

# Investigation of Influencing factors of liquid metal embrittlement for AHSS expansion

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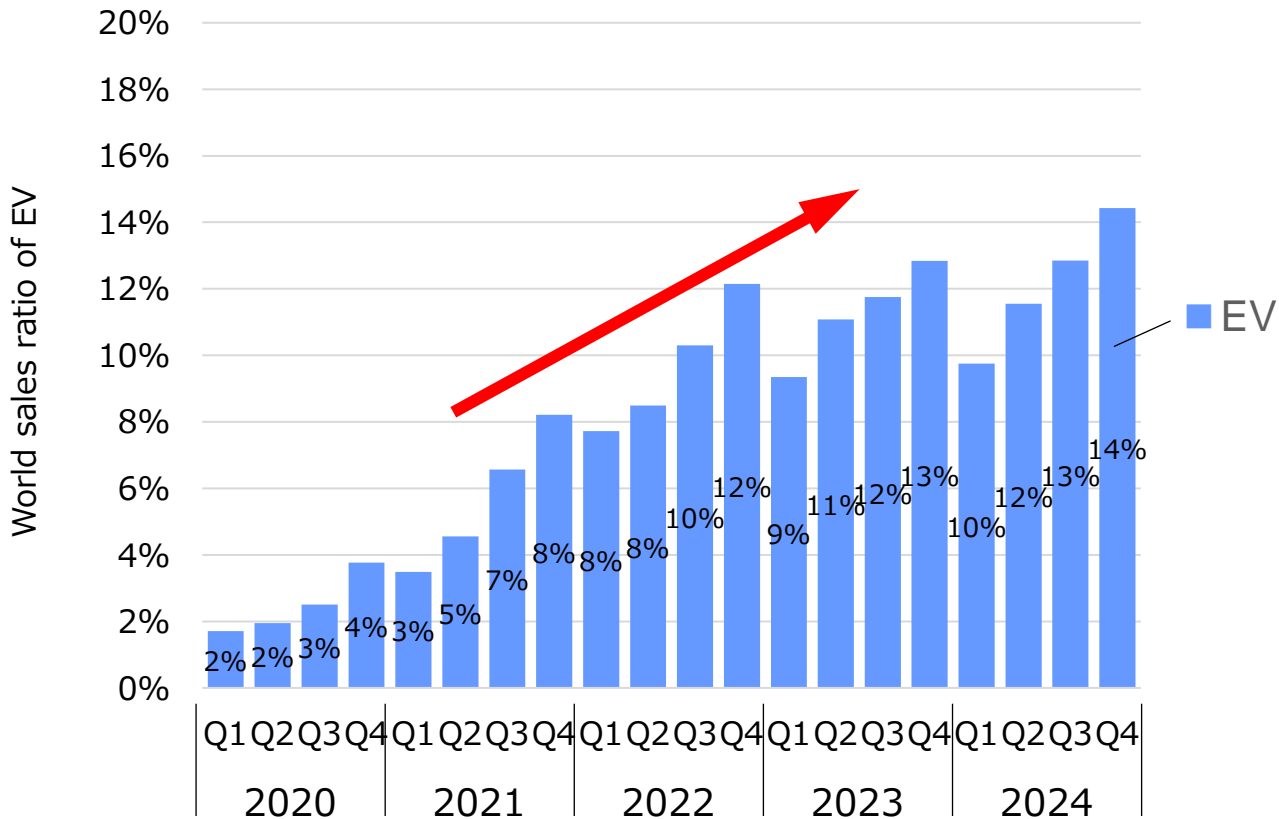
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1. Background / Goal
2. Hypothesis
3. Material information / Test condition
4. Test results
5. Prediction occurrence of LME
6. Conclusion

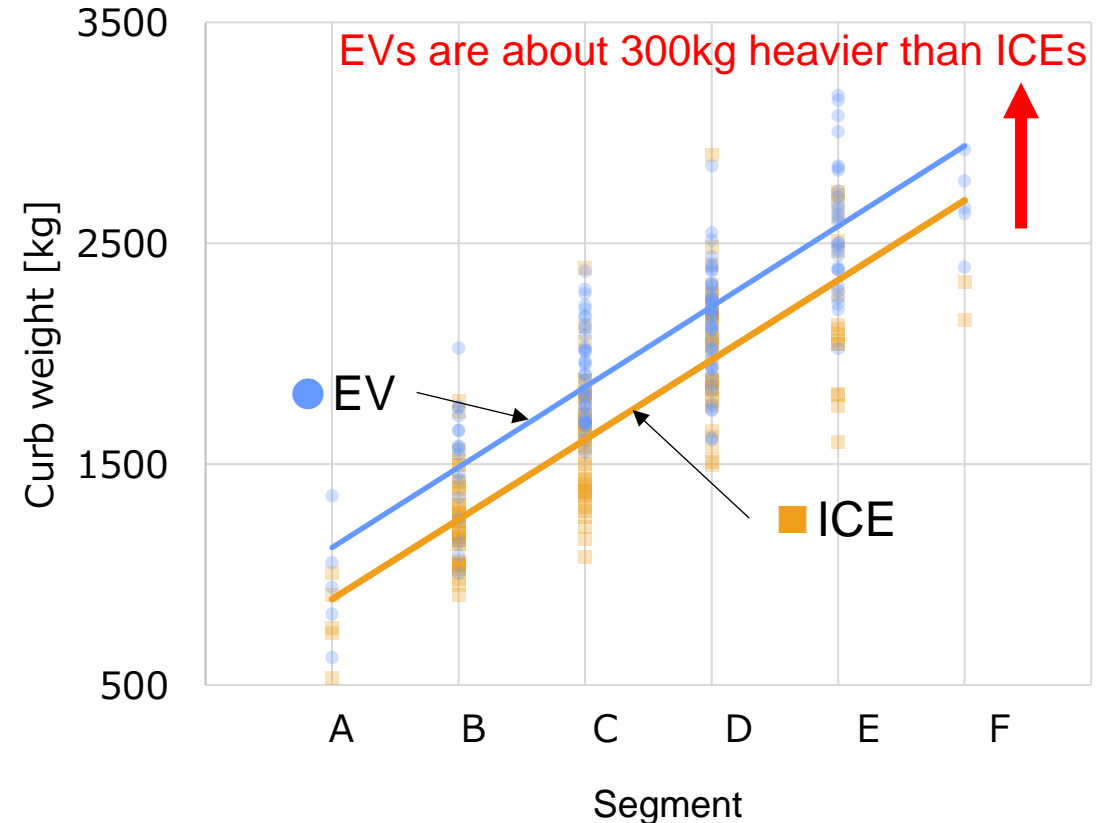
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# Background

- In recent years, EVs have become more widespread with increasing sales volumes.
- EVs are heavier than ICEs. Therefore, lightweighting and crash performance are important.



