西南交通大学

ICRI webinar

Experimental study on wear and RCF damage of wheel/rail materials under complex environment conditions

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Content

1. Wear and RCF of wheel/rail under complex environment

- Low temperature
- Windblown sand condition

2. Microstructure evolution of wheel/rail materials

3. Wear and RCF prediction

- Wear rate−Tγ/A
- Shakedwon map

4. Rail grinding

1.1 Effect of temperature

Low temperature

High speed train wheel

2013.3.29

2013.7.8

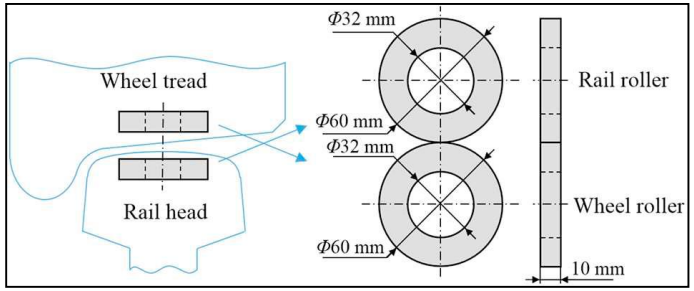
RCF damage is severer in winter

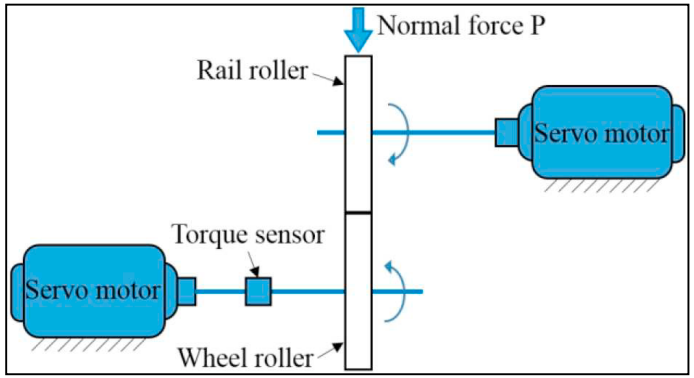
1.1 Effect of temperature: Experimental equipment

- Wheel/rail twin-disc rigs
- Low temperature (0~-60℃)

JD-1 wheel/rail simulation rig

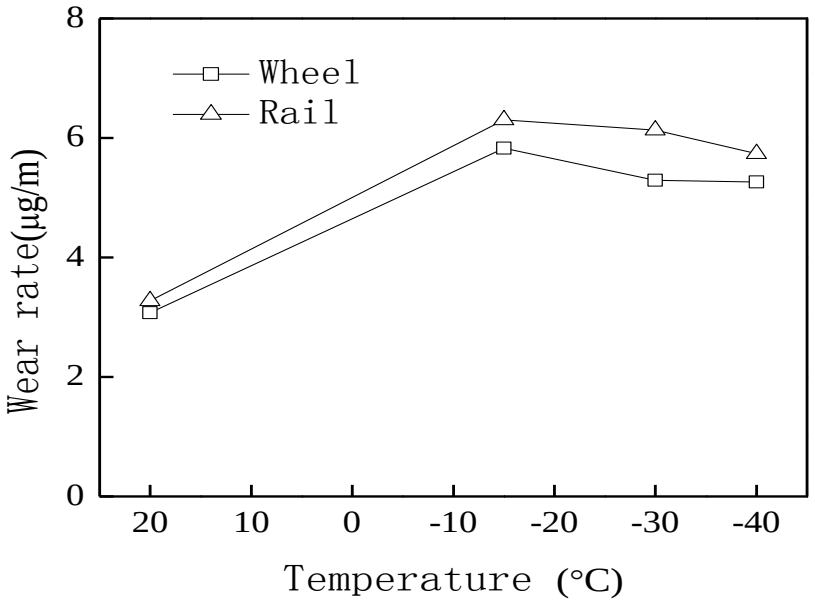
Twin-disc rig with temperature control system





1.1 Effect of temperature

Wear

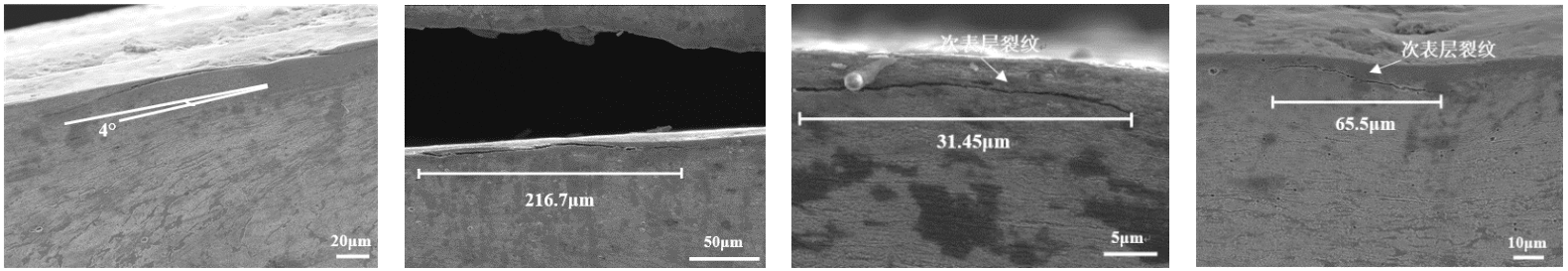


- ❖ **At low temperature: wear↗↗**
- ❖ **Low T from -15℃ to -40℃ : wear↘**

1.1 Effect of temperature

RCF

20℃ -15℃ -30℃ -40℃



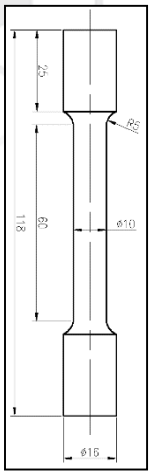
- At low tem[illegible]ture: RCF↗↗
- Low T f[illegible]n -1[illegible]o -40℃ : RCF↘
- Wear & R[illegible]si[illegible]r trend

Temperature	Surface cracks	
	Angle (°)	Depth (μm)
20 ℃	8.14±2.11	11.76±2.21
-15 ℃	14.28±8.38	12.06±10.41
-30 ℃	10.66±5.59	6.20±2.17
-40 ℃	9.33±3.77	7.68±2.76

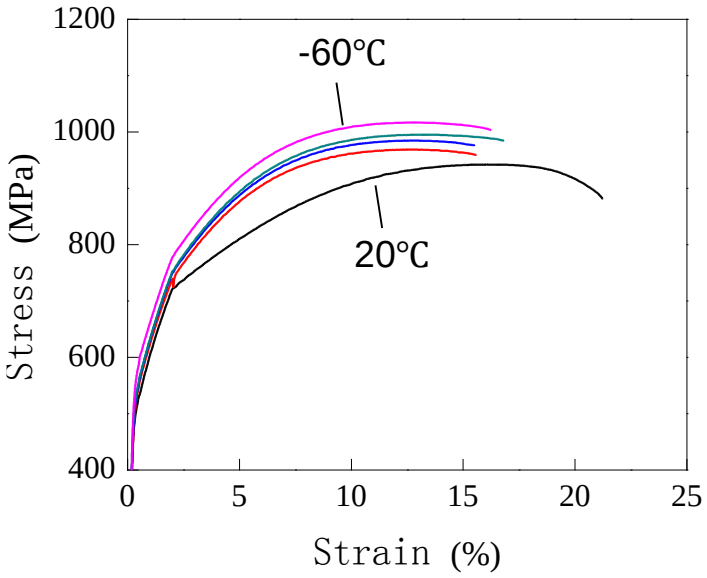
Temperature	Subsurface cracks
	Length (μm)
20 ℃	38.77±2.89
-15 ℃	74.97±51.33
-30 ℃	57.76±46.84
-40 ℃	52.69±39.14

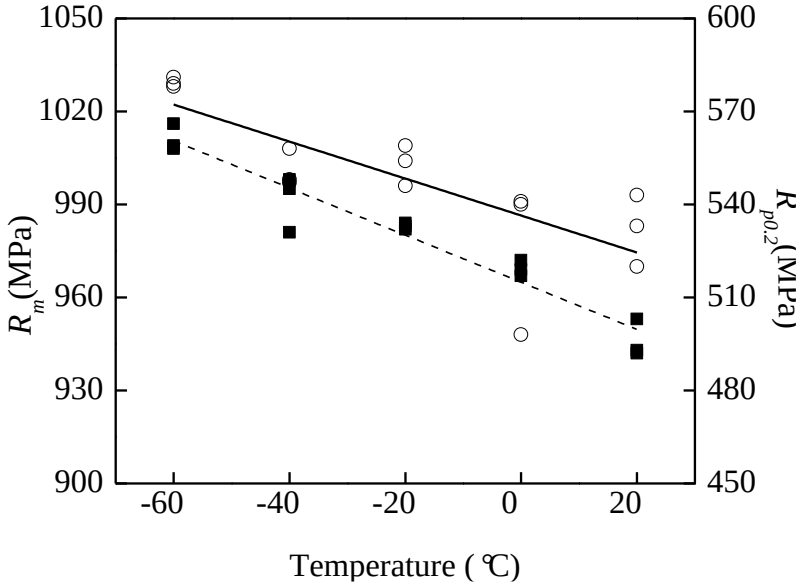
1.1 Effect of temperature

Mechanical properties



Tension test



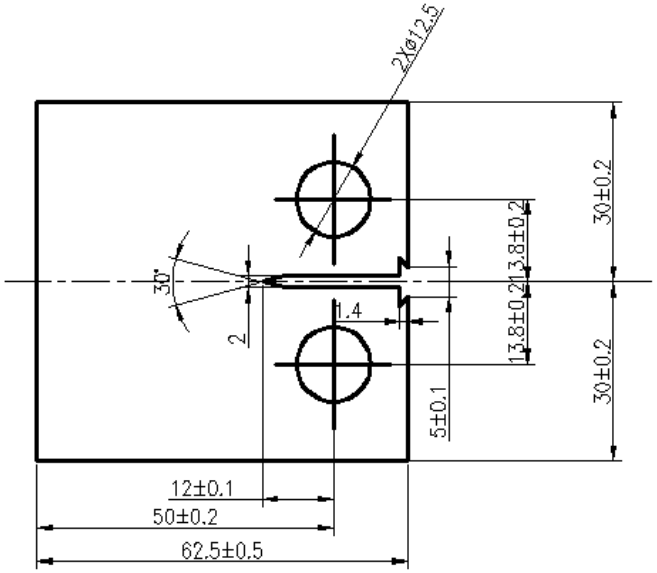


Temperature↘:

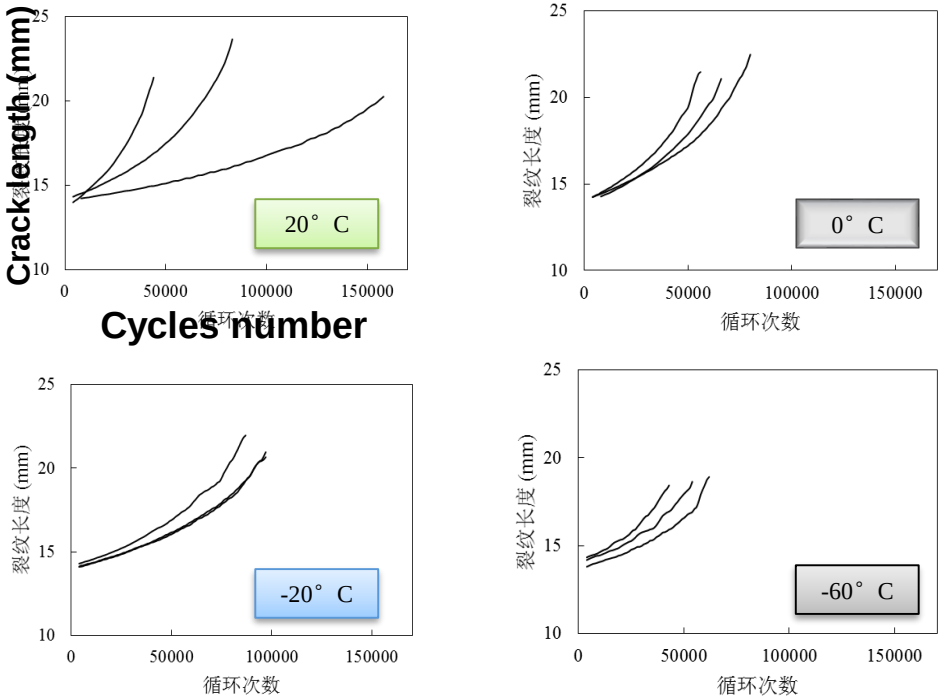
- **Ultimate tensile strength R_m ↗**
- **Yield strength $R_{p0.2}$ ↗**

