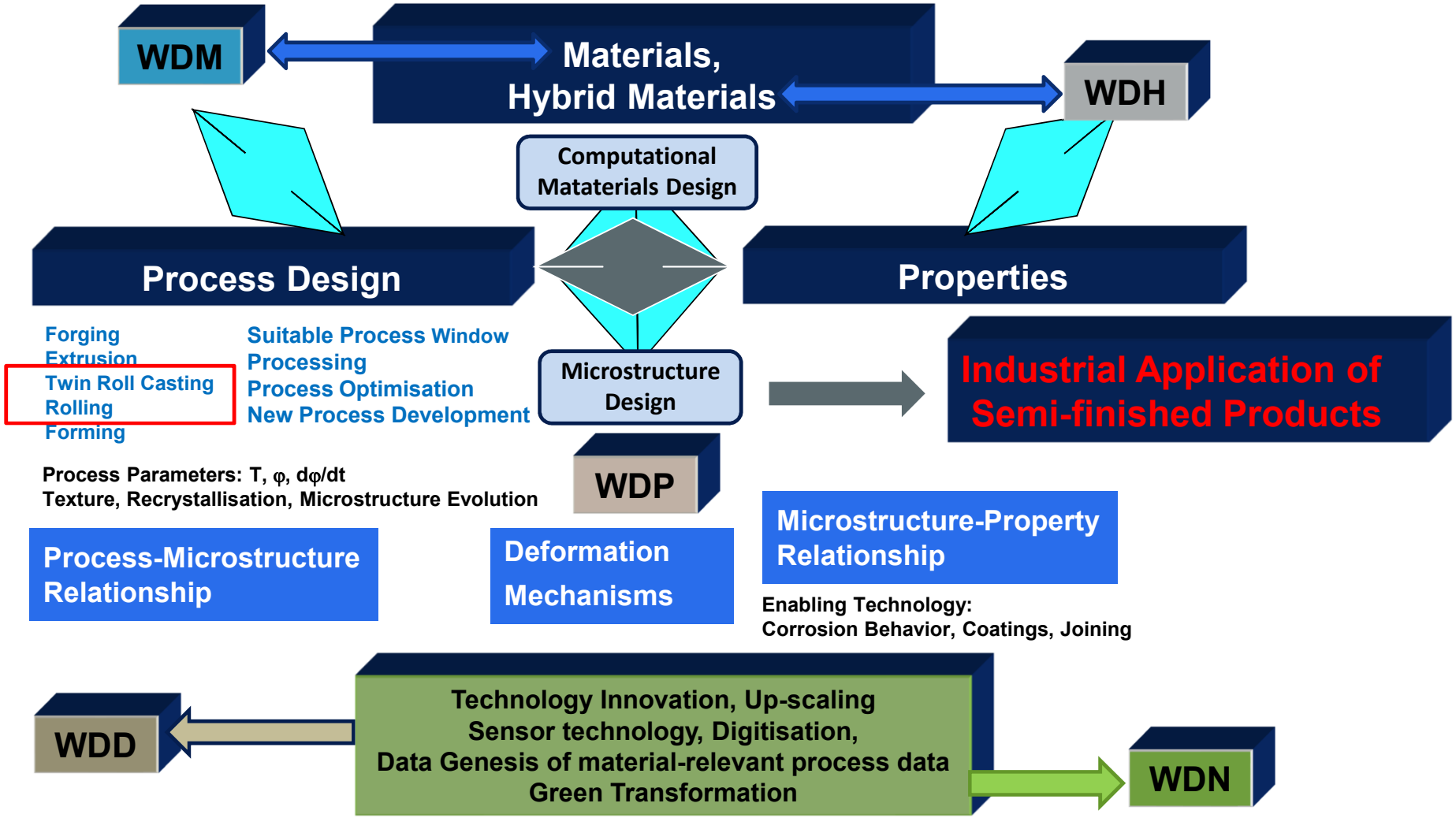
Program MSE
MSE Day 18.11.2022

# Improving the forming behavior and precipitation hardness of the ductile Magnesium alloy ZAX210 by TRC

Dr. Sumi Jo and Dr. Gerrit Kurz

HELMHOLTZ

# Institute of Materials and Process Design (WD)



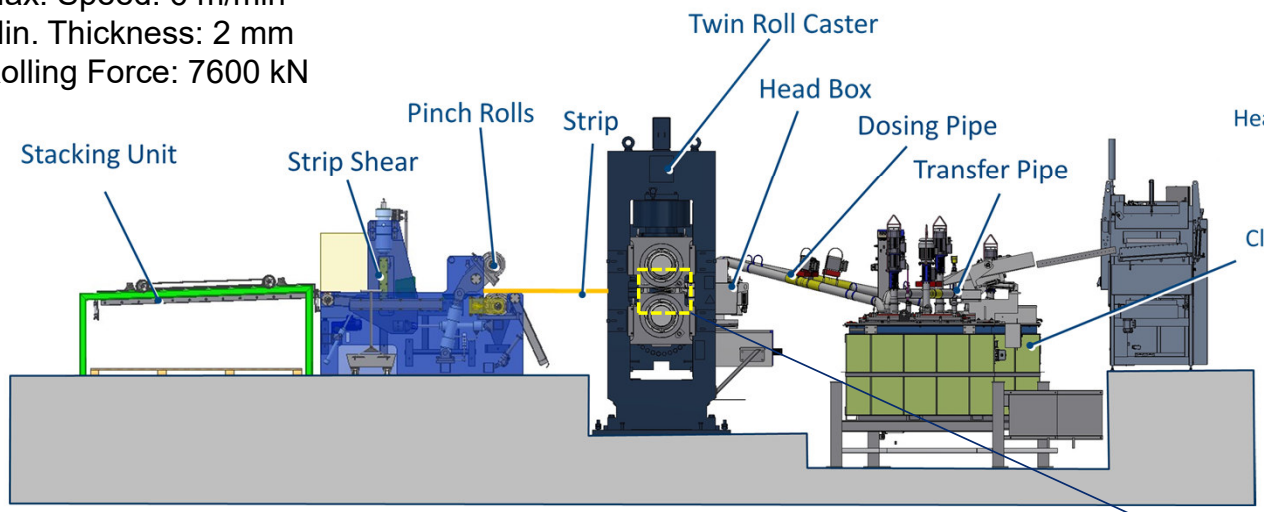
# Pilot-scale Instrument

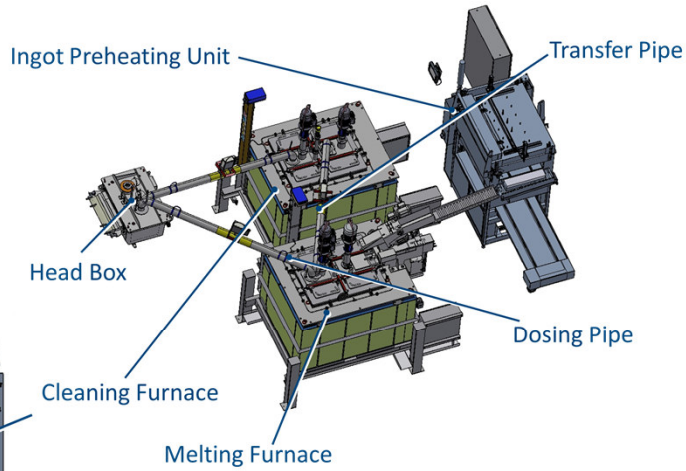
# Twin roll caster (TRC) and furnace line