Source: Marklines

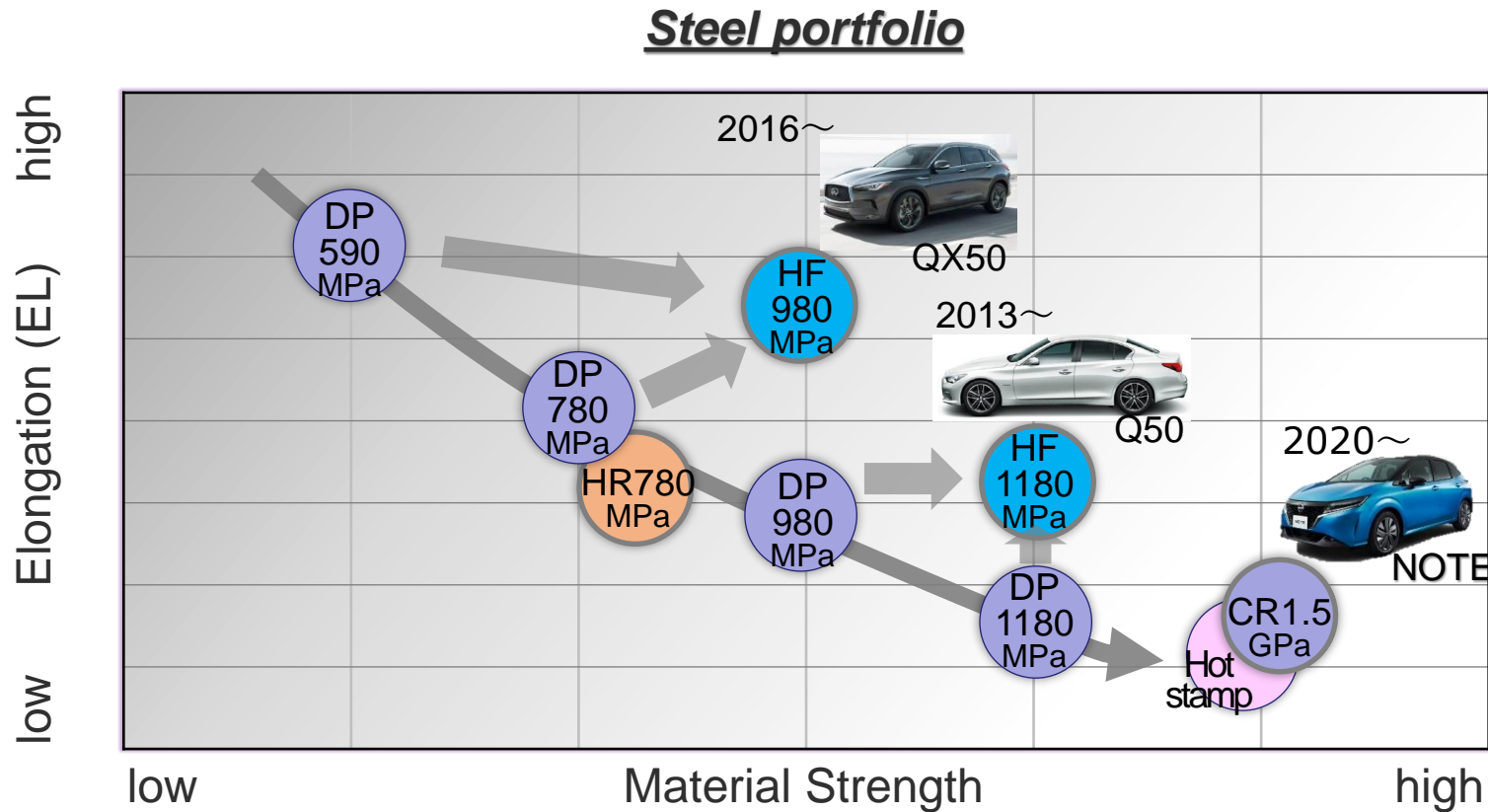


Source: A2MAC1

※Mass production vehicles after 2020

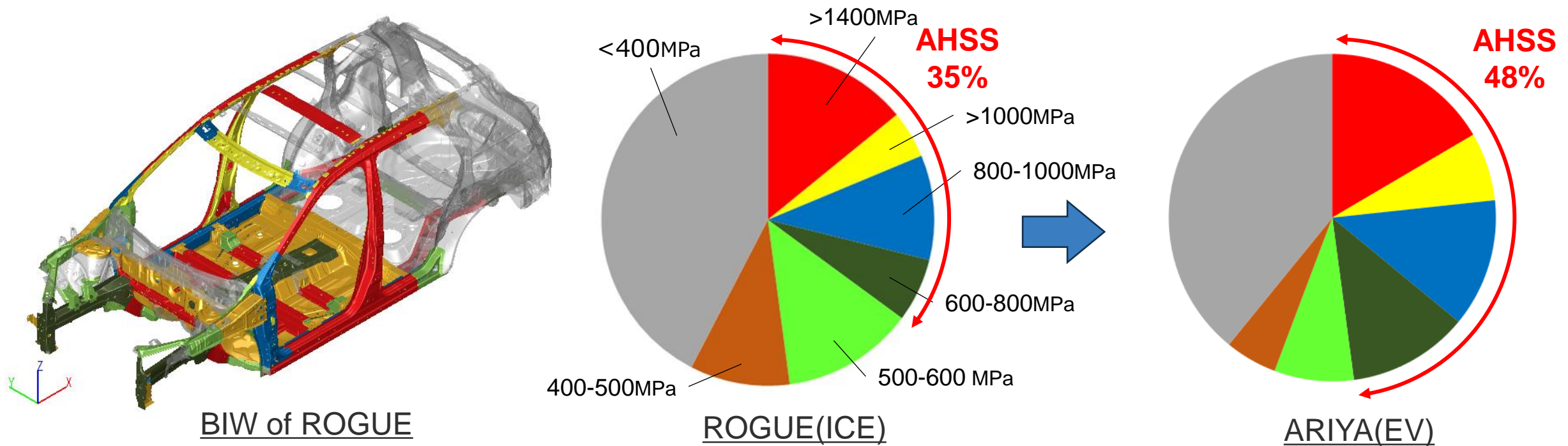
# AHSS development

- Nissan developed HF1180MPa since 2013 in Q50. Then, HF980 MPa and CR1.5GPa were developed.
- Nissan applied AHSS to BIW and leads adoption of AHSS globally.



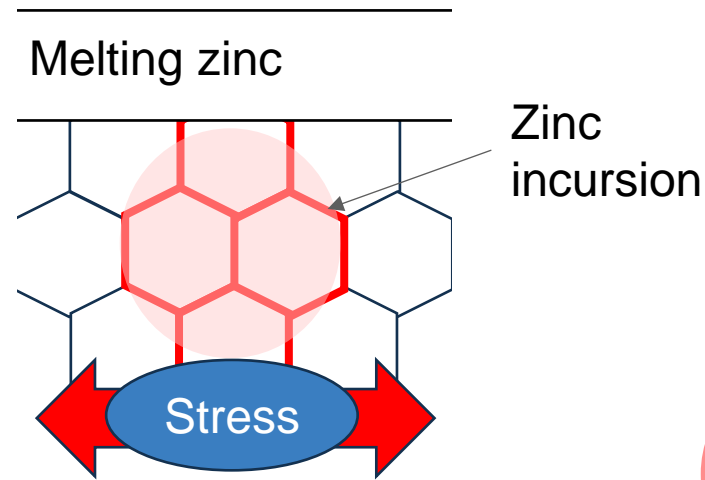
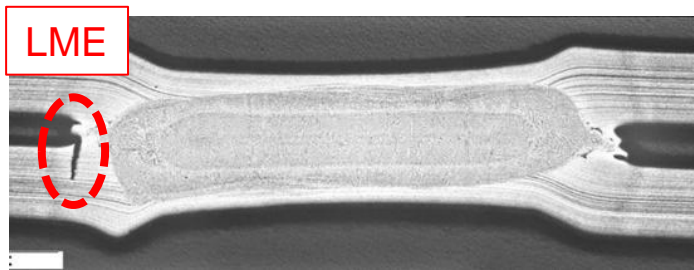
# AHSS application

- AHSS ratio of 780MPa or more is increased for lightweighting and crash performance improvement due to EV. Especially, AHSS ratio is increased from 35% in the ROGUE to 48% in the ARIYA
- In the future, 1.5GPa or more steel is applied widely.

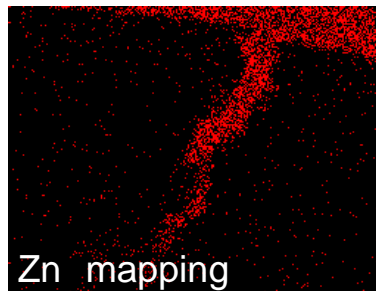


# LME (liquid Metal Embrittlement)

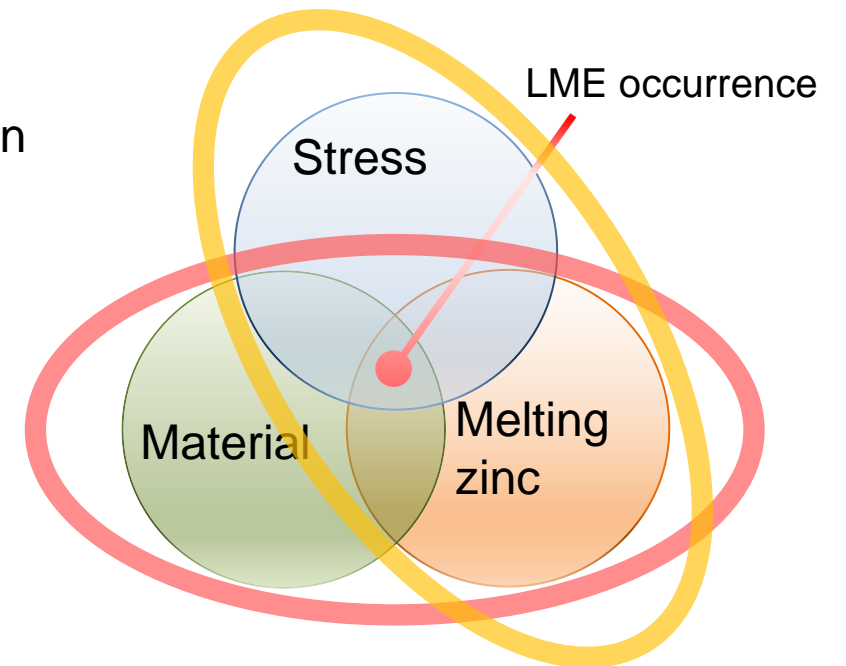
- There is an issue of LME for AHSS.
- LME, liquid metal embrittlement, is a phenomenon that is caused by melting zinc on steel surface and stress due to heat generated in spot welding.
- When three factors, material, stress and melting zinc occur are met, LME occurs.