1.1 Effect of temperature

Mechanical properties



Repeated tension and compression test

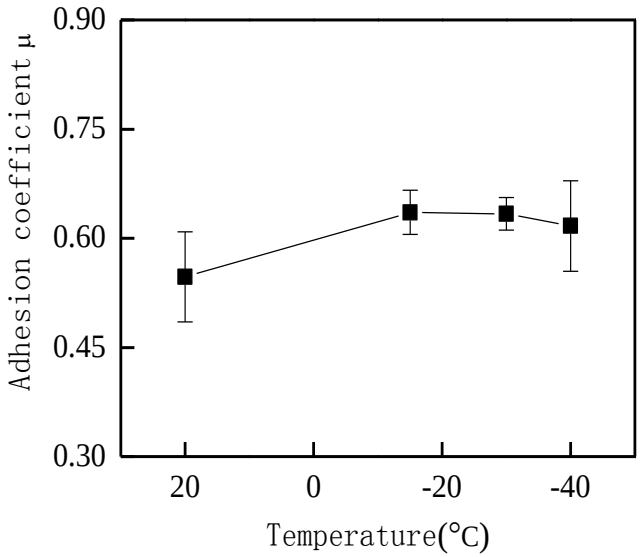


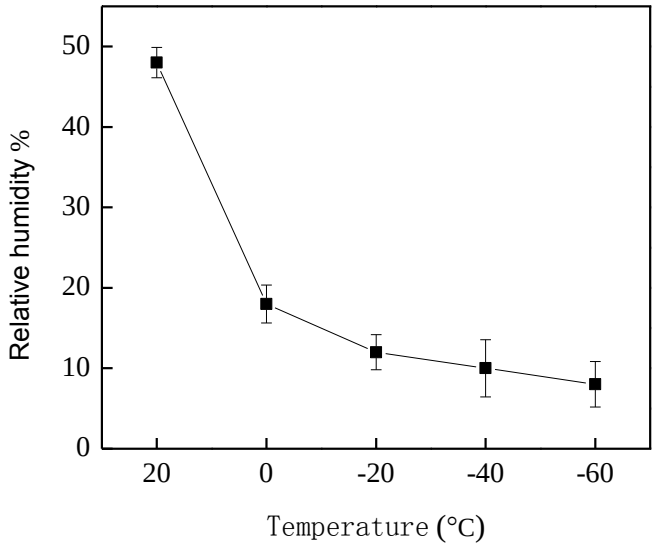
Temperature↘: Crack growth rate ↗

1.1 Effect of temperature

Rolling sliding contact

Adhesion coefficient





- ❖ **At low temperature: RH↘↘, CoA ↗↗, Tangential force ↗↗**
- ❖ **Low T from -15℃ to -40℃ : RH↘, CoA ↘, Tangential force ↘**

1.1 Effect of temperature

Room T ↘ low T:

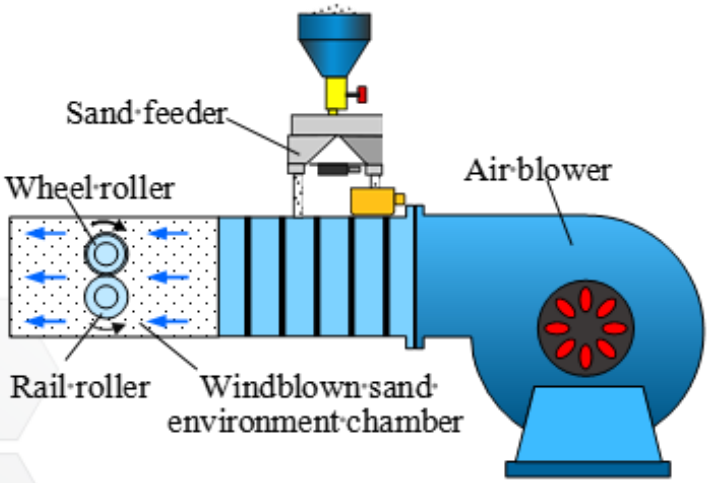
- **Strength ↗**
- **Crack growth rate ↗ (brittleness ↗)**
- **Wear ↗ ↗**
- **RCF ↗ ↗**

low T -15℃ ↘ -40℃ :

