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A study of the effect of grinding machine parameters on acoustic rail roughness and surface quality

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Abstract

Rail grinding is performed by infrastructure managers to control, reduce or prevent the growth of rail defects, such as rolling contact fatigue and corrugation. This is done using preventive methods (to attempt to prevent defects from forming) or corrective methods (to remove defects present in the rail). Trials were undertaken on preventive rail grinding machines used by Network Rail, with the aim of improving the finished quality of the rail whilst still achieving the metal removal and reprofiling required. An important aspect considered in the trials was the acoustic rail roughness and its relationship with grinding surface quality indices. The results demonstrated that, in the case of the operational machines used by Network Rail, the largest impact on the overall surface quality was the age and conditioning of the grinding stones. The trials also demonstrated the differences in Standard requirements for achieving good surface quality indices for grinding and good acoustic roughness levels. They further highlighted the importance of identifying rail corrugation prior to preventive grinding to reduce the likelihood of the grinding signature increasing roughness at corrugation wavelengths.

Keywords: rail roughness, rail grinding, corrugation, rolling noise, railway noise.

Introduction

As the wheels of a railway vehicle run over the rails, the contact between them is both small in dimension and high in force. Consequently, the contact pressures are very large and often result in the formation of defects on both wheel and rail surfaces. These defects can be both discrete and continuous, including rail corrugation[1], and rolling contact fatigue[2] (RCF). RCF is one of the most common defect types and can occur in both wheels and rails. On rails, it is identified by a regular pattern of cracks along the head of the rail, usually initiating around the gauge corner. If left untreated, it can lead to rail breaks and derailment, such as the Hatfield rail disaster in the UK in 2000[3].

Irregularities in the wheel/ rail interface can also lead to an increase in noise. The main source of noise on the railway infrastructure is rolling noise caused by surface roughness, which leads to excitation of both the wheel and the rail[4]. The main roughness wavelengths contributing to rolling noise are in the range 5 mm – 500 mm; this is referred to as 'acoustic roughness' and measured using EN 15610[5]. The influence and process for evaluation of rolling noise has been well understood since the development and validation of the TWINS model[6]. The frequency content of the noise is related to the roughness wavelength by

$$v = f\,\lambda \qquad (1)$$

where v is the train speed, f is the frequency, and λ is the wavelength of the roughness.

Defects in the rail head or the wheel are usually managed through material removal – this generally involves turning of the wheel or grinding of the rail head. Rail grinding in the UK is typically undertaken using two methods – preventive grinding and corrective grinding. Corrective grinding is generally used where RCF has been identified and needs removing. The treatment method is stipulated in the Network Rail Standard NR/L2/TRK/001/mod07[7] which states that where RCF is present at a depth of less than 3 mm, train-borne profile treatment should be used. This focusses on both restoration of the rail transverse profile and removal of a small amount of material from the rail surface to remove shallow cracks. It is therefore conventionally used once defects are present and can be identified. Preventive grinding or "in-traffic" grinding is used as a form of RCF prevention and is generally pre-planned. This is typically carried out at higher speeds than corrective grinding, using different machines that require only a single pass from the grinding train, rather than the multiple passes used for corrective grinding. Preventive grinding is used across the UK network to reduce the likelihood of RCF cracks requiring corrective treatment. It is typically undertaken based on traffic seen by the rail - every 15 Equivalent Million Gross Tonnes (EMGT) for curves with a radius of less than 2500 m, and 45 EMGT for curve radii greater than 2500 m or for straight track. This is governed by Network Rail Standard NR/L2/TRK/001/mod10[8]. A significant amount of work has been done over the last 60 years to improve preventive grinding, both theoretically and in practice[9].

Grinding does, however, have its drawbacks. Rail grinding trains most commonly use numerous rotating grinding stones which pass over the head of the rail in an orientation transverse to the direction of travel. This helps to ensure a correct transverse rail profile but impacts the longitudinal roughness profile of the rail by leaving facets in the rail head. This pattern left behind can cause an increase in irregularities in the railhead, often with a characteristic "grinding signature". This may occur at specific wavelengths which are a product of the grinding train speed and the rotational speed of the grinding stones[10]. This results in a more tonal noise according to the relationship between wavelength and frequency shown in equation (1). In addition to the wavelength of the grinding signature, there are other factors of the grinding process which may influence the amplitude of these wavelengths and therefore the sound pressure level. These include the pressure applied to the rail by the grinding stones, the type of stones used, and also their orientation. Understanding of these factors is therefore important in order to improve surface quality.

Craven et al. demonstrated that, following the introduction of a programme of rail grinding in the UK to address RCF, the average acoustic roughness and rolling noise were reduced across the network[11]. In Germany, "Specially Monitored Track" sections have been introduced, where regular train-borne noise measurements are used to support scheduling of rail grinding for acoustic purposes[12]. Croft et al. demonstrated the influence of different grinding options for improving acoustic surface roughness and their influence on rolling noise[13].