- Residual stress in spot welding
- Thermal stress

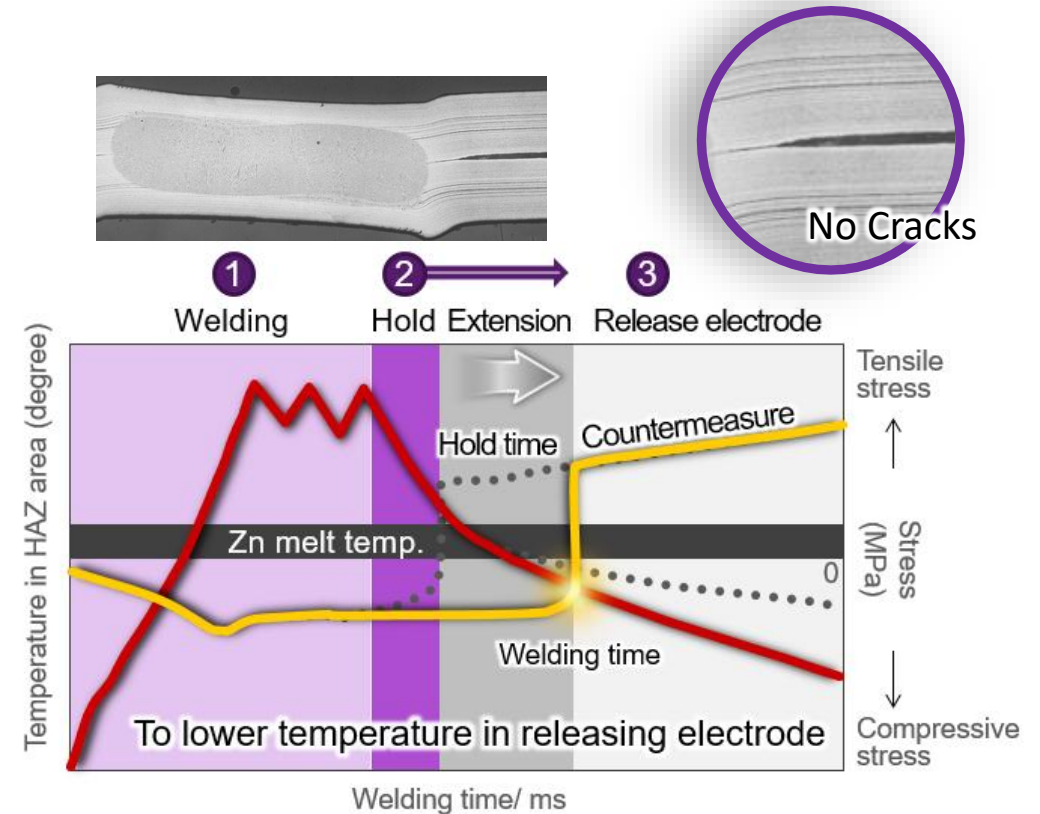
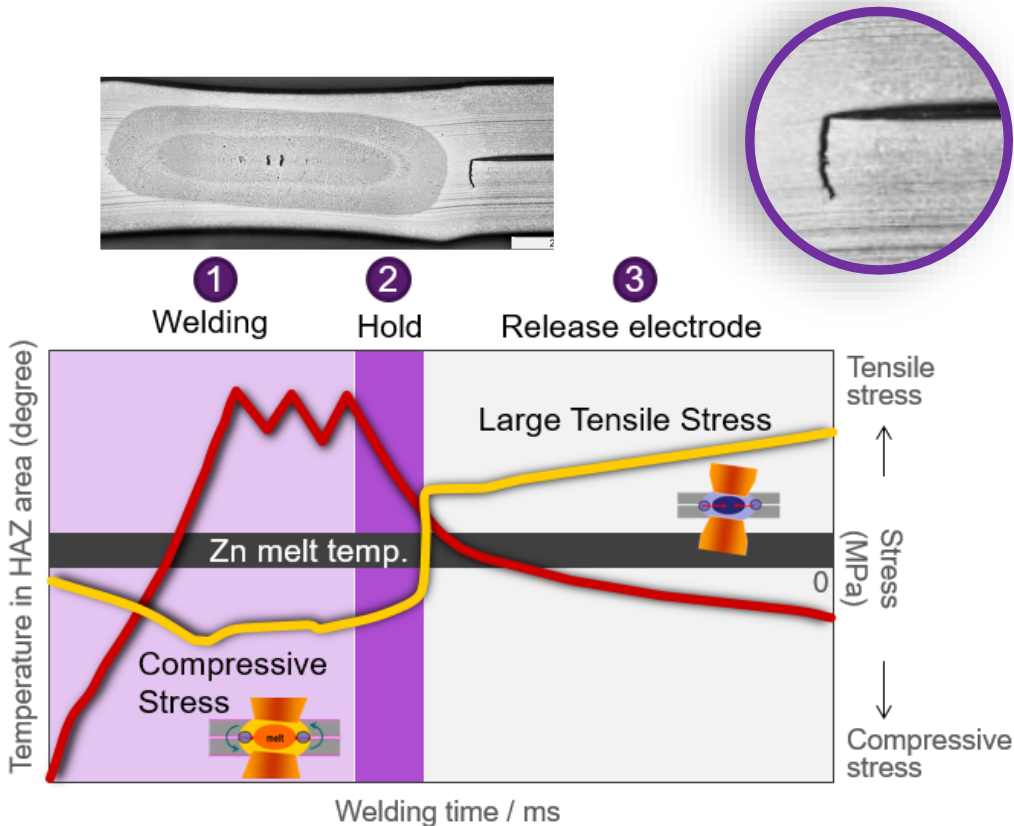


Zn mapping



# Past approach

- In past approach, hold time was extended to avoid LME. However, it was found that the risk of LME occurs depending on condition of combination of flat steel.



**Goals** : To expand the application of AHSS for lightweighting and crash performance improvement.

**Approach** : In order to avoid LME, each influencing factor was analyzed.

## **Influencing factor**

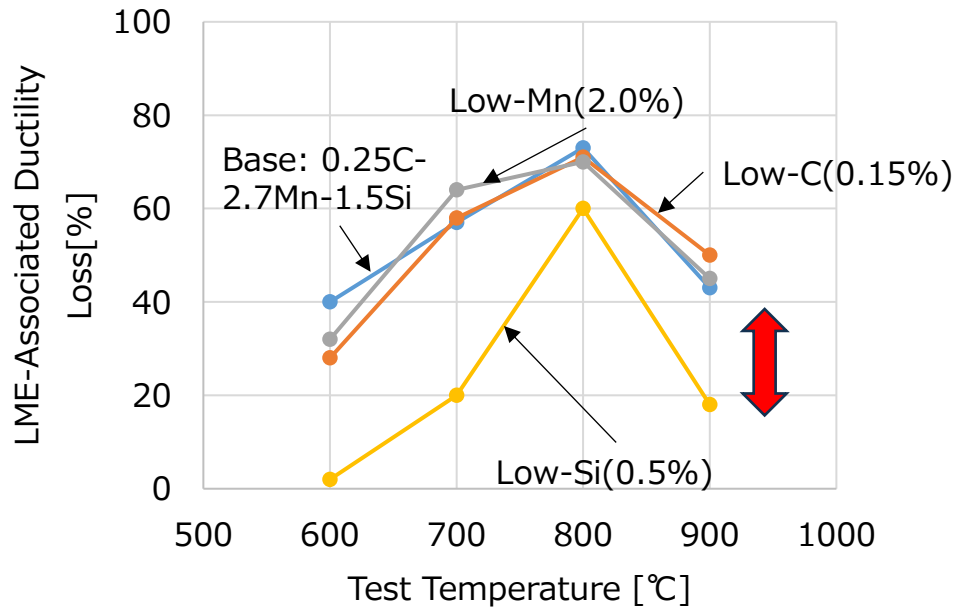
- (1) Chemical compositions (C / Si / Mn) of AHSS
- (2) Thickness of stack
- (3) Disturbances of spot welding (Electrode angle / Sheet gap)