**Technical Data Twin Roll Caster**

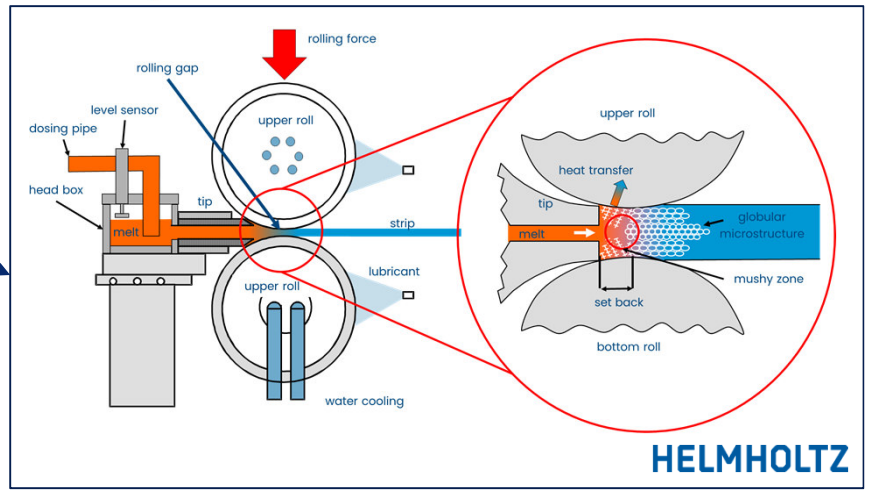
Strip Width: 125 / 350 / 650 mm
Roll Diameter: 600 mm
Max. Speed: 6 m/min
Min. Thickness: 2 mm
Rolling Force: 7600 kN




**Technical Data Furnace Line**

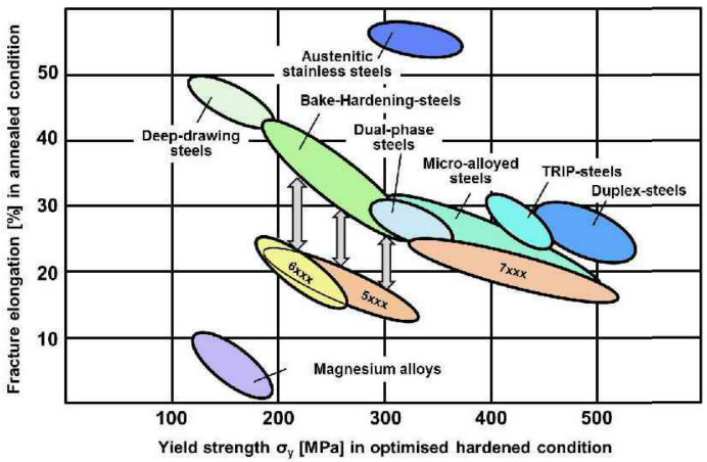
Volume of the Furnaces: 2 x 900 kg
Max. temperature: 750 °C
Temperature Accuracy: +/- 3 °C

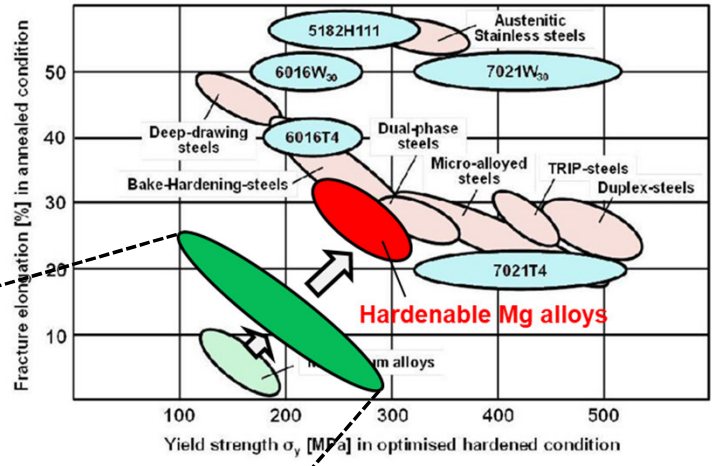


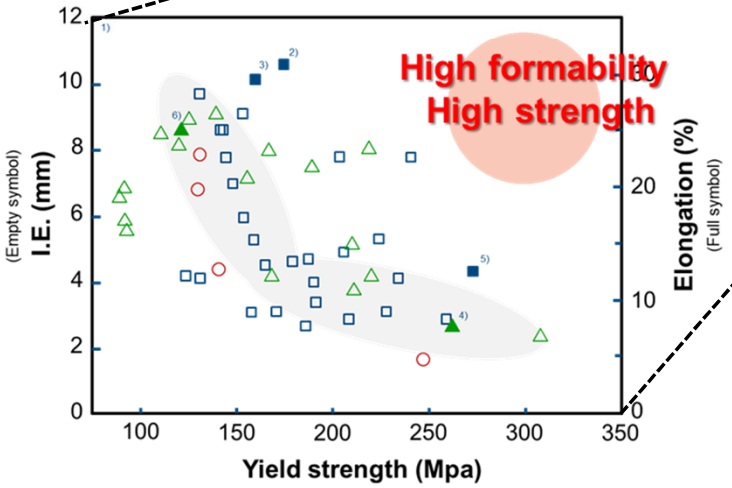
# Why heat-treatable wrought Mg alloys should be investigated?



7) **Development of high strength and ductility Strength and ductility of Steel, Al and Mg alloys**




□ ■ Al-based alloys

△ ▲ Zn-based alloys

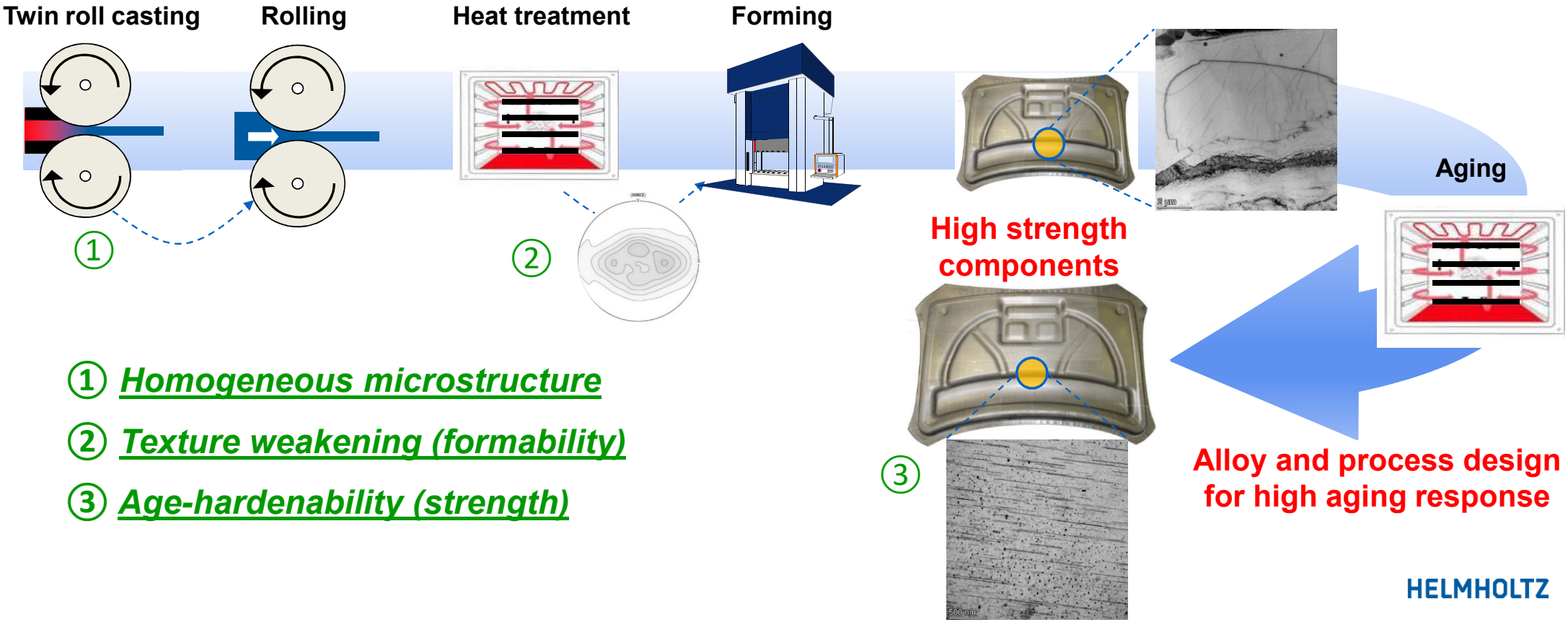
○ RE-based alloys


1) M.Z. Bian et al., Acta Mater. 158 (2018) 278-288
2) R. Pei. et al., Mater. Sci. Eng. A 763 (2019) 138112
3) T. Nakata et al., Scripta Mater. 180 (2020) 16–22
4) T. Nakata et al., Mater. Sci. Eng. A 772 (2020) 138690
5) T. Nakata et al., Mater. Sci. Eng. A 737 (2018) 223-229
6) Y. Chino et al., Mater. Trans. 51 (2010) 818-821
7) R. Schneider et al., https://doi.org/10.1177/1464420713501734

