# Influence of Railway-Track Grinding on the Track Material Condition and Tribological Behaviour

**Eckart Uhlmann[1], Mykola Bobyr[2], Yuriy Borodiy[2], Pavlo Lypovka[1], Pavel Protsenko[2], Janis Thalau[1,]***

[1]*Chair of Machine Tools and Manufacturing Technology, Institute for Machine Tools and Factory Management (IWF), Technische Universität Berlin, Berlin, 10587, Germany*
[2]*Igor Sikorsky Kyiv Polytechnic Institute, National Technical University of Ukraine, Kiev, 03056, Ukraine*

*Corresponding author: Tel: (+49) 30 314 79344; E-mail: thalau@iwf.tu-berlin.de

**Received: 15 August 2018, Revised: 27 November 2018 and Accepted: 27 November 2018**

DOI: 10.5185/amlett.2019.2234
www.vbripress.com/aml

## Abstract

As societies have a rising demand regarding mobility as well as an increasing ecological awareness, the energy efficiency, noise emissions and availability of transportation in urban environments become essential for growing cities. In this context, the role of rail-bound traffic in urban environments as well as in intercity-connections is of rising importance. To guarantee travelling comfort and safety, shorter downtimes as well as power efficiency, the condition of the railway network is subject to rising quality requirements. Therefore, the maintenance, repair and overhaul as well as the material quality of railway-tracks is faced with new challenges.

An important part of track maintenance is track grinding. To ensure an economically reasonable track life cycle and to prolong the time period between repair tasks, grinding processes should not induce damage such as cracks and hardening. On the other side, high productivity of track grinding, which tends to induce damage, is crucial to reduce disruptions and delays from repair. Research work presented in this paper aims at reducing the lack of knowledge concerning interactions between the track grinding parameters, grinding tool specifications and the topology of the track's surface and damage of the track's sub-surface. Industrial track grinding processes were tested under laboratory conditions with a variation of the grinding wheel circumferential speed and depth of cut. Afterwards the ground tracks specimens were evaluated with regard to the achieved surface roughness as well as the micro-hardening, induced cracks and residual stresses in the sub-surface zone. Furthermore, the influence of different external factors such as environmental conditions on the results of track grinding is analysed by evaluating the influence of the track's initial temperature on the process results. As a result, the main influencing factors on the surface quality and the sub-surface damage in track grinding were identified and their influence on the tribological behaviour of the ground tracks in contact with an opposing steel disc was analysed. Based on these considerations, recommendations on eligible track grinding strategies, which lead to highly productive yet low-damage track repair, are derived. Copyright © VBRI Press.

**Keywords:** Railway maintenance, track grinding, tribology.

## Introduction

The main aim of rail grinding is to increase the life time of the rails and ensure the operational safety as well as cost-effectiveness of the railway transport. By rail grinding, damaged material layers, which can cause head checks, corrugation and material pitting, are removed and the required dimensional and shape accuracy is ensured. Though some research work for analysing the rail grinding as part of the life cycle costs (LCC) [**1, 2, 3**] and regarding the influence of the rail grinding on the pass-by noise [**4, 5**] has been carried out, the fundamental knowledge concerning the interactions between the grinding process design, the grinding results and the tribological behaviour of ground tracks is mostly missing. Hence, the knowledge about the integrity of the achieved surface and surface layer quality after rail grinding are important for ensuring suitable operational behaviour of the rail and optimal passenger comfort. The first investigations in this field were performed by UHLMANN, LYPOVKA [**6, 7**] and FAU *et al.* [**8**], who determined a significant influence of the process parameters on the processing results and the rail operational behaviour after grinding. Furthermore, due to the fact that rail grinding is carried out under generally inconsistent weather conditions, it is possible that the rail temperature becomes a significant factor on the results of rail grinding. In order to examine the interactions between rail temperature, process parameters, process characteristics and processing results, technological investigations of rail grinding were carried out. Subsequently, specimens were cut out from the ground track pieces. These specimens were then examined in a tribometer to assess the influence of the grinding process on the wear behaviour of the tracks.

