Investigation of white and brown etching layers on wheel surfaces generated using laser technology

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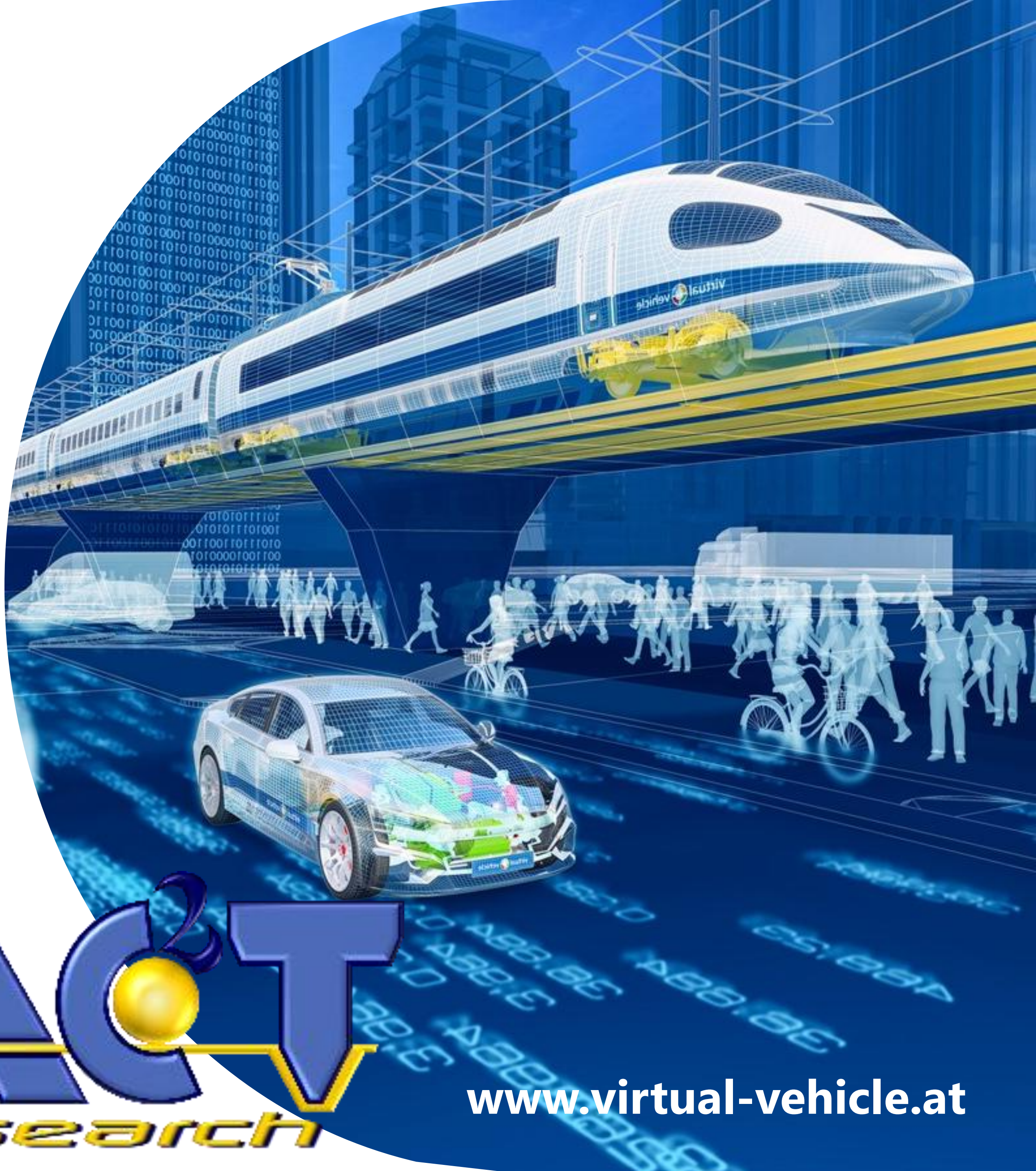

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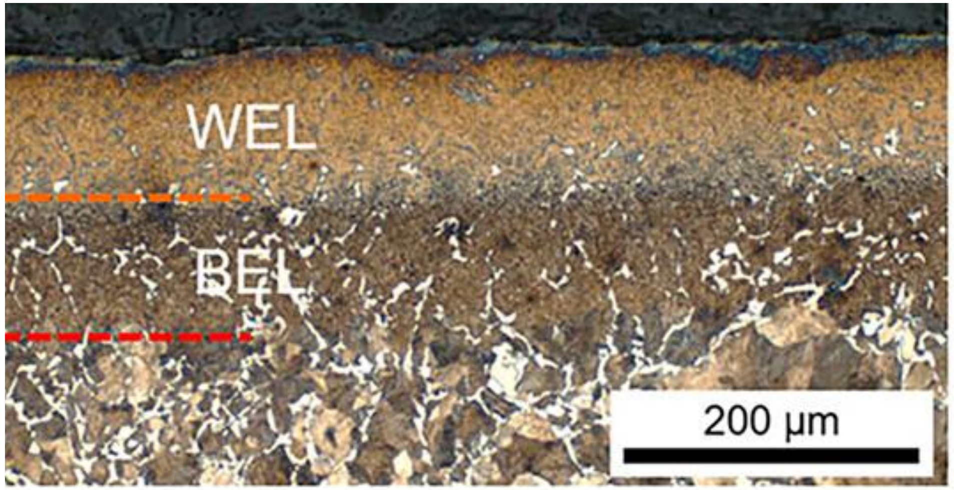
Motivation

- thermally induced White (WEL) and Brown Etching Layers (BEL) on the surfaces of wheels and rails cause initial damage, from which cracks can initiate and propagate
- BELs are mainly regarded in the literature as tempered WELs
- it is believed that WELs and BELs may play an important role in the development of squats
- thermally induced WELs and BELs are produced e.g. by massive wheel-rail sliding events