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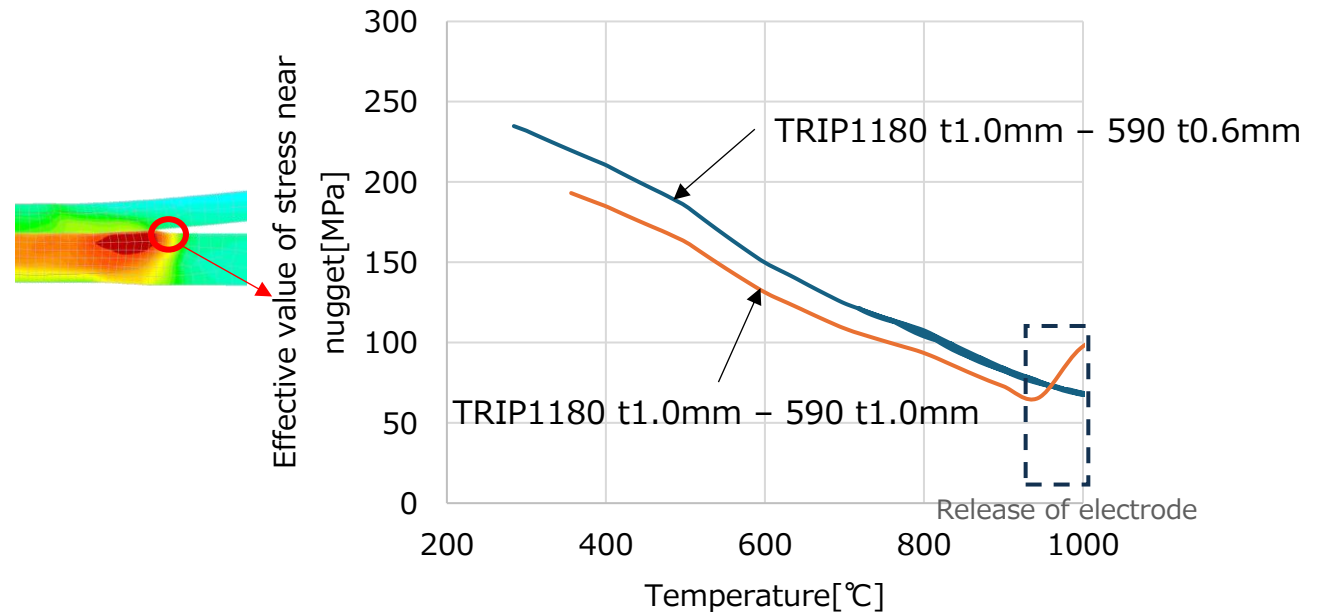
# Hypothesis

- C, Mn are not sensitive and Si is sensitive from Gleeble test in past reference data.
- Thickness is sensitive from stress results near nugget after release of electrode by simulation data of SORPAS®.

Gleeble test results for chemical composition of C, Mn and Si



Effective value of stress results after release of electrode for difference thickness by SORPAS®



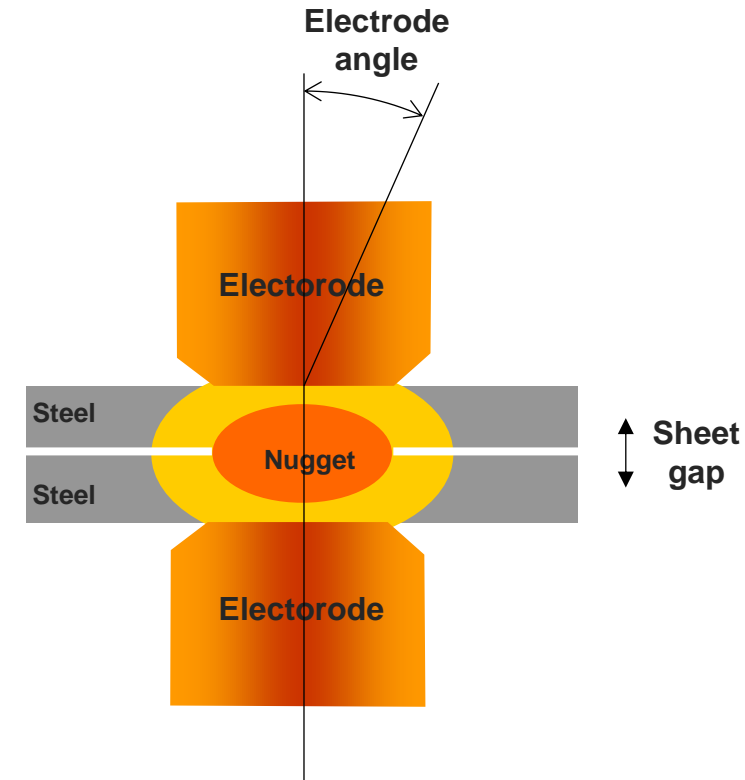
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# Material information and test condition

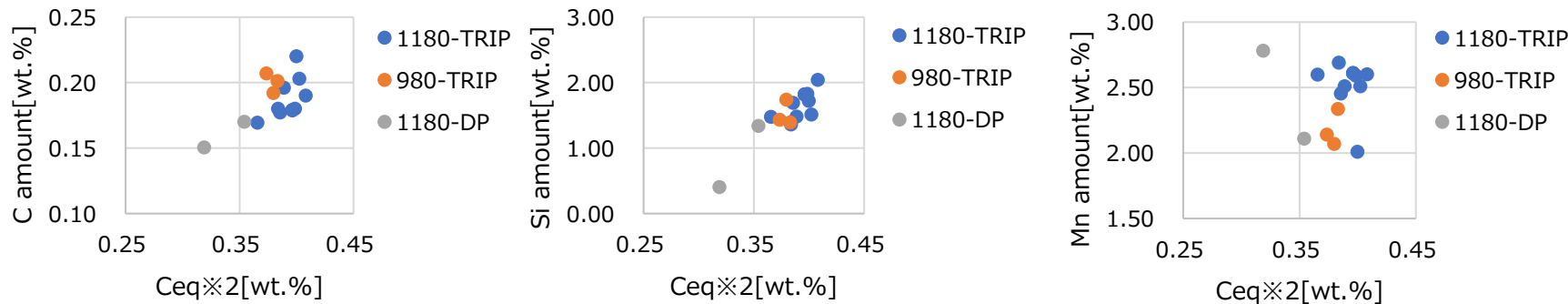
- Materials, 980MPa TRIP, 1180MPa TRIP and 1180MPa DP were used.
- Disturbance conditions of spot welding were changed by electrode angle and sheet gap.

Material information			Disturbance	
Strength	Micro-structure	Thickness	Electrode angle	Sheet gap
<ul style="list-style-type: none"> <li>•980MPa</li> <li>•1180MPa</li> </ul>	<ul style="list-style-type: none"> <li>•TRIP※1</li> <li>•DP※1</li> </ul>	1.0mm~ 1.6mm	<ul style="list-style-type: none"> <li>•5°</li> <li>•10°</li> </ul>	<ul style="list-style-type: none"> <li>•0mm</li> <li>•2mm</li> </ul>

※1 TRIP (Transformation induced plasticity)  
DP (Dual phase)



## Chemical composition for each material



※2 Ceq (Carbon equivalent) = C + Si/30 + Mn/20 + 2P + 4S

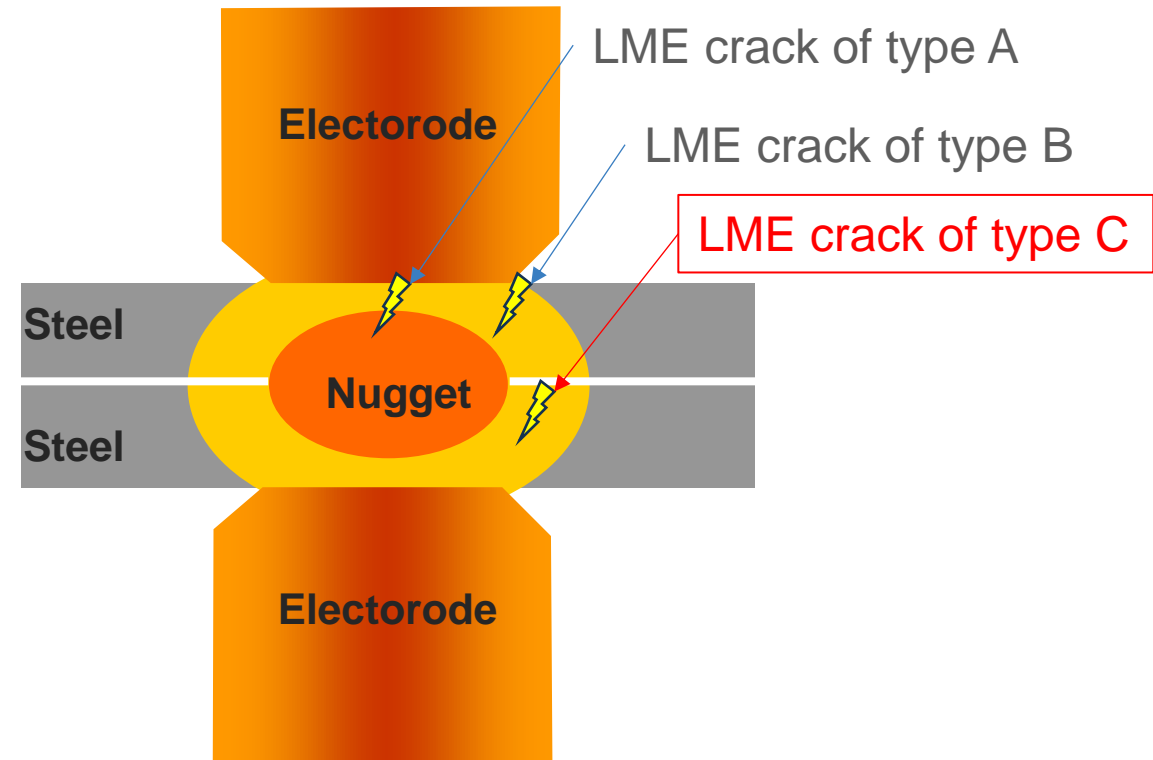
# Test approach

- Verification of LME was carried out in stack of steel assumed in actual parts for BIW.
- LME occurrence rate was evaluated for LME crack of type C only at this time.