## Research Background

# TRC as a key process for age-hardenability and texture modification

- **Process for age-hardenable Magnesium alloy component**




① ***Homogeneous microstructure***

② ***Texture weakening (formability)***

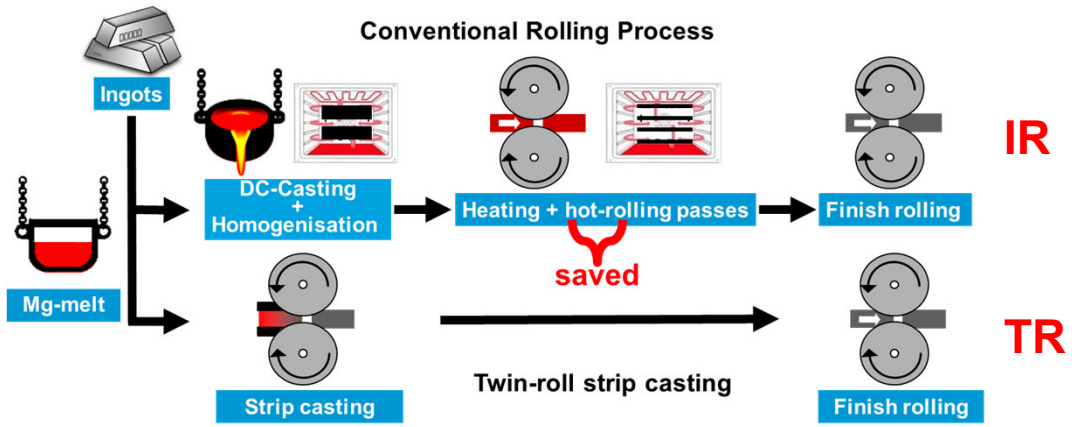
③ ***Age-hardenability (strength)***

HELMHOLTZ

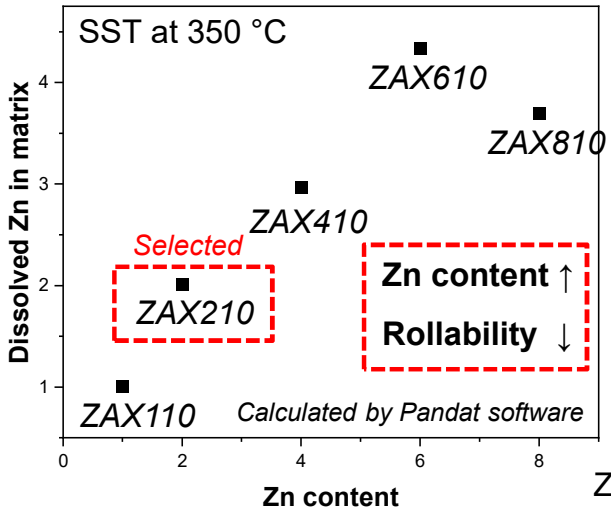
# Experimental Procedure

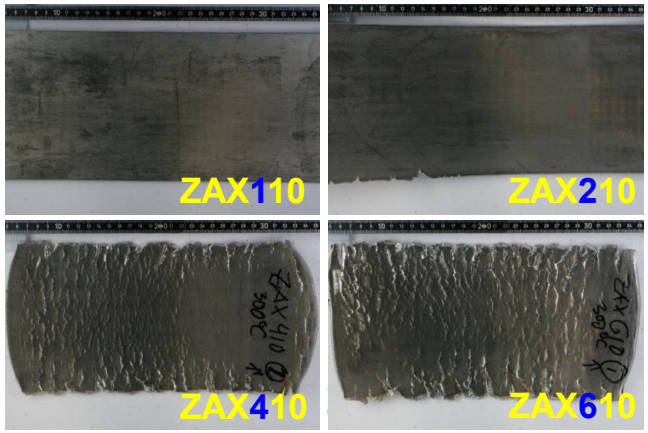
# ZAX210 alloys manufactured by using different feedstocks



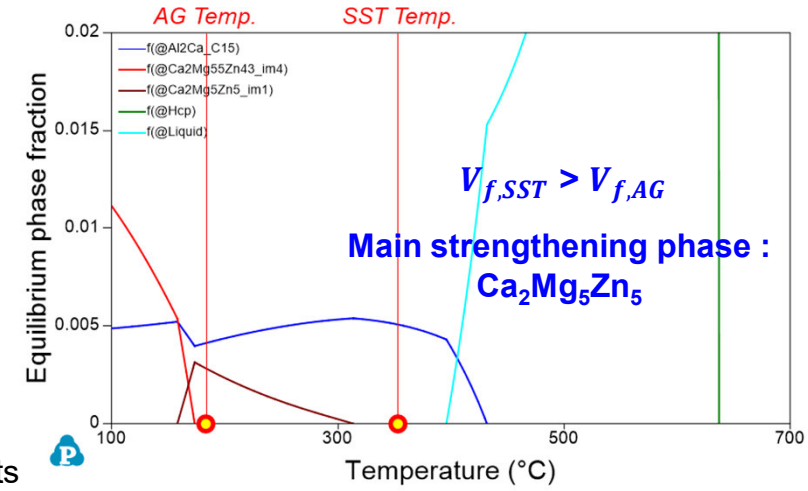



| TRC-rolling sheet (TR) | Ingot-rolling sheet (IR) |
|---|---|
| **Twin-Roll Casting (TRC)**<br>- Casting temperature : 700 °C<br>- Casting speed : 1.4 – 1.5 m/min<br>- Colling rate : 10 K/min | **Casting**<br>- Casting into steel mould<br>- Protection gas Ar + $SF_6$<br>- Homogenization: 350°C for 3 hrs |
| **Hot Rolling**<br>- Rolling temperature: 350°C<br>- Initial thickness : 10 mm<br>- Reduction degree per step (φ) : 0.1 → 0.3 | **Hot Rolling**<br>- Rolling temperature: 350°C<br>- Initial thickness : 4 mm<br>- Reduction degree per step (φ) : 0.1 → 0.2 |