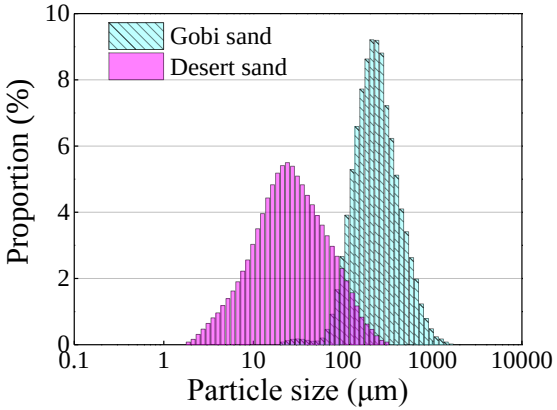
- **CoA ↘**
- **Wear ↘**
- **RCF ↘**

1.2 Effect of windblown sand

Windblown sand environment

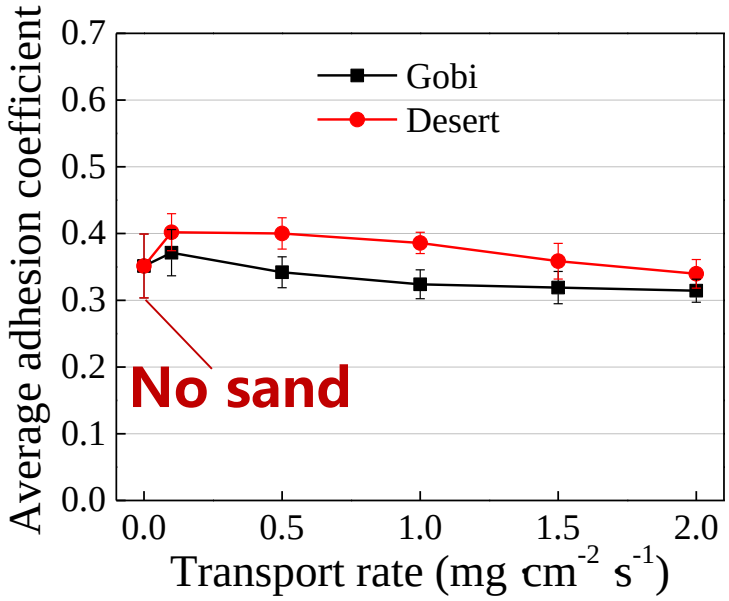


Twin-disc rig with windblown sand



1.2 Effect of windblown sand

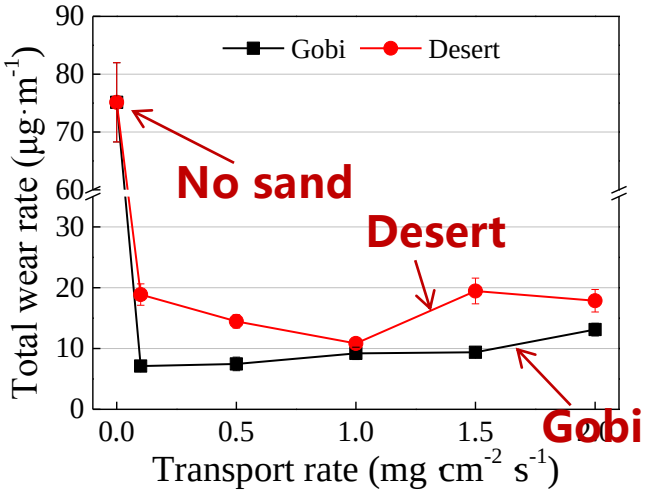
Adhesion coefficient

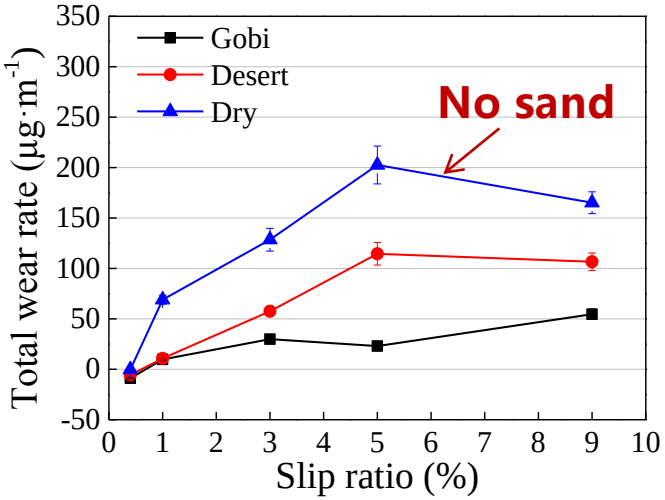


- ❖ **Feed rate↗ : CoA↘**
- ❖ **Gobi < desert**

1.2 Effect of windblown sand

Wear

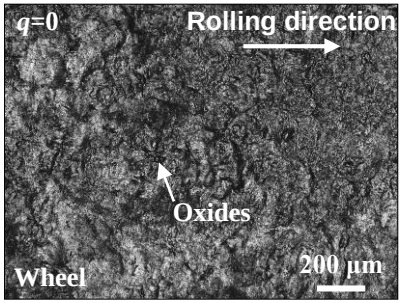




Gobi < desert < no sand

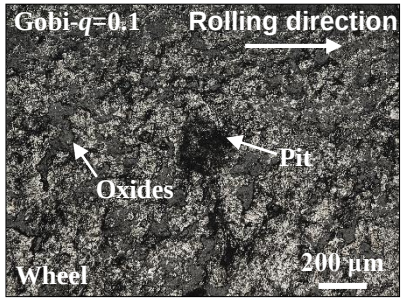
1.2 Effect of windblown sand

RCF Wheel

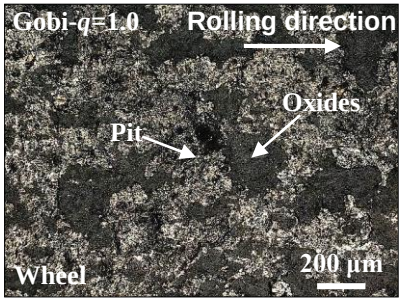


No sand

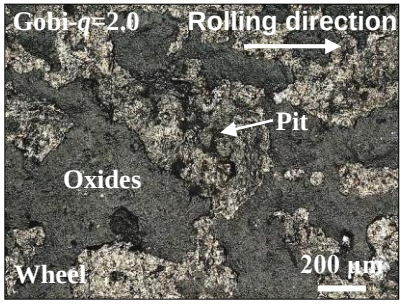
Feed rate=0.1



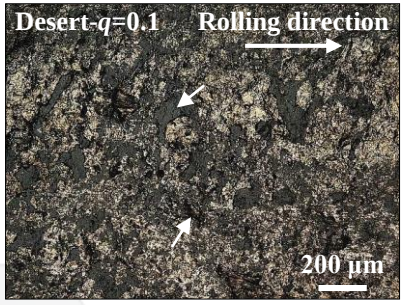
Feed rate=1.0

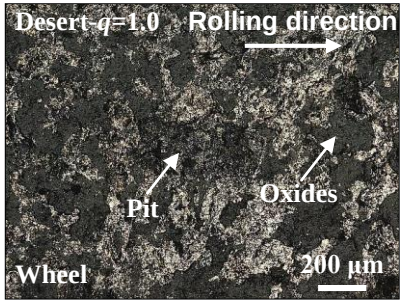


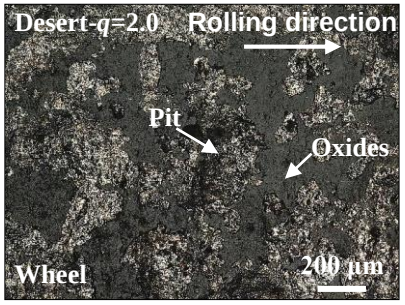
Feed rate=2.0



Gobi







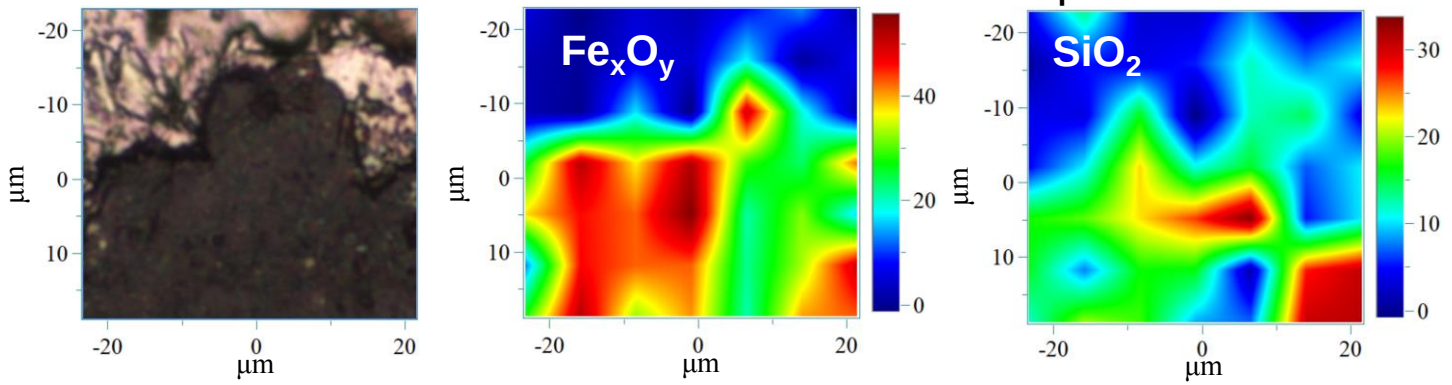
Desert

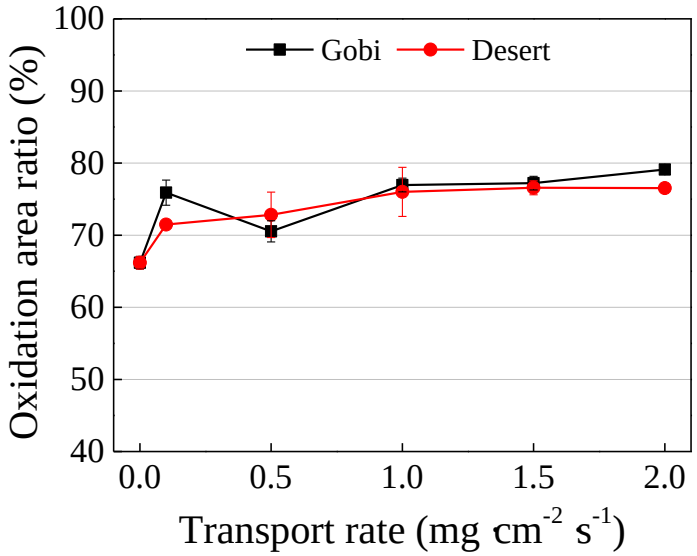
Oxides

1.2 Effect of windblown sand

RCF Wheel

Raman maps



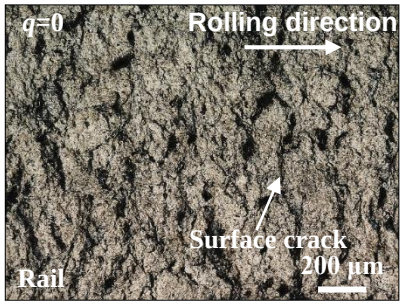


Oxides content ↗

1.2 Effect of windblown sand

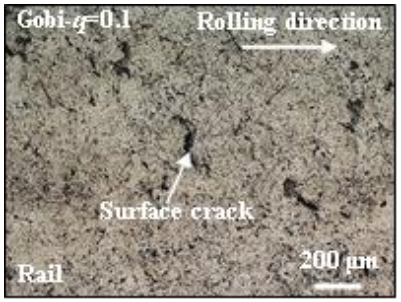
RCF

Rail

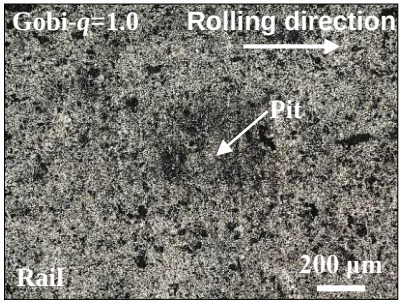


No sand

Feed rate=0.1



Feed rate=1.0



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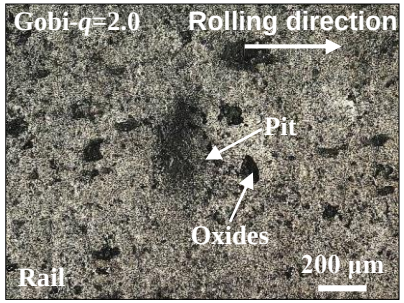
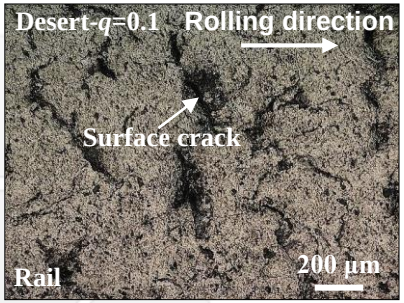
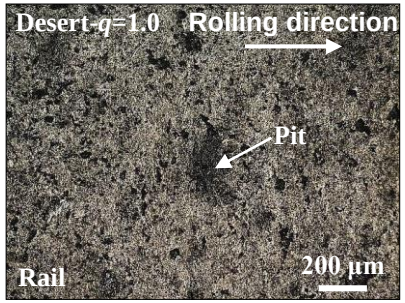
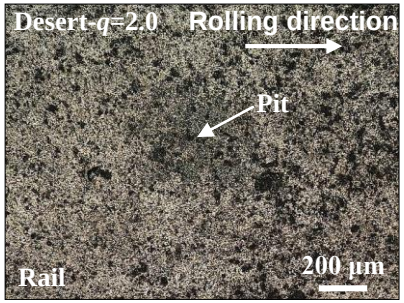