$$\text{LME occurrence rate} = \frac{\text{LME crack number (type C)}}{\text{Test sample number}}$$

※ Test sample number: n10 or n20

※ LME crack of type A and type B was not scope

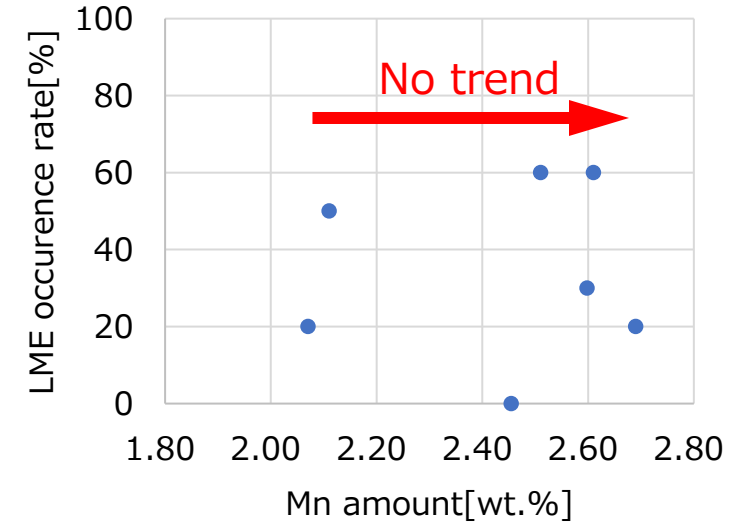
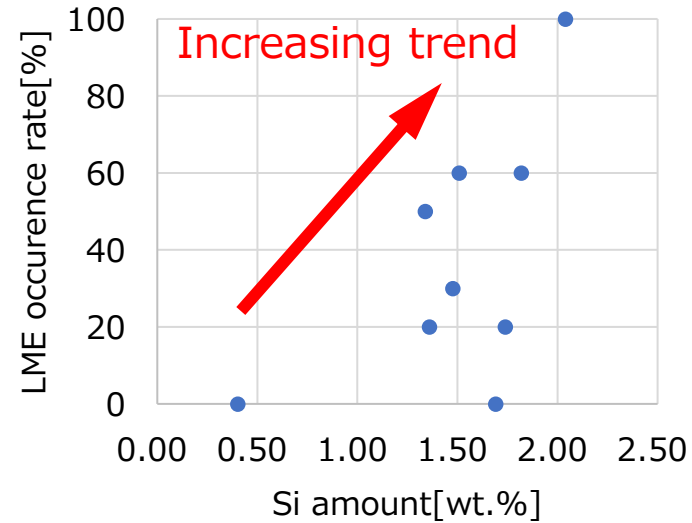
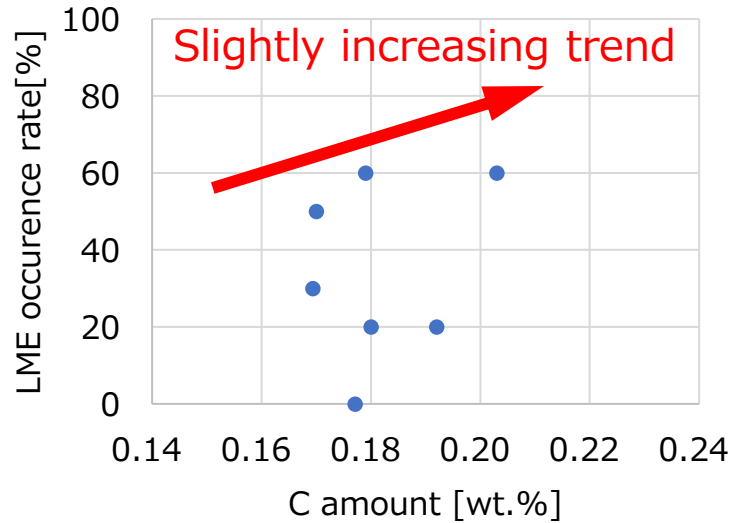


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# Chemical compositions (C, Si, Mn)

- LME occurrence rate were;
  - C : slightly increasing trend and low correlation
  - Si : increasing trend and middle correlation
  - Mn : no trend and no correlation

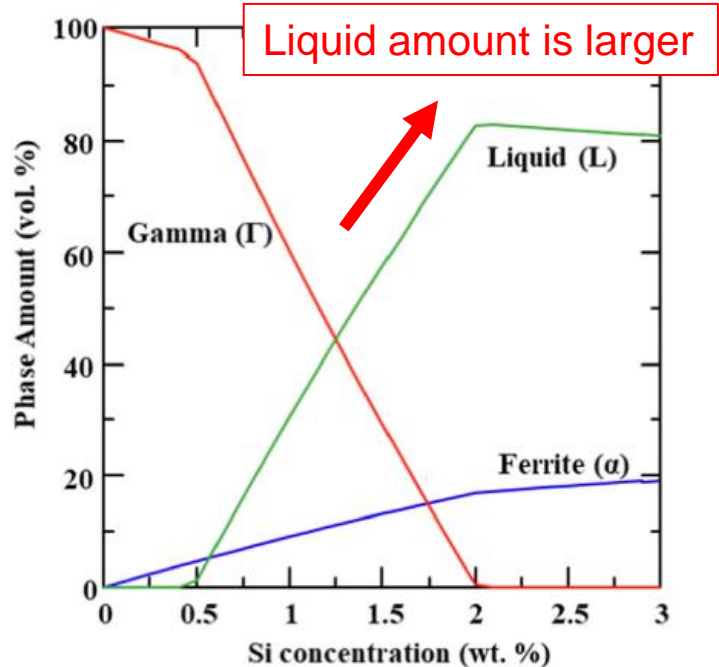
Stack information
1180 TRIP UC – t1.6mm 590 GA – t0.70mm
1180 DP UC – t1.6mm 590 GA – t0.70mm
980 TRIP UC – t1.6mm 590 GA – t0.70mm



# Consideration of Si effect

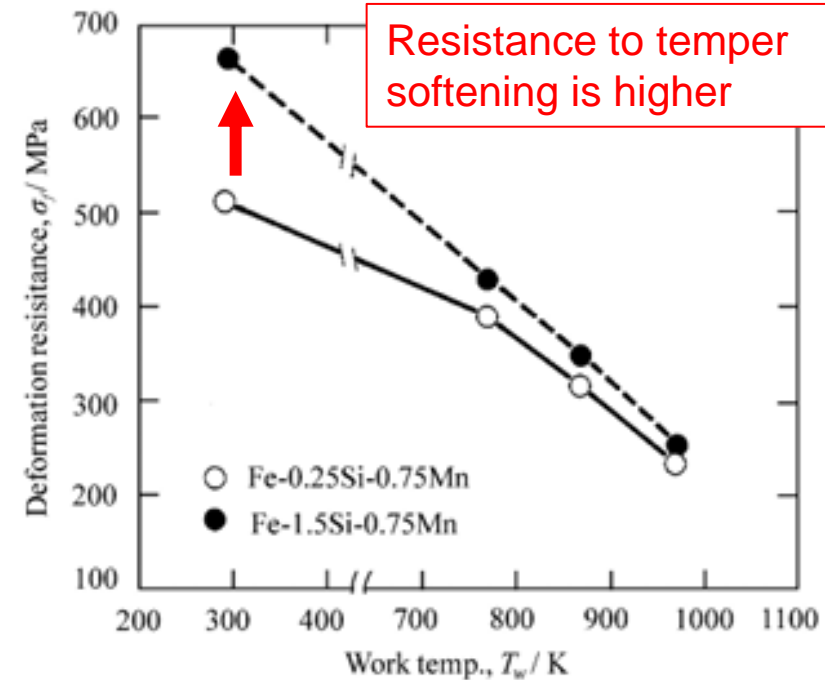
- Fe-Zn with 0.5% Si is  $\alpha+\Gamma$  phase and not liquid at 700°C. However, Fe-Zn more than 0.5% Si is  $\alpha+\Gamma$  phase + liquid and this is more susceptible to LME.
- Stress influence on LME is higher because the more Si, the higher the resistance to temper softening.