## Experimental setup

The rail grinding experiments were carried out on the face and profile grinding machine Profimat 408 of BLOHM JUNG GMBH, Hamburg, Germany, **Fig. 1**. Flat bottom rails S49 (Steel R 260) with a length of l = 140 mm were used as workpieces for the technological tests, in which only the rail heads were ground. In order to ensure consistent contact conditions within the entire contact zone between the grinding wheel and rail head, a rib with a width of $b_r$ = 20 mm was prepared on the railhead. Consequently, the grinding contact width $a_p$ was equal to the width of the rib $b_r = a_p$ = 20 mm. Coarse-grained fused corundum grinding wheels with resinoid bonding of the specification 1A20B5 of STELLA KERAMIK GMBH, Schwarzenbach, Germany, were used. To heat the rails a drying cupboard T 5050 E of the HERAEUS HOLDING GMBH, Hanau, Germany, was used. The rails were cooled with a laboratory deep freezer Frigor GLK 20 of VIBOCOLD A/S, Viborg, Denmark.

The technological tests were carried out without cooling lubrication. The following three parameters were varied for the grinding experiments.

- Rail temperature while grinding:
  $T_g$ = - 60 °C; 20 °C; 80 °C
- Depth of cut:
  $a_e$ = 7 µm; 14 µm; 21 µm
- Grinding wheel circumferential:
  speed $v_s$ = 30 m/s; 40 m/s; 50 m/s

The feed speed remains constant for all experiments with $v_f$ = 22000 mm/min. All experiments were carried out three times to statistically ensure the results. To analyse the surface quality the mean roughness depth Rz was measured tactile using the device Marsurf M300C of MAHR GMBH, Göttingen, Germany. For the non-destructive qualification of the rail sub-surface layer, the Barkhausen-noise was measured. Barkhausen-noise describes the material surface layer properties consisting of material hardness, microstructure and residual stresses [**9**]. Thus it can be used to identify thermal rail damage. Within the technological tests, the maximal amplitude of Barkhausen-noise $M_{max}$ was measured using the measuring device 3MAII of FRAUNHOFER IZFP, Saarbrücken, Germany. For the destructive microhardness measurements in the rail surface layer, the measuring device Fischerscope H100C of HELMUT FISCHER GMBH & CO, Sindelfingen, Germany, was used. The segments for micro-hardness measurements were cut from the middle of the rail after grinding using wire-cut eroding.

**Face and profile grinding machine**

| | | | | |
|---|---|---|---|---|
| Type | Profimat MT 408 HTS | | | |
| Manufacturer | BLOHM JUNG GMBH, Hamburg, Germany | | | |
| Max. feed speed | $v_{f,max}$ | = | 180 | $m \cdot min^{-1}$ |
| Max. acceleration | $a_{f,max}$ | = | 50 | $m \cdot s^{-2}$ |
| Max. spindle power | $P_{s,max}$ | = | 45 | kW |
| Max. spindle speed | $n_s$ | = | 10000 | $min^{-1}$ |

