AITC-AIT 2006
International Conference on Tribology
20-22 September 2006, Parma, Italy

RUNNING-IN BEHAVIOUR OF RAIL AND WHEEL CONTACTING SURFACES

J.LUNDMARK, E.HÖGLUND, B.PRAKASH

Luleå University of Technology, Division of Machine Elements
SE-97187 Luleå, Sweden
`jonas.lundmark@ltu.se, erik.hoglund@ltu.se, braham.prakash@ltu.se`

ABSTRACT

Rail grinding has been used since the 1980s in maintaining optimal rail profile as well as for elimination of surface defects such as corrugations and head-checks. Likewise, the wheel sets also require re-turning to remove surface defects and restore the desired profile. However, at present there are no well defined guidelines regarding the surface topographies of the ground rails and repaired wheel sets. The present study focuses on investigating the running-in behaviour of new rail and wheel surfaces of different initial roughness values. Field measurements have been carried out with a view to investigating the influence of traffic on both surface roughness and rail profile after grinding or re-turning of wheels. The results obtained from a 3D optical surface profiler show that the surface roughness of a newly ground rail changes rather rapidly during the initial stages. During the first one and a half days of traffic or 26 800 tonnes, the S_a-value of the newly ground surface in the running band changed from ~10 µm to ~1 µm. Further investigations are being carried out in the laboratory in an effort to understand the influence of initial surface topography on the roughness of run-in surfaces, running-in period, wear and traction behaviour by the use of a two disc machine.

KEYWORDS Rail grinding, surface roughness, wear, running-in.

---

1 INTRODUCTION

Finding the optimal surface roughness is an important step in finding the most cost effective way of grinding rails and turning wheels. Establishing guidelines regarding the optimal surface topographies of the rails and wheels will thus go a long way to reducing maintenance costs as well as enhancing the performance of rails and wheels. Producing too smooth a surface will have a negative influence on the productivity of the maintenance operation as the time for removing the specified amount of metal will increase. It will lead to prolonged interference with the time schedules on the part of grinding the contractor and significantly higher total costs for the railway company. Likewise, the reduced productivity in the turning operation will lead to non-availability of wheels and/or the necessity for having larger stocks of wheels. On the other hand, rougher wheel/rail surfaces may result in deterioration of performance and service life owing to premature crack initiation and high wear rates. This will lead to shorter maintenance intervals and increased overall operating costs. As illustrated in Figure 1, establishing guidelines for optimal wheel/rail surface topographies from performance and service life points of view will enable reductions in maintenance costs and improvement of the overall operating economy.

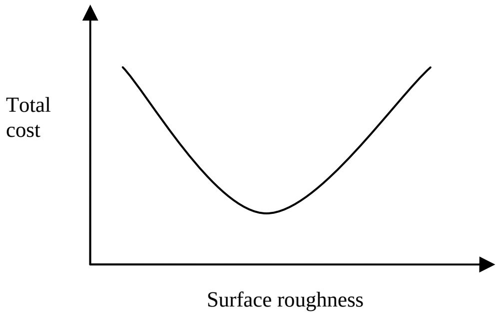


Figure 1: Total cost as a function of surface roughness.

Presently there are no scientifically derived “standard” grinding specifications for heavy haul conditions. The maximum permissible surface roughness (R_a) on rails after grinding acceptable to the Swedish National Rail Administration is 10 µm. Different railway companies have their own guidelines mainly based on their experience and rules of thumb [1]. The wheels from the ore trains are re-turned at different workshops when the tolerances on the wheel profile and wear are reached. However, their surface roughness is rarely measured.

In the past, several studies pertaining to wheel/rail surface topographies have been conducted but most of these have focussed only on the noise and vibration aspects [2, 3]. The role of resultant surface roughness of ground rails and its influence on wear in the rail-wheel contact has been indicated but it has not yet been thoroughly investigated [4, 5, 6]. The role of rail surface roughness is also likely to be much more significant in view of trends towards the use of harder and two-material rails. Field tests on the Malmbanan in Sweden with two-material rails have shown that grinding marks were still visible after tests conducted between 27 September 2001 and 2 May 2002, (or 6.7 MGT equivalent [7]). The presence of water/moisture or lubricant in the wheel/rail contact after grinding can also have an adverse effect on their wear and surface damage. An earlier study by using a two disc test machine showed that oil is more effective in reducing crack face friction while water penetrates the crack tip more easily [8]. In studies on the Malmbanan, it was found that the roughness of the running band changed rapidly following the passage of 43,500 tonnes equivalent about one day’s traffic [6].