Gobi







Desert

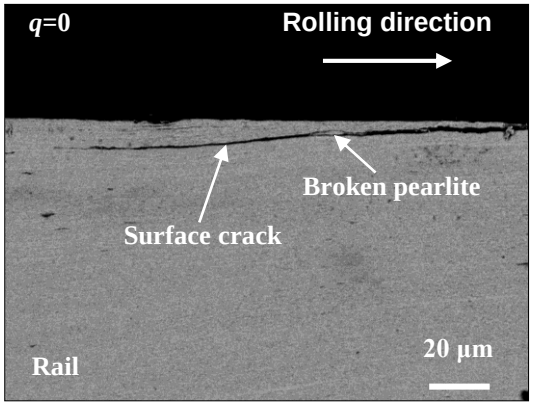
Surface damage

- **No sand : dense RCF**
- **Gobi < desert**
- **Feed rate ↗ : RCF↘**

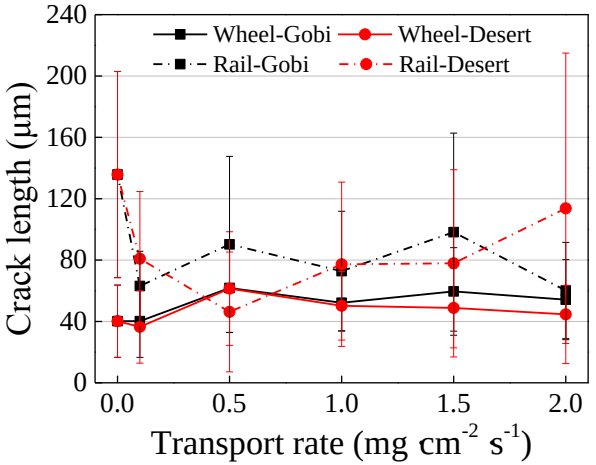
1.2 Effect of windblown sand

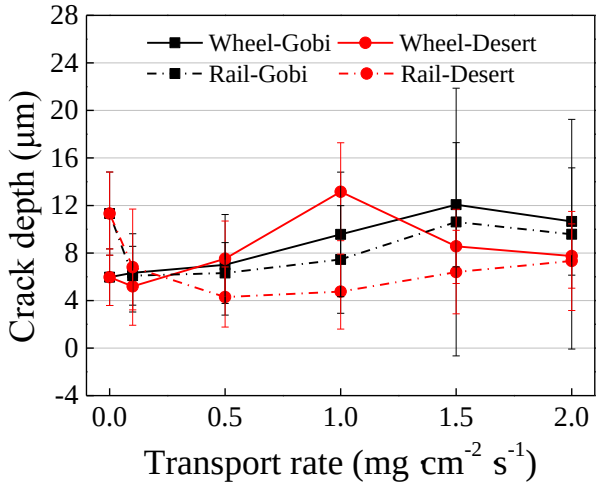
RCF

Rail

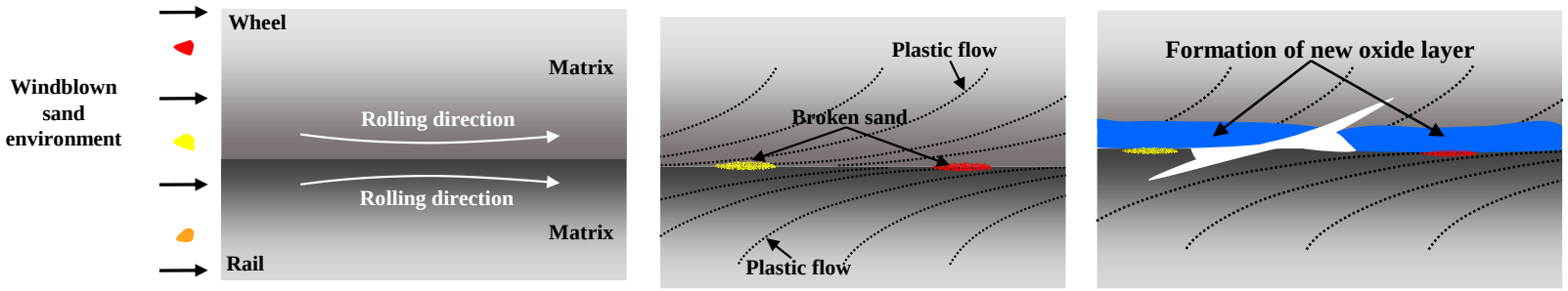


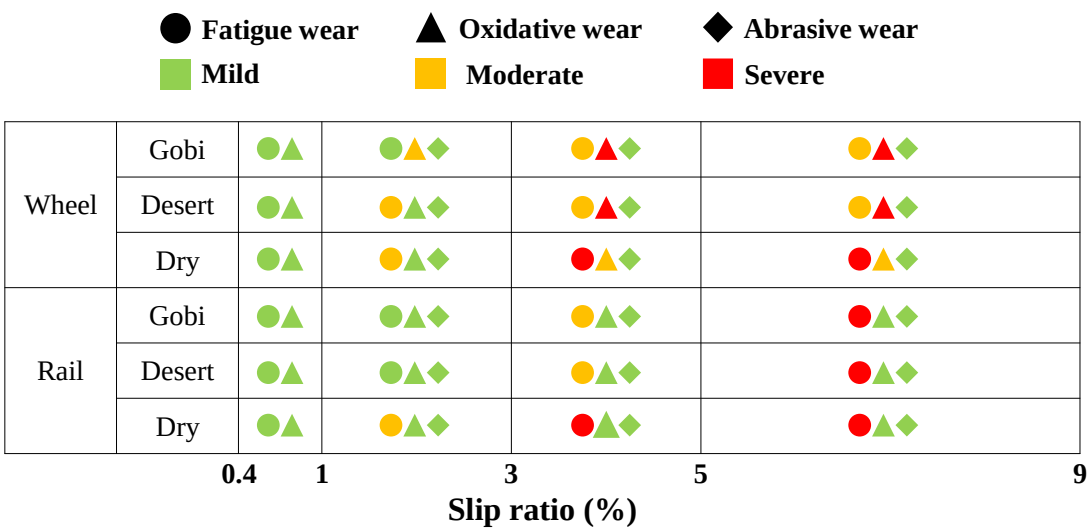
RCF observed on cross sections





1.2 Effect of windblown sand



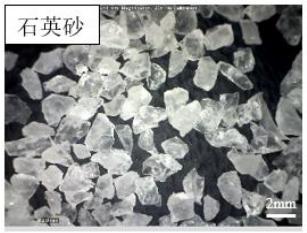


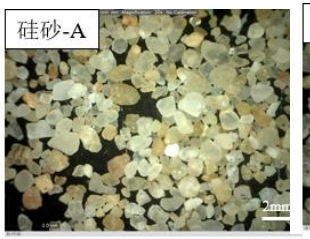
Windblown sand vs. Sanding

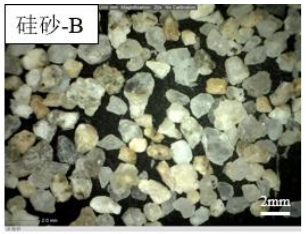
≈35μm

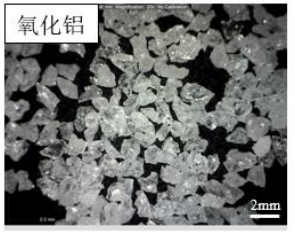
≈270μm

□ For sanding

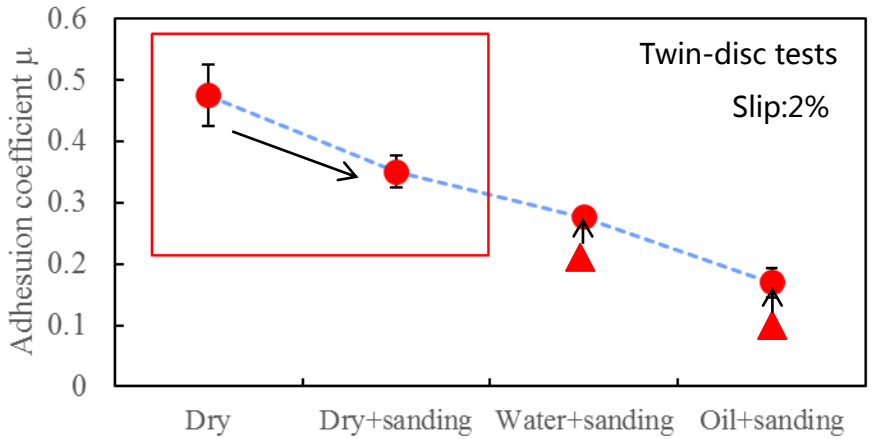








>1mm



Content

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- Low temperature
- Windblown sand condition

2. Microstructure evolution of wheel/rail materials

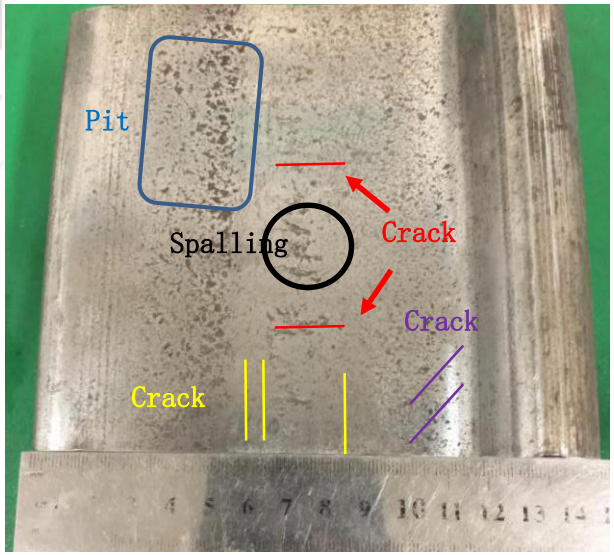
3. Wear and RCF prediction

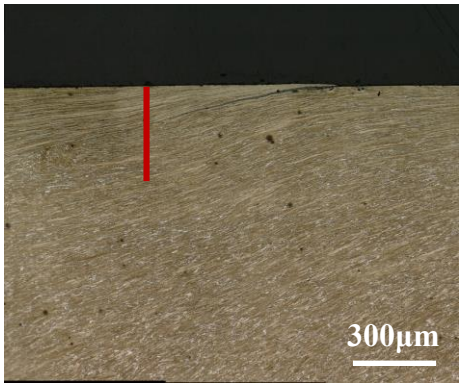
- Wear rate−Tγ/A
- Shakedwon map

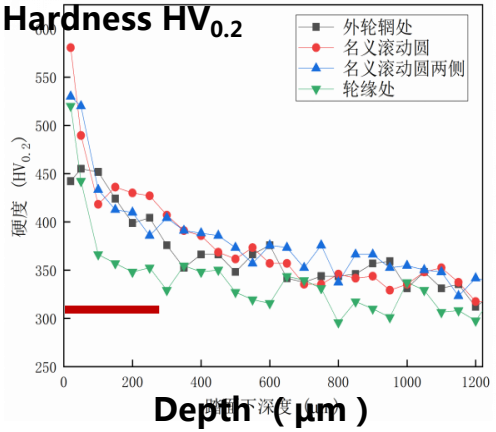
4. Rail grinding

2. Microstructure evolution of wheel/rail materials

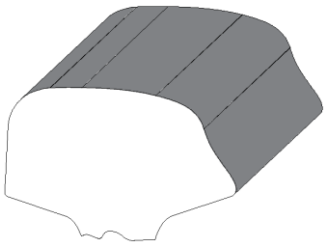
Locomotive wheel





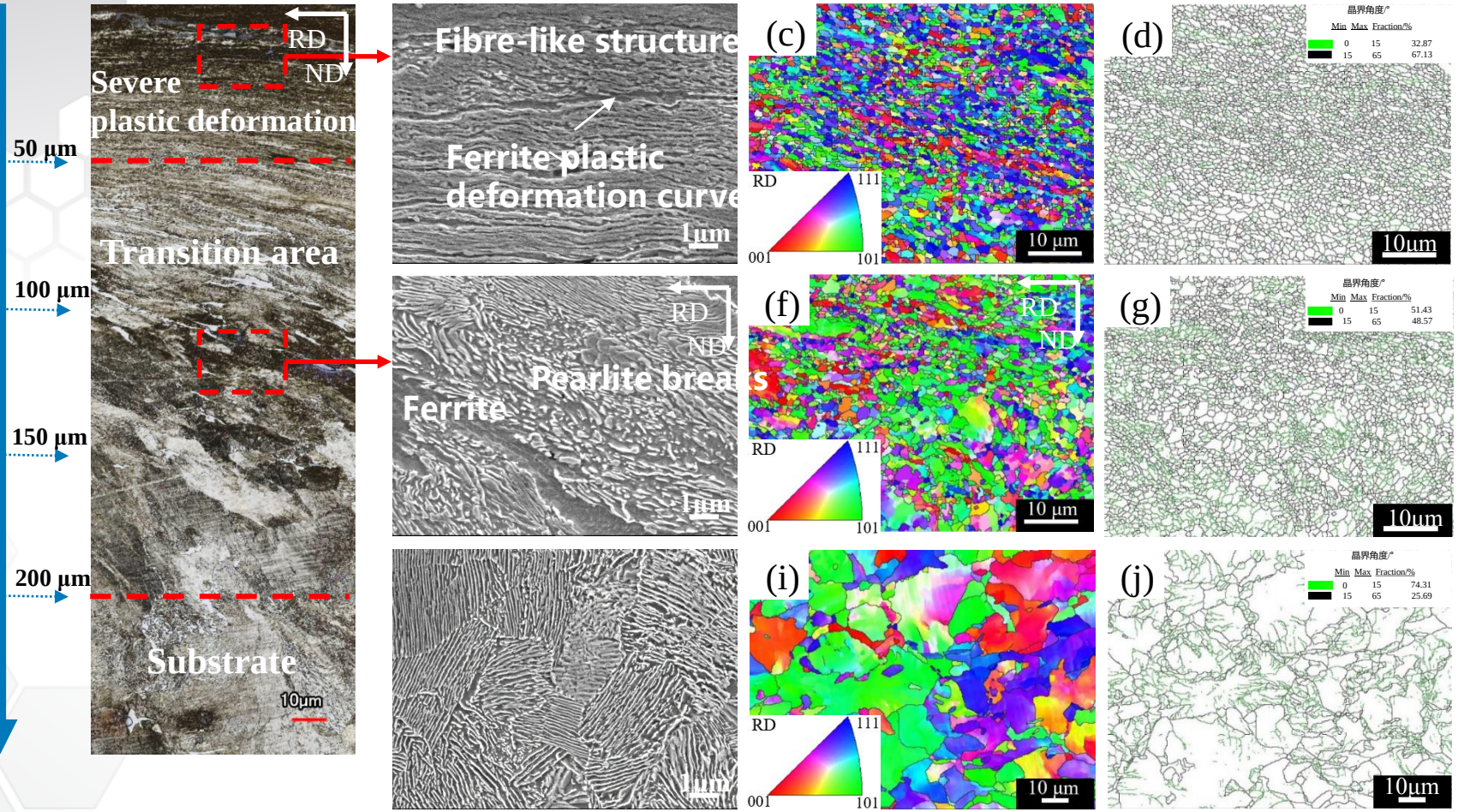


Rail



2. Microstructure evolution of wheel/rail materials

Wheel，0.91%，850MPa



OM **SEM**

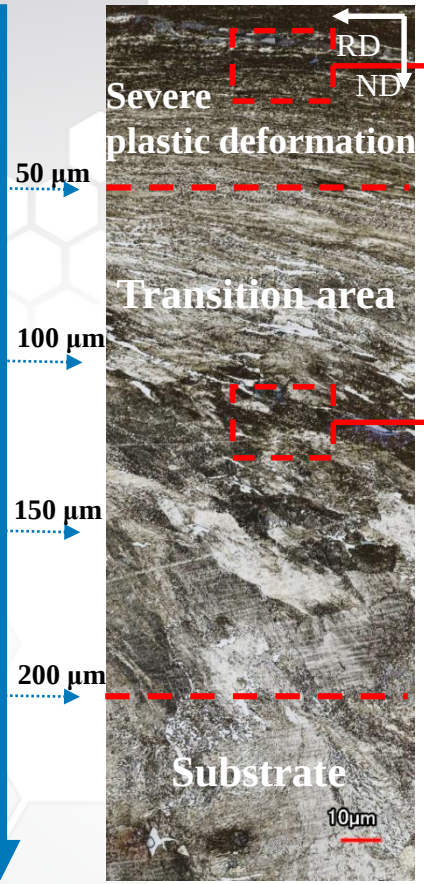
inverse pole figure（IPF）
color—crystal orientation

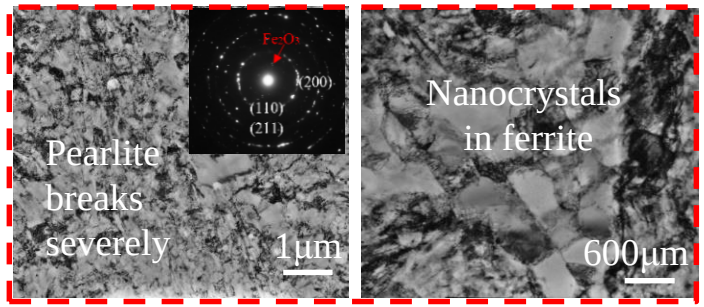
Grain boundary figure
Black: HAGBs
Green: LAGBs