ZAXx10 alloy sheets after hot rolling by using the ingots

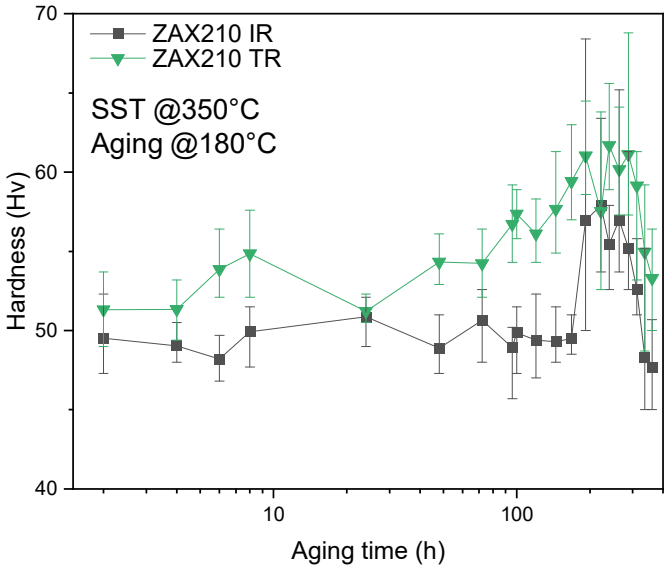


# Experimental Results

# Precipitation hardening of ZAX210 alloy sheets

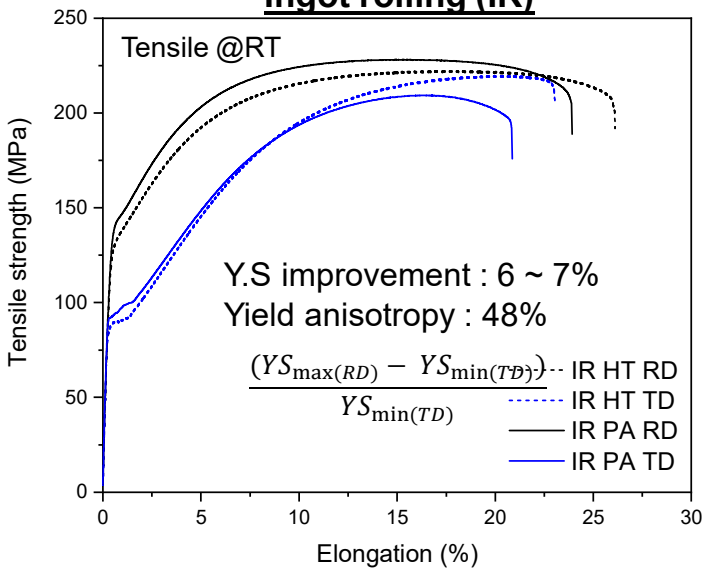


## Hardness

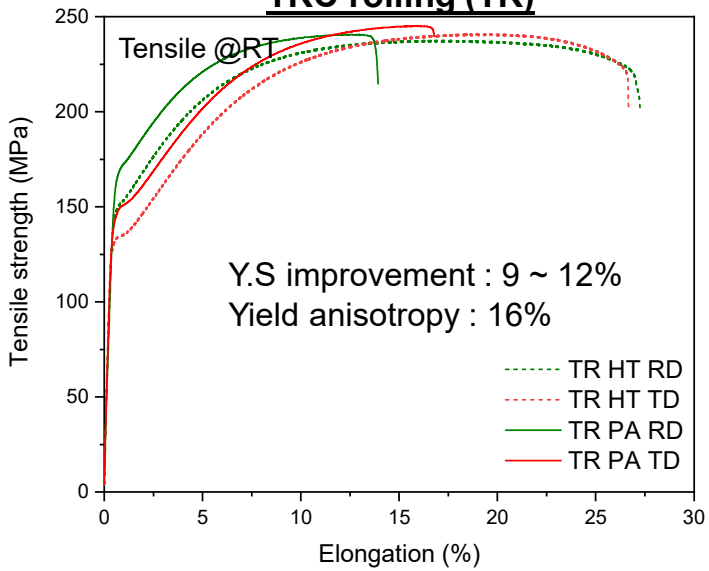



## Tensile properties

### Ingot rolling (IR)




### TRC rolling (TR)




| Alloys | Ini. Hardness (Hv) | Peak hardness (Hv) | Improvement (%) | Time to reach the peak (h) |
|---|---|---|---|---|
| ZAX210 IR | 46 | 58 | 26 | 264 |
| ZAX210 TR | 51 | 62 | 22 | 240 |

| Alloys | IR-HT (RD/TD) | IR-PA (RD/TD) | TR-HT (RD/TD) | TR-PA (RD/TD) |
|---|---|---|---|---|
| YS (MPa) | **136 / 92** | **145 / 98** | **158 / 136** | **177 / 149** |
| UTS (MPa) | **224 / 226** | **226 / 215** | **242 / 242** | **238 / 243** |
| El. (%) | **25 / 21** | **21 / 20** | **22 / 22** | **10 / 21** |

HELMHOLTZ

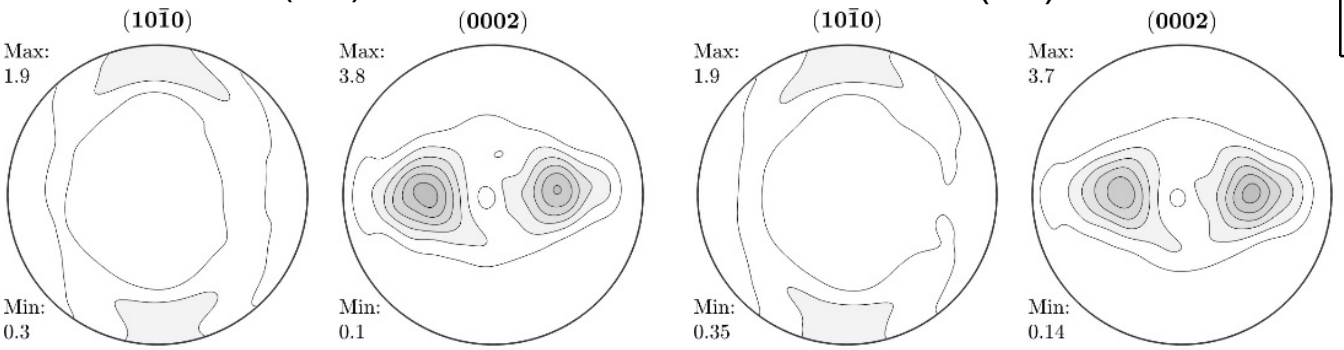
## Experimental Results

# Texture and room temperature formability of ZAX210 alloys

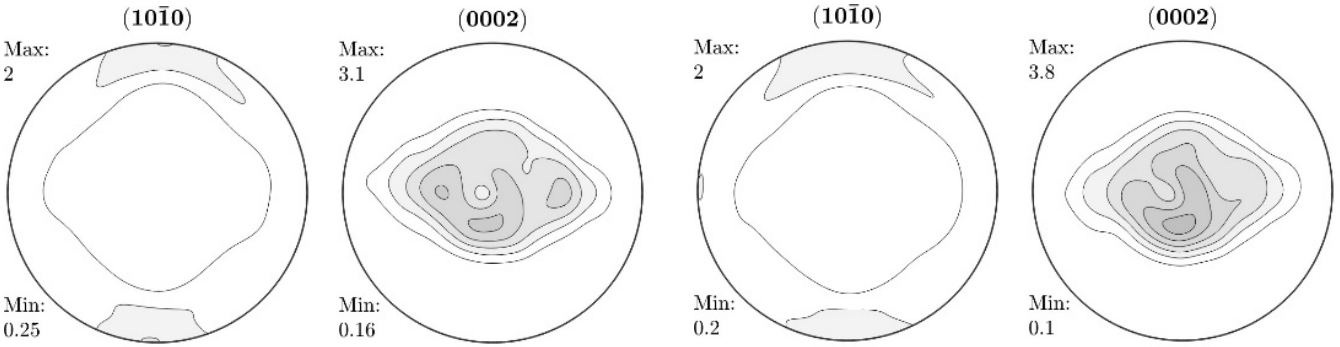
Solution-treated (HT)

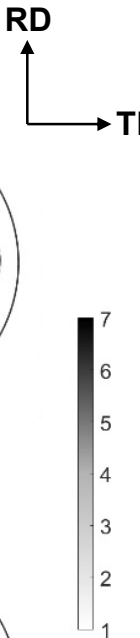
Peak-aged (PA)

**Ingot-rolling (IR)**




**TRC-rolling (TR)**




**I.E : 8.0 ± 0.5**

**TD-split texture**

**High yield anisotropy (48%)**

Example of deep drawn cup with ears

**I.E : 6.9 ± 0.4**

**Quadrupole texture**

**Low yield anisotropy (16%)**

Example of deep drawn cup without ears



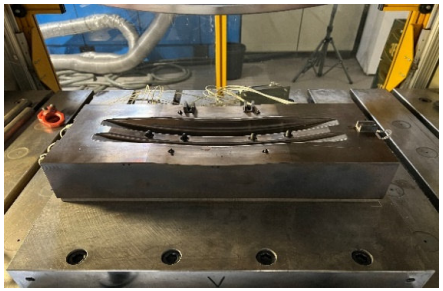
HELMHOLTZ

# Experimental Results – Collaboration with Hannover University

# Experimental setup for the forming tests

## Forming tool in a hydraulic double-column press by Dunkes

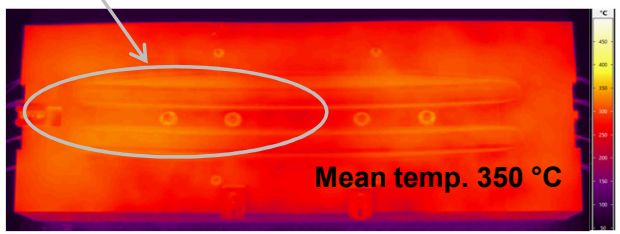

Test setup in the hydraulic double-column press



**Bumper tool in the installed state**

**Formed sheet metal component**

Readjusting the heating cartridges to maintain the tool surface temperature




**Temperature distribution on the tool surface**

| Parameter | Value |
|---|---|
| Heating temp. | 230 °C |
| $T_{\mathrm{form},1}$ | 213 °C |
| $T_{\mathrm{form},2}$ | 195 °C |
| $T_{\mathrm{form},3}$ | 185 °C |
| $T_{\mathrm{form},4}$ | RT |