Amount of  $\alpha$ ,  $\Gamma$  and L on 700°C in a ternary Fe-Zn-Si alloy at a fixed Fe/Zn weight ratio of 20:80



Source: Influence of selected alloying variations on liquid metal embrittlement susceptibility of quenched and partitioned steels, D. Bhattacharya, 2022

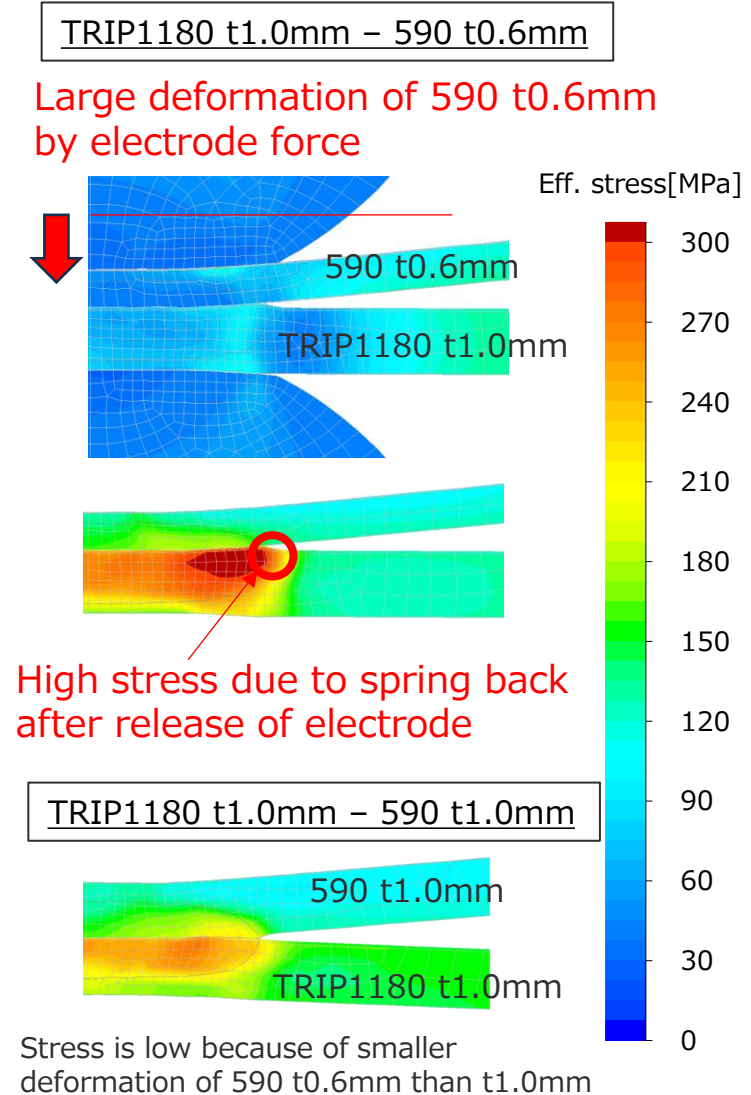
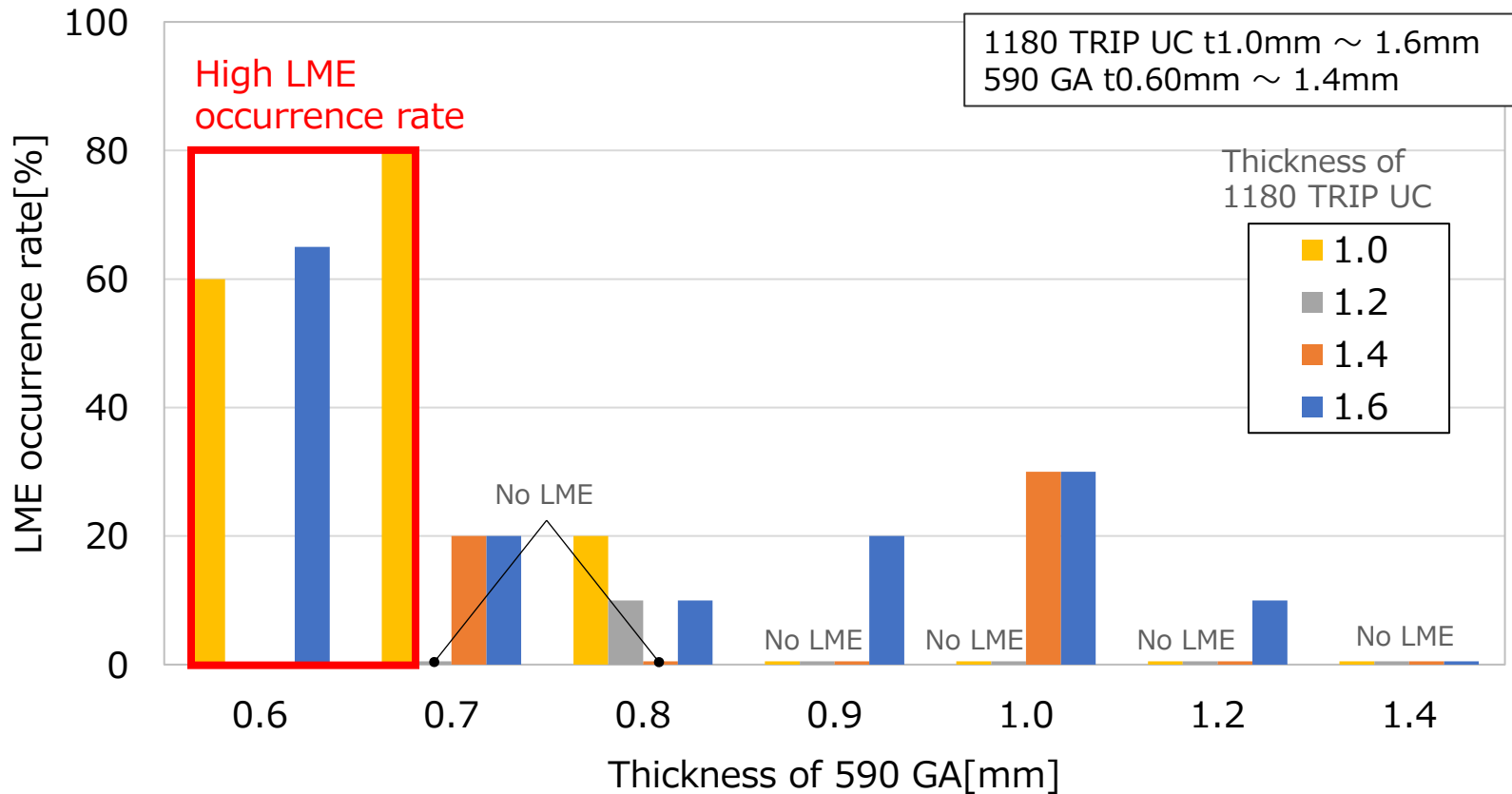
Effect of Si content on relationship between working temperatures and deformation resistance



Source: Deformation Resistance during Warm Working and Strength of Warm Worked Products of Middle Carbon Steels, Tatsuro Ochi, 2012