The maintenance of the ore car wheels running on the Malmbanan is performed at two different workshops: Duroc in Luleå and MTAB in Kiruna. In the absence of any roughness measurement after re-turning the wheels, their surface topographies may be assumed to differ.

The present study is thus aimed at investigating the changes in surface topography of the re-turned wheels and the ground rails through actual field measurements during the initial running-in stage.

Field measurements on rails have been performed on the Malmbanan, which runs from the mines in Gällivare and Kiruna down to Luleå in the east and to Narvik in Norway. The iron ore line is some 500 km long and carries ore trains, passenger trains and goods trains. The southern segment (Luleå-Boden-Gällivare-Kiruna), where the tests have been performed, carries 7 million net tonnes per year. The iron ore line is being upgraded presently to carry trains with a 30-tonne axle load.

After the analysis of the results of the measurements on rail surfaces on the Malmbanan, additional measurements were performed on the newly ground rails during the initial running-in stage. These were carried out in order to investigate the influence of the traffic on topographical changes at the wheel and rail surfaces. For these measurements, a new location on the Malmbanan called Malmryggen was chosen as the test site. Malmryggen is a side track at Boden train station and was built to avoid hindrance to the ore trains by the passenger trains. As such, the traffic on Malmryggen is only that of ore trains and it is well suited for the running-in measurements. Visual examination of the wheel/rail surfaces was done and replicas prepared for subsequent analysis by 3D optical surface profiler with a view to investigating the changes in surface topography, presence of wear debris or embedded particles etc. These results will enable a realistic choice of surface topographies for experimental simulation of wheel/rail contacts in the laboratory by using a two disc rolling/sliding test machine.

2 METHOD

In all field measurements, plastic replica moulds, Master Exact[1] were prepared from the wheel/rail surfaces. The surfaces were thoroughly cleaned by n-heptane and wiped with a cloth before the replica material was applied. A blow torch was used to remove any residual solvent from the surfaces and also to heat the surfaces in cases where the prevailing temperatures were low. The replicas provide negative images of the surfaces. These replicas were then used for the measurement and analysis of surface topographies in a 3D optical surface profiler (Wyko NT-1100). The change of eight surface roughness parameters were monitored in all field tests. These were: R_k; R_{pk}; $R_{vk;}$ S_a; $S_{ku;}$ $S_{sk;}$ S_c; and S_{dq}. Changes in all these surface roughness parameters showed similar trends. As such, only the S_a-values have been presented here. The surface of a new wheel from Lucchini was used as a reference for the wheel tests. Rail profile measurements using Miniprof were also performed initially on the Malmbanan. However, due to extremely cold conditions, no data for the profile change could be recorded during the last measurement.

2.1 Measurements on the Malmbanan

A rail track having a 655 metre radius curve on the Malmbanan was selected as the test site. The first measurement was done directly after the rail was ground to get the initial roughness. Both high and low rails have been monitored at three different locations, called 37, 38 and 39, with 50 metres spacing in between them. The rails were marked on the sides of the rail heads to ensure that the measurements were done at the same position every time. All measurements on replicas were performed on the same grinding facet in the running band where the largest change in roughness occurred.

---

[1] Oriola Dental AB, www.oriola.se

Measurement schedule on the Malmbanan:

1. 8 September, newly ground rail
2. 9 September, approximately 26 800 ton of traffic
3. 15 September, approximately 259 000 ton of traffic
4. 16 November, approximately 2 070 000 ton of traffic

The initial profile after grinding was recorded and used as the reference profile when compared with measurements taken after 259 000 tonnes, or 1,5 weeks, after the rail was ground. Wear was calculated through the changes in profile by using the Miniprof software. The changes in profile are measured at three different locations on the rail head; vertical (W1); horizontal (W2) and 45° (W3) wear, see Figure 2. The wear is calculated as the difference between the measured profile and the reference profile, in this case the profile produced directly after grinding.