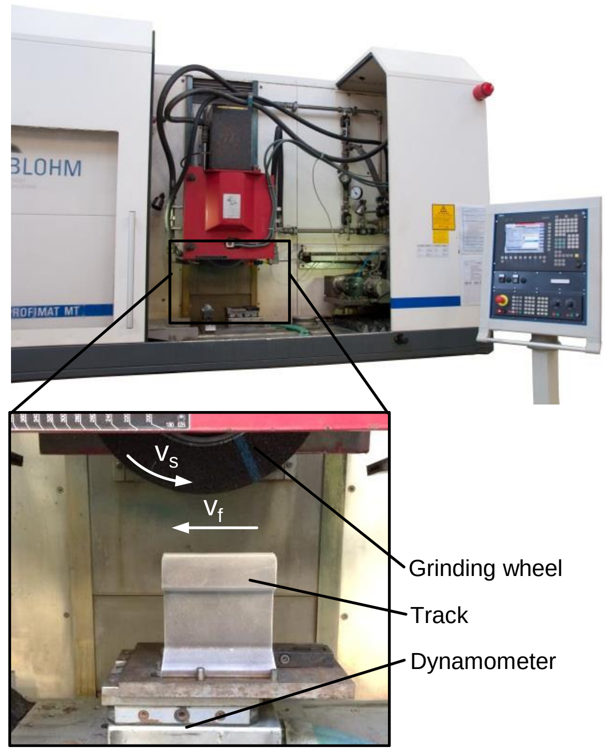



**Fig. 1.** Grinding test setup with temperated track.

Due to the dry processing with high material removal rates, the generated energy during the grinding process was calculated to as indicator for thermal influences on the workpiece. For this purpose, the contact area specific grinding energy $E''_c$ is calculated according to Eq. 1. In previous investigations a direct correlation between the contact area specific grinding energy $E''_c$ with the hardness of the rail surface layer was identified [**6**].

$$E''_c = P''_c \cdot \Delta t = F'_t \cdot v_s \cdot v_f \quad (1)$$

The tribological testing was done using the tribometer M-22 at the Igor Sikorsky Kyiv Polytechnic Institute. The ground specimens were tested in a disc/surface-test configuration, **Fig. 2**. While the specimens are fixed within the setup the counter disc is mounted on a driven shaft which allows sliding velocities of 0.5 m/s ≤ $v_g$ ≤ 6 m/s between the specimen surface and the disc. The tests were conducted with the maximal sliding velocity of $v_g$ = 6 m/s for a duration of t = 6000 s. The material of the counter disc matches the steel specification typically used for train wheels. To minimise the wear of the counter disc, the surface was shot peened in order to increase its hardness. This leads to negligible wear rates of the disc compared to the specimens. During the experiments the specimens were pressed against the disc with a constant pressing force of $F_a$ = 1000 N. While the rail temperature is varied in the grinding experiments, the temperature remains constant in the tribological tests at $T_t$ = 20 °C. The lubricating conditions also remain constant for all experiments. The mass of the specimens was measured prior and after each tribological test to determine the wear mass Δm of the specimens.

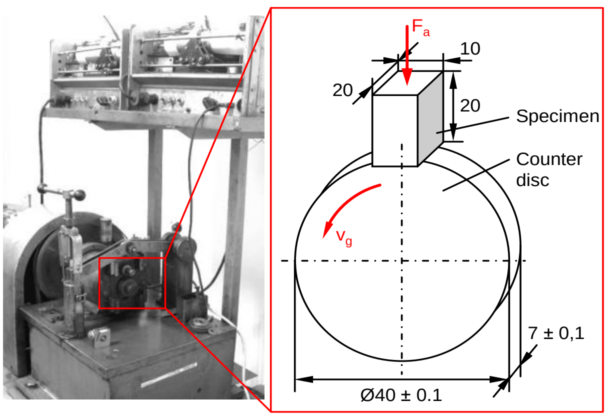



**Fig. 2.** Tribometer disc/surface-test setup for ground rail specimens.

## Results and discussion

Since in most cases it is not possible to control the weather conditions during maintenance periods, extreme rail temperatures can occur while grinding. To investigate the influence of temperature extremes on the wear behaviour, rails were ground at different initial temperatures of $T_g$ = -60 °C, $T_g$ = 20 °C and $T_g$ = 80 °C. Besides the grinding performance as well as the grinding results, the rails were then tested regarding their tribological behaviour. Subsequently, the correlation between the grinding process results and the wear behaviour will be investigated in order to develop grinding strategies optimised with regard to their resistance to wear.

