Investigating AlSi coating fracture at hot stamping

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- Experiments investigating AlSi coating fracture
- Modeling AlSi coating fracture
- Recommendations
- Conclusions

Introduction

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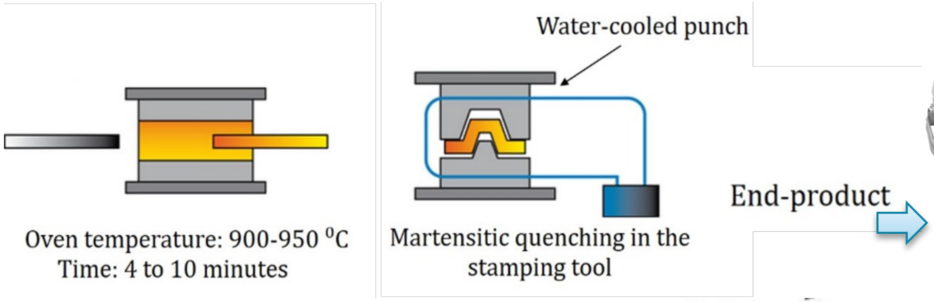
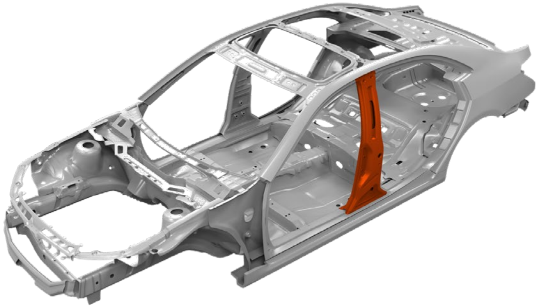
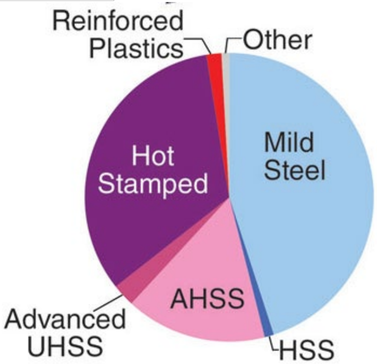
Introduction

Applications of hot stamping in the industry

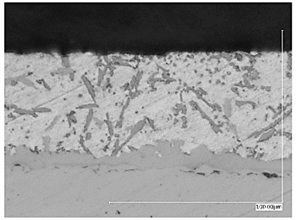


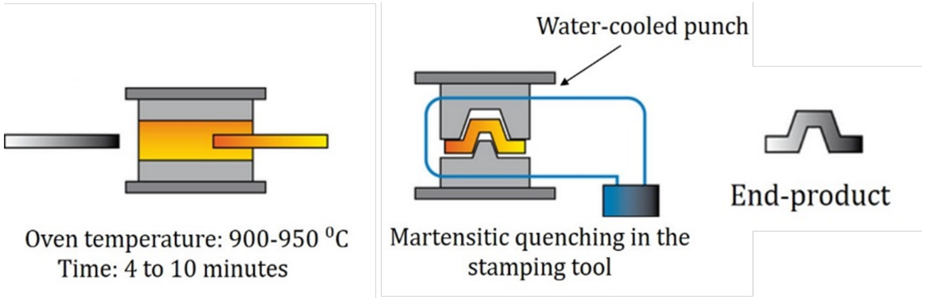


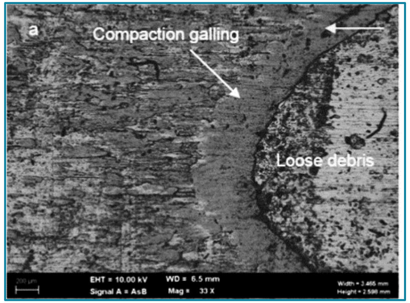


Introduction

Problems during hot stamping



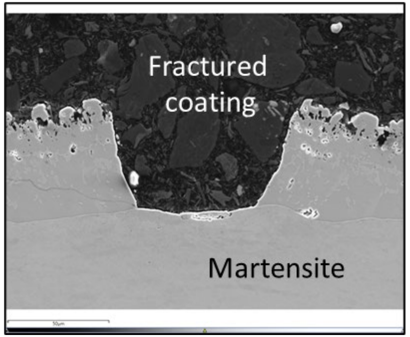




✦ <u>Observation</u>

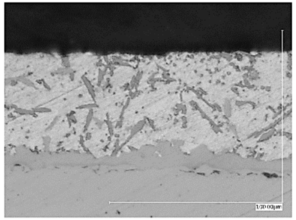
Tool wear
Affects friction

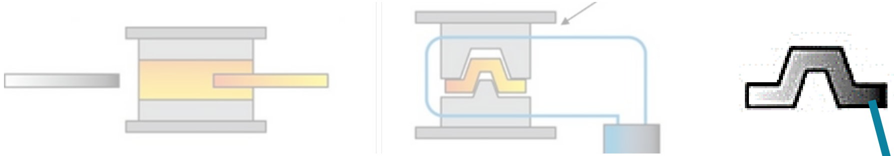
Al-Si coating fracture
Poor surface quality

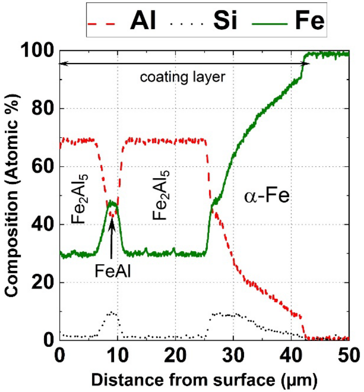


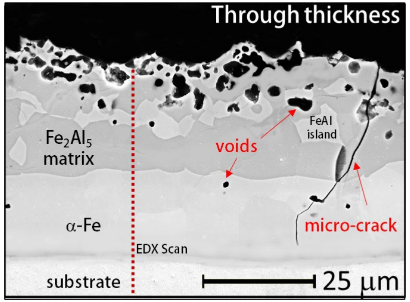
Introduction

Evolution of the coating layer







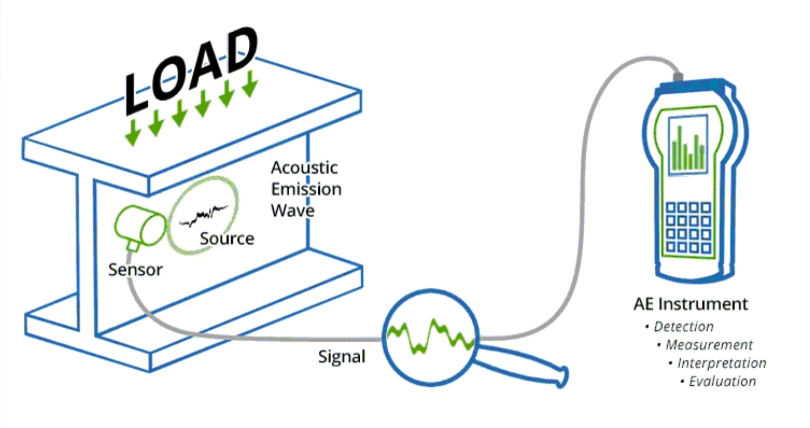


Introduction

Detecting coating fracture using acoustic emission sensors

- Acoustic emission (AE) sensors detect stress waves.

- **Signal Types**
  Continuous AE → low intensity
  Burst AE → high intensity



Introduction