- **Pearlite breaks**
- **Ferrite plastic deformation curve**
- **Fibre-like structure**
- **Grain size decreases**

2. Microstructure evolution of wheel/rail materials

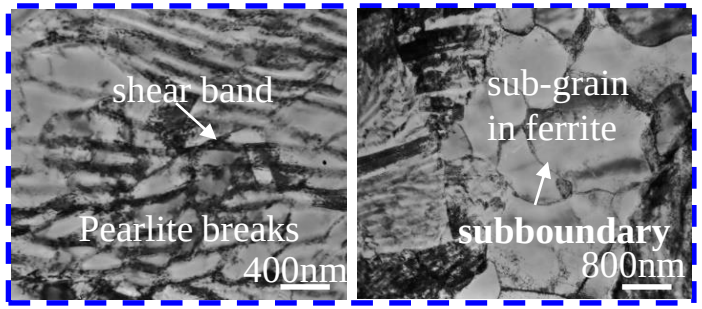
Wheel，0.91%，850MPa





Severe plastic deformation

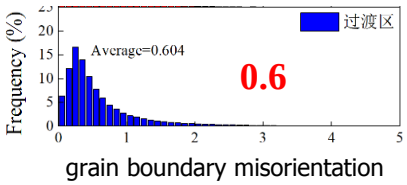
- Pearlite breaks severely
- Nanocrystal structure

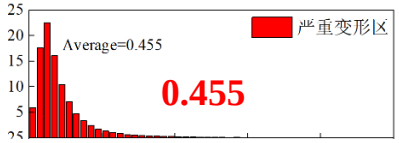


Transition area

- Shear band
- Sub-grain

Transition area → **Severe plastic deformation**





HAGBs：48.57%

HAGBs：67.13%

Dislocation density ↓

- Recrystallization

HAGB ↑

Content

1. Wear and RCF of wheel/rail under complex environment

- Low temperature
- Windblown sand condition

2. Microstructure evolution of wheel/rail materials

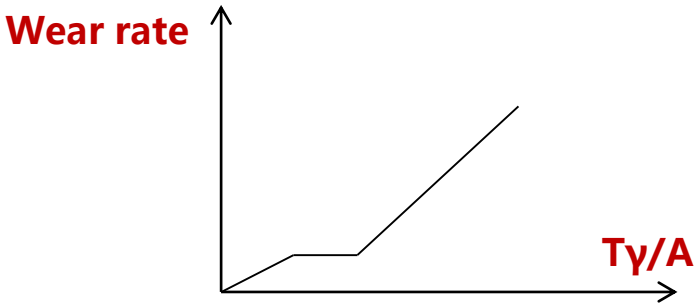
3. Wear and RCF prediction

- Wear rate−Tγ/A
- Shakedwon map

4. Rail grinding

3.1 Wear rate – Tγ/A model

Wear rate – Tγ/A model : basis of wear prediction



Wear rate : μg/m/mm²

T : tangential force
γ : slip ratio
A : contact area

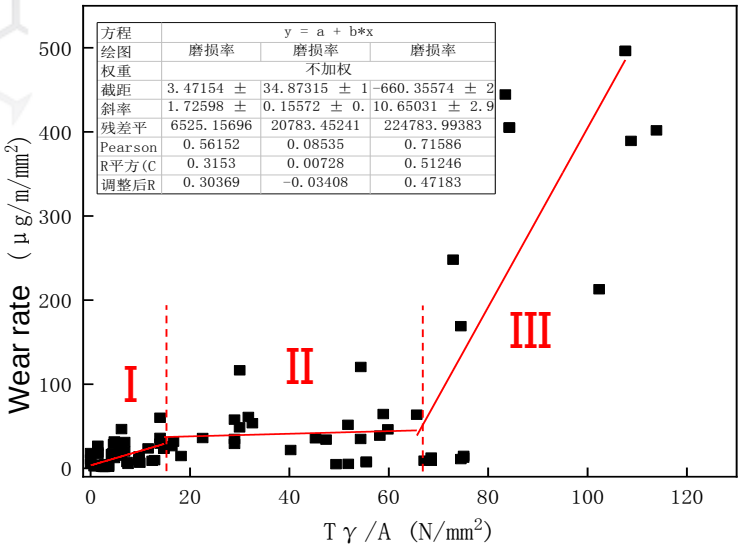
Construction of Wear rate – Tγ/A model for individual mateiral

Twin-disc tests

Axle load
Speed
Slip ratio

3.1 Wear rate – Tγ/A model

U75V rail

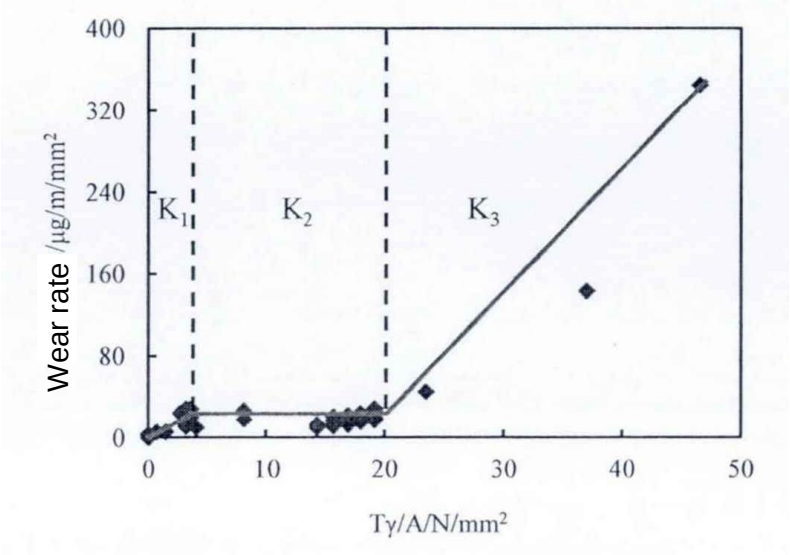


I region : y = 1.73x + 3.5

II region : y = 0.16x + 34.9

III region : y= 10.7x - 660

CL60 wheel



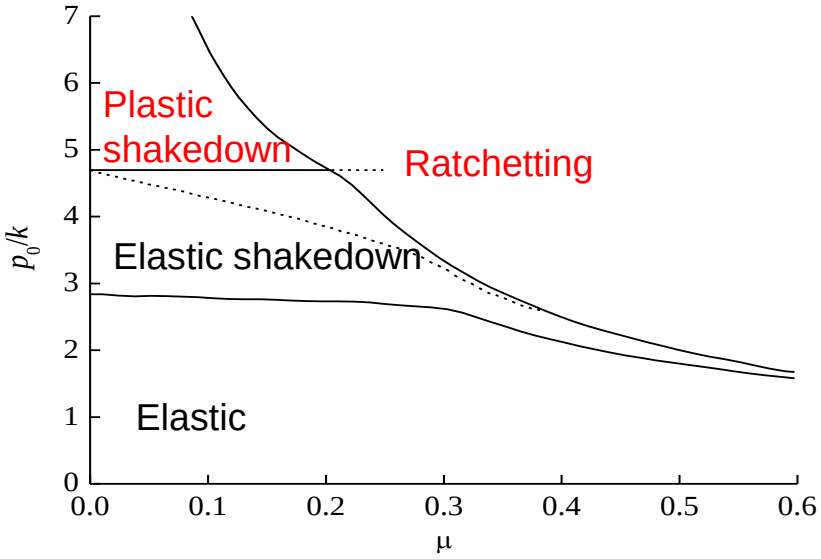
I region : y = 3.58x (x<5)

II region : y = 17.9 (5<x<20)

III region : y= 12.3x – 228 (20<x)

3.2 Shakedown map construction

Shakedown map : basis of RCF prediction



p_0: maximum contact pressure

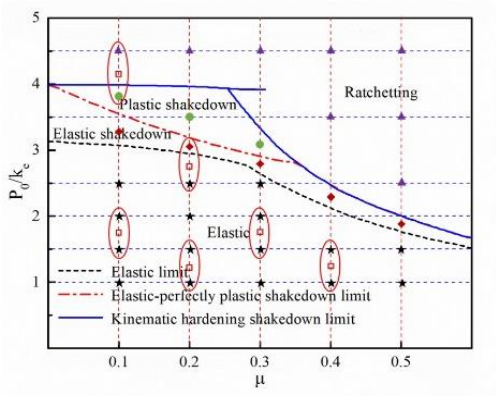
k: pure shear yield strength

μ: traction coefficient

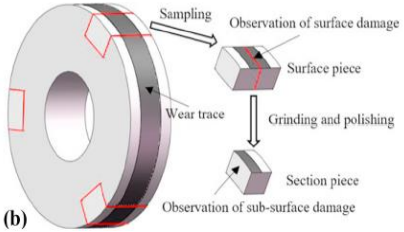
- Plastic shakedown region
- Ratchetting region

3.2 Shakedown map construction

Construction of shakedown map for individual mateiral



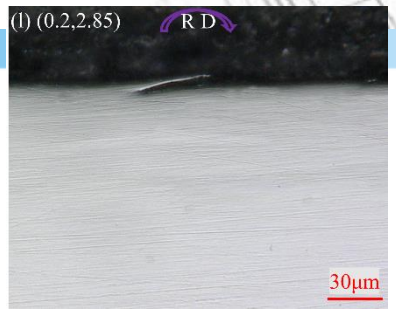
- ❖ U75V rail
- ❖ Experimental details
  - Different μ values: via different slip ratios
  - Different P_0 values
- ❖ Analysis of samples



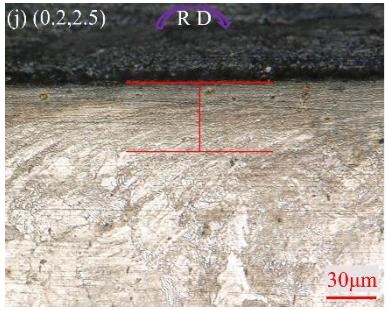
- ❖ Stable wear/damage state: 40 000 cycles
- ❖ Determination of damage types, i.e. shakedown map regions
  - ❖ Ratchetting region: RCF cracks
  - ❖ Plastic shakedown region: No cracks + plastic flow
  - ❖ Elastic shakedown region：No plastic flow
  - ❖ Elastic region

3.2 Shakedown map construction

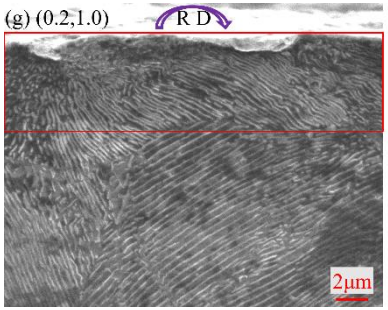
- Ratchetting region: RCF cracks



- Plastic shakedown region: No cracks + plastic flow



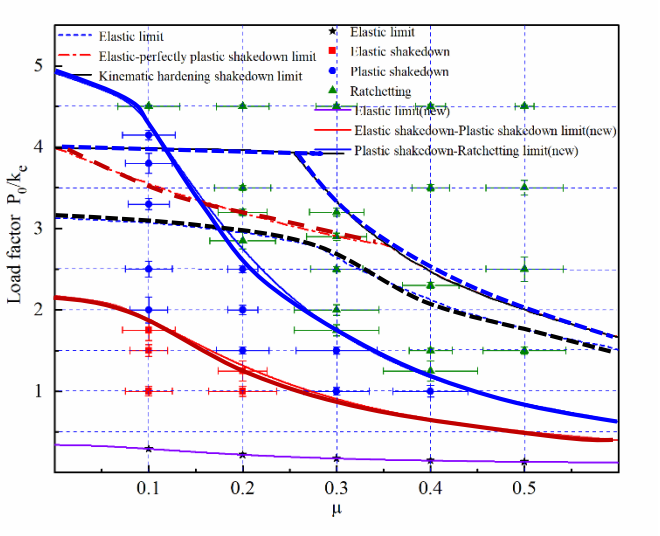
- Elastic shakedown region： No plastic flow