**Fig. 3** illustrates the grinding process results and the wear of rails ground at different temperatures. The specific grinding energy E"c, which was calculated under consideration of the circumferential grinding wheel speed $v_s$, the feed speed $v_f$ and the specific tangential grinding force $F'_t$ according to Eq. 1 is an indicator for thermal energy generated by the grinding process. Since the rails were ground without cooling lubricant, the generated thermal energy is distributed among the grinding chips, the tool and the workpiece. Therefore, it can be assumed that any thermal damage within the workpiece correlates with the grinding energy, which can therefore perspectively be used as control value to monitor the grinding process.

It can be observed, that higher rail temperatures lead to decreasing specific grinding energies $E''_c$. This development can be explained with an increasing ductility of the material at higher temperatures. Depending on the material properties, the grain geometry as well as the penetration depth of the grain different chip formation mechanism can occur [**10**].

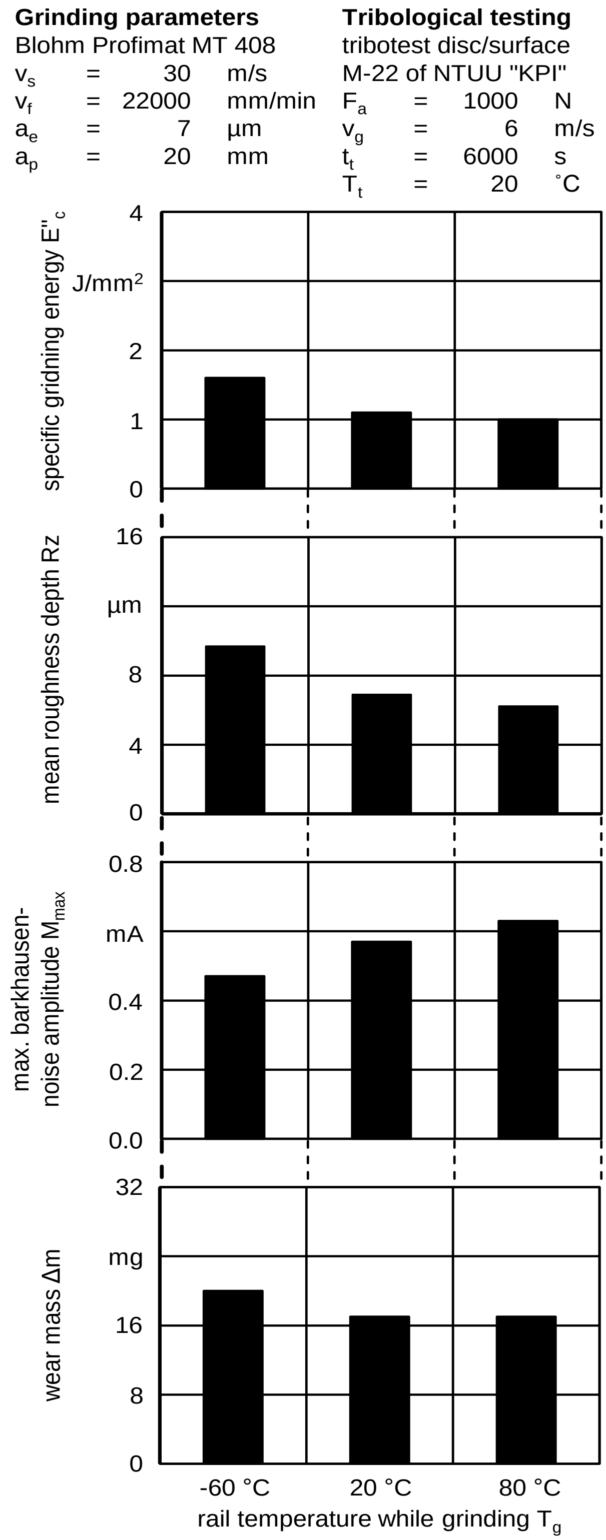



**Fig. 3**. Influence of the rail temperature while grinding on the grinding result and the tribological behaviour of the ground rails