- Heating the sheet metal blank up to 230 °C
- Manual transfer of the sheet metal into the forming tool
- Carrying out the forming tests with various forming temperatures
- Removal of the formed components



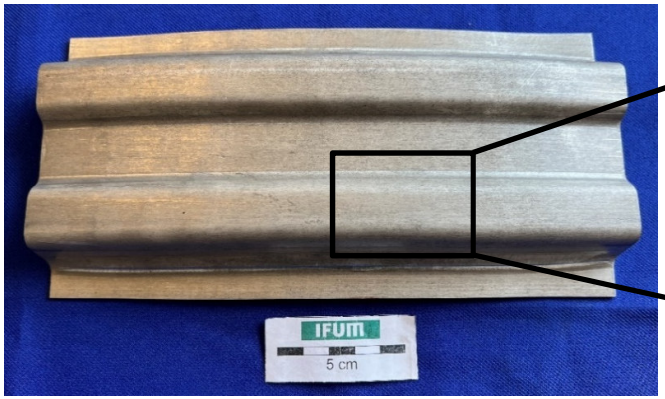
IFUM Institut für Umformtechnik und Umformmaschinen

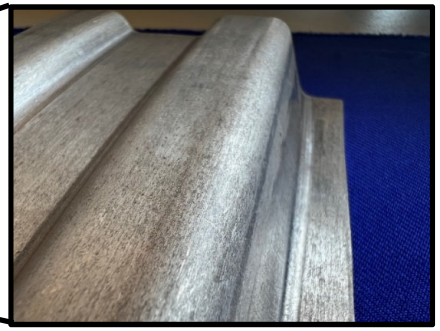
HELMHOLTZ

# Experimental Results – Collaboration with Hannover University

## Analysis of the formed components

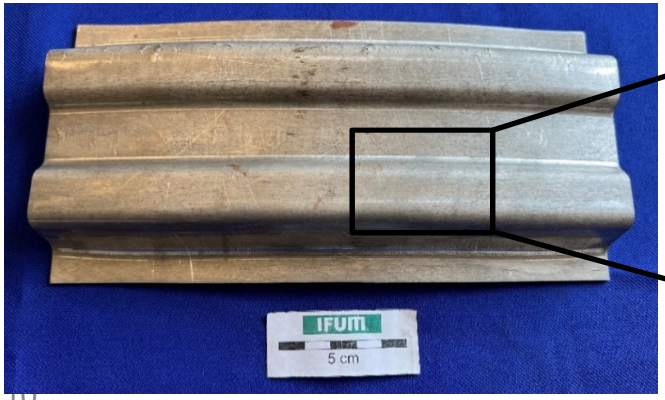
**Results of the forming tests with cooled tool system**



Component without surface defects

**Forming temperature 195 °C**




Component with surface defects

**Forming temperature 185 °C**

**Formable Mg sheet at low temperature**

- Determination of the critical forming temperature
- Defect-free forming of sheet metal components possible at a forming temperature of 195 °C

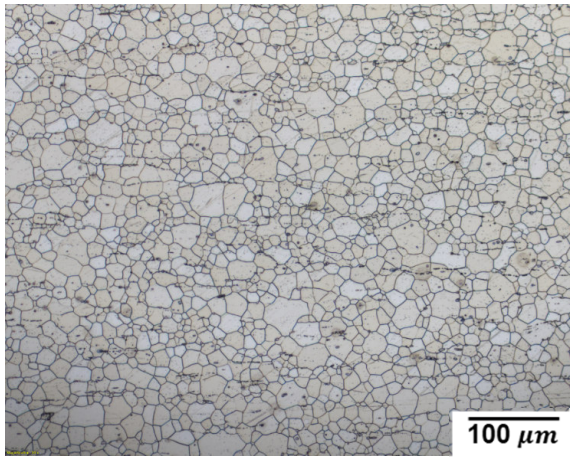
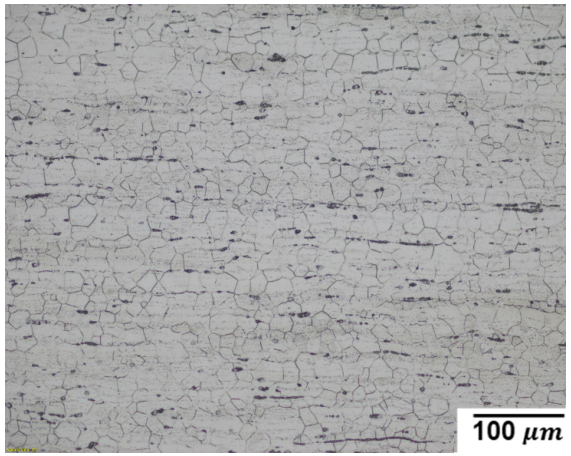
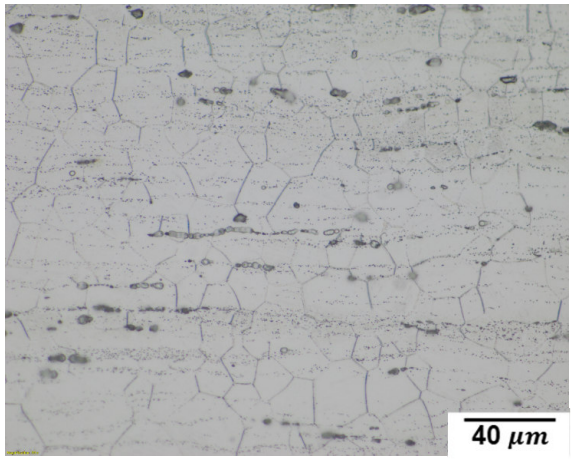
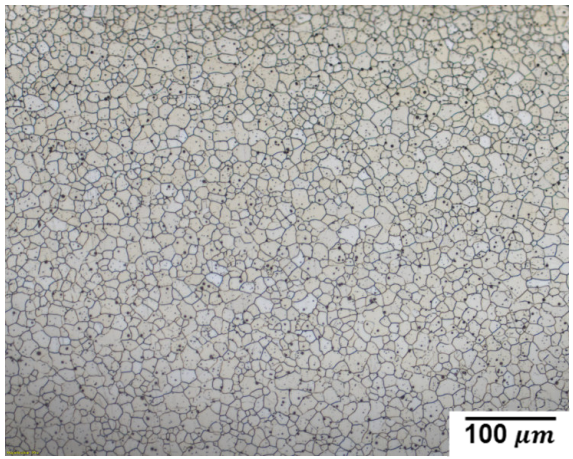
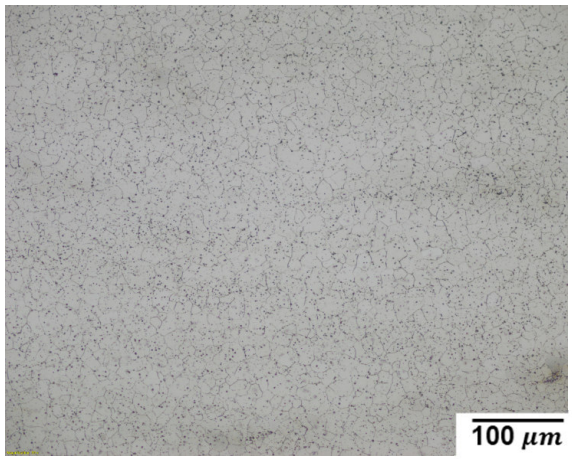
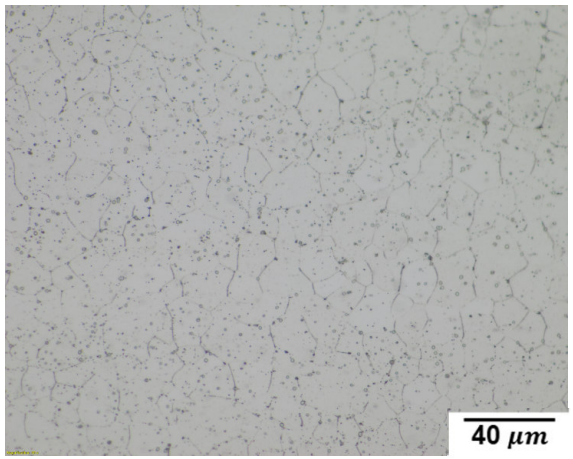