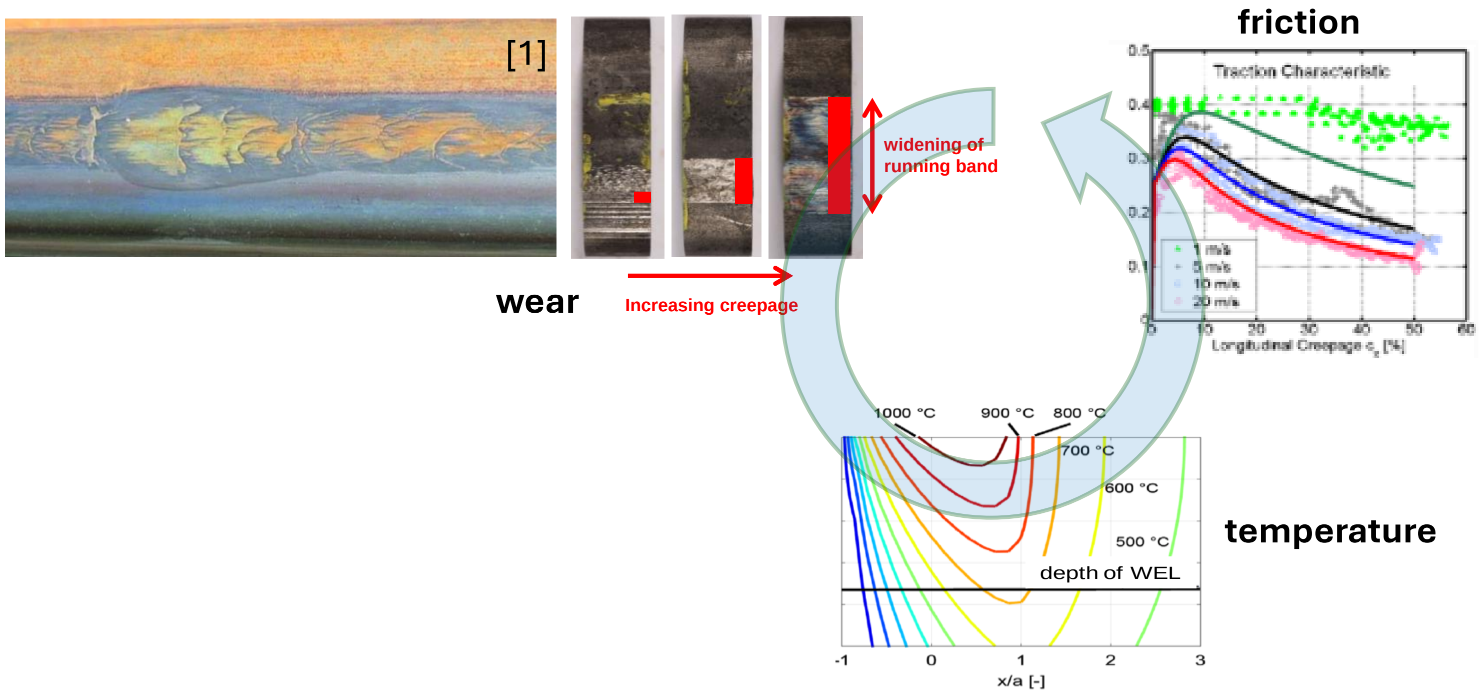
Research gaps and questions

- how were the WELs and BELs observed in the field produced?
  → **uncontrolled environment**
- how maintenance relevant damage patterns like squats develop from WELs and BELs is still unknown → **critical thickness and size?**
- what is the **influence of the material and its microstructure** on the development of WELs and BELs and resulting damage patterns?

- a systematic approach is needed
- how to produce systematically and reproducible WELs and BELs?

Challenges in producing WELs and BELs

- even in lab experiments it is challenging to produce well defined WELs and BELs by large wheel-rail creepages

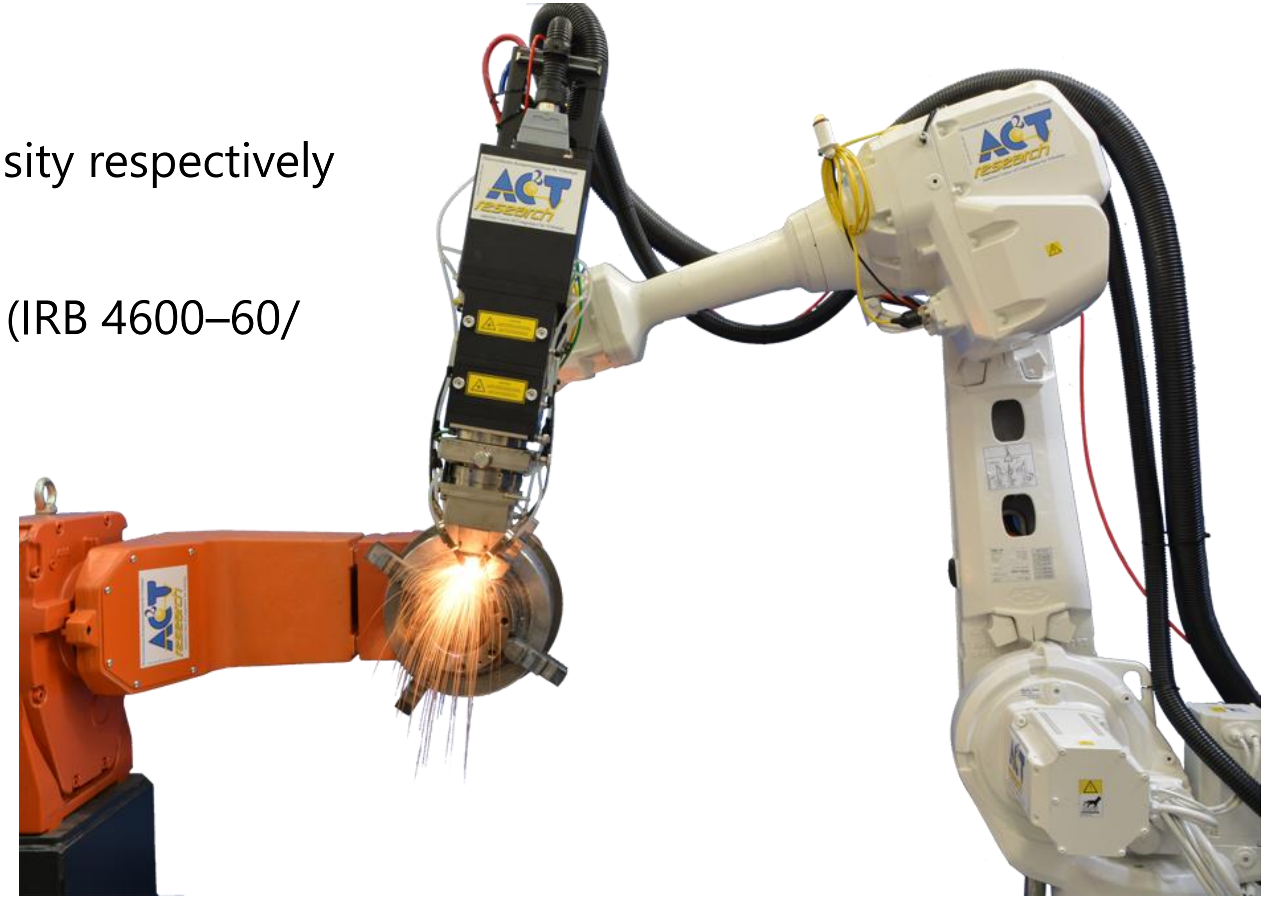


the wear resistance of the material, friction and temperature dependencies influence the heat input on surfaces, thereby affecting material phase changes → **better control with laser technology**

[1] Linsel R., Meißner K. (2019) Schienen und Schienenschweißen. In: Fendrich L., Fengler W. (eds) Handbuch Eisenbahninfrastruktur. Springer Vieweg, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-56062-4_3

Laser

- Direct Diode Laser System (HighLight 8000D, Coherent, U.S.)
- dimensions of the rectangular laser spot:
  - 3 mm (in moving direction)
  - 24 (36) mm in the lateral direction
- constant surface temperature and power density respectively
- linear speed: 12 mm/s
- Laser system mounted on a 6-axis robot arm (IRB 4600–60/ 2.05, ABB, Austria)