For ductile materials the chip formation process takes place in three stages [**11**]. After the first contact of the grain, the workpiece material is elastically deformed while the friction between the grain and the workpiece surface generates heat. Once the elastic deformation exceeds the yield point of the workpiece material, plastic deformation occurs in the form of lateral bulging next to the penetration zone of the grain. After the material-dependent specific grain cutting depth $T_\mu$ is reached, the chip formation begins. In all phases friction between the grain and the workpiece surface occurs and causes frictional heat and force [**11**]. The more brittle the machined material, the more likely is the occurrence of micro-fracturing and micro-cracks at the surface of the workpiece while ideal chip formation mechanisms become less frequent [**10**]. This leads to significantly higher grinding forces when machining brittle materials [**12**]. Since the material properties, especially the ductility, depend significantly on the temperature, the higher specific grinding energies $E''_c$ at lower rail temperatures appear plausible. While less grinding forces and thus energy is necessary at higher rail temperatures, the changed chip formation mechanisms also lead to a decreased surface roughness at higher rail temperatures.

Contrary to initial expectations lower rail temperatures eventually lead to higher thermal loads on the machined rail. This assumption is confirmed by the maximal Barkhausen-noise amplitude $M_{max}$ that decreases for rails ground at lower temperatures, which indicates more thermal and mechanical stress and changes in the sub-surface zone. Consequently, rails ground at lower temperatures show an increased wear: The wear mass of rail ground at $T_g$ = 80 °C is 15 % lower than the wear mass of rail ground at $T_g$ = -60 °C. Besides the higher thermal loads on the rails at lower temperatures, the higher surface roughness might also affect the tribological behaviour of the ground rail.

As mentioned before, in most maintenance scenarios the rail temperature is an unchangeable value. Against this background, the changed wear behaviour of rails ground at deviating ambient temperatures can only be encountered with an adapted process management. To develop process strategies depending on changed weather conditions grinding experiments were conducted with a variable depth of cut $a_e$ and a variable grinding wheel circumferential speed $v_s$. The results of the grinding experiments as well as the tribological behaviour of rails ground at different circumferential speeds $v_s$ are shown in **Fig. 4**. While the specific tangential grinding force $F'_t$ decreases for higher circumferential speeds $v_s$, the specific grinding energy $E''_c$ increases nonetheless, since the specific tangential grinding force $F'_t$ decreases disproportionately in relation to the contact time $\Delta t$. This indicates higher friction values causing less efficient chip formation mechanisms. A higher circumferential speed $v_s$ leads to an increased quantity of active grains while grinding. Since the specific material removal $V'_w$ remains unchanged, the machined volume is distributed amongst more grains and thus, more chips. A reduced chip thickness leads to a lower surface on the one hand and to a higher thermal load while grinding due to more friction and elastic deformation within the contact zone. The higher thermal load manifests itself in lower maximal Barkhausen-noise amplitudes $M_{max}$ and a significantly worse wear behaviour of the rails ground with higher grinding wheel circumferential speed $v_s$. The mass wear $\Delta m$ of the rails ground with a circumferential speed of $v_s$ = 50 m/s is almost 60 % higher compared to the rails ground with $v_s$ = 30 m/s.