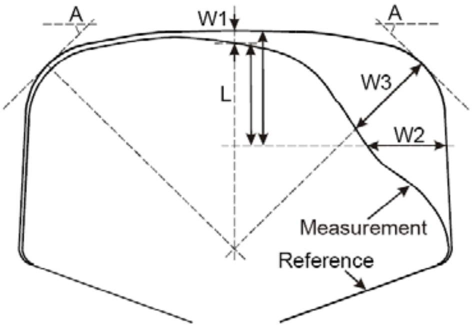


Figure 2: Wear calculations in Miniprof software

2.2 Measurements on Malmryggen

During field measurements on Malmryggen, only one of the rails was investigated due to limitations of time since both the grinding and preparation of the replica had to be undertaken between the passage of two trains. The high rail was chosen for the investigations. As the test site had only ore train traffic, it was specially suited for running-in tests since precise information regarding train weights and number of axels was available. A smaller grinding machine, usually used in grinding switches was used due to the grinding campaign of the contracted grinding entrepreneur having expired. This smaller grinding machine operates with a finer grinding stone, at lower grinding speed, lower stone pressure and produces a relatively smoother surface than that produced by the grinding train operating on the Malmbanan (owned by Speno International). The initial S_a-value from the smaller grinder was ~ 2 µm as compared to that of ~ 10 µm produced by the grinding train.

Surface replicas were prepared after the rail was ground and subsequently after passage of each of the first three trains sets. The first train set passing the test site after grinding was loaded, the second empty and the third was again loaded, see Table 1. To get the roughness of the run-in surface, a measurement was made approximately one month later, after the passage of 270 train sets.

Train type	Number of axis	Total weight [tonnes]
Loaded	220	5479
Empty	220	1400
Loaded	220	5498

Table 1: Configuration of the first three train sets

2.3 Measurements of wheels

A randomly selected ore car was chosen and equipped with pairs of newly turned wheels from each of the two workshops. An axle of this car was also mounted with a new pair of wheels from Lucchini. Plastic replicas from the wheel surfaces were prepared before the ore car was first used. New replicas were than taken after each of the three first journeys between Malmberget and Luleå, a distance of approximately 200 km, as can be seen from Table 2. The last replica was made after 27 journeys or 5400 km when the change in surface roughness had reached a steady state. On the journey from Malmberget to Luleå, the ore cars were loaded and the maximum axle load was 30 tonnes. The axle load of the empty ore car on the return journey was 5.4 tonnes.

Number of Journeys	From	To	Axle load (tonnes)	Total length (km)
1	Malmberget	Luleå	30	200
2	Luleå	Malmberget	5.4	400
3	Malmberget	Luleå	30	600
27	Malmberget	Luleå	30	5400

Table 2: Operating conditions for wheel surface run-in tests

Due to the tight time schedule, replicas could only be taken when the ore train had reached its final destination during loading and unloading. The plastic replicas were examined in a 3D optical surface profiler. Each replica was measured at two different locations: on the running band (high pressure) and on the outer side of the rim (low pressure), see Figure 3.