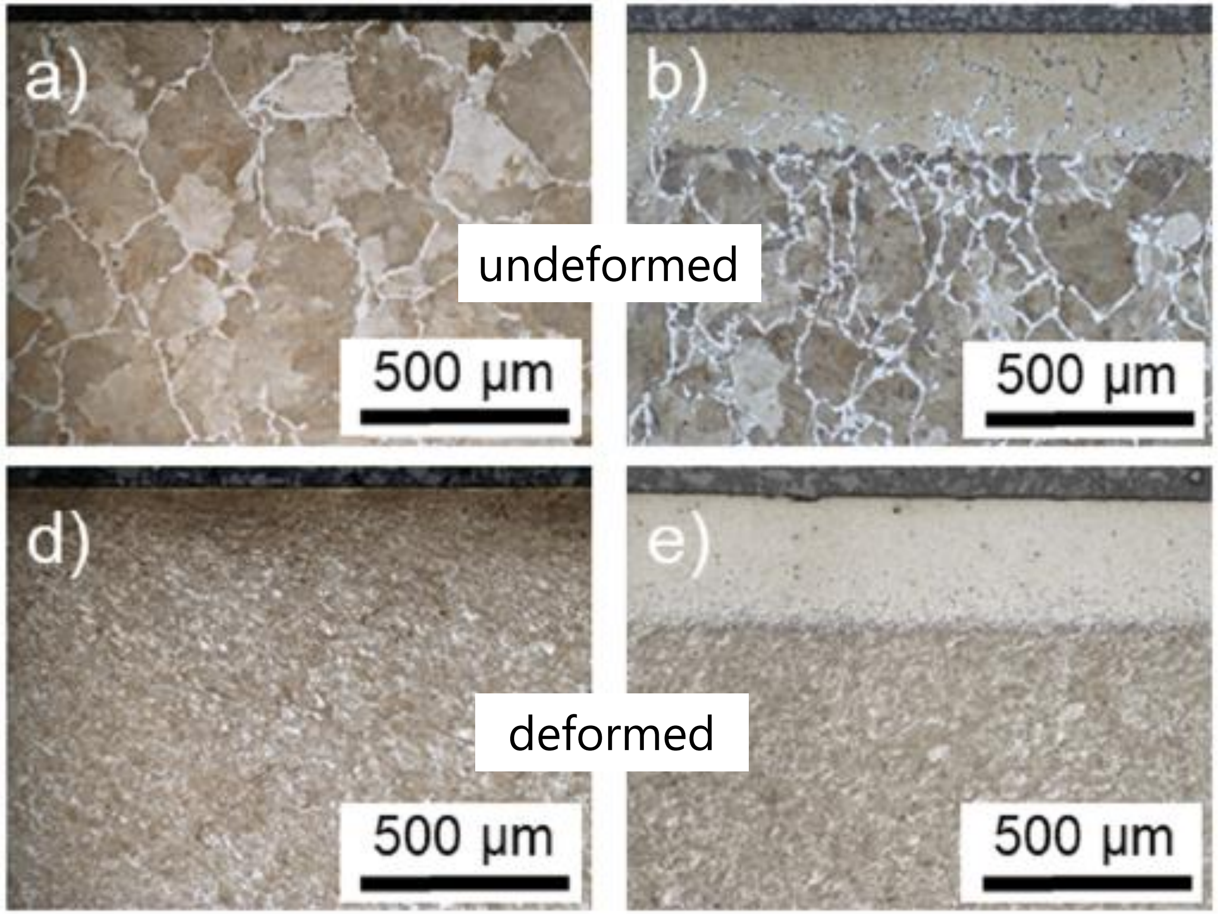


are WELs/BELs found in the field and produced with lasers even comparable?

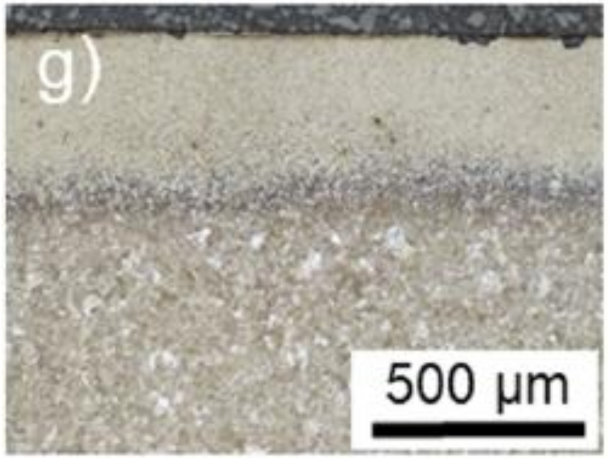
Laser vs field (ER7) [2]

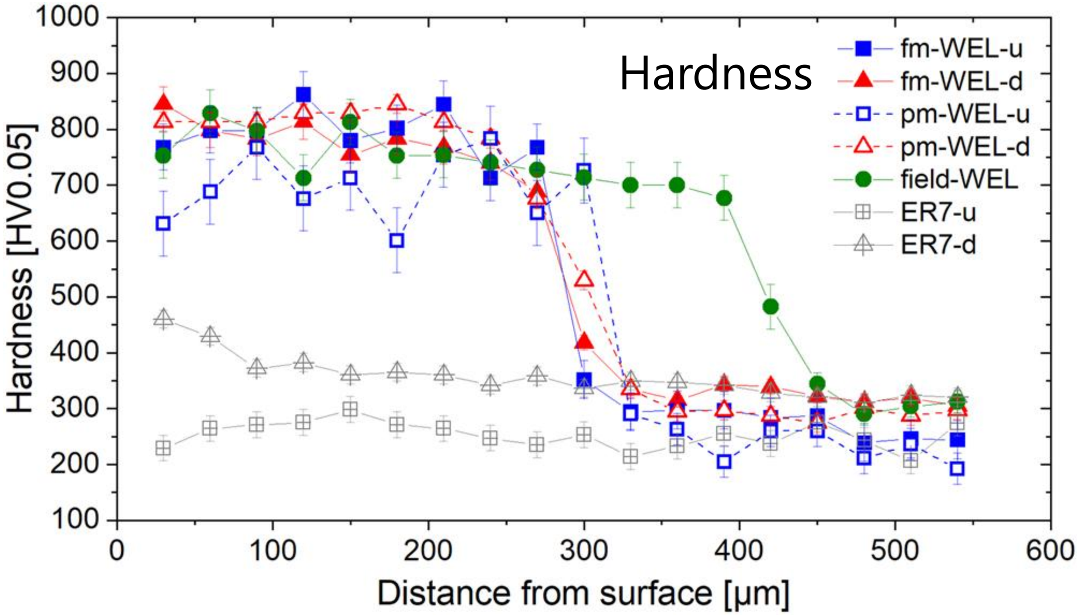
[2] M. Freisinger, H. Rojacz, K. Pichelbauer, A. Trausmuth, G. Trummer, K. Six, P.H. Mayrhofer, Comparative study on the influence of initial deformation and temperature of laser-induced white etching layers on rail wheels, Tribology International (2023), 177, 107990, https://doi.org/10.1016/j.triboint.2022.107990

Laser



Field

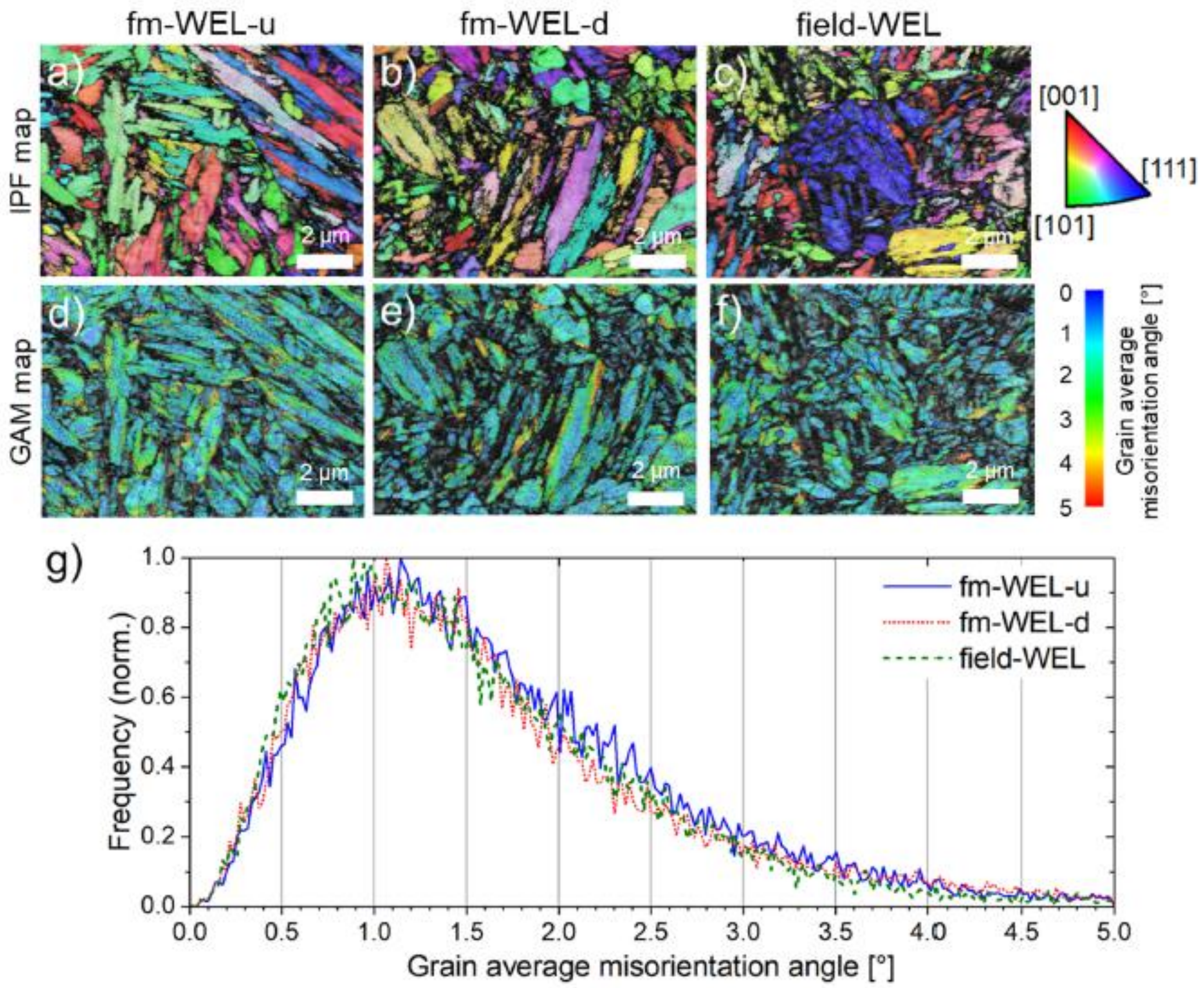




LOM images

Laser vs field (ER7) [2]