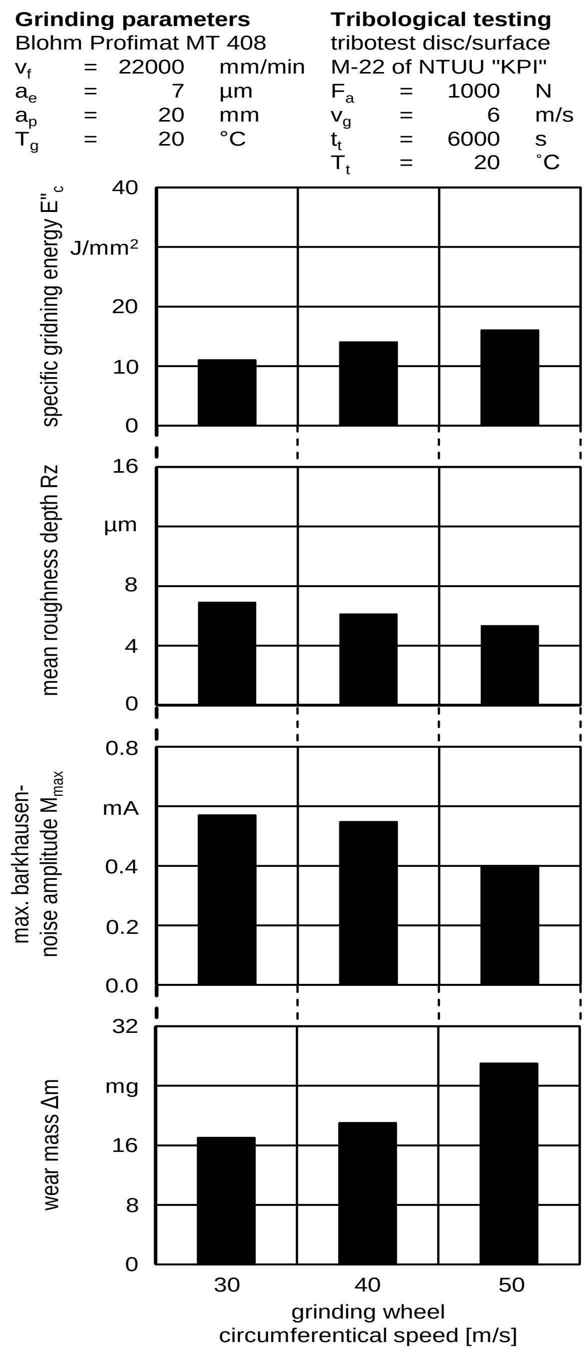



**Fig. 4.** Influence of the grinding wheel circumferential speed $v_s$ on the grinding result and the tribological behaviour of the ground rails.

For varying rail temperatures, it was not clearly identifiable, whether the improved surface roughness or the less damaged sub-surface zone led to an improved wear behaviour of rails ground at higher temperatures. Since the rails ground with higher grinding wheel circumferential speeds $v_s$ have a rougher surface, but show a significantly worse wear behaviour, it is obvious that the state of the sub-surface zone substantially determines the operational behaviour of the rail.

While a change of the grinding wheel circumferential speed $v_s$ does not change the productivity of the grinding process, an increased depth of cut $a_e$ increases the productivity as long as the remaining process parameters like the feed speed $v_f$ are unchanged. For these investigations the depth of cut was varied between $a_e = 7$ µm, $a_e = 14$ µm and $a_e = 21$ µm, which results in specific material removal rates of $Q'_w = 2.56$ mm³/mm·s, $Q'_w = 5.13$ mm³/mm·s and $Q'_w = 7.7$ mm³/mm·s respectively. Due to the larger chip thicknesses and the increasing specific material removal rate $Q'_w$, an increasing depth of cut $a_e$ leads to a higher specific grinding energy $E''_c$ as well as a higher surface roughness and larger thermal loads on the workpiece sub-surface zone, **Fig. 5**. This leads to significantly increasing mass wear of the ground tracks that have been machined with higher depths of cut $a_e$.

**Table 1.** Influence of the depth of cut $a_e$ on the rail sub-surface zone after grinding and the wear behaviour of the ground rails.

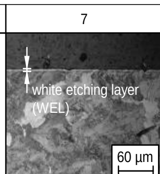
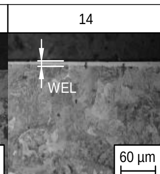
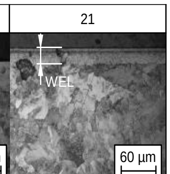
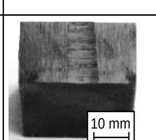
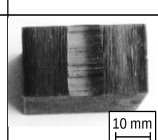
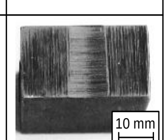
| Depth of cut $a_e$ | µm | 7 | 14 | 21 |
|---|---|---|---|---|
| Rail sub-surface zone after grinding | |  white etching layer (WEL) 60 µm |  WEL 60 µm |  WEL 60 µm |
| Case hardening depth CHD HV 0.3 | µm | 7 | 12 | 26 |
| Track specimen after tribological testing | |  10 mm |  10 mm |  10 mm |
| Wear mass Δm | mg | 17 | 23 | 26 |