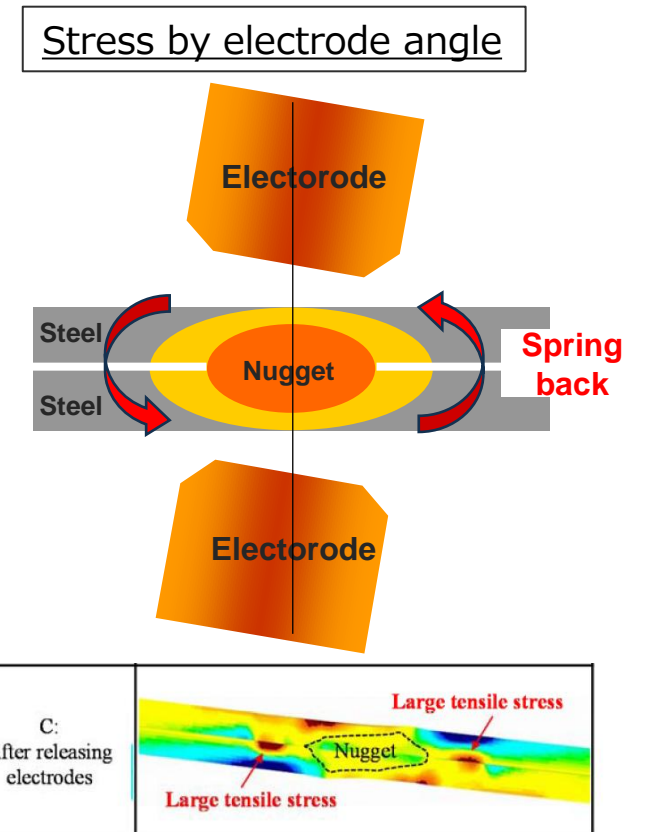
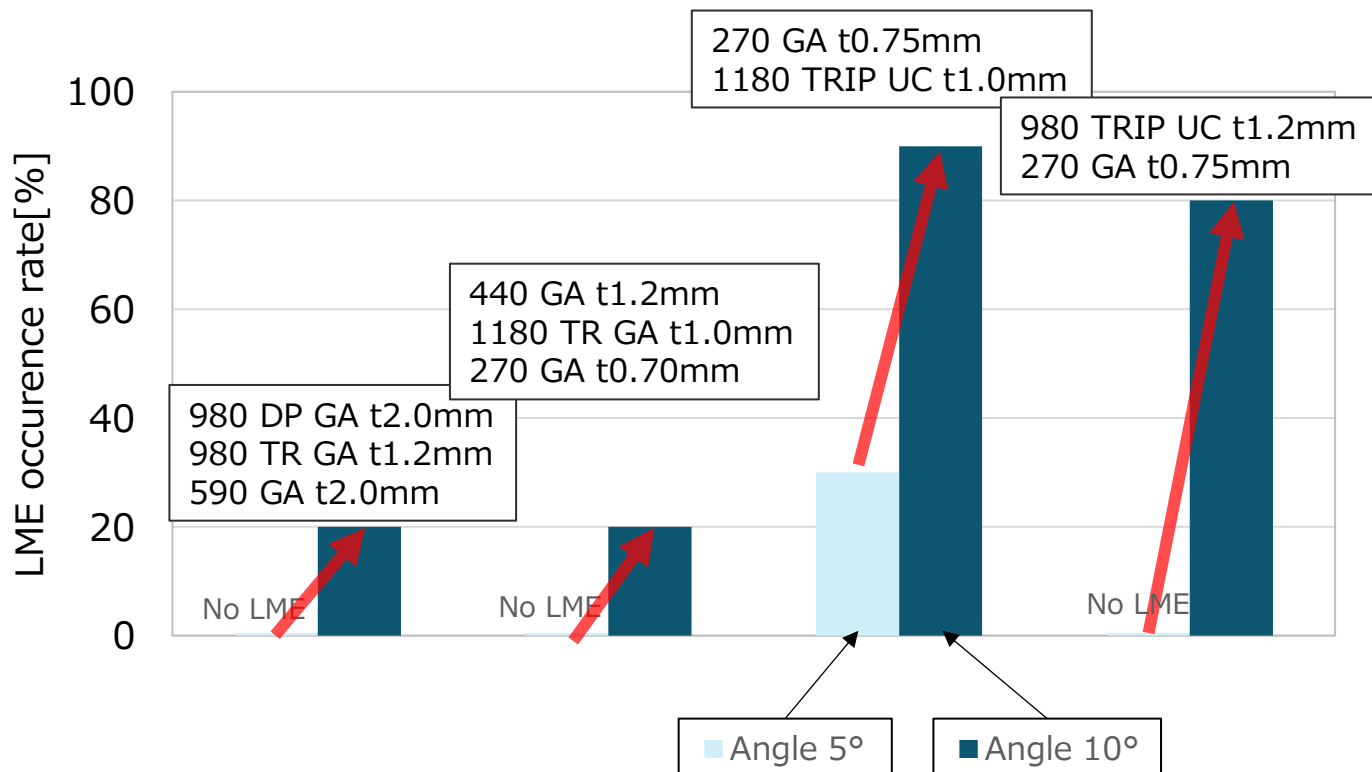
# Thickness

- LME occurrence rate was high in stack including thin flat steel.
- Stress near nugget was higher due to deformation in 0.60mm thinner stack condition.



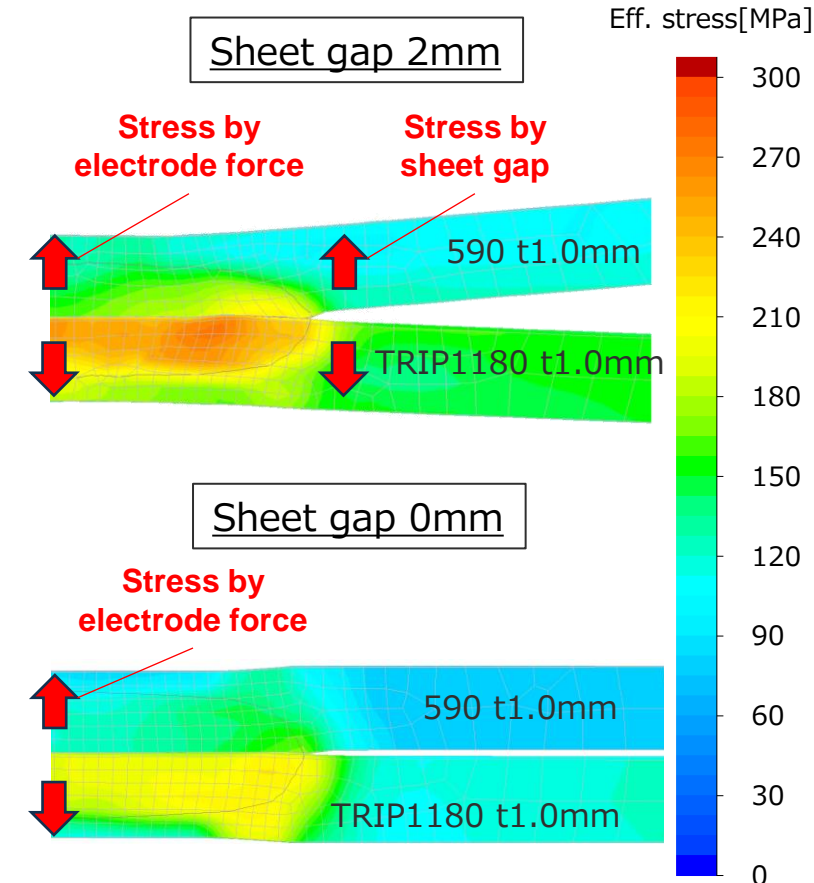
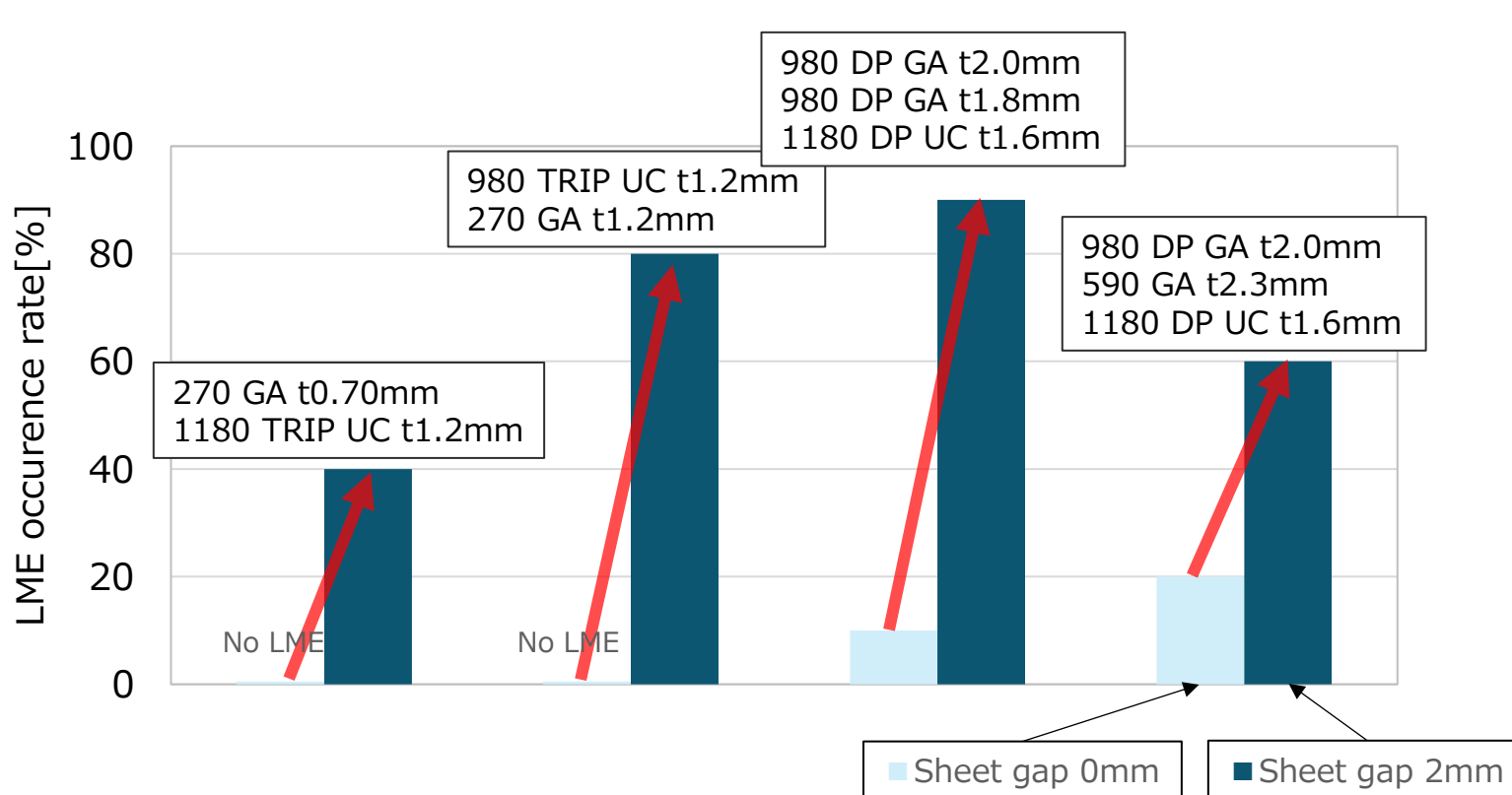
# Disturbances #1 (electrode angles)

- LME occurrence rate with electrode angles  $10^\circ$  was higher than  $5^\circ$ .
- Stress near nugget with electrode angle  $10^\circ$  was higher due to spring back by electrode angle after release of electrode. Especially, 2-sheets were lower rigidity than 3-sheets and LME occurrence rate was high by electrode angle.