- Elastic region

3.2 Shakedown map construction

- U75V rail



- Boundaries were drawn according to the RCF damage

Content

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4. Rail grinding

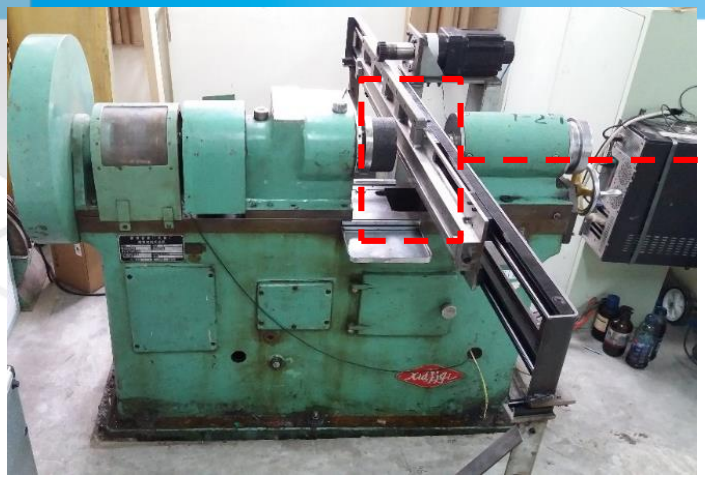
4 Rail grinding

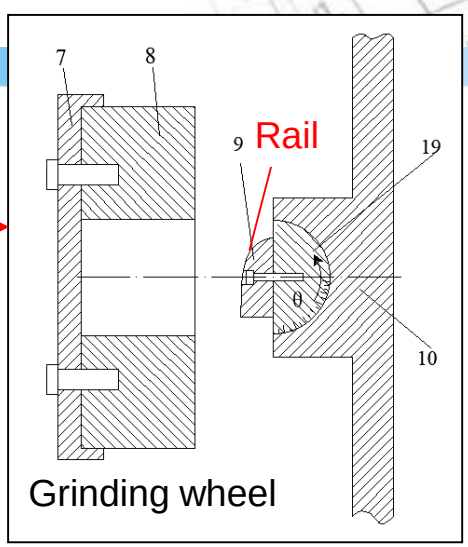
RCF damage

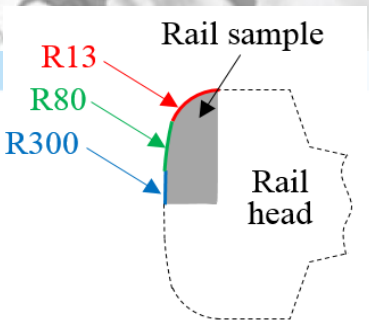
Profile change (wear)

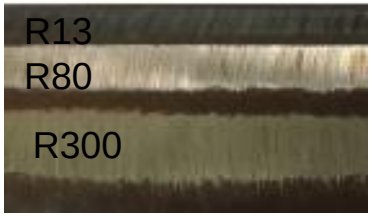
Rail grinding

4 Rail grinding





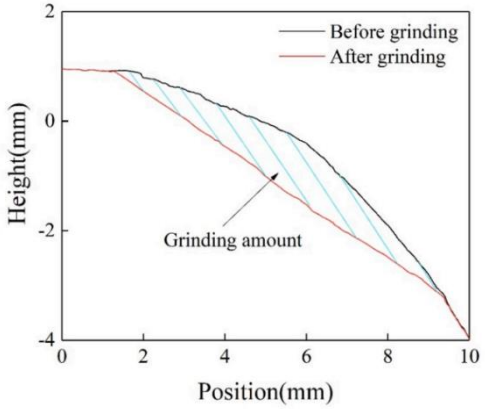


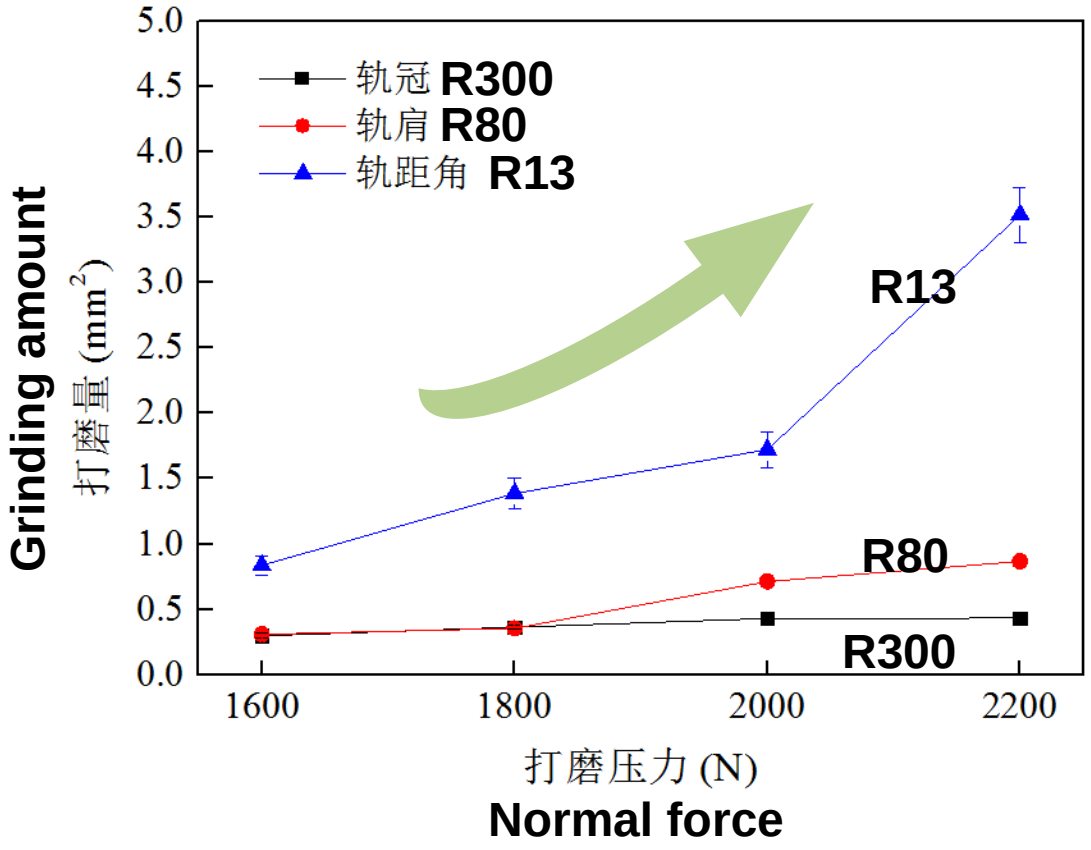


Position	Normal force	Forward speed（km/h）	Rotational speed of stone（r/min）
R13, R80, R300	1600, 1800, 2000, 2200	1, 2, 3, 4	2500, 3000, 3500, 4000

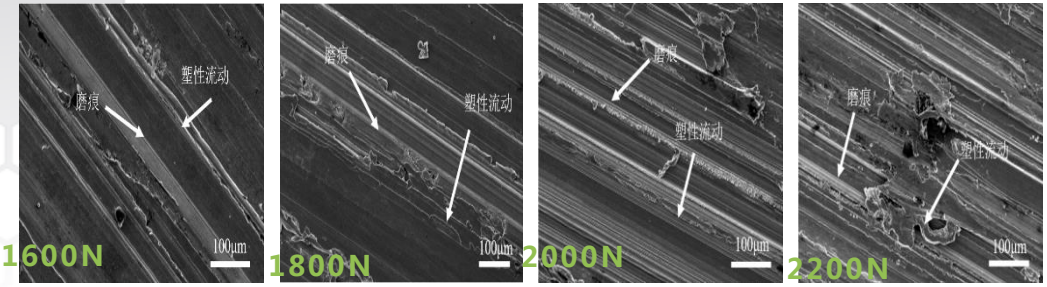
Analysis: surface mophology, burn, white etching layer, etc