**Table 1** shows the state of the rail specimens after the tribological testing in dependence of the sub-surface zone after the grinding process for different depths of cut $a_e$. With an increasing depth of cut $a_e$ and thus, increasing mechanical and thermal load during the grinding process, a wider white etching layer (WEL) occurs at the surface of the ground rails. WEL occur due to mechanical or thermal loads which cause a formation of martensite structure from the mostly pearlitic rail bulk material [**13**]. Furthermore, for higher depths of cut $a_e$ and wider WEL respectively, an increase of the case hardening depth CHD HV 0.3 was detected, that results from excessive mechanical and thermal loads caused by the grinding process. Due to the thermal loads high tension residual stresses in the sub-surface zone occur that increase the probability of crack formation and growth into the bulk material. The larger the WEL, the more likely it is, that cracks occur and cross into the bulk material potentially causing rail damage and a shortened rail lifetime [**14**].

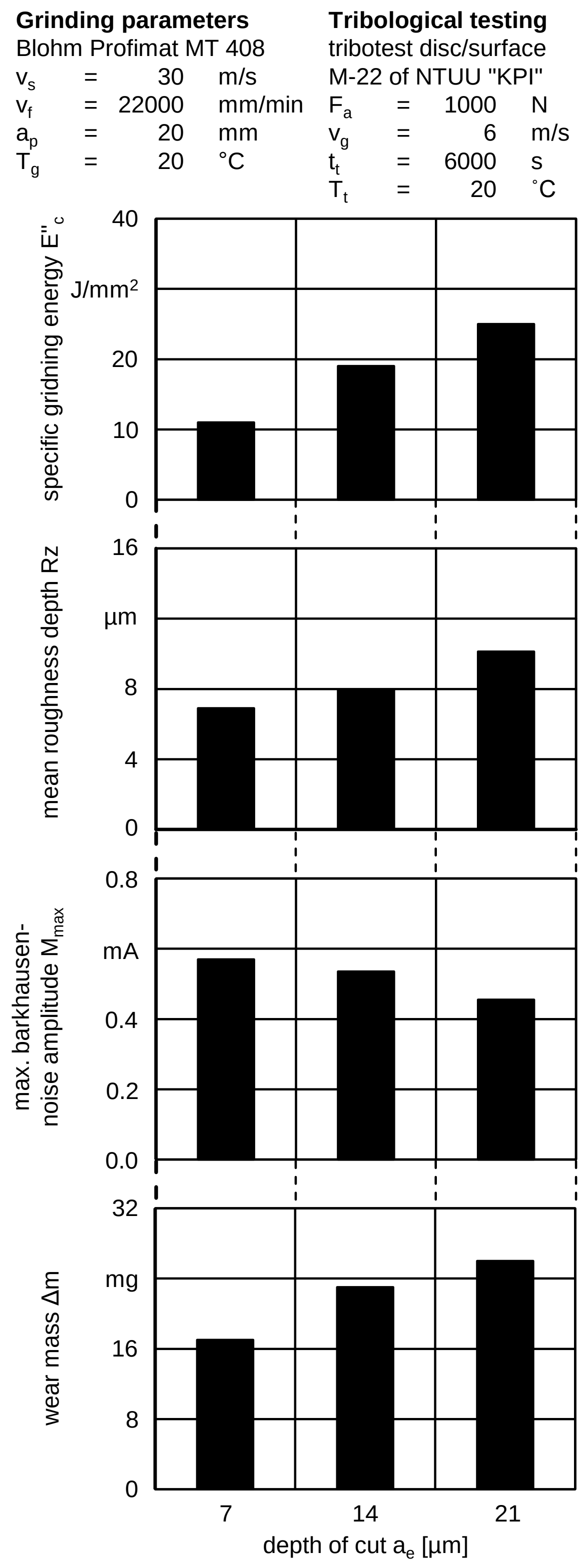



**Fig. 5.** Influence of the depth of cut $a_e$ on the grinding result and the tribological behaviour of the ground rails.

