which translates into an average metal removal rate of 0.5 mm per pass. Only a single grinding pattern covering the full rail head width from 70° gauge side to 5° field side was designed, thus ensuring an equal amount of metal removal over the entire specified area, allowing the grinding work to be interrupted whenever needed for operational reasons.

Execution

According to plan, the aforementioned 12 passes were executed during a single night shift. Prior to grinding and after every pass, measurements were carried out, using Miniprof, at four different locations. At the same time, the surface crack situation on the high rail was checked by using a manually-pushed eddy-current measuring trolley. Ultrasonic measurements conducted locally, pass-by-pass, recorded the defect reduction progress.

Result

Following the final grinding pass, all defects were completely removed! The amount of metal removed corresponded perfectly to the values calculated by the simulation model, which took into account the deployment of high-performance grinding stones.

Finally, two finishing passes with a high grinding speed of 16 km/h were executed, in order to achieve the low level of rail surface roughness required for the specific line, in view of its location in a noise-sensitive area – upon completion, a surface roughness R_a of about 2 microns was measured.

In Figs. 5, 6 and 7, respectively, the rail surface after 3.5 mm and 6 mm of metal removal, and following completion of the finish grinding, are shown. The pass-by-pass changes in transverse profile are shown in Figs. 8a and 8b.

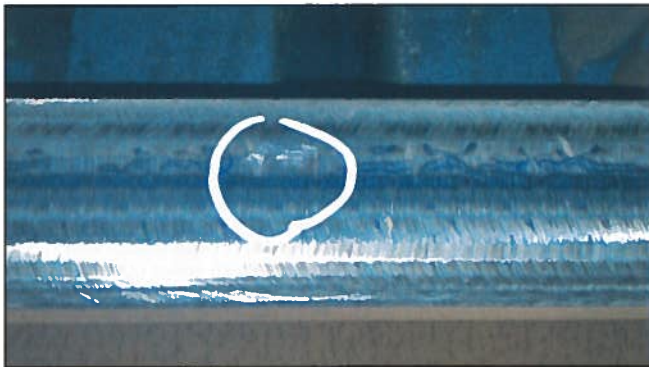


Fig. 5: Status following the removal of 3.5 mm of metal



Fig. 6: Status following the removal of 6 mm of metal

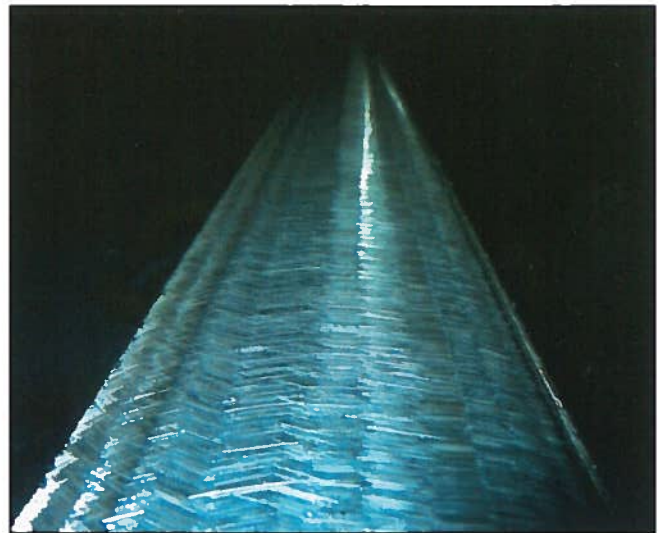


Fig. 7: Finished ground rail

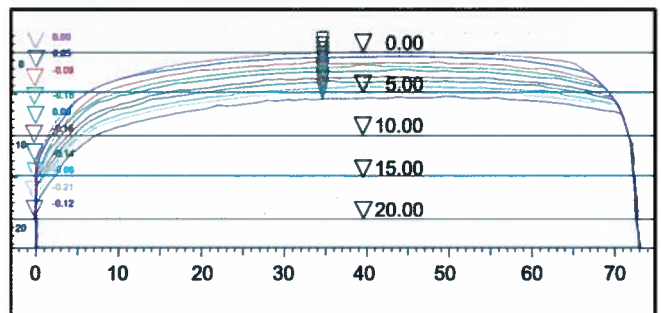


Fig. 8a: Metal removal – profile prior to grinding, and following grinding passes 1-9

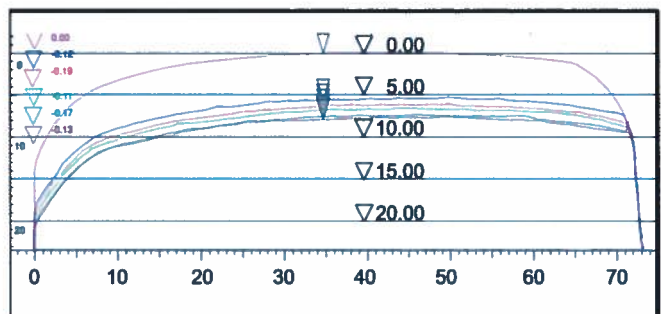


Fig. 8b: Metal removal – profile prior to grinding, and following grinding passes 9-12, 14

Squat removal during a routine grinding program (48-stone grinder)

In another case, squats were removed during a routine grinding program, using a 48-stone grinding machine. In Fig. 9a, the rail surface prior to grinding is shown.