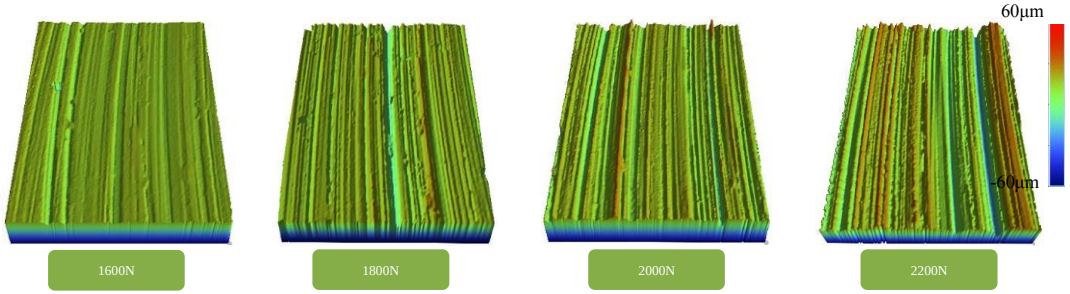
4 Rail grinding

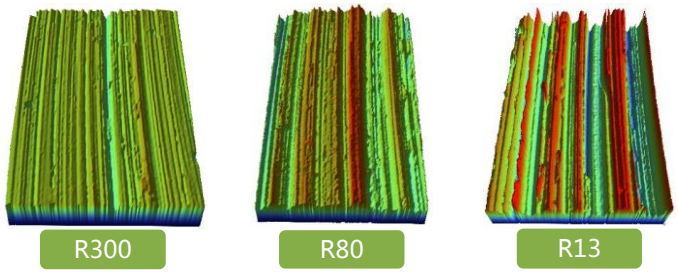


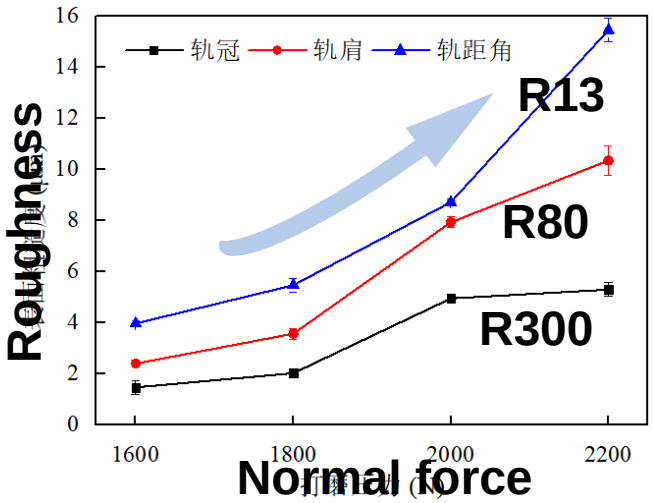


4 Rail grinding





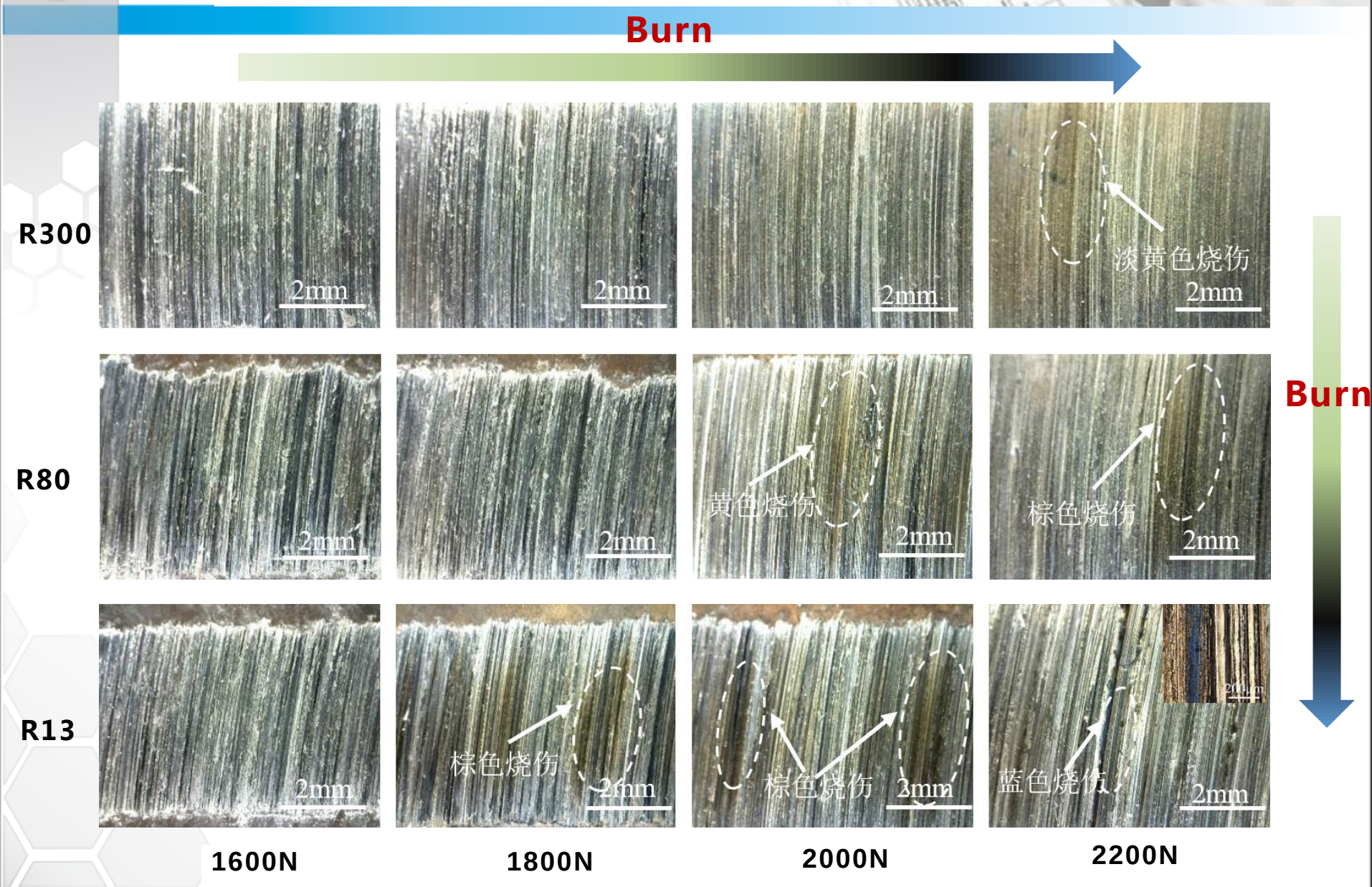




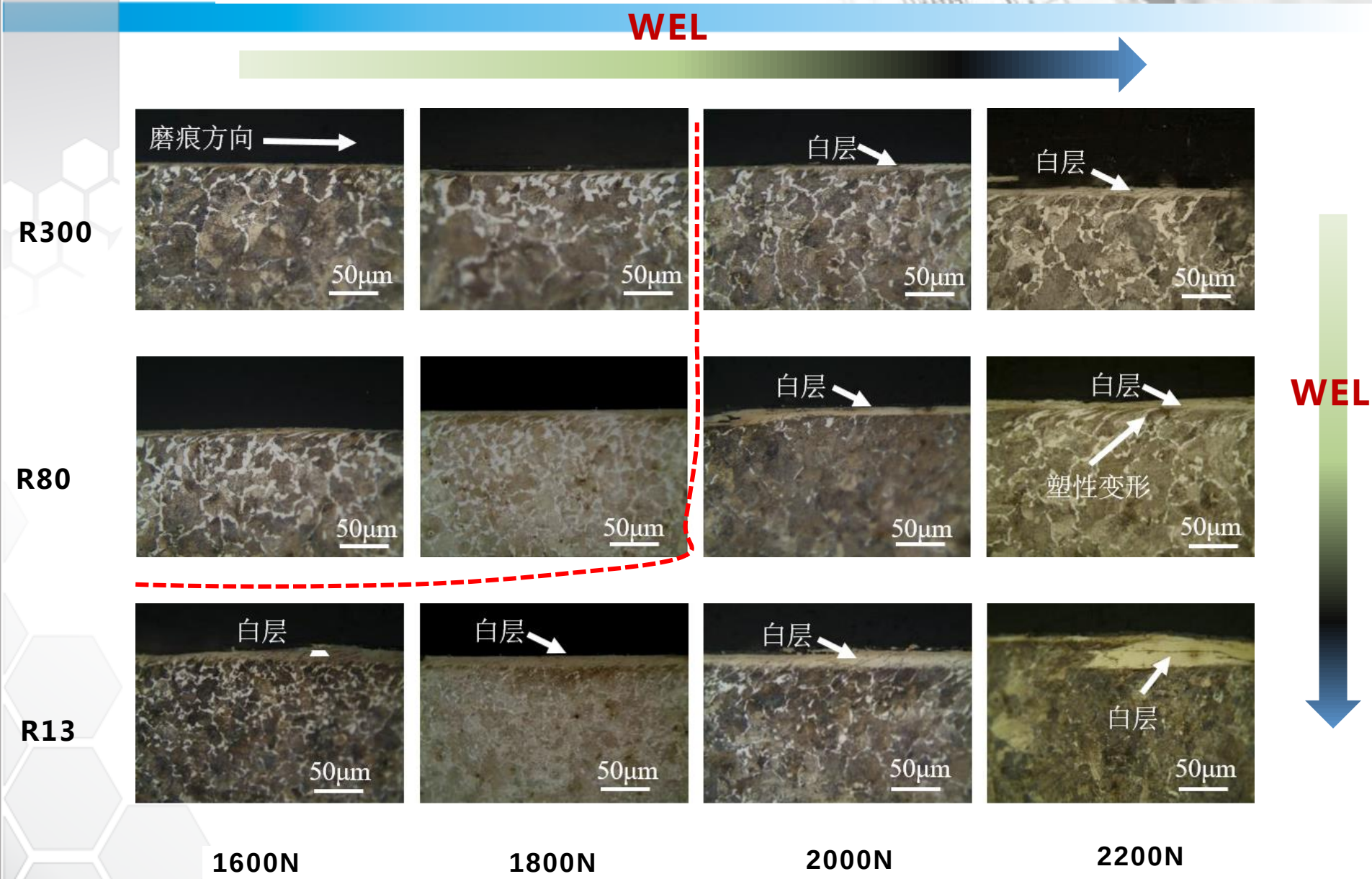
Normal force↗, roughness ↗

Radius↘， roughness ↗

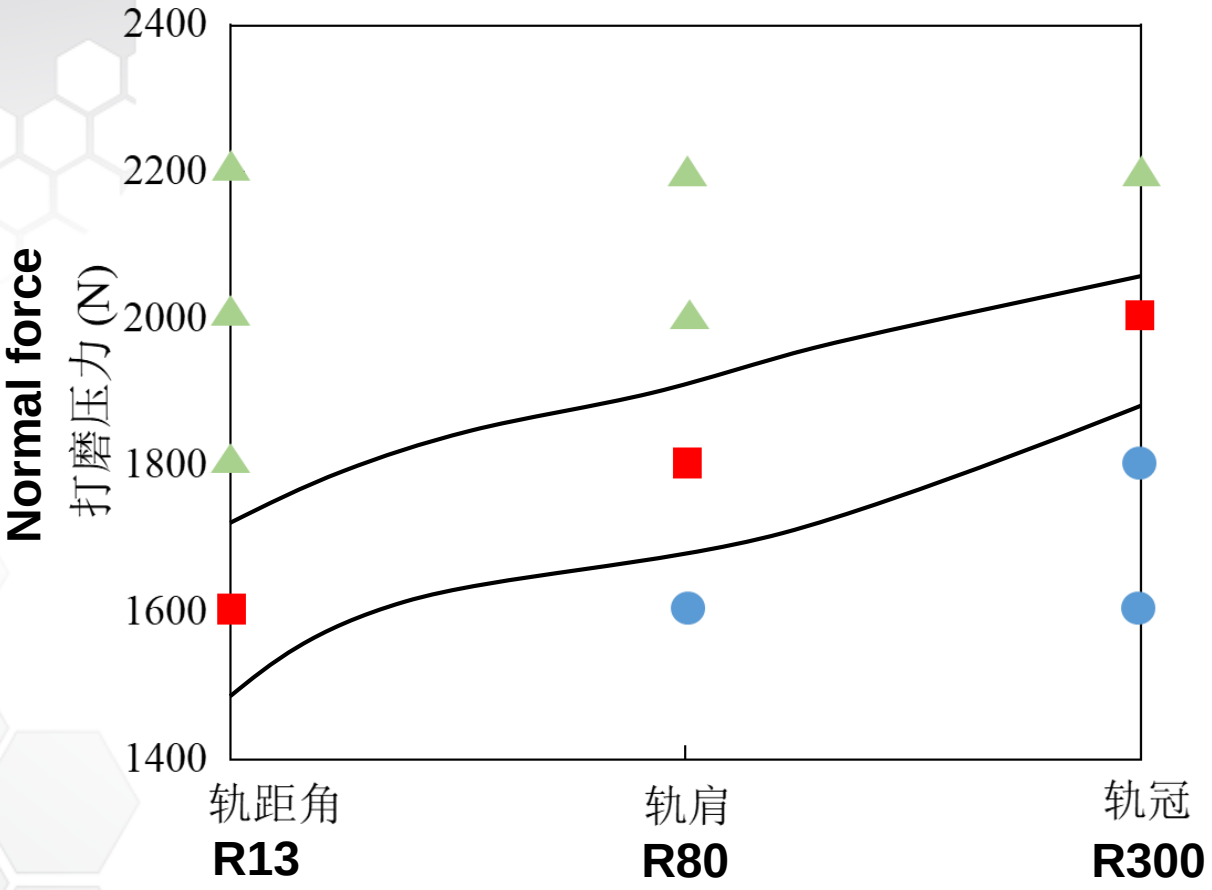
4 Rail grinding



4 Rail grinding



4 Rail grinding

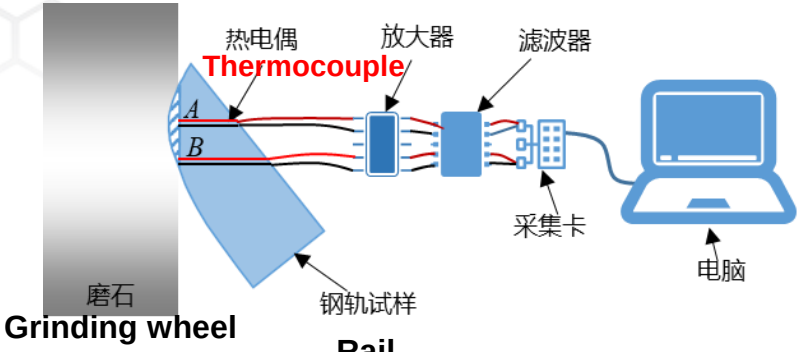


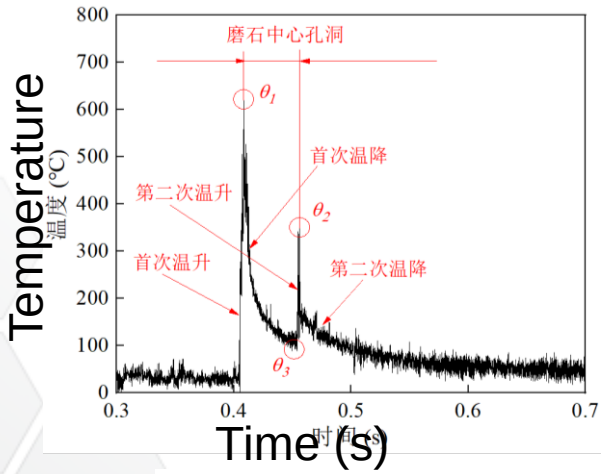
- Good efficiency, bad quality
- Good efficiency, good quality
- Bad efficiency, good quality