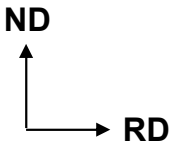
IFUM Institut für Umformtechnik und Umformmaschinen

HELMHOLTZ

## Experimental Results

# Microstructure evolution of IR and TR sheets

| | Solution-treated (HT) | Peak-aged (PA) | Peak-aged (PA, higher mag.) |
|---|---|---|---|
| **IR** |   |   |   |
| **TR** |   |   |   |




Less uniformly distributed particles

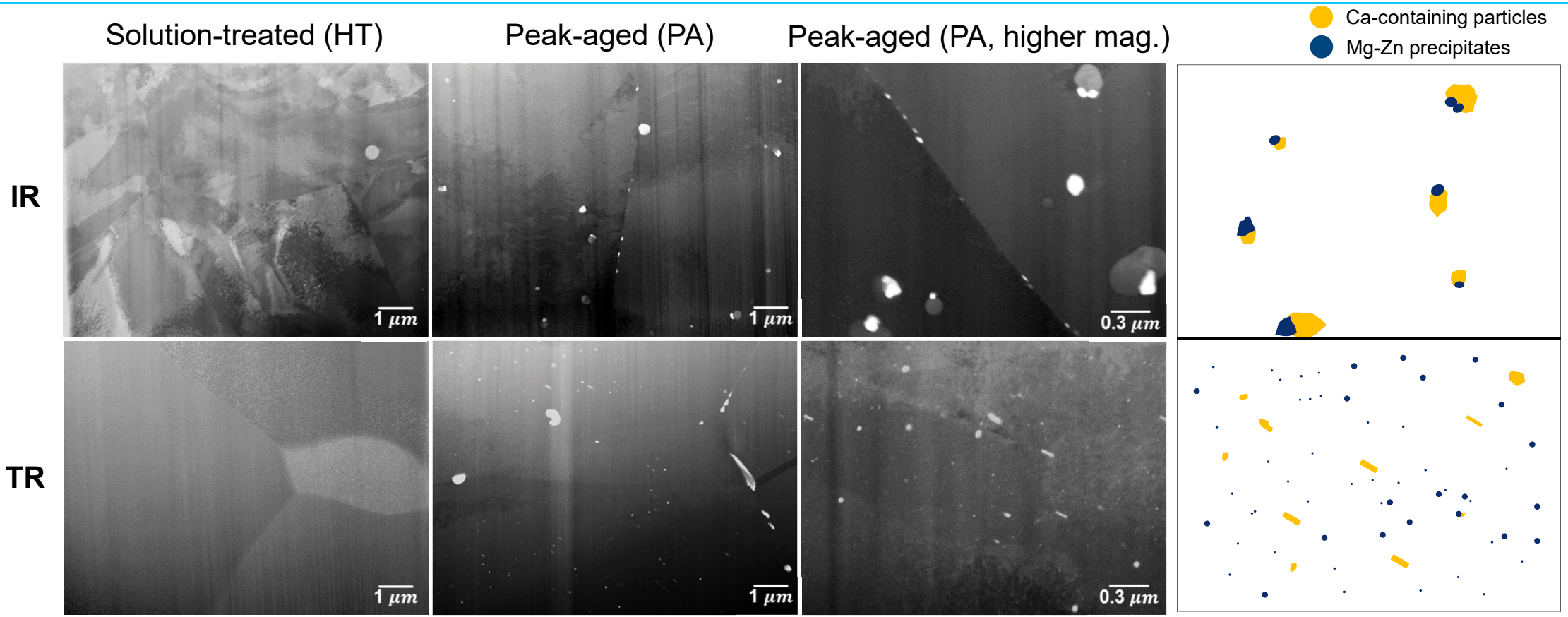
Finely and uniformly distributed particles



HELMHOLTZ

## Experimental Results

# Microstructure evolution of IR and TR sheets after aging



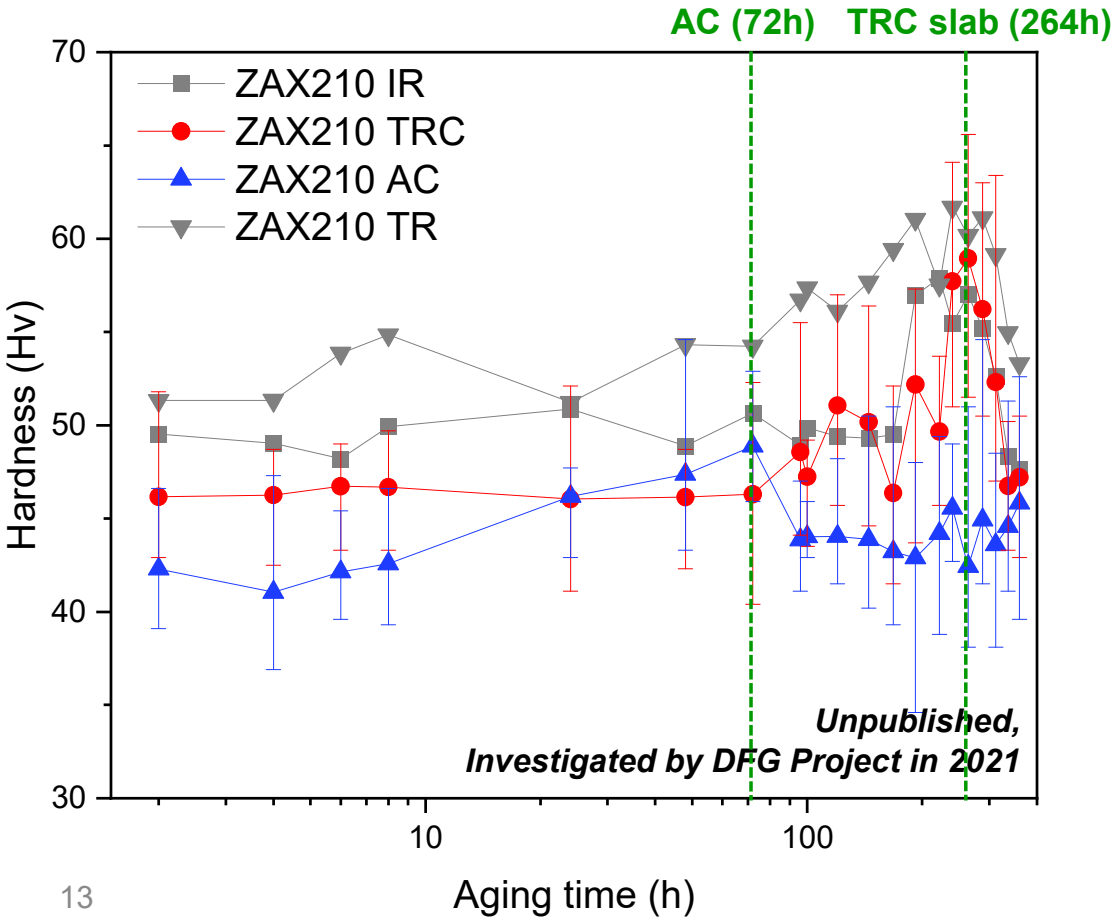

- TRC-rolling (TR) sheet shows finely distributed precipitates after aging treatment.
- TRC process would attribute to the fine distribution of precipitates.