Other studies have set acoustic roughness limits immediately after grinding for the machine operators to fulfil[14]. However, the specific grinding parameters required to achieve the acoustic requirements have not been widely shared and it is therefore generally left to the grinding machine operator to assess surface quality after reprofiling.

Acoustic roughness and surface quality are usually assessed independently of one another. EN 13231-2[15] is used to determine the surface quality following rail grinding. This requires the waviness profile to be removed from the primary measurement profile and the resultant roughness to be evaluated to assess the facets left behind by the grinding process. The relevant measurement systems therefore focus on short wavelengths (due to the removal of the waviness profile, this is generally below 10 mm). ISO 3095[16], on the other hand, considers longer wavelengths responsible for rolling noise, see equation (1). The Standard specifically covers up to 400 mm, but most measurement devices are capable of measuring wavelengths up to 1 m. EN 15610[5] specifies the measurement procedure for acoustic rail roughness, while ISO 3095 prescribes limits for rail roughness from an acoustic perspective relating to the measurement of pass-by noise from railway vehicles. These limits apply specifically to measurements of the noise from new vehicles but are also seen as an indication of best practice.

It is important to consider the impact of both surface quality and acoustic roughness when considering the effectiveness of rail grinding; the defect removal should be the primary reason for grinding but preferably without significant detriment to the acoustic properties of the track. This study therefore aims to quantify the grinding parameters required to achieve a high surface quality with low acoustic roughness while obtaining an acceptable amount of material removal from the railhead during preventive grinding to remove defects. The objective of this study is to improve understanding of how defect removal can be achieved whilst reducing rail roughness.

Method

Network Rail operates a fleet of Loram C44 grinding machines for preventive grinding operations. The use of these machines is focused on re-profiling the rail and removing a small amount of material from the head and gauge face of the rail in a single pass. In order to understand ways to reduce the impact of the grinding signature on the surface quality and acoustic rail roughness, a trial investigating C44 machine parameters and their influence on the grinding signature was developed and carried out.

This study focusses on identifying the specific parameters likely to influence the grinding signature (and therefore the rail roughness). The parameters considered were:

a) Grinding speed (the speed at which the grinding machine moves along the head of the rail)
b) Grinding stone material (the influence of stone material and grain size on facet shape/ size)
c) Grinding stone age (the impact of new stones vs. used stones)
d) Grinding pressure (the pressure applied to the head of the rail through the stones)
e) Grinding pattern (the preset orientations of the grinding stones to achieve a desired material removal rate or transverse rail profile)

With respect to grinding stone material, an alternative coated grinding stone was to be trialled to identify if facet depth at initial set down of the stones could be improved, as well as surface grinding quality. The coated stones are both softer in material than the conventional stones (resulting in a higher wear rate) and utilise a polymer coating targeted at improving initial set-down of the stones during first use. The results of this trial when compared to the conventional grinding stones used by Network Rail are included in this study.

Although there are other operational parameters which may influence the surface quality, such as rotational speed of the grinding stones, these have not been considered within this study as these would affect the operational limits of the grinding machine. It was essential that any improvements to the surface quality should be achievable within existing machine constraints, such that machine performance for defect removal is unaffected.

A testing protocol was produced, and the variables included in this are listed in Table 1. All test sections were in tangent track, with the exception of sections 7 – 14 which were situated on a 1000 m radius curve. There were 24 consecutive trial sites with different settings, each 100 m long (to allow sufficient time for the machine to adjust to the change in settings and a representative grind to be achieved). The trial sites were located on a test track constructed from concrete sleepers, BS 113A (CEN 56E1) rails with R260 grade rail steel and Pandrol elastic fastenings.

Table 1: Grinding parameters for evaluation. LR = left rail, RR = right rail

Site	Pattern	Pressure (%)	Speed (km/h)	Stone type / age
1	7	80	13	Used, Conventional
2	7	100	13	Used, Conventional
3	9	80	13	Used, Conventional
4	9	100	13	Used, Conventional
5	10	80	13	Used, Conventional
6	10	100	13	Used, Conventional
7	11	80	13	Used, Conventional
8	11	100	13	Used, Conventional
9	7	80	13	Used, Conventional
10	7	80	16	Used, Conventional
11	9	80	16	Used, Conventional
12	9	100	16	Used, Conventional
13	10	80	16	Used, Conventional
14	10	100	16	Used, Conventional
15	11	80	16	Used, Conventional
16	11	100	16	Used, Conventional
17	7	80	13	New, Conventional (LR), coated stones (RR)
18	7	100	13	New, Conventional (LR), coated stones (RR)
19	9	80	13	New, Conventional (LR), coated stones (RR)
20	9	100	13	Used, Conventional (LR), coated stones (RR)
21	10	80	13	Used, Conventional (LR), coated stones (RR)
22	10	100	13	Used, Conventional (LR), coated stones (RR)
23	11	80	13	Used, Conventional (LR), coated stones (RR)
24	11	100	13	Used, Conventional (LR), coated stones (RR)

The grinding patterns (7, 9, 10, 11), described further in the Results section, were selected as those most commonly used by operators on the C44 machines for defect removal, and the differences between the patterns is discussed further in the Results section.