- EBSD analyses



Laser vs field (ER7) [2]

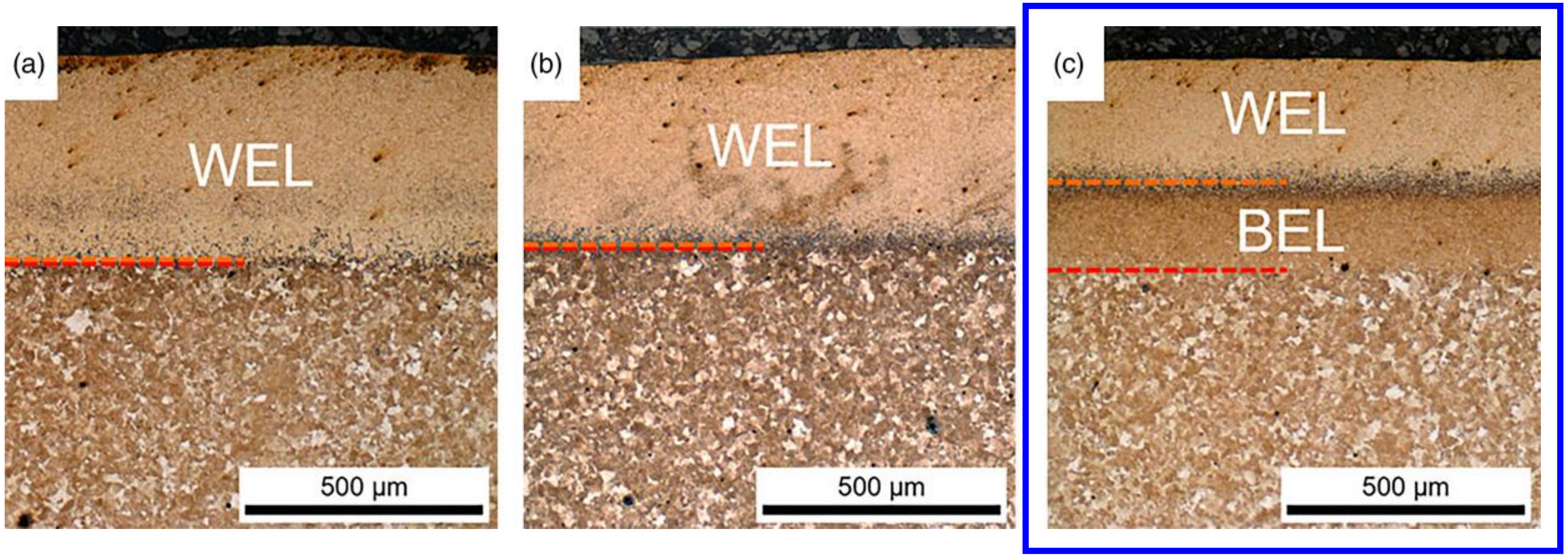
Summary

- Laser-WEL: undeformed vs deformed material
  - plastic deformation showed some influence on WEL thickness
  - Vickers hardness similar
  - microstructure was different with a pronounced proeutectoid ferrite present in the WEL on the undeformed material
- Field-WEL:
  - showed similar hardness and martensitic microstructure as Laser WELs on deformed material
  - Field-WEL exhibited significant deformation and grain size gradient

Generation of WELs and BELs [3]

- same microstructure: undeformed E7
- different laser treatment

P_i … Laser power



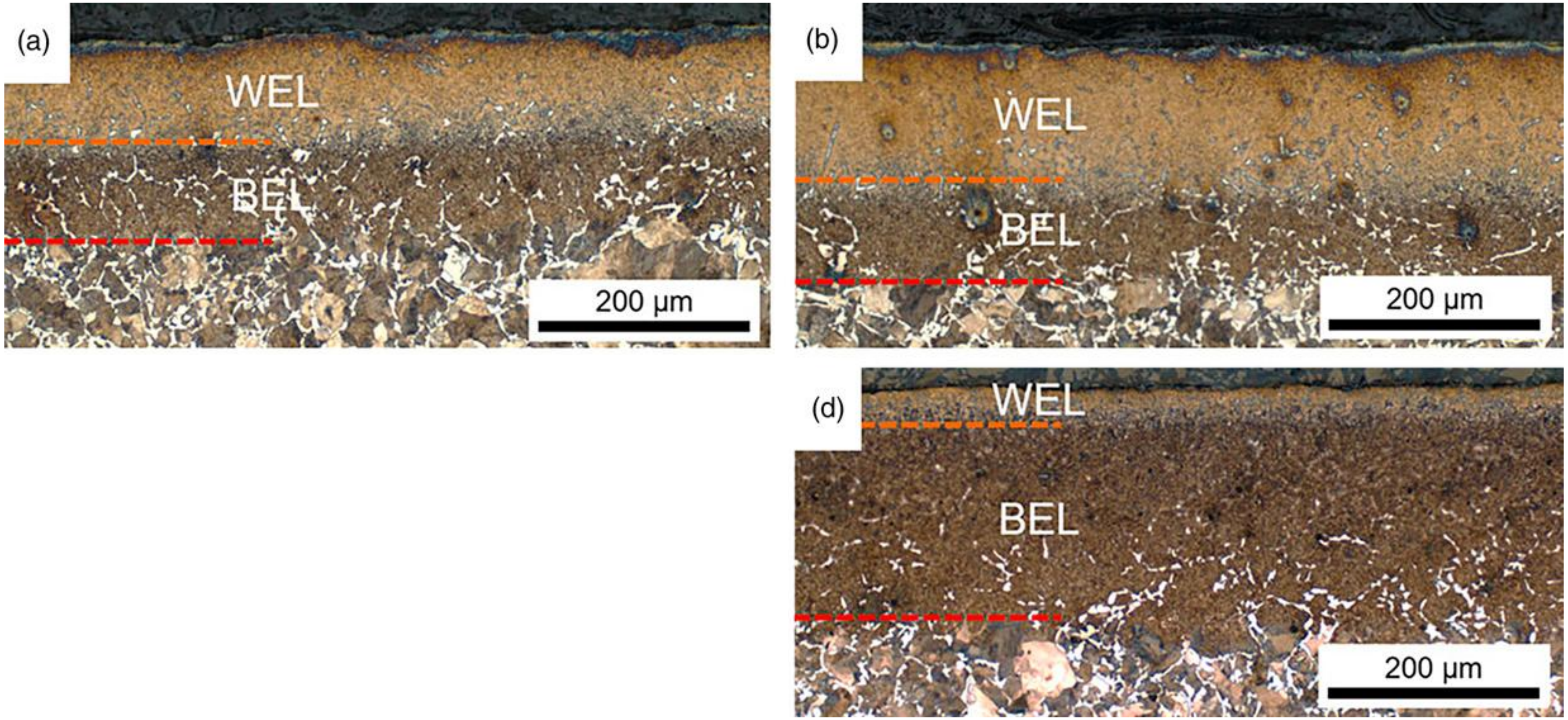
$P_1 = P_2$ $P_1 < P_2$ $P_1 > P_2$

[3] M. Freisinger, K. Pichelbauer, G. Trummer, K. Six, Influences of thermal loading parameters and microstructure on the formation of stratified surface layers on railway wheels, Proc IMechE Part F: Journal of Rail and Rapid Transit (2024), https://doi.org/10.1177/09544097241229121