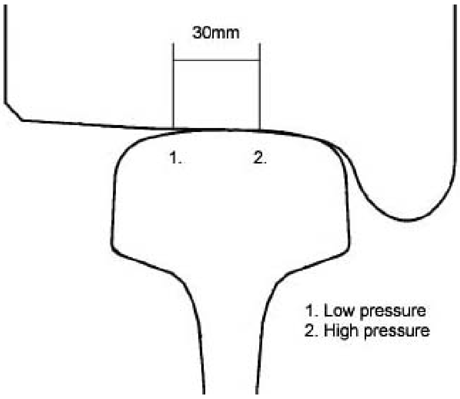
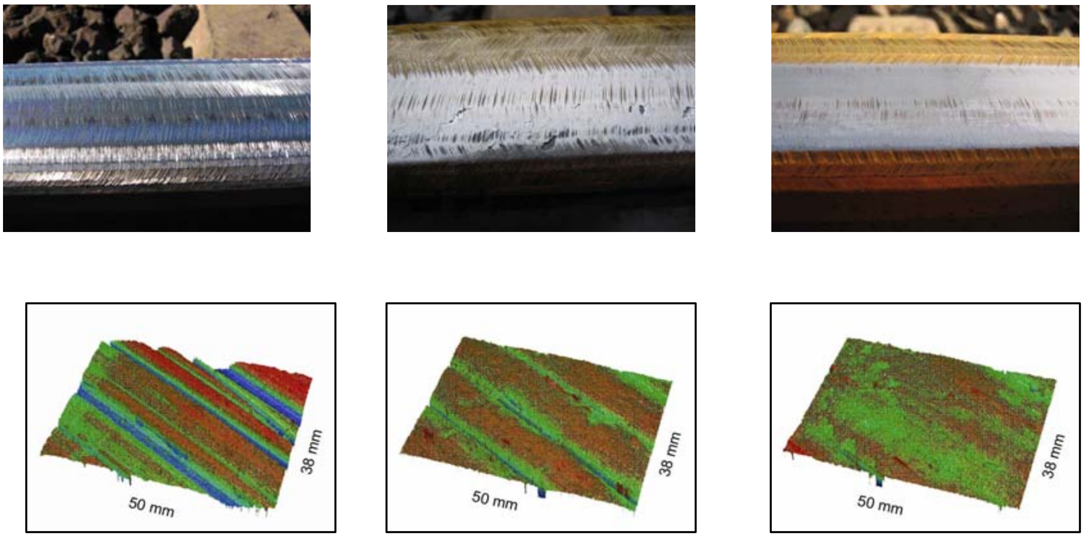


Figure 3: Low and high pressure locations

3 RESULTS AND DISCUSSION

3.1 Malmbanan

The results obtained from field measurements on the newly ground rails and during the initial running-in stage are presented as 3D images in Figure 4 and in terms of roughness parameter S_a in Figure 5. These results are based on three measurements on each replica and the results shown in Figure 5 indicate an average of three measurements. It can be seen that the topography of the ground rail in the running band changes quite rapidly due to the passage of traffic. In approximately 35 hours, or 26 800 ton, the roughness of the surface was reduced from $S_a \sim 10$ µm to $S_a \sim 1$ µm. These results indicate that the run-in of a newly ground rail on the Malmbanan essentially takes place during the first day of traffic. The change in roughness after the first day's traffic is almost negligible. Further, it can also be seen from Figure 5 that the spread in the results is rather small after the rail surface has been run in.



Newly ground rail

Same rail after 1,5 days or
26 800 ton of traffic

Same rail after 10 days or
259 000 ton of traffic

Figure 4: Running-in process of newly ground rail

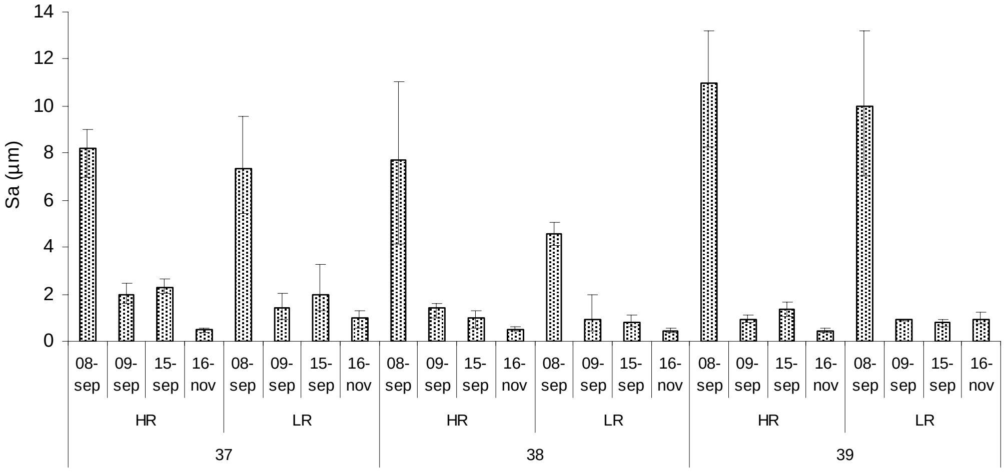


Figure 5: Running-in of ground rail

The results from the Miniprof measurements in Figure 6 show that the largest change of the profile, after 259 000 tonnes of traffic, can be seen in location 39 which is closest to the centre of the curve. The negative change of the profile in location 39 is due to the plastic flow of material.