The measurement devices used, and their purposes are:

a) RailMeasurement CAT - Measurement of rail longitudinal profile including acoustic roughness and corrugation
b) Vogel & Plötscher RM 150HR - Measurement of rail surface quality following grinding
c) Greenwood Engineering MiniProf - Measurement of rail transverse profile and metal removal.

Measurements were taken before and after grinding on both left and right rails. After testing had been completed for the used stones (sites 1-16), the machine grinding stones were exchanged for new conventional stones on the left-hand side (in the direction of travel) and new coated stones on the right-hand side. The machine was then reset, and the grinding trial continued for sites 17-24 using the same measurement protocol as before. After completing 300 m of operation, it was considered that the stones were sufficiently worn in, and the previously new stones were then treated as “used”.

The rail roughness measured with the CAT has been analysed with curvature correction and pit/ spike removal in accordance with EN 15610[5]. Repeatability tests indicated that a walking speed of approximately 0.5 ms^{-1} is required when measuring rail roughness after grinding.

Measurements using the V&P RM150 HR followed the requirements laid out within EN 13231-2[15] which defines the measurement of rail surface quality. The Standard focusses on roughness wavelengths shorter than 10 mm by removing the waviness profile from the primary measured profile of the track. It utilises a quality index (QI) in microns to determine the quality class of the rail surface. The QI targets the grinding facets left behind by grinding. As the waviness profile is removed, the Standard limits evaluation to short wavelengths and does not consider the effectiveness of the grinding operation on longer wavelength features of relevance to noise generation such as rail corrugation.

The quality index is divided into three quality classes according to EN 13231-2[15]:

- Quality class 1 (QI ≤ 3): Tracks with very high demands on surface quality;
- Quality class 2 (QI ≤ 5): Tracks with particular demands on surface quality;
- Quality class 3 (QI ≤ 10): All other tracks.

Measurements using the MiniProf have been used to establish changes in rail transverse profiles and material removal after grinding.

The 24 trial sites were ground by the Loram C44 grinding machine utilising a 64 stone, 4-car layout (32 stones per rail). All sites were marked out on the track and the 100 m sections were ground according to the trial protocol. Due to the requirement for the machine to change its operating conditions between each section, 20 m at the start and end of each section was disregarded from the measurement. The CAT was utilised to measure over a 20 m evaluation length at the centre of each section (between 40 m and 60 m). The MiniProf and RM150 HR measurements were each taken at the 60 m location within each trial site. The MiniProf was used to take five sample measurements of the transverse profile at each location, spaced approximately 100 mm apart. Both left and right rails were measured by all devices.

Results

Figure 1 shows the acoustic rail roughness one-third octave spectra measured throughout the test site (both before (a) and after (b) grinding) to give an indication of consistency and variability of the results. Whilst the spectra vary in magnitude and wavelength, this is also true of the operational environment and is included to allow relative starting conditions of rail roughness to be taken into account at each given location. The spectra in Figure 1 are generally consistent in the 100 mm – 1000 mm wavelength range, while showing greater variability at shorter wavelengths. The largest amount of variability in the results after grinding is in the 10 mm – 100 mm wavelength range, whereas the results converge at short wavelengths. Note the presence of corrugation at 63 mm wavelengths in the results prior to grinding, which in many cases is amplified after grinding, as discussed further below. For comparison, the mean surface quality index was 10.27 μm with a standard deviation of 7.44 μm.