Generation of WELs and BELs [3]

- same microstructure: undeformed E7
- different laser treatment

P_1 = 2.3 kW
P_2 = 1.7 kW



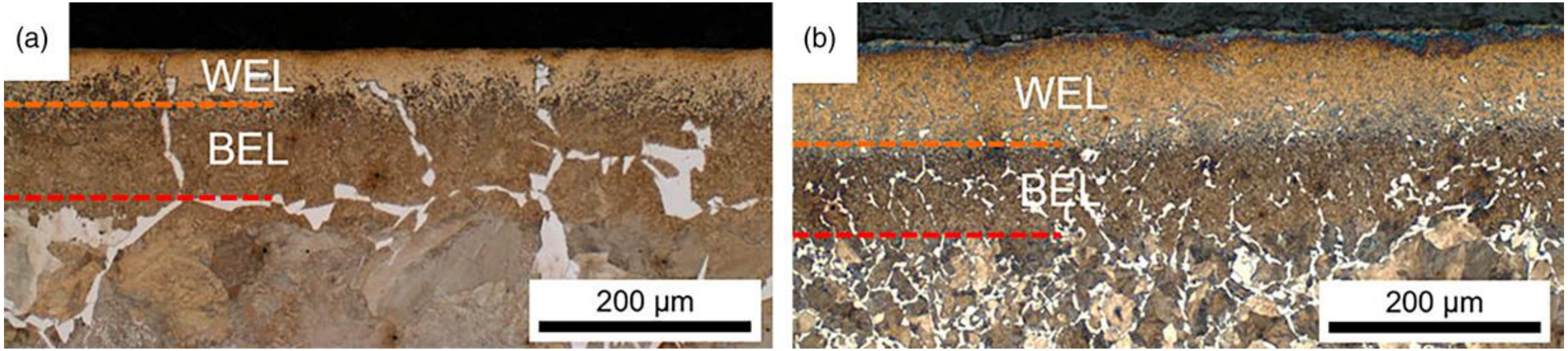
P_1 = 2.4 kW
P_2 = 1.8 kW

P_1 = 2.4 kW
P_2 = 1.6 kW

Generation of WELs and BELs [3]

Influence of initial microstructure: ER7 undeformed

- same material chemistry, different heat treatment
- same laser treatment: P_1 = 2.3 kW ; P_2 = 1.7 kW



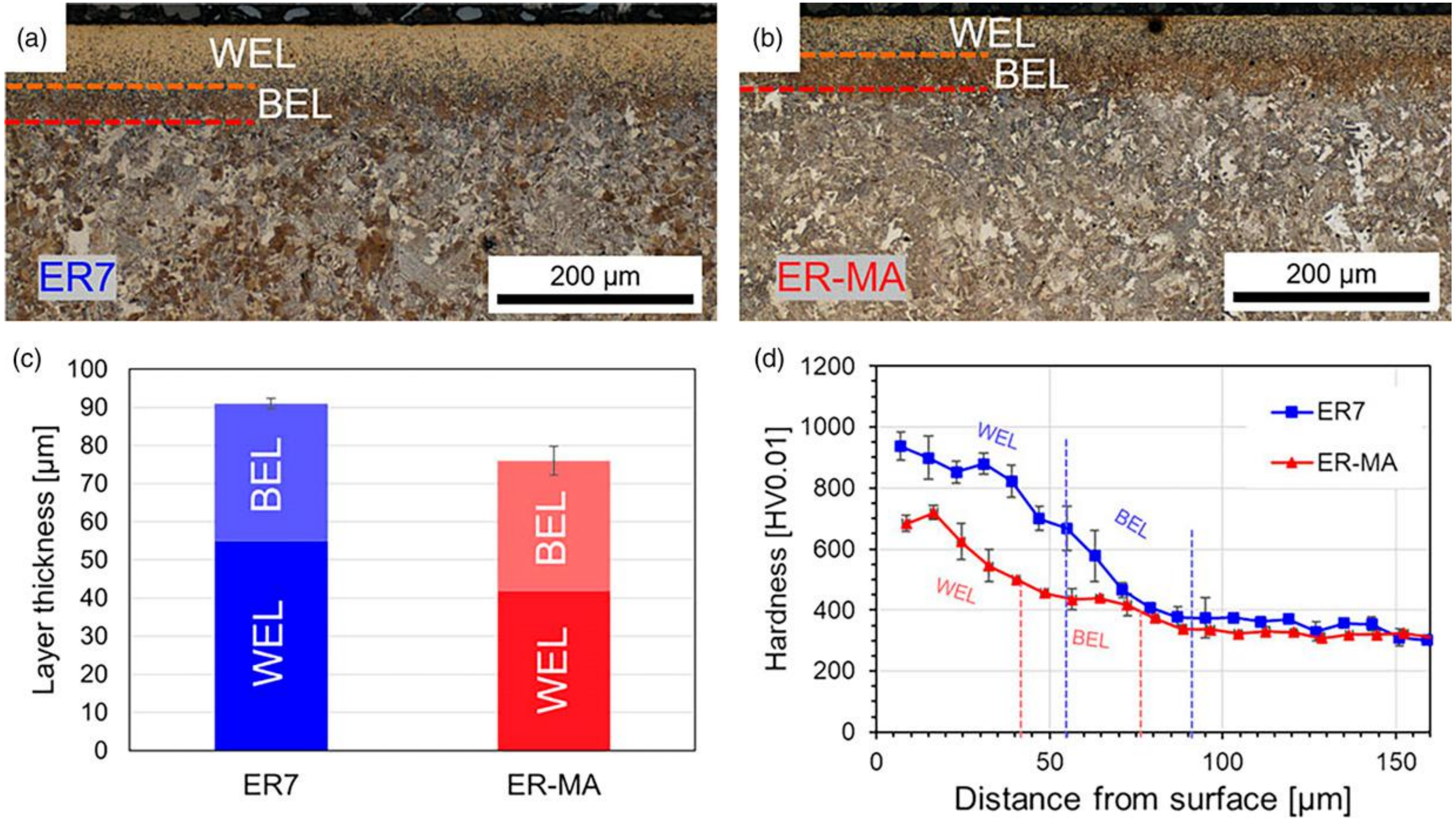
initial microstructure influences WEL/BEL thickness

Generation of WELs and BELs [3]