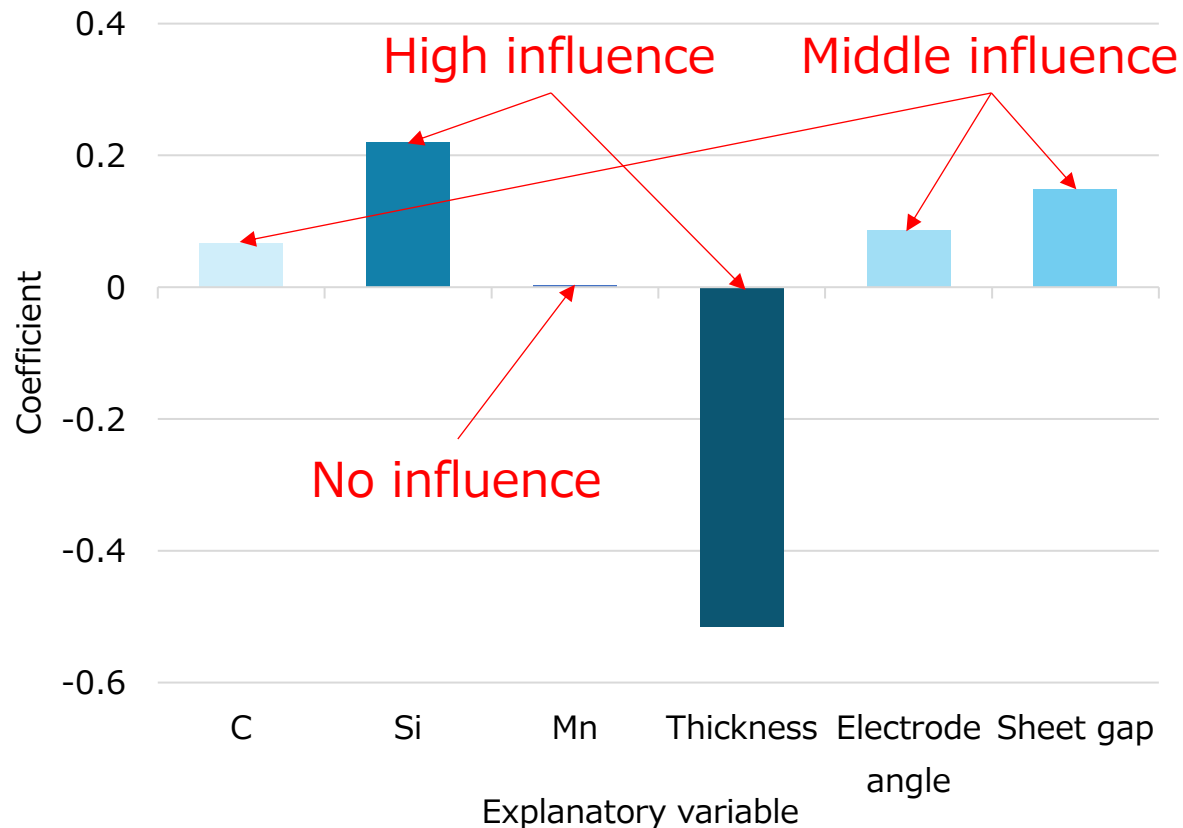
# Disturbances #2 (sheet gap)

- LME occurrence rate with sheet gap 2mm was higher than 0mm.
- Stress near nugget with sheet gap 2mm was higher due to spring back by sheet gap and electrode force. Especially, LME occurrence rate was high in thick sheet and high strength steel due to high rigidity.



# Influencing factor summary

- Si and thickness were high influence and sensitive for LME.
- C, electrode angle and sheet gap were influence and sensitive.
- Mn was no influence.



## Multiple regression analysis

$$y = a_1x_1 + a_2x_2 + a_3x_3 \dots + a_nx_n + b$$

Response variable;  
• LME occurrence rate

Explanatory variable;  
• Chemical composition (C, Si, Mn)  
• Thickness  
• Electrode  
• Sheet gap

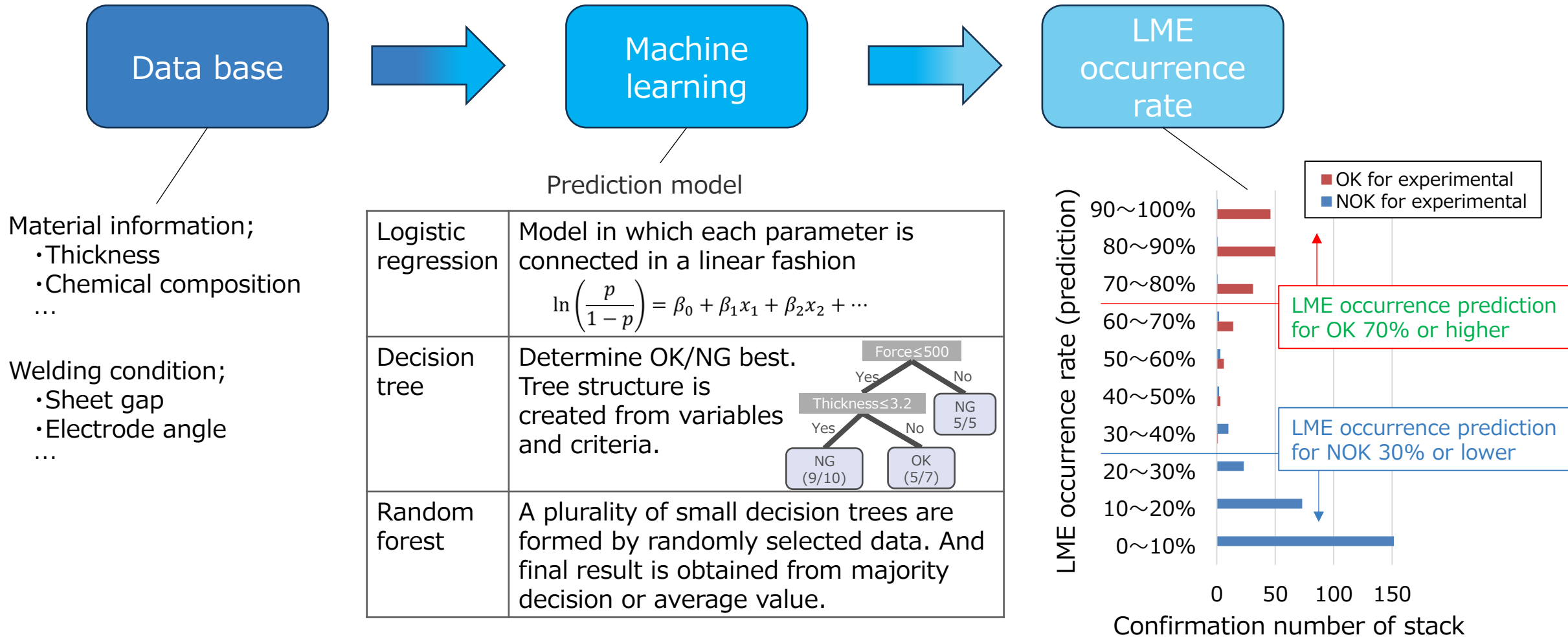
Coefficient

※Precondition: Standardization for response variable and explanatory variable

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# Next step – prediction occurrence of LME –

- It is possible to predict occurrence of LME by machine learning for next step.



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The following findings were obtained for LME;

- Si was high LME occurrence between 1.5 wt.% and 2.0 wt.%. C was sensitive but Mn was not sensitive.
- Thickness was sensitive. Especially, LME was high occurrence in stack including 0.60 and 0.70mm
- Electrode angle was more sensitive in angles  $10^{\circ}$ .
- Sheet gap was more sensitive in 2mm.

**Thank you**