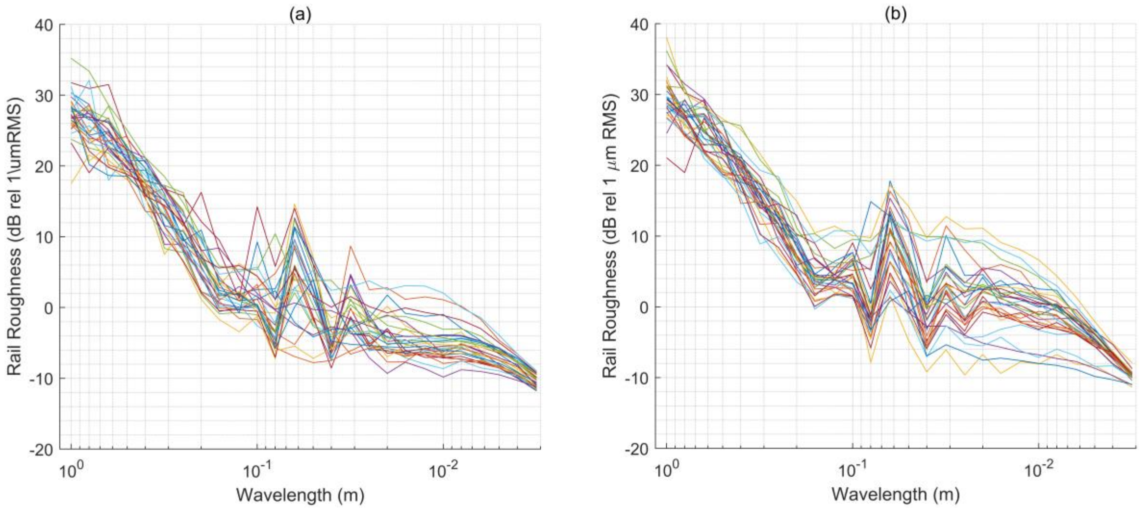

Figure 1: Rail roughness measured at each site (a) before and (b) after grinding

The Loram C44 grinding machines have the option to use up to 50 patterns when grinding. The pattern determines the areas of focus on the rail head and orientation of the 32 grinding stones applied to each rail. The stones can be orientated at -15° to +70° relative to the grinding axis, and multiple stones can be focussed in a particular orientation to increase material removal at a specific transverse location on the rail, e.g. at the gauge corner or within the running band.

Figure 2 shows the expected metal removal for the four most commonly used patterns, which are considered here. An increase in the area between the lines in Figure 2 illustrates an increased focus on grinding at that part of the rail profile. To achieve this, more stones are oriented to that position to achieve the additional cut depth required.

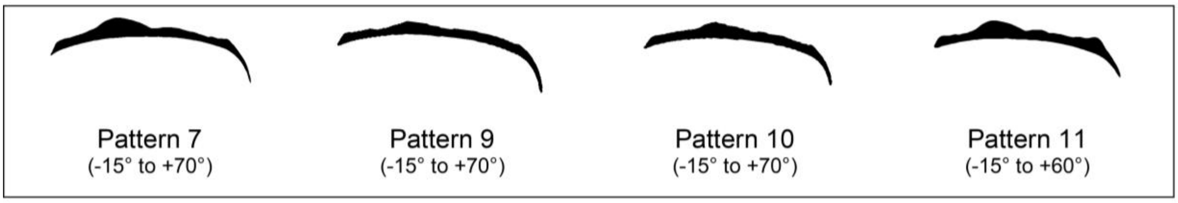

Figure 2: Commonly used grinding patterns (from Loram operational instructions)

The effect of using each of these patterns on the rail roughness spectra is shown in Figure 3(a) for patterns 7 and 9, and Figure 3(b) for patterns 10 and 11. The ISO 3095 limit curve is also shown for reference. The mean changes in acoustic roughness across the 10 – 100 mm wavelengths for patterns 7 and 9 were 1.1 dB (increase) and -1.2 dB (decrease) respectively. Corrugation at 63 mm wavelength was reduced by 10.2 dB using pattern 9 but increased with pattern 7 by 2.5 dB. For patterns 10 and 11, the mean acoustic roughness change (10 mm – 100 mm) was 0.9 and 1.2 dB (increase) respectively. At the 63 mm corrugation wavelength, pattern 10 decreased the acoustic roughness by 9.0 dB, whilst pattern 11 reduced the roughness amplitude by 1.2 dB.

The surface quality (QI) of the grinding pattern is similar across all patterns, with patterns 7 and 10 giving the lowest.

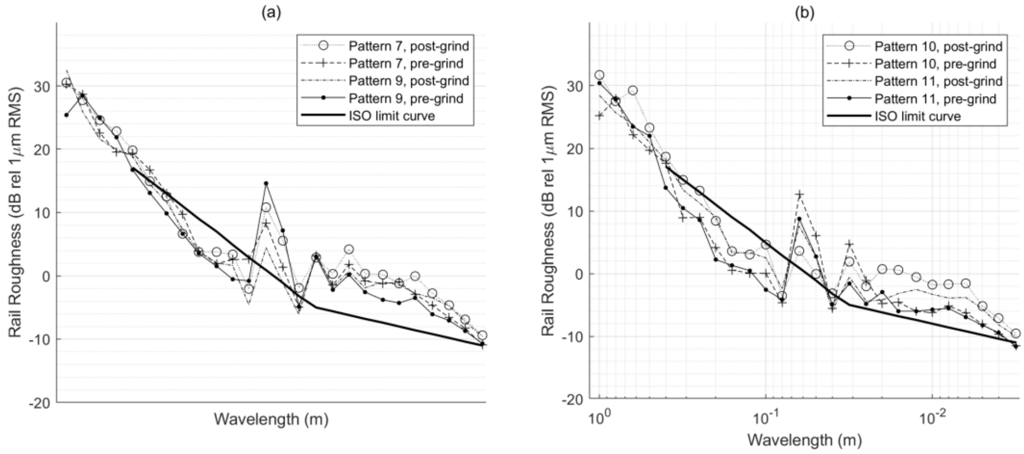

Figure 3: The effect of grinding pattern on rail roughness with a speed of 13 km/h and 80% pressure. (a) pattern 7 & 9 (sites 1 & 3), and (b) pattern 10 & 11 (sites 5 & 7). Quality index for pattern 7 = 7.98 μm, pattern 9 = 11.25 μm, pattern 10 = 8.61 μm, pattern 11 = 12.18 μm