Influence of material

- ER7 vs ER7-MA
- undeformed
- same heat treatment
- same laser treatment

material chemistry influences WEL/BEL formation



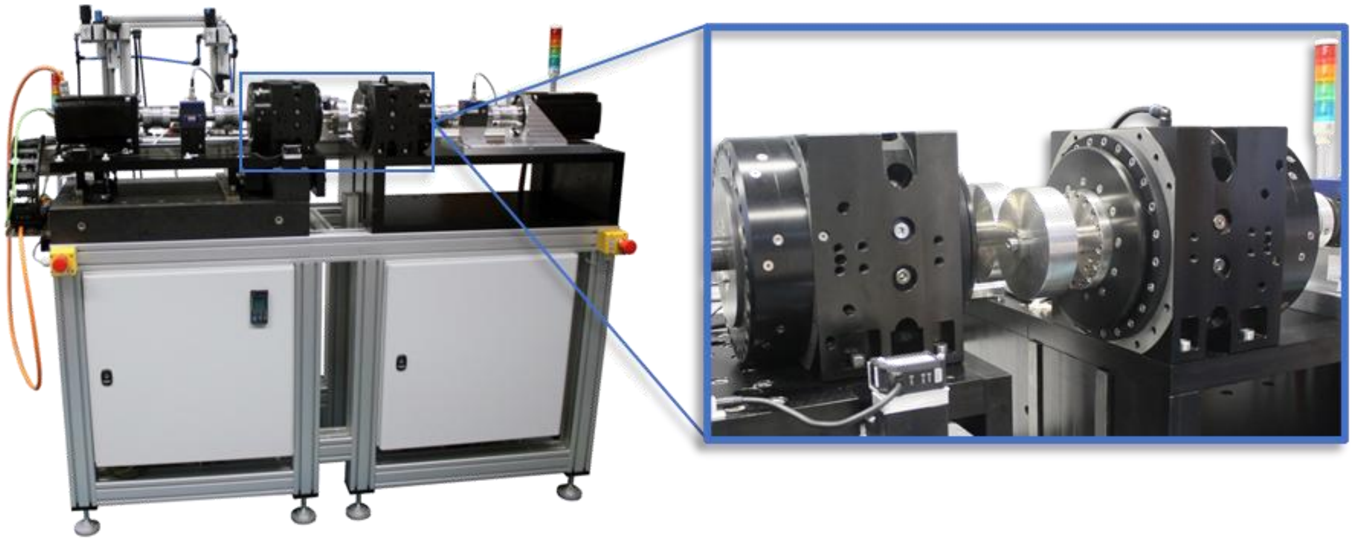
	C	Si	Mn	Cr	Cu	Ni	P	S	Mo	V	Nb
						wt%					
ER7	**0.54**	0.30	0.60	0.25	0.15	0.10	0.001	0.02	0.04	0.001	0.002
ER-MA	**0.43**	0.30	0.60	0.25	0.15	0.10	0.001	0.02	0.04	**0.015**	**0.015**

WELs, BELs → cracks [4]

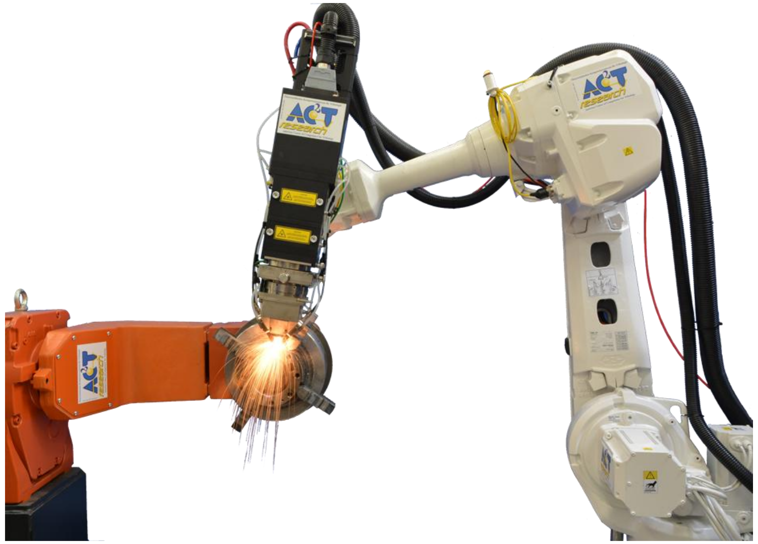
[4] M. Freisinger, B. Jakab, K. Pichelbauer, G. Trummer, K. Six, P. Mayrhofer, Fatigue crack initiation in the presence of stratified surface layers on rail wheels, International Journal of Fatigue (2023), 177, 107958, https://doi.org/10.1016/j.ijfatigue.2023.107958

Twin Disc tests

- disc diameter ~50 mm
- line contact
- normal load: 800 N
- Hertzian stress: 770 MPa
- 100k cycles
- 500 rotation/min
- 1% creepage

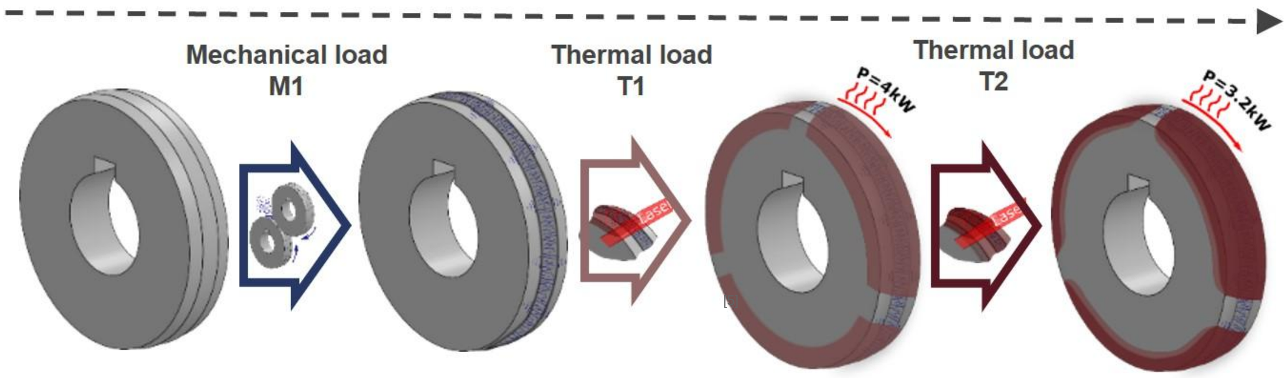


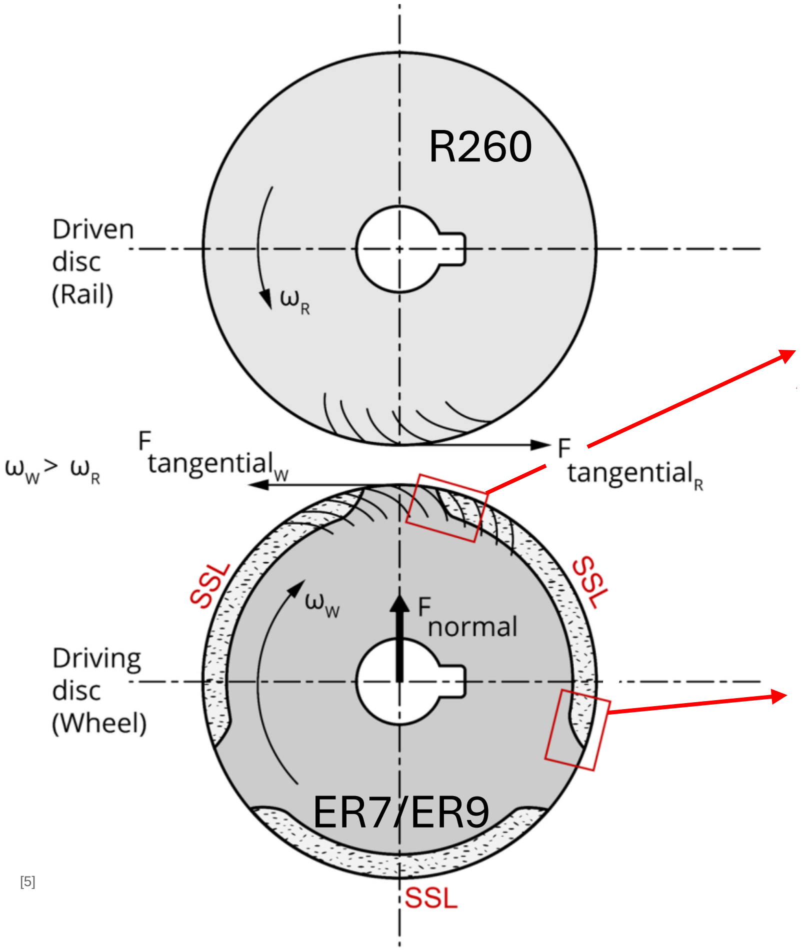
- creation of WELs and BELs on one disc with laser