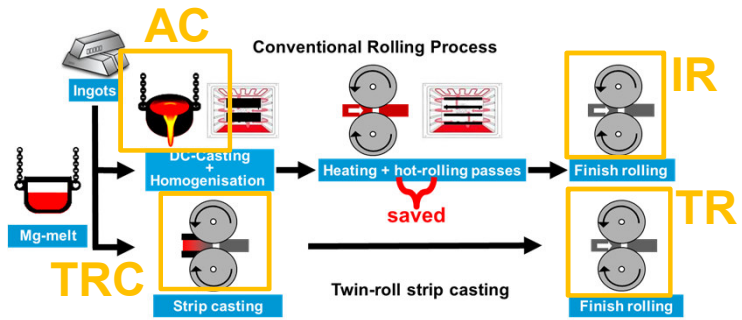


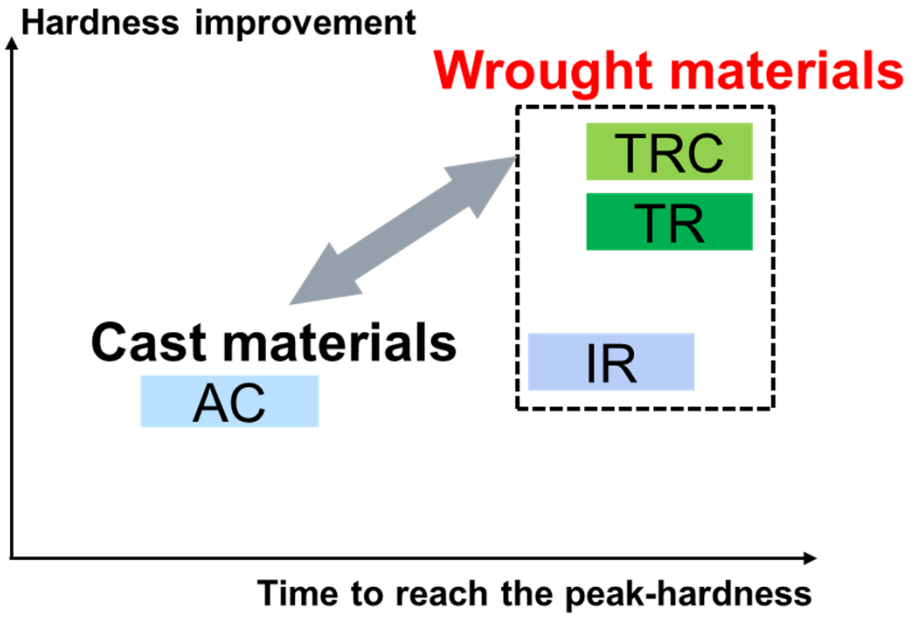
HELMHOLTZ

## Experimental Results – Effect of initial materials

# Contribution of TRC process on the precipitation behavior

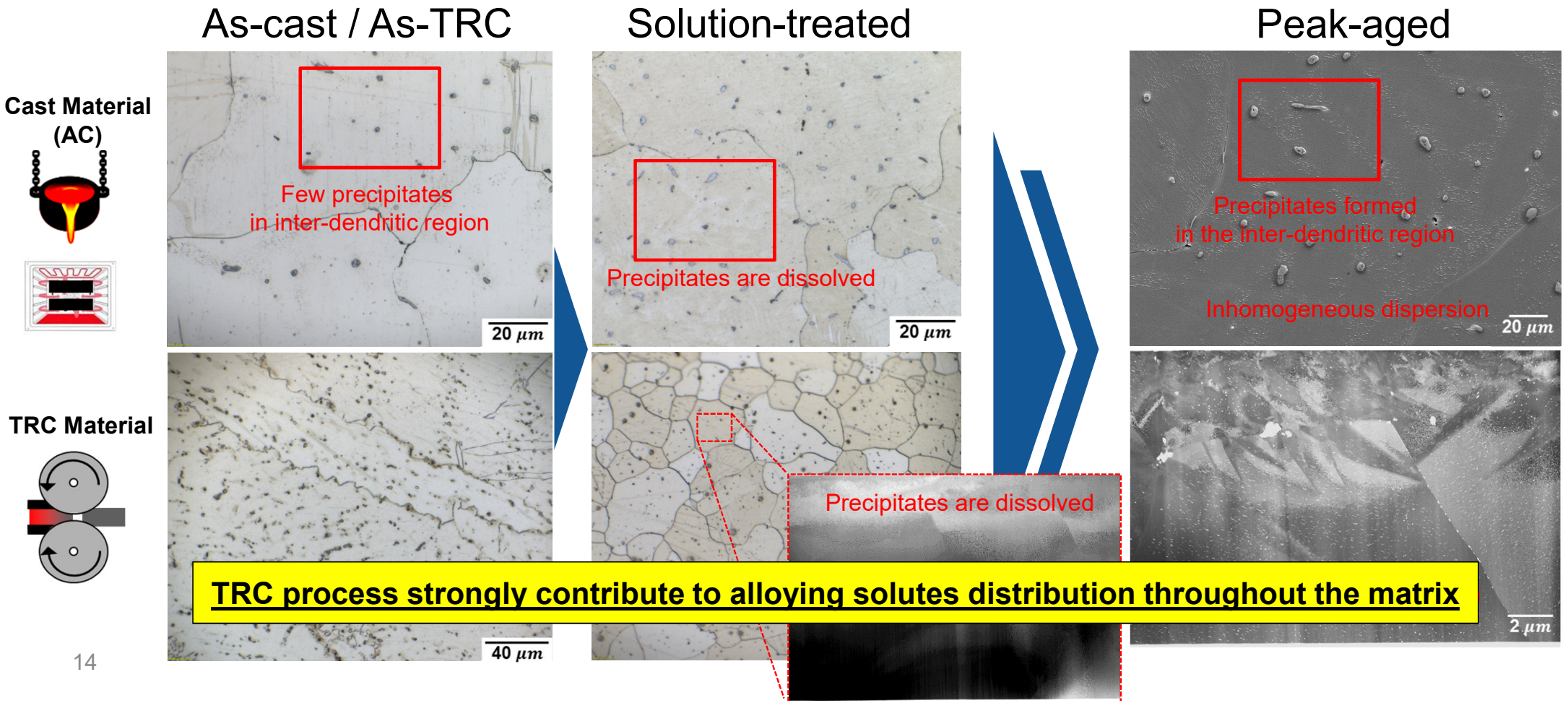


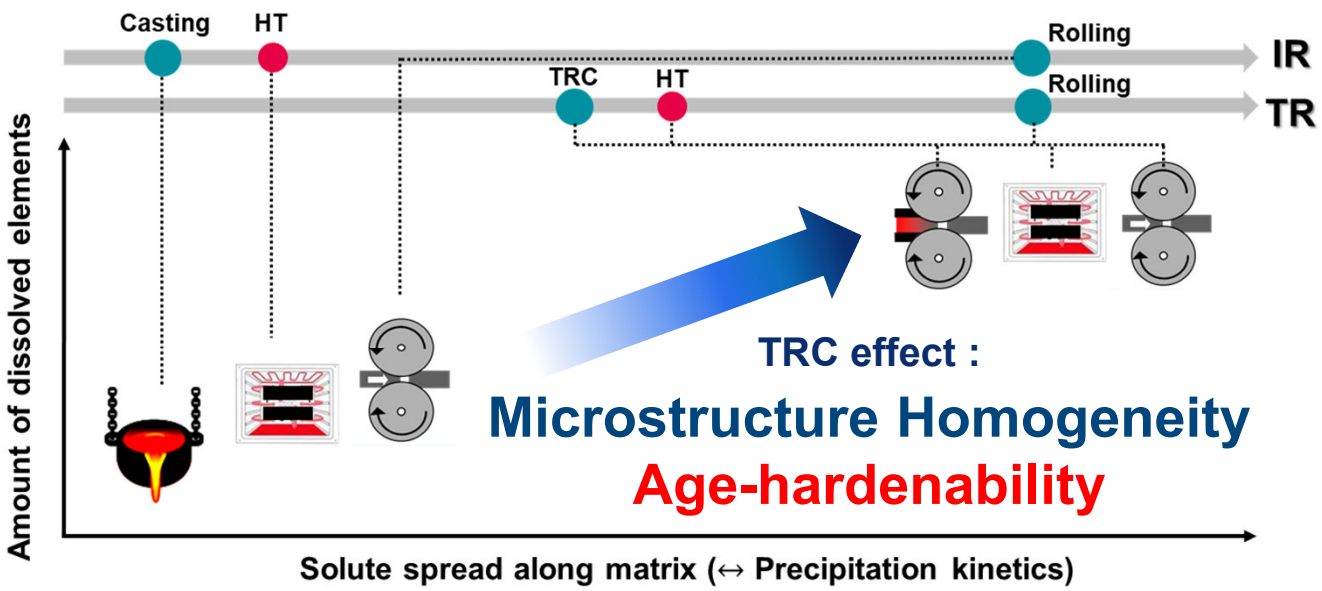
## Experimental Results – Effect of initial materials