The grinding machine speed was varied from 13 km/h to 16 km/h during testing as noted in Table 1. These are the minimum and maximum speeds the C44 grinder would typically use in the operational environment. The impact of the speed change can be seen in Figure 4, which shows acoustic rail roughness obtained using grinding pattern 7 and an applied machine pressure of 80%. Similar trends were also seen for other pressures and patterns. For a speed of 13 km/h the results show a mean increase of 8.1 dB in rail roughness in the range 10 mm – 100 mm, with a maximum increase of 6.6 dB at 63 mm (the corrugation wavelength). For a rotational speed of 3600 rev/min (60 Hz) and a machine velocity of 13 km/h, the grinding signature would be expected to appear at 60 mm. Thus, it can be inferred that the grinding signature corresponds to this peak in wavelength. For a speed of 16 km/h, a mean increase of 6.6 dB was found in the range 10 mm – 100 mm, with a peak roughness increase of 12.5 dB at 80 mm wavelength (again relating to the wavelength of the grinding signature). The surface quality index (QI) at 16 km/h was also higher than that for 13 km/h.

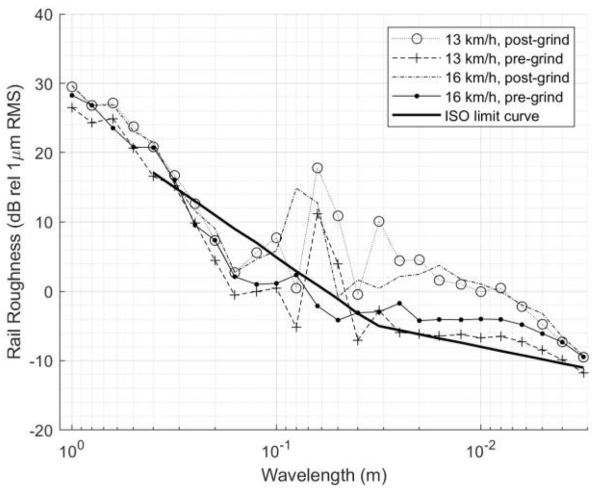

Figure 4: The effect of grinding speed on rail roughness. Surface quality index for 13 km/ h = 6.84 μm. Surface quality index for 16 km/h = 10.03 μm (Site 9 & 10)

Figure 5(a) shows the impact of age on the conventional Network Rail grinding stone. The increase in mean rail roughness for a new stone was 12.1 dB in the range 10 – 100 mm, with a notable increase of 14.7 dB at 63 mm. For the used conventional stone, an increase of approximately 14.5 dB at 63 mm wavelength is observed, and a mean roughness increase of 8.2 dB in the range of 10 mm to

100 mm. For the coated stone (Figure 5(b)), the increase in mean rail roughness for a new stone (10 to 100 mm wavelength) was 11.9 dB; for the used stone this reduced to 5.1 dB. Prior to grinding, there was no clear or apparent corrugation, though after grinding a peak can be seen at 63 mm, which reflects a 21.6 dB increase in roughness. In the used stone case, the same is also true but less pronounced, with an increase of 13.3 dB.

It should also be noted from Figure 5 that there is a significant increase in roughness for new stones after grinding in the 100 mm – 1000 mm wavelengths. For the conventional stones (Figure 5(a)), the mean change in roughness for new stones is 8.2 dB, but only 1.0 dB for used stones. Likewise, for the coated stones (Figure 5(b)), the mean change in roughness between 100 mm and 1000 mm for new stones is 4.2 dB, and for the used stone there is a decrease in mean roughness of 0.8 dB.

As previously noted in the Method section, the grinding stone ages are identified as "new" and "used". Prior to testing, the "new" stone had no contact with the rail, and neither of the stones had been dressed/ conditioned prior to contact with the rail. The results in Figure 5 demonstrate the significant effect on roughness and the importance of conditioning the stone, with a significant reduction in measured rail roughness and QI. The results shown were measured at a grinding speed of 13 km/h and a machine operational pressure of 80%.