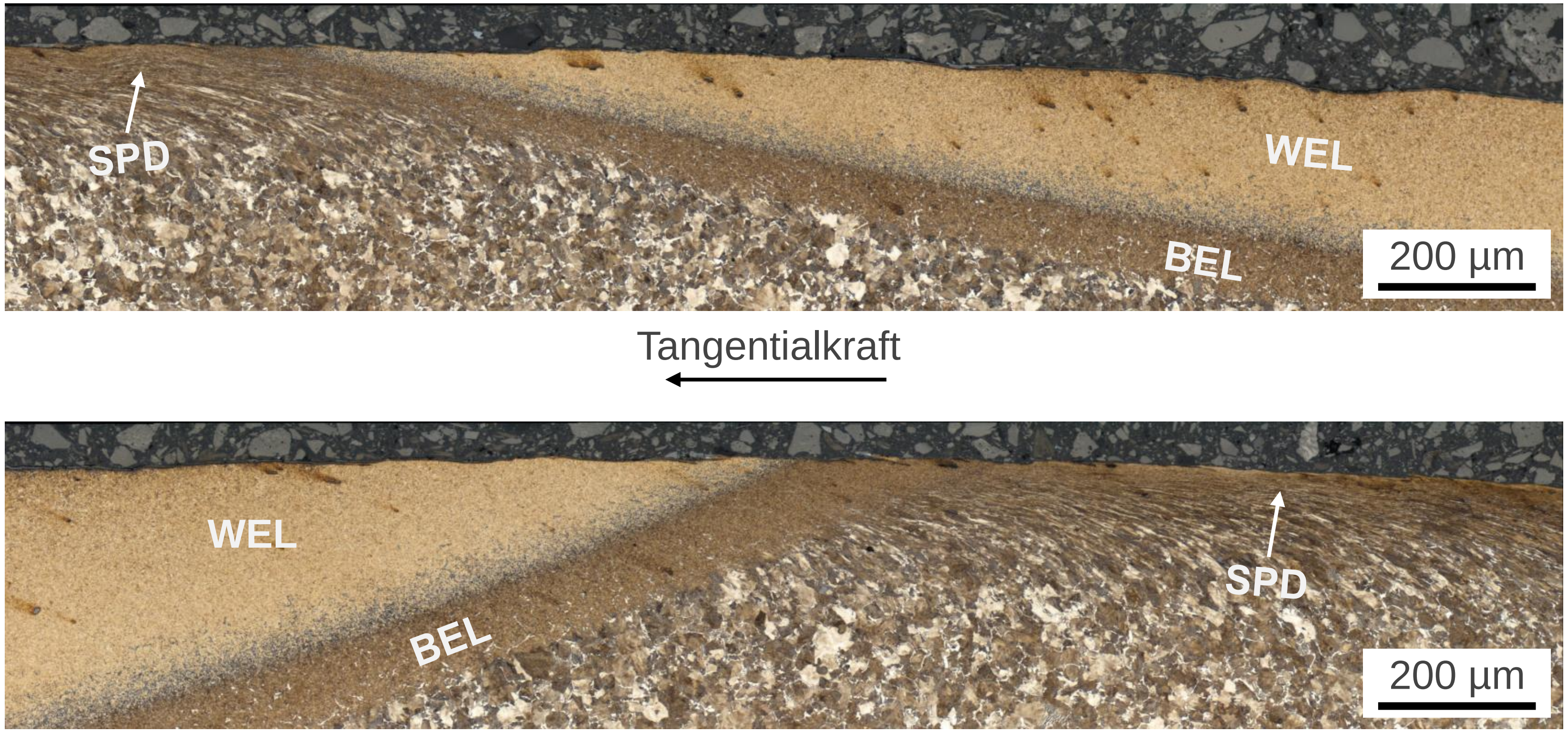
WELs, BELs → cracks [4]

SSL…Stratified Surface Layer (WEL+BEL)





[5]



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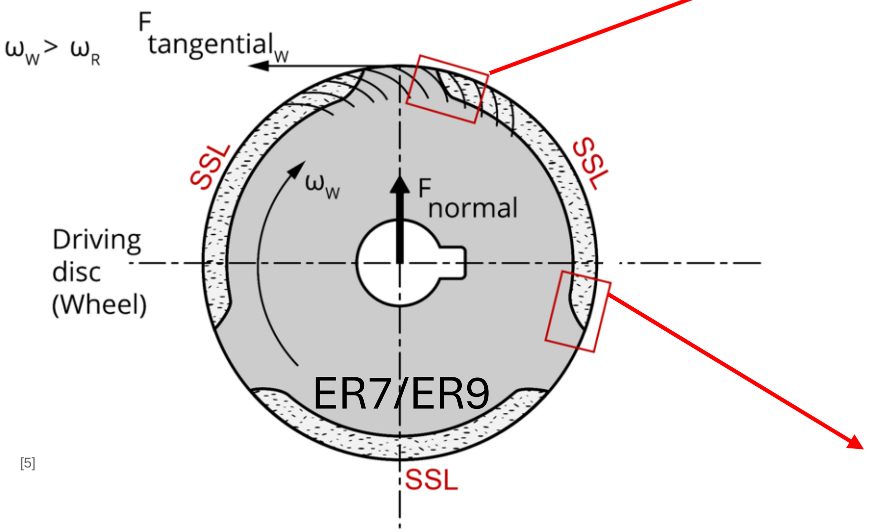
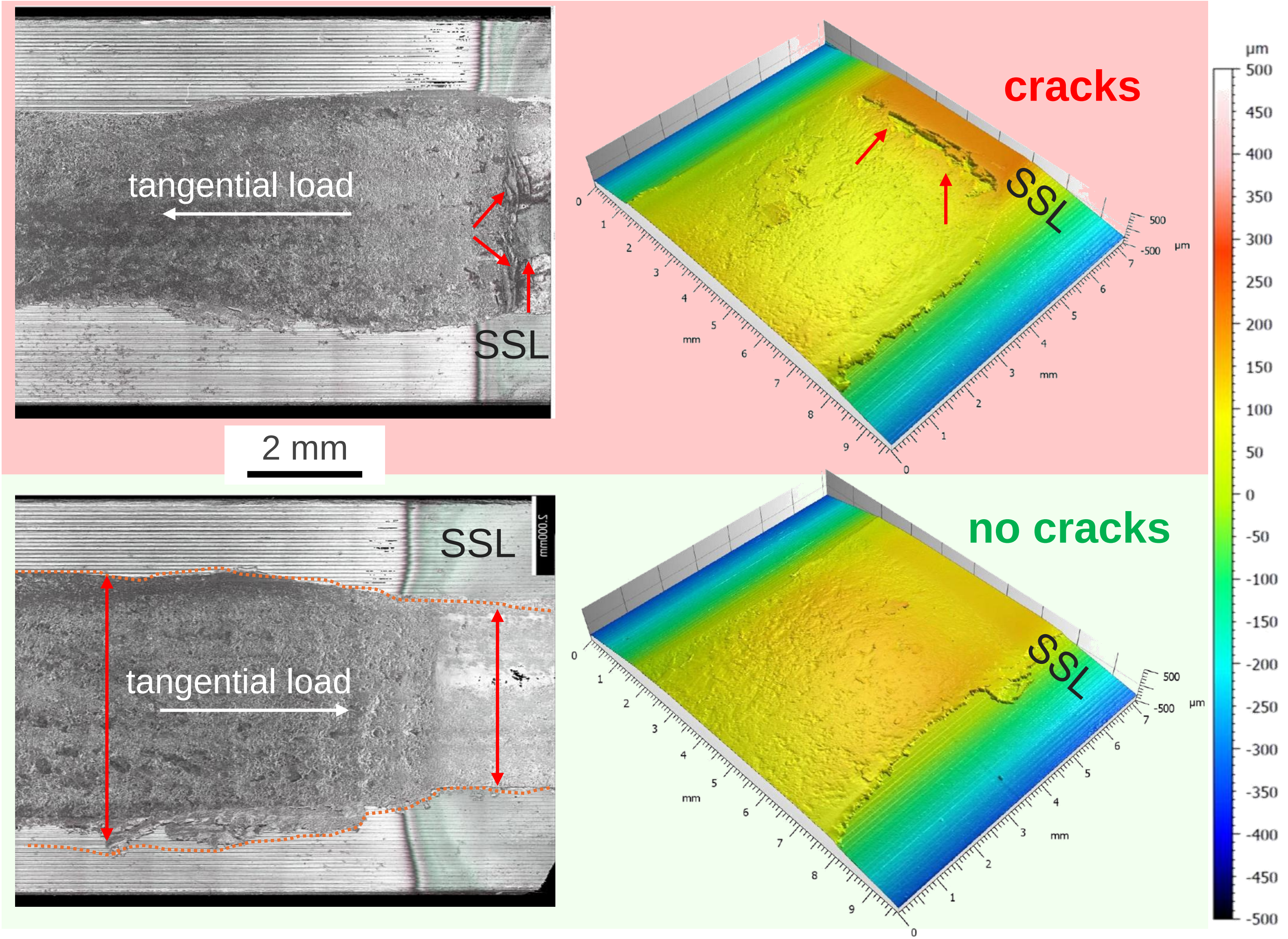
WELs, BELs → cracks [4]