## Conclusion

The presented work shows clear correlations between the grinding process design and the tribological behaviour of ground rails. Since most rail grinding processes are applied without any cooling lubricant, a significant share of the grinding energy is conducted into to rail in form of thermal energy. The thermal as well as the mechanical load can lead to considerable effects on the sub-surface zone of ground rails.
These loads can lead to the occurrence of while etching layers (WEL). It has been found, that the width of the occurring WEL depends substantially on the grinding process parameters. While the WEL has a higher hardness than bulk material on the one hand it shows a significant vulnerability for crack formation and growth due to the high tensile residual stresses within the WEL at tribological stresses on the other hand. Furthermore, the investigations show that the rail temperature influences the grinding process noticeable due to the changes of the material properties at different temperatures. Especially the decreased ductility at lower temperatures leads less efficient chip formation mechanism while grinding, which causes more that more thermal heat is conducted into the rail surface and subsequently leads to higher wear of the rails in the tribological tests. Since the rail temperature cannot be influenced in most maintenance scenarios the gained knowledge about the impact of the grinding process parameters on the condition of the surface and sub-surface quality of ground rails can be used to compensate uncontrollable environmental influences. Exemplary, at warmer climatic areas, an adapted process design can help to make the maintenance of rails more productive and cost efficient, while the process can be adapted at cold temperatures to avoid rail damage and a reduction of the rail lifetime.

### Acknowledgements

All authors acknowledge the financial support provided by the Deutsche Forschungsgemeinschaft (DFG). The presented results are part of the DFG-project Uh 100/203-1.

### References

1. Zarembski, A.; Palese, J.; Evaluation of the effectiveness of rail grinding on reducing rail defects on North American Class 1 Railroad. AREMA Conference, Chicago, **2010**.
2. Hempe, T.; Siefer, T.; Schienenschleifen als Bestandteil einer technisch-wirtschaftlichen Instandhaltung. ZEVrail Glasers Annalen, **2007**, *131*, 3.
3. Patra, A.; RAMS and LCC in rail track maintenance. Lulea, Sweden. PhD thesis, **2007**.
4. Lichtenberger, B.; Combating rolling noise of trains by means of rail grinding. Rail Engineering International, **2005,** *34*, 6-12.
5. Schöch, W.; Railway noise abatement by rail grinding (German). Der Eisenbahningenieur, **2015**, *11*, 23.
6. Uhlmann, E.; Lypovka, P.; Analyse der Randzonenbeschaffen-heit beim Schienenschleifen. wt-online, **2014**, *6*, 352.
7. Uhlmann, E.; Lypovka, P.; Influence of rail grinding process parameters on rail surface roughness and surface layer hardness. Wear Special Issue CM2015, **2015**.
8. Gorgels, C.; Formation and avoiding of burning at discontinuous gear flank grinding (German). RWTH Aachen, Germany, Dissertation, **2011**.
9. Klocke, F.; Fertigungsverfahren 2 - Zerspanung mit geometrisch unbestimmter Schneide; Springer: Germany, **2017**.
10. Martin, K.; Yegenoglu, K.; HSG-Technologie.; Handbuch zur praktischen Anwendung. Stetten a.k.M.-Frohnstetten Guehring Automation, **1992**, pp 247-262.
11. Schröer, N.; Spannutschleifen von Hartmetall-Schaftwerkeugen mit gradierten Schleifscheiben. Technische Universität Berlin, Germany, Dissertation, **2018**.
12. Newcomb, S.B.; Stobbs, W.M.; *Materials Science and Engineering*, **1984**, *66*, 195.
13. Carroll, R.I.; Beynon, J.H.; *Wear*, **2007**, *262*, 1253.