# Contribution of TRC process on the precipitation behavior



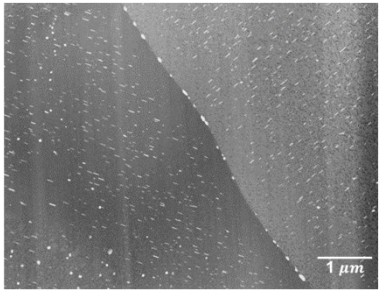
## Experimental Results – Effect of initial microstructure

# Contribution of TRC process on the precipitation behavior



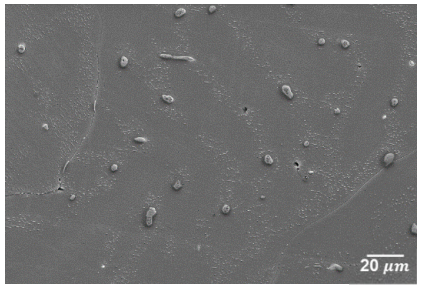


**TR (Peak-aged)**

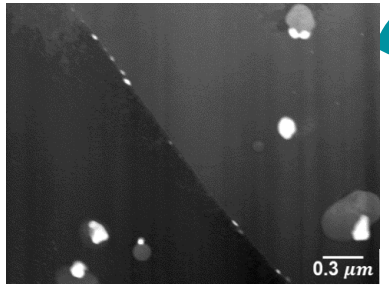



**TRC (Peak-aged)**

**AC (Peak-aged)**

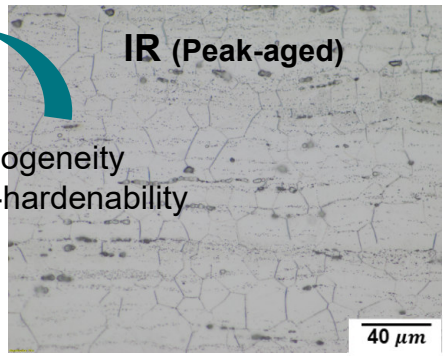



**IR (Peak-aged)**

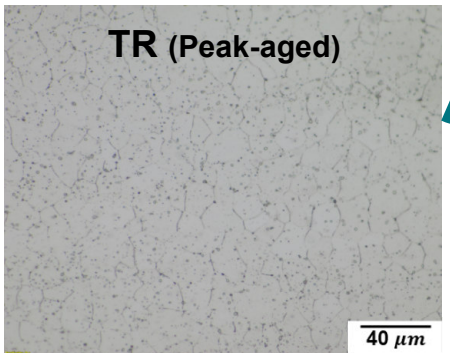



Low homogeneity
Low age-hardenability

**IR (Peak-aged)**




**TR (Peak-aged)**



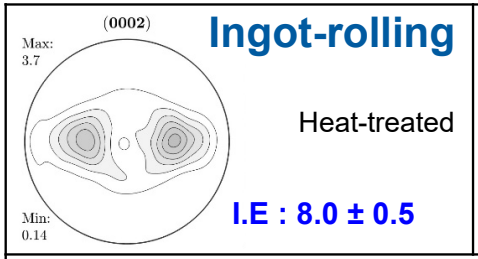

High homogeneity
High age-hardenability

HELMHOLTZ

# Future plan and conclusion

# Development of magnesium alloy with high strength and formability

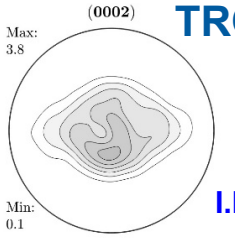
## *Conclusion*




**Ingot-rolling**

Heat-treated

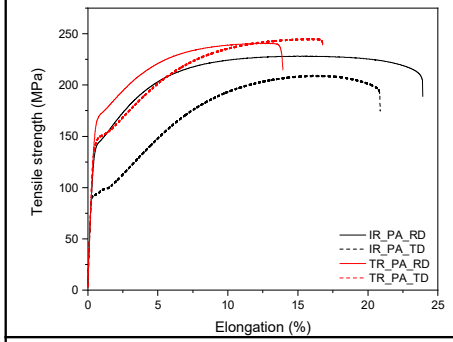
**I.E : 8.0 ± 0.5**




**TRC-rolling**

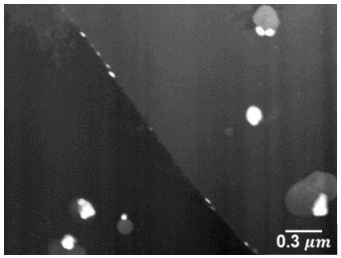
Heat-treated

**I.E : 6.9 ± 0.4**




**TRC-rolling sheet** :
Higher strength after aging
Lower yield anisotropy along RD/TD

Peak-aged




Peak-aged


**TRC-rolling sheet** :
Finer and much uniform distribution of precipitates

## *Future plan*

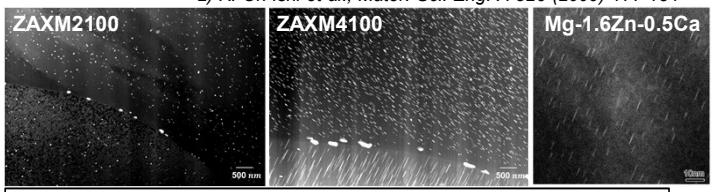
### Alloy optimization

In Mg-Zn-Ca alloy,

**Zn content > 2wt.%**
Amount of MgZn precipitates ↑

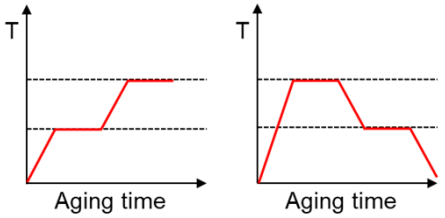
**Zn content < 2wt.%**
GP zone formation

*1) S. Jo et al., Materials 15 (2022) 5239*
*2) K. Oh-ishi et al., Mater. Sci. Eng. A 526 (2009) 177-184*



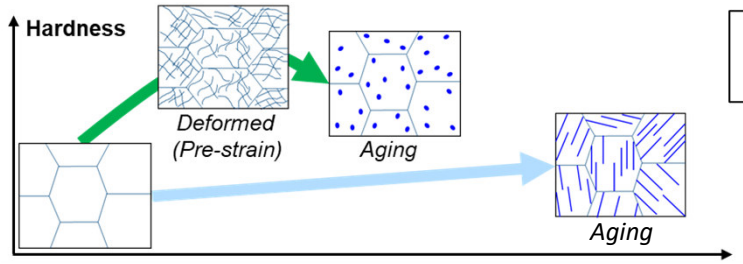

Control of Zn content and other alloying elements to improve the age response

### Process optimization - Ⅰ. Double-step aging




**Control precipitates size via temperature**
Finer precipitates, Rapid precipitation

### Process optimization - Ⅱ. Pre-strain




**Aging treatment of defomed part**

***Thank you for your attention***