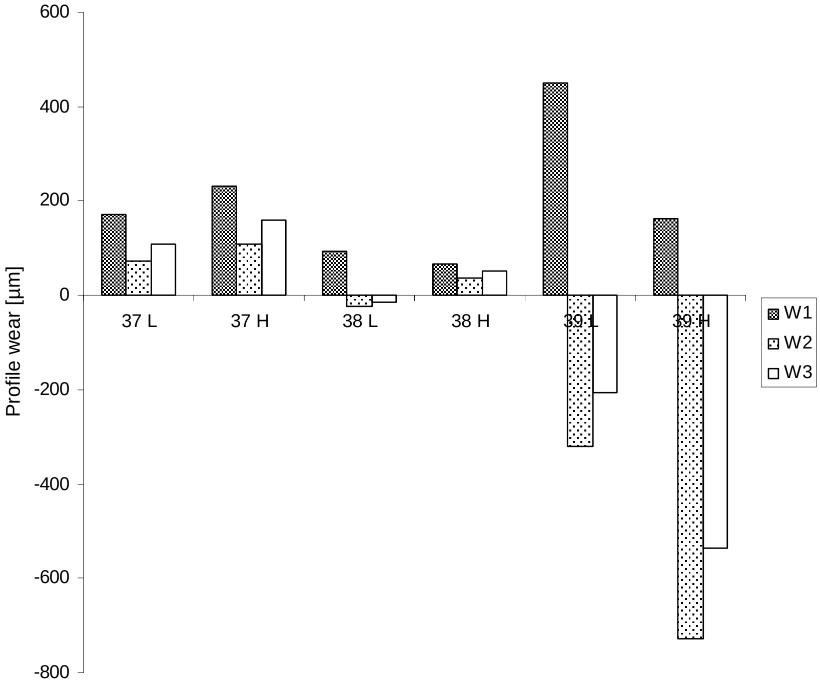


Figure 6: Profile wear after one and a half weeks, or 259 000 ton of traffic. Both high rail (H) and low rail (L) are displayed for each of the three measured locations

The vertical profile wear, W1, is calculated at the same position on the rail head where surface roughness measurements from Figure 5 are made. The profile wear, W1, is relatively large in comparison to the roughness change shown in Figure 5, although the grinding marks can clearly be seen in Figure 4. This indicates that the rail profile has been plastically deformed during the first day of traffic, see Figure 7.

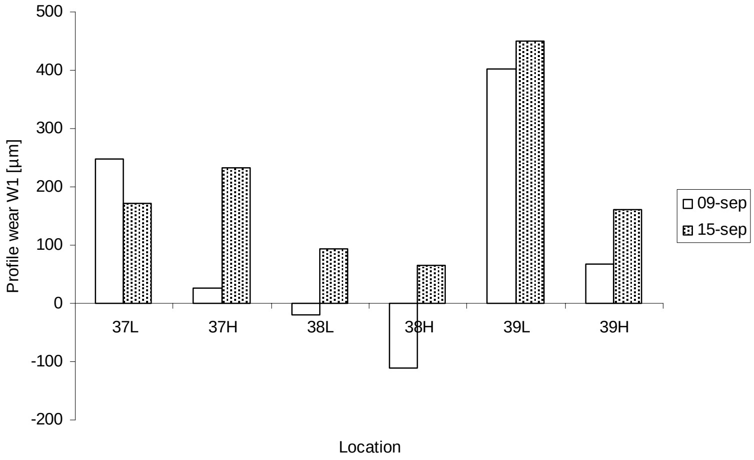


Figure 7: Vertical rail wear, W1, from 8th September to 9th September and to 15th September. Both high rail (H) and low rail (L) are displayed for each of the three locations

The visual inspection of the rail directly after grinding revealed that surface fatigue cracks were still present, especially on the high rail. It was also found that an accelerated rate of flaking occurred after the rail was ground due to the presence of surface fatigue cracks, see Figure 8.