4 Rail grinding

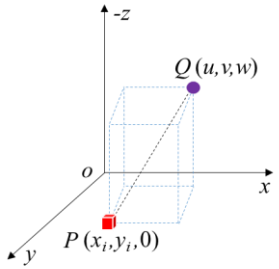
Grinding heat

Experiments

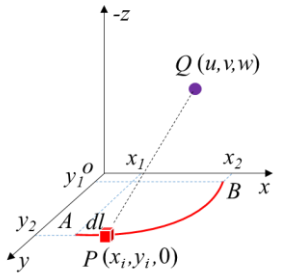




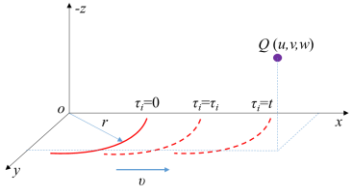
Numerical calculation

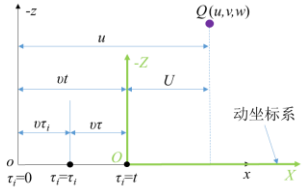


$$d\theta=\frac{q_l dl}{c\rho(4\pi\alpha\tau)^{3/2}}e^{\frac{(u-x_i)^2+(v-y_i)^2+w^2}{-4\alpha\tau}}$$



$$\theta=\int_{y_1}^{y_2}\frac{q_l}{c\rho(4\pi\alpha\tau)^{3/2}}e^{\frac{(u-\sqrt{r^2-y^2})^2+(v-y)^2+w^2}{-4\alpha\tau}}\sqrt{1+\frac{y^2}{r^2-y^2}}dy$$





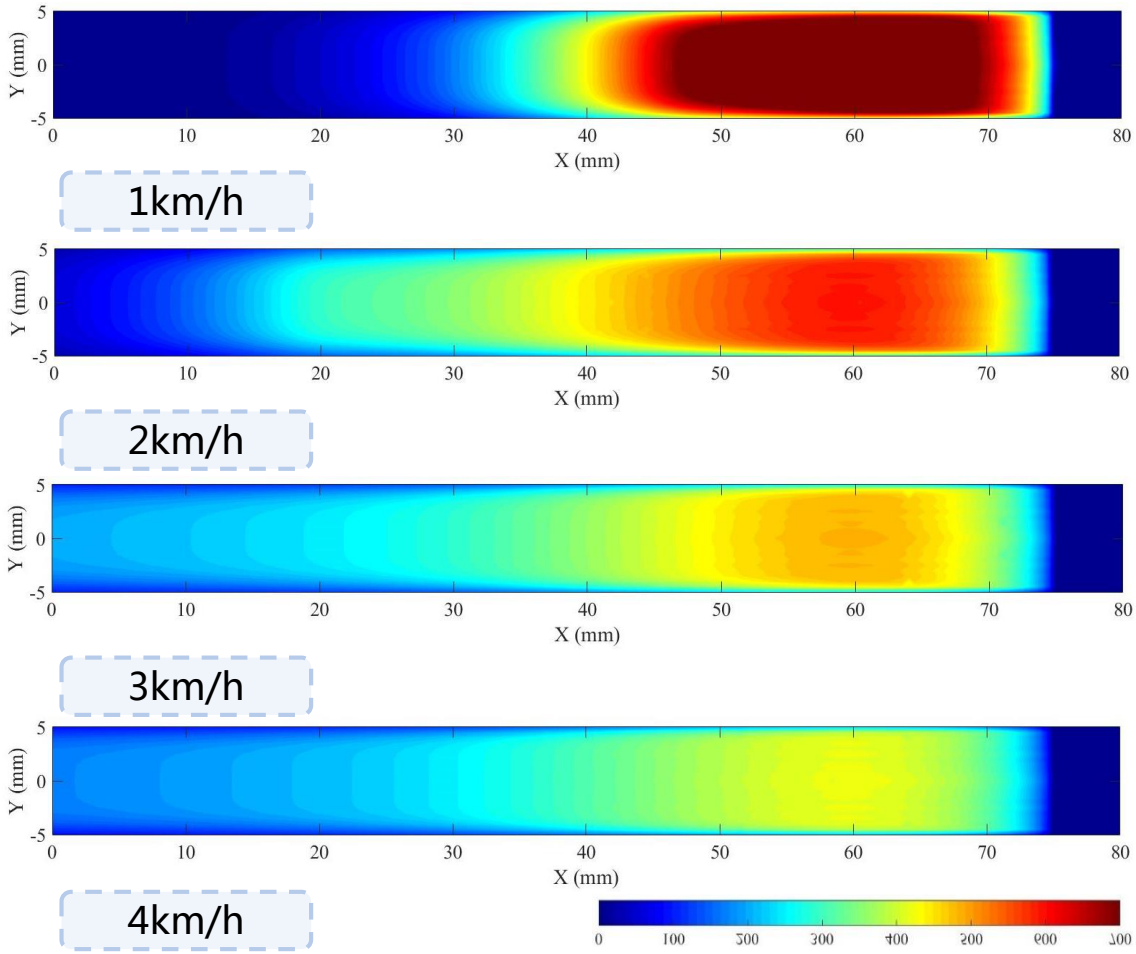
$$\theta=\int_0^t\int_{y_1}^{y_2}\frac{q_l}{c\rho(4\pi\alpha\tau)^{3/2}}e^{\frac{\left(U+v_\omega\tau-\sqrt{r^2-y^2}\right)^2+(V-y)^2+W^2}{-4\alpha\tau}}\sqrt{1+\frac{y^2}{r^2-y^2}}dld\tau$$

$$\theta=\int_{R_1}^{R_2}\int_0^t\int_{y_1}^{y_2}\frac{q_r}{c\rho(4\pi\alpha\tau)^{3/2}}e^{\frac{(U+v_\omega\tau-\sqrt{r^2-y^2})^2+(V-y)^2+W^2}{-4\alpha\tau}}\sqrt{1+\frac{y^2}{r^2-y^2}}dld\tau dr$$

4 Rail grinding

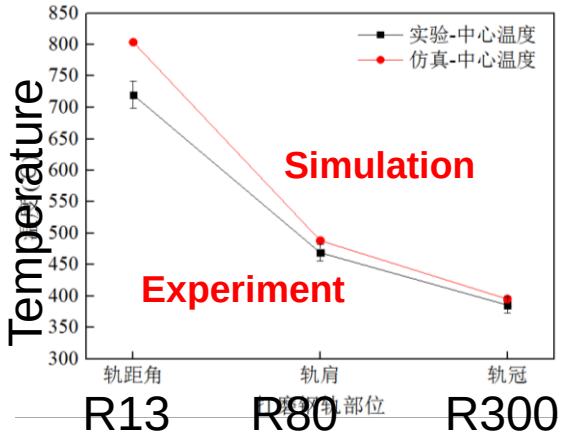
Grinding heat

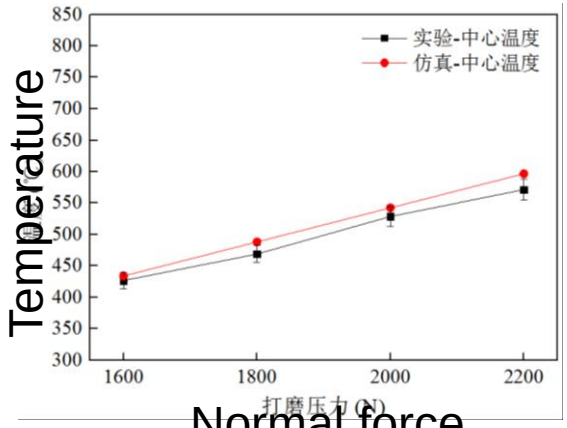
Forward speed

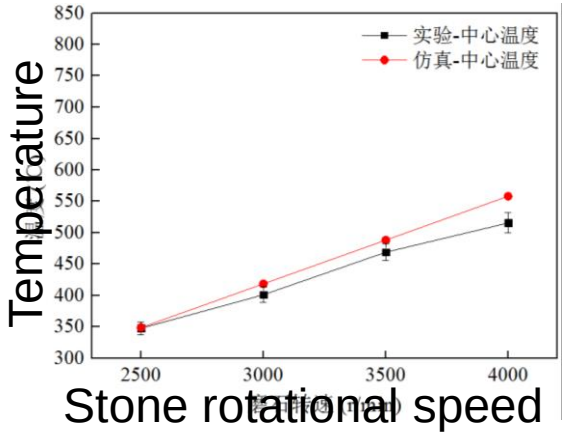


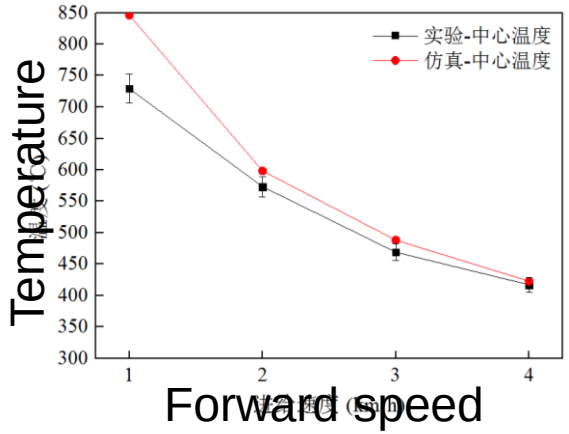
4 Rail grinding

Grinding heat



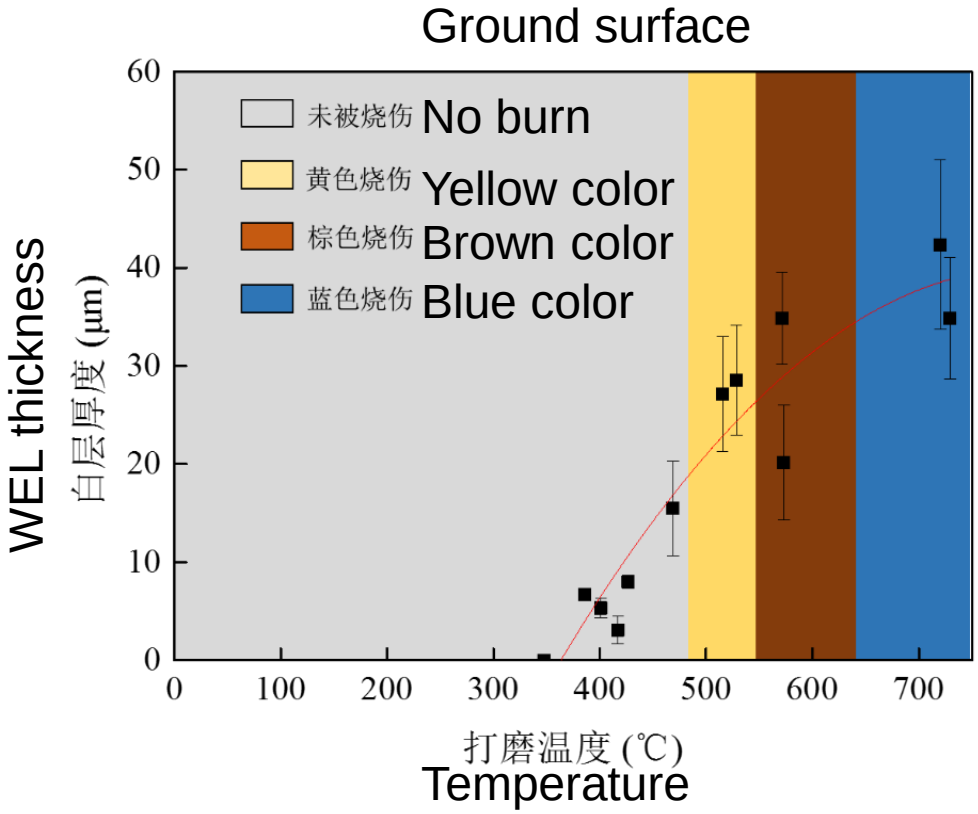






4 Rail grinding

Grinding heat



Temperature vs. WEL thickness

Summary

1. Wear and RCF of wheel/rail under complex environment

- Low temperature: brittleness & RCF↗
- Windblown sand condition : CoA & Wear ↘

2. Microstructure evolution of wheel/rail materials

3. Wear and RCF prediction

- Wear rate−Tγ/A
- Shakedwon map

4. Rail grinding

Grinding parameters VS. grinding efficiency and quality

Thank you for your attention !

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