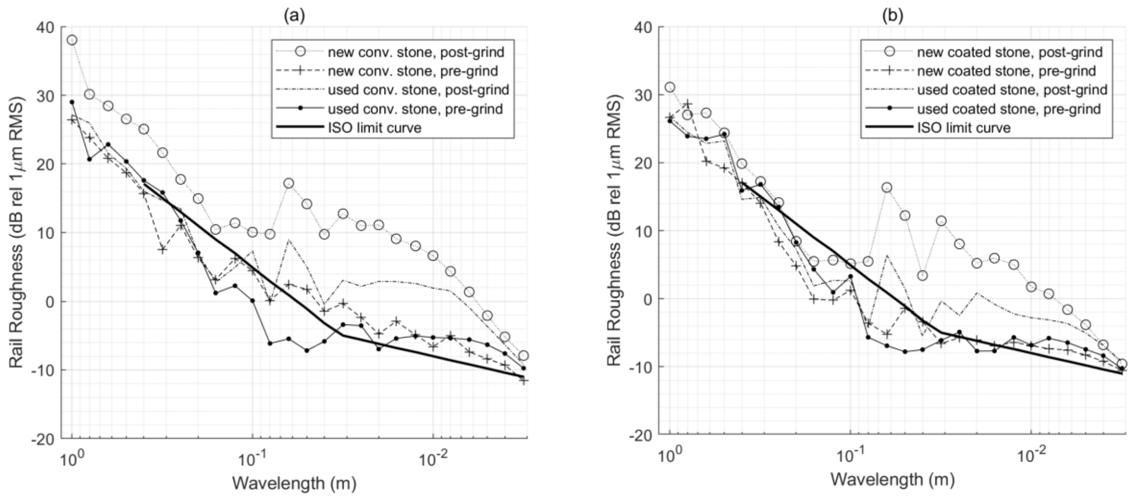

Figure 5: The effect of grinding stone age on rail roughness for (a) conventional stones (sites 17 & 21 – left rail), Quality Index (new, conv.) = 10.91 μm, (used, conv.) = 9.59 μm. (b) coated grinding stones (sites 17 & 21 – right rail). Quality Index (new, coated) = 29.30 μm, (used, coated) = 7.56 μm

Grinding pressure is measured by the grinding train as a percentage of motor current based on the load applied to the rail. The percentage is based on a maximum allowable current within the operational parameters of the machine, and not necessarily a maximum current for the motor. Pressure, in percent, is a common parameter used by grinding machine operators in the UK and is a commonly recorded metric in grinding reports. The operational limits are often set at 80% for "low" pressure grinding, and 100% for "high" pressure grinding, and these limits are very rarely exceeded.

Figure 6 shows the impact of grinding pressure on the grinding signature by comparing results at 80% ("low") and 100% ("high") pressure. Whilst the difference in acoustic roughness is only slight, there are larger differences in the surface quality (QI), reflecting the localised, short wavelength roughness measured by the RM150 HR. The mean change in roughness between 10 and 100 mm is 1.1 dB (increase) for 80% pressure and -0.3 dB (a decrease) for 100% pressure. The corrugation at 63 mm shows an increase of 3.3 dB for 80% pressure and 1.2 dB for 100% pressure. The results shown in Figure 6 are based on a speed of 13 km/h using pattern 7, though similar trends are found across other patterns for a similar speed.

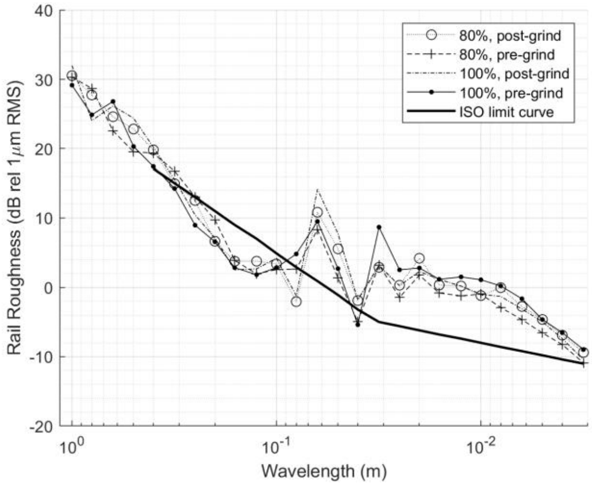

Figure 6: The effect of grinding pressure on rail roughness (sites 1 and 2). Quality index (80%) = 7.98 μm. Quality Index (100%) = 4.12 μm

Discussion

For brevity, example results have been shown to demonstrate the effect of each parameter in turn, though similar results have been seen across the analyses, to a greater or lesser extent. It was clear from the results that the acoustic roughness and the grinding quality index (QI) did not always yield similar results in quantifying the performance for each parameter. For the infrastructure manager, this may mean assessing acoustic roughness and surface quality separately according to the Standards or defining an alternative methodology for assessing surface roughness.

In many of the trial sites, grinding resulted in an increase in peak roughness at the rail corrugation wavelength. Equation (1) demonstrates that at the usual speeds of the preventive grinding vehicles and speed of grinding stone rotation, the preventive grinding signature often occurs at 60 – 74 mm. Various forms of corrugation[1] are commonly found between 30 – 100 mm and therefore identifying corrugation wavelengths prior to setting machine grinding speeds may be a consideration for infrastructure maintainers to prevent increasing roughness at corrugation wavelengths. It should be noted that this would not necessarily be detected if evaluating grinding performance using EN 13231, as the grinding signature is longer than the 10 mm evaluated using the Standard.