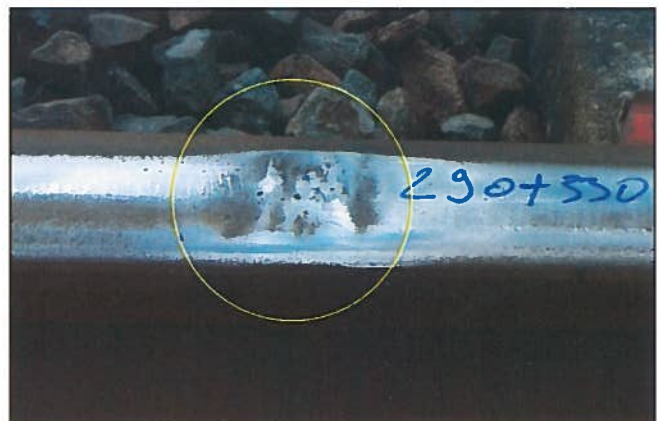


Fig. 9a: Squat removal – prior to grinding



Fig. 9b: Squat removal – after 6 grinding passes

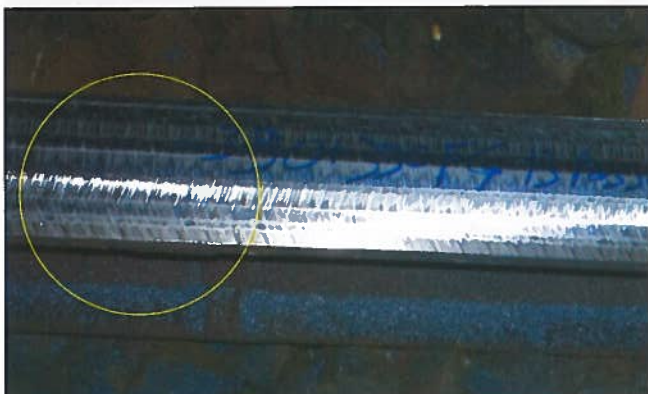


Fig. 9c: Squat removal – after grinding

As can be observed in Fig. 9b, after six grinding passes, the longitudinal and transverse rail profile did not exhibit any irregularities. However, as the crack had grown deep into the rail head, additional metal removal was required. Finally, it took 13 passes in total to remove the squat completely – the totally crack-free rail surface is shown in Fig. 9c. In total, 4.5 mm of metal was removed, as can be seen from the profile superposition before and after grinding for the same spot depicted in Fig. 9d.

FINAL REMARKS

As has been shown in this article, the removal of severe RCF defects, requiring the removal of a large amount of metal, can efficiently and effectively be undertaken by means of heavy-duty grinding machines; of course, it requires a careful planning of the grinding program, including a calculation of the required grinding capacity. In this respect, the grinding simulation model of Speno International SA has shown to be an accurate and valuable planning tool for such specific work.

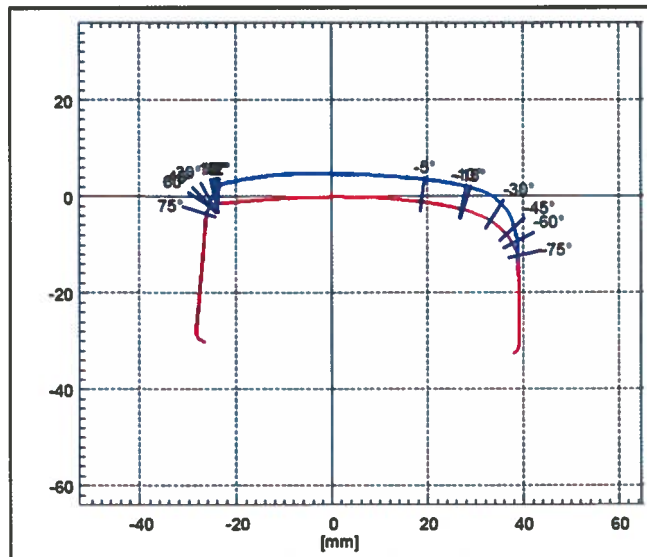


Fig. 9d: Squat treatment – 4.5 mm of metal removal

The removal of severe RCF defects by means of heavy corrective grinding is a viable solution so long as the remaining service life of the rail following the intervention is long enough – i.e. when, as regards the total life-cycle cost (LCC) of the rail, the investment in the grinding intervention is cheaper than an exchange of the affected rail. Thus, by carefully calculating the amount of metal that has to be removed and determining the target profile required, as well as pre-programming the necessary grinding pattern and passes, the use of heavy corrective grinding can remedy severe RCF defects in a very efficient and effective manner.

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Dr.-Ing. habil. Rüdiger G. Wettschureck, Consulting Engineer in Technical Acoustics, who has many years of experience and expertise in this field, offers his assistance for:

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- the interpretation/construction of structure-borne noise reduction measures for both above and underground railway line projects (bridges of different design, open lines, tunnels);
- consultancy during the planning, tendering and execution process of structure-borne noise reduction measures with respect to planned and/or existing railway lines (e.g. resilient rail fastenings, resilient sleeper pads, ballast mats, floating slabs, mass-spring systems);
- the calculation of expected reduction of structure-borne noise levels after the installation of reduction measures, by means of proven and certified calculation methods and models (wheel/rail impedance models, Timoshenko beam and elastic half-space, etc. (see, for example, DIN V 45673-4, Edition July 2008)).

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