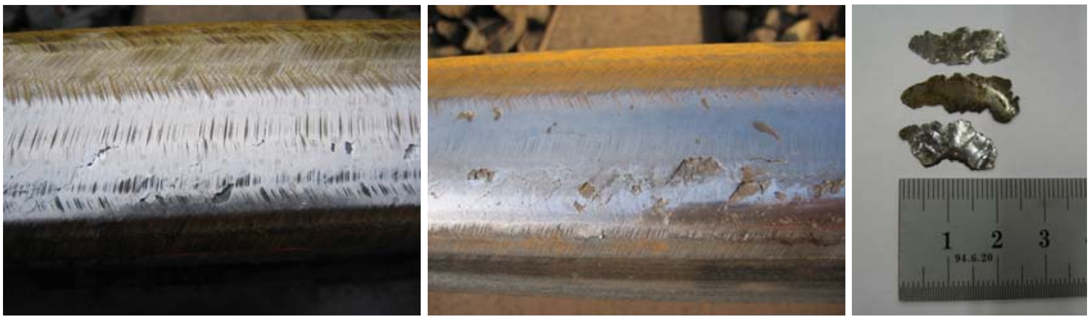


Figure 8: Surface fatigue cracks on high rail on the Malmbanan, 9th September and 15th September and worn-off flakes, (scale in millimetres).

Samples of the flaked-off material were collected for hardness measurements. The micro-hardness measurements on these samples showed signs of work hardening. Six measurements were made on each of the four collected wear flakes and the mean hardness of all wear flakes was ~ 502 HV at 300g load, which is substantially higher than the original hardness of the UIC 1100 rail (340-380HV).

3.2 Malmryggen

The change of surface roughness due to traffic on Malmryggen is shown in Figure 9 for both the curved and the straight track. Results from the Malmbanan measurements have shown a large change of roughness following the first day of traffic and the same behaviour has been confirmed by measurements on Malmryggen. These results also show a rapid change in roughness during the initial stages on the newly ground surface. The most rapid change can be seen in the curve where the S_a-value has changed from 2,1 µm to 0,7 µm after the passage of three trains sets. The same S_a -value was recorded after a month of traffic, or 270 trains sets later. The running-in of the surface on the straight track took more than three passages as can be seen from Figure 9.

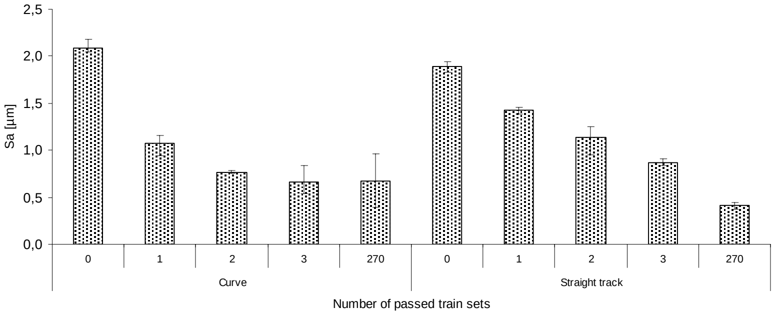


Figure 9: Change of surface roughness on rail due to traffic

From the first four measurements on Malmryggen, the running-in of a grinding facet in the running band was closely followed. The grinding facets are subjected to the highest contact pressures and therefore run-in quickly. The distance between the ridge and the surface 2,5 mm away from the ridge was measured as can be seen in Figure 10. The height of the ridge directly after grinding was 104 µm. After the passage of only one ore train, this height was reduced to 52.2 µm.