Some grinding locations did yield strong overall results where both high acoustic quality and surface quality could be reached. Results for 13 km/h, using 100% pressure, and used, coated stones were available using pattern 10, which showed very good results. The results for this case (site 22) are shown in Figure 7.

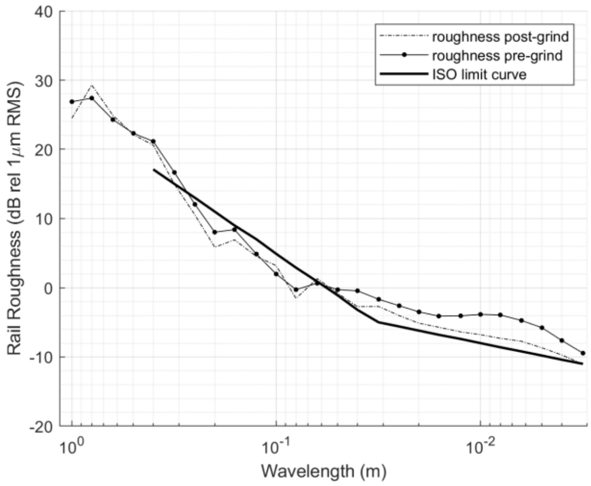

Figure 7: Rail roughness for the highest performing combination (Pattern 10, 13 km/h, 100% pressure with "used", "coated" stones). Quality Index = 2.90 μm

Figure 7 shows that the rail roughness remains relatively uninfluenced at wavelengths greater than 40 mm and decreases slightly below this (with a maximum decrease of 3 dB at 8 mm wavelength). A Quality Index of 2.90 μm was achieved, which corresponds to quality class 1 (tracks with very high demands on surface quality) according to EN 13231-2.

As discussed in the Introduction, it is also important to consider the amount of metal removed from the rail as a result of these grinding operations, as the primary purpose of grinding is to remove rail defects. The MiniProf was used to determine the amount of metal removed at each test location. Whilst the native software of the MiniProf is able to calculate metal removal at given locations, it was found to be important to check these results manually for alignment, as even small variations in the vertical axis coordinates of each measurement can result in significant (erroneous) changes in metal removal. The raw data from the five individual MiniProf profiles (after grinding) from each site were extracted from the device. These profiles were then overlaid against the five baseline profiles (before grinding) to determine material removed across the profile.

The average material removed at each of the five locations at site 22, as measured by the MiniProf, is shown in Figure 8. Note that results have only been determined for distances of 15 – 35 mm across the head of the rail (from the gauge point), focussing on the material removed in the region of the rail head usually in contact with the wheel tread. From the results, an average of 0.18 mm of material is removed at 35 mm from the gauge point – increasing to 0.35 mm of material at 15 mm from gauge point. The maximum material removed is 0.45 mm. Based on previous measurements both on the UK infrastructure and overseas[12], a preventive grind depth of 0.2 mm – 0.3 mm could be considered normal, and the parameters used in Figure 7 can therefore be considered to be effective for defect management. Whilst average material removed for other sites does vary, the orders of magnitude are broadly the same indicating that this site was also representative of a normal grinding operation.

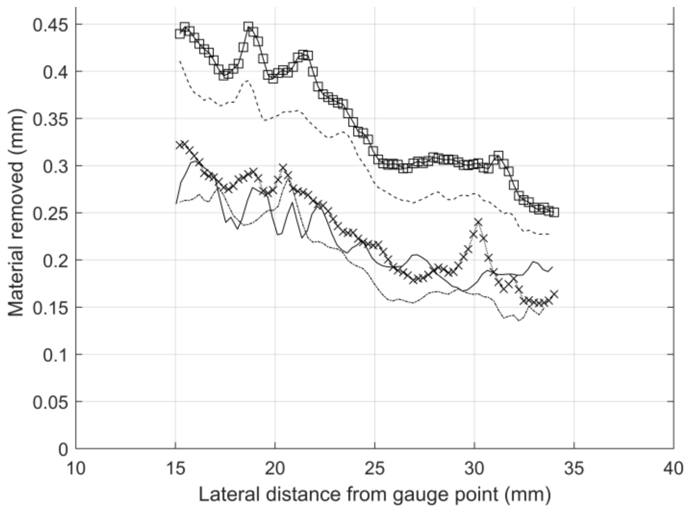

Figure 8: Material removed at combination of parameters considered in Figure 7. The five lines correspond to different MiniProf measurement sections

As previously mentioned, it is evident from the results presented that the surface quality index according to EN 13231 and the acoustic roughness according to ISO 3095 may give different ranking of the various parameters. Figure 9 summarises the results from all sites by plotting a single value indicator for the change in acoustic roughness against the surface quality index. As the largest changes in acoustic roughness occur in the wavelength range 10 mm – 100 mm (as seen in Figure 1) the single value indicator used here for the acoustic roughness is the mean difference in roughness before and after grinding in the 10 mm – 100 mm wavelengths. It should be noted that this does not account for the large change in acoustic roughness seen in the 100 mm – 1000 mm wavelengths for "new" stones.