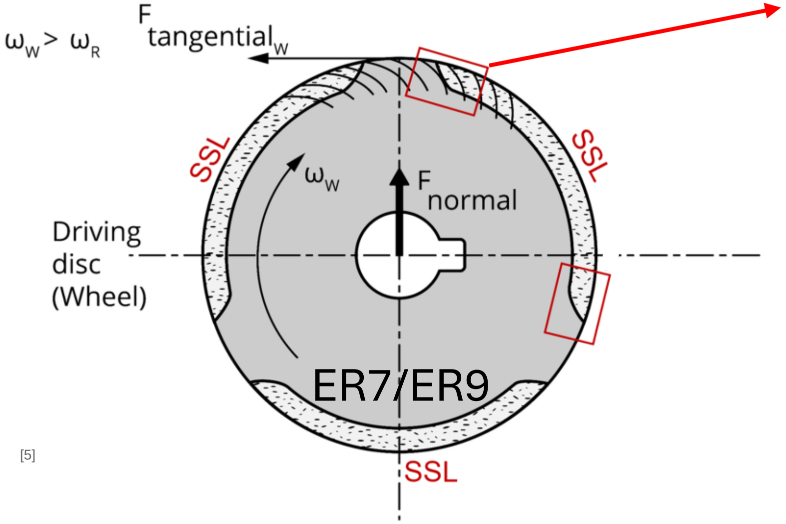




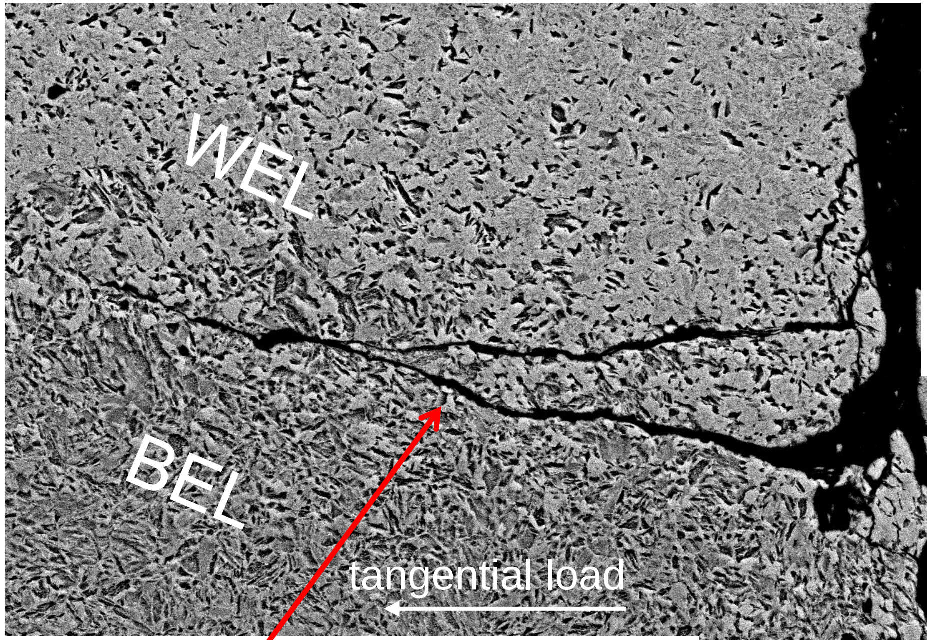
SSL…Stratified Surface Layer (WEL+BEL)

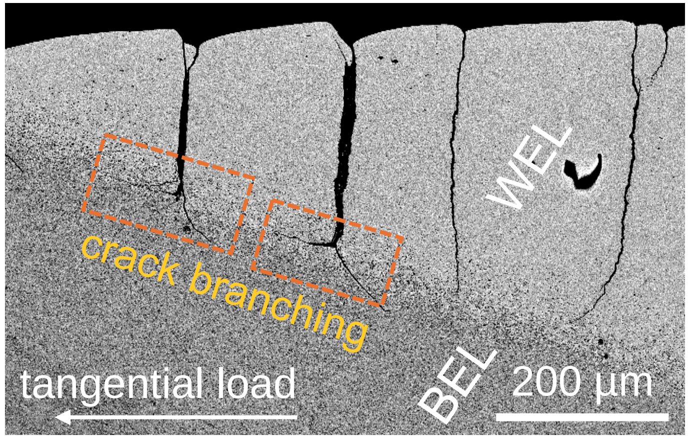
WELs, BELs → cracks [4]

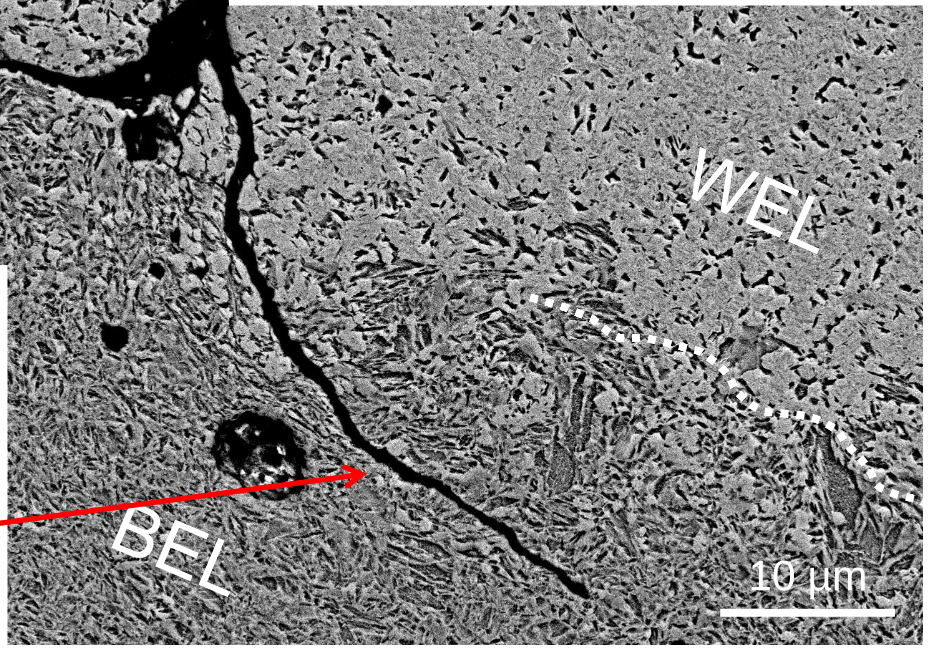
- crack propagation through WEL, perpendicular to surface
- crack branching in WEL-BEL transition zone



[5]







in WEL-BEL transition zone
in direction of $F_{tangential}$

into BEL
opposite to $F_{tangential}$

SSL…Stratified Surface Layer (WEL+BEL)

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Conclusion

- Laser technology is an effective method of producing WELs and BELs on wheel and rail surfaces

  → to investigate how the microstructure influences the thickness of WELs and BELs

  → to study the effect of material chemistry on the thickness of WELs and BELs

  → to create well-defined WELs and BELs on wheels and rails for small- and full-scale experiments, and to investigate the development of relevant damage patterns

  → ...

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