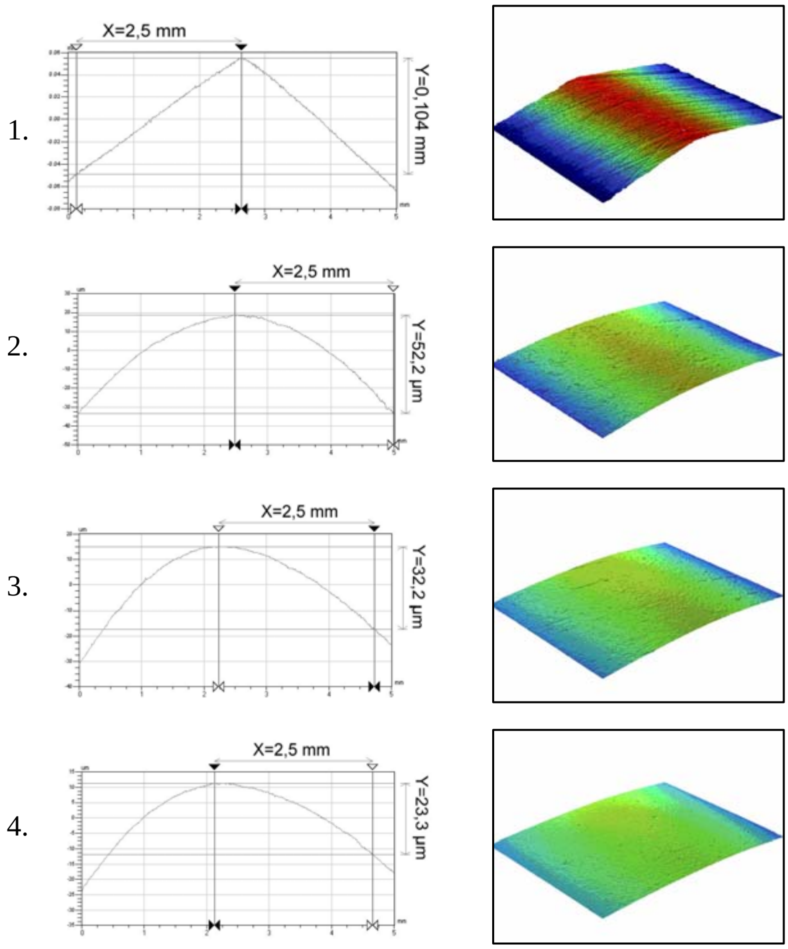


Figure 10: Change of the grinding facet ridge height due to the passage of the first three train sets.

3.2 Wheels

Results from the wheel replica measurements are summarised in Figure 11. It can be clearly seen from these results that the surface roughness values of the new wheels and the re-turned wheels at the two workshops differ quite significantly. The wheel surface produced at Duroc is the roughest (R_z ~ 92 µm) and it is three times rougher when compared to that re-turned by MTAB.

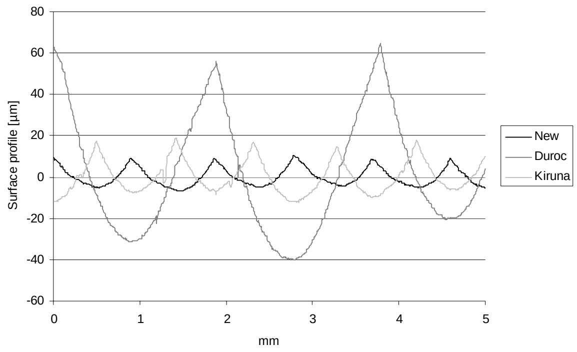


Figure 11: Initial surface roughness on wheels

On both the high and low pressure sites on the wheels, three measurements were made. The results displayed are the mean values. In the running band on the wheels, the initial surface roughness has very little influence on the running-in time as can be seen from Figure 12. The Duroc and Lucchini wheels run-in after the first journey (200 km) whereas the MTAB wheel run-in after two journeys (400 km).