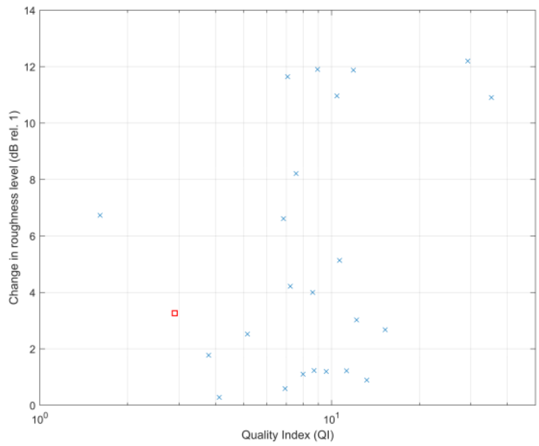

Figure 9: Summary of results. (□) = combination of parameters considered in Figure 7, (×) = all other post-grinding results

Figure 9 further highlights that the quality index, which focuses on wavelengths shorter than 10 mm, and the acoustic roughness which is mostly affected between 10 and 100 mm, are largely uncorrelated. This highlights the importance of considering both quantities when determining the quality requirements for rail reprofiling.

Conclusions

Results showing the influence of speed, pressure, stone type, stone age and grinding pattern on rail surface quality and acoustic roughness have been presented. Of these parameters, stone age appears to have the largest influence, indicating that proper grinding stone conditioning should be considered prior to rail grinding on the infrastructure. The grinding pattern used also appears to cause variations in surface quality and acoustic rail roughness, which indicates that appropriate selection for both defect management and rail roughness should be considered. Further study of the influence of grinding patterns should be considered to improve understanding of this.

In many cases, the preventive grinding signature is between 60 and 74 mm, which also corresponds with common corrugation wavelengths. As a result, at a number of the sites the roughness appears to increase at corrugation wavelengths after preventive grinding. This should therefore be considered by infrastructure managers when considering grinding strategies in areas with existing corrugation.

Acknowledgments

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References

1. Grassie SL. Rail corrugation: characteristics, causes and treatments, Proc. Instn Mech. Engrs, Part F, Journal of Rail and Rapid Transit 2009; 223F: 581-596.
2. Evans JR, Burstow MC. Vehicle/track interaction and rolling contact fatigue in rails in the UK. Vehicle System Dynamics 2006; 44(Supplement): 708–717.
3. Office of Rail Regulation. Train Derailment at Hatfield: A Final Report by the Independent Investigation Board. July 2006.
4. Thompson DJ. Railway Noise and Vibration: Mechanisms, Modelling and Means of Control 2008; Elsevier Science.
5. EN 15610 (2019). Railway applications – Acoustics – Rail and wheel roughness measurement related to noise generation. European Committee for Standardization (CEN), Brussels.
6. Thompson DJ. On the relationship between wheel and rail surface roughness and rolling noise. Journal of Sound and Vibration 1996; 193(1), 149-160.
7. Network Rail Standard. NR/L2/TRK/001/mod07. Management of rail defects. Issued 5th December 2020.
8. Network Rail Standard. NR/L2/TRK/001/mod10. Rail profile management. Issued 1st December 2012.
9. Magel E, Roney M, Kalousek J, Sroba P. The blending of theory and practice in modern rail grinding. Fatigue and Fracture of Engineering Materials and Structures 2003; 26: 921-929.
10. Hölzl GL, Werner K. Die leise Schienenoberfläche durch Schleifen. Eisenbahntechnische Rundschau 1993; 42.
11. Craven N, Bewes OG, Fenech BA, Jones R. Responding to the Environmental Noise Directive by demonstrating the benefits of rail grinding on the Great Britain's railway network. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit 2013; 227: 668-676.
12. Asmussen B, Onnich H, Strube R, Greven LM, Schröder S, Jäger K, Degen KG. Status and perspectives of the "Specially Monitored Track". Journal of Sound and Vibration 2006; 293: 1070-1077.
13. Croft BE, Reimer M, Miller A, Hanson D. Rail acoustic roughness outcomes following maintenance interventions.2023; Proceedings of Meetings on Acoustics 52: 040005.
14. Rothhämel J, Kendl F, Lütke B, et al. Tonal noises and high-frequency oscillations of rails caused by grinding procedures. In: Degrande G (ed) Proceedings of 13th International Workshop on Railway Noise, Ghent, Belgium 16-20 September 2019; Notes on Numerical Fluid Mechanics and Multidisciplinary Design. Springer, Cham, 2021, 150, pp. 277–285.
15. EN 13231-2 (2020). Railway applications — Track — Acceptance of works. Part 2: Acceptance of reprofiling rails in plain line, switches, crossings and expansion devices. European Committee for Standardization (CEN), Brussels.
16. EN ISO 3095 (2013). Acoustics. Railway applications. Measurement of noise emitted by railbound vehicles. European Committee for Standardization (CEN), Brussels.