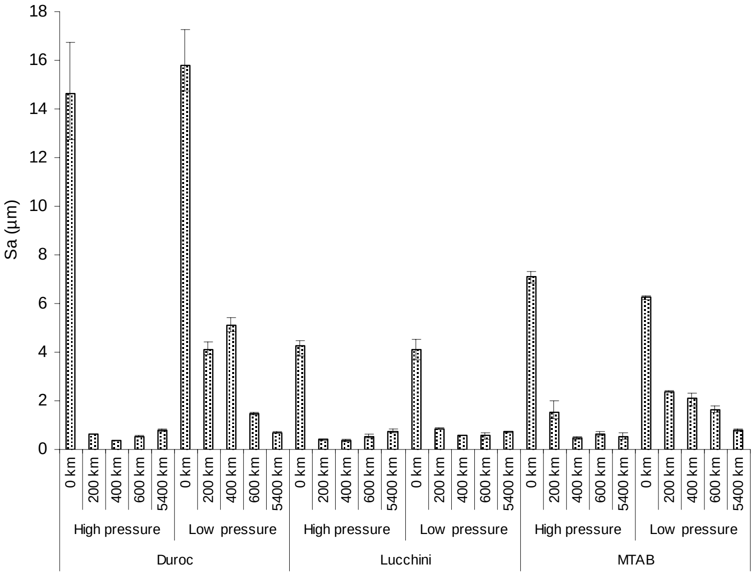


Figure 12: Change of surface roughness on wheels due to traffic

The running-in results obtained in this work are in line with those reported by Grassie [6] where field measurements were made on the same ore line. Grassie did not however closely follow the running-in of wheel/rail surfaces since his work focussed more on transverse railhead profiles. Field measurements are quite tedious but useful in studying the running in behaviour as these results have shown. However, these field measurements are useful only in revealing the surface topographical changes during the running-in of wheels and rails. Experimental studies will have to be conducted with a view to investigating the influence of surface roughness on wear, traction and contact fatigue damage.

4 CONCLUDING REMARKS

Detailed field measurements on wheel/rail surfaces have been carried out. The results obtained from these measurements indicate that the wheel/rail surfaces run-in rather rapidly. In the case of a newly ground rail, S_a-values decreased from 10 µm to 1 µm after one and a half days of traffic or 260 800 tonnes. The roughness values of the re-turned wheels from different workshops differ significantly.

The initial wheel/rail surface roughness has almost negligible influence on the running-in behaviour as all the surfaces run-in rapidly to almost the same roughness value ($S_a \sim 1$ µm) irrespective of their initial roughness values. The effect of intial wheel/rail roughness on traction, wear, and contact fatigue damage is unclear and further studies are required to investigate these aspects.

Acknowledgements

The financial support for this work from Banverket, LKAB/MTAB and Speno International is gratefully acknowledged. The authors also wish to acknowledge the help and support from Tord Karlsson (MTAB) and Timo Hiltunen (Banverket).

References

[1] J.Cooper, Specifying rail grinding requirements, 6th International Heavy Haul Conference, Cape Town, South Africa, 6-10 April, 1997

[2] T.X.Wu, D.J.Thompson, Vibration analysis of railway track with multiple wheels on the track, Journal of Sound and Vibration, 239, 69-97 , 2001

[3] P.C.Dings, M.G.Dittrich, Roughness on Dutch railway wheels and rails, Journal of Sound and Vibration, 193, 103-112, 1996

[4] E.Magel, M.Roney, J.Kaluosek, P.Sroba, The blending of theory and practice in modern rail grinding, Fatigue Fract Engng Mater Struct 26, 909-919, 2003

[5] E.Magel, J.Kalousek, The application of contact mechanics to the rail profile design and rail grinding, Wear, 253, 308-316, 2002

[6] S.Grassie, Requirements for transverse railhead profile and railhead roughness following grinding, 6th International Heavy Haul Conference, Cape Town, South Africa, 6-10 April, 1997

[7] M.Hiensch, P-O.Larsson, O.Nilsson, D.Levy, A.Kapoor, F.Franklin, J.Nielsen, J.W.Ringsberg, B.L.Josefson, Two-material rail development: Field test results regarding rolling contact fatigue and squeal noise behaviour, 6th International Conference on Contact Mechanics and Wear on Rail/Wheel Systems (CM2003), Gothenburg, Sweden, 10-13 June, 2003

[8] N.Gao, R.S.Dwyer-Joyce, D.G.Grieve, Disc machine testing to assess the life of surface-damaged railway track, Proceedings of the Institution of Mechanical Engineers, 215, 4, 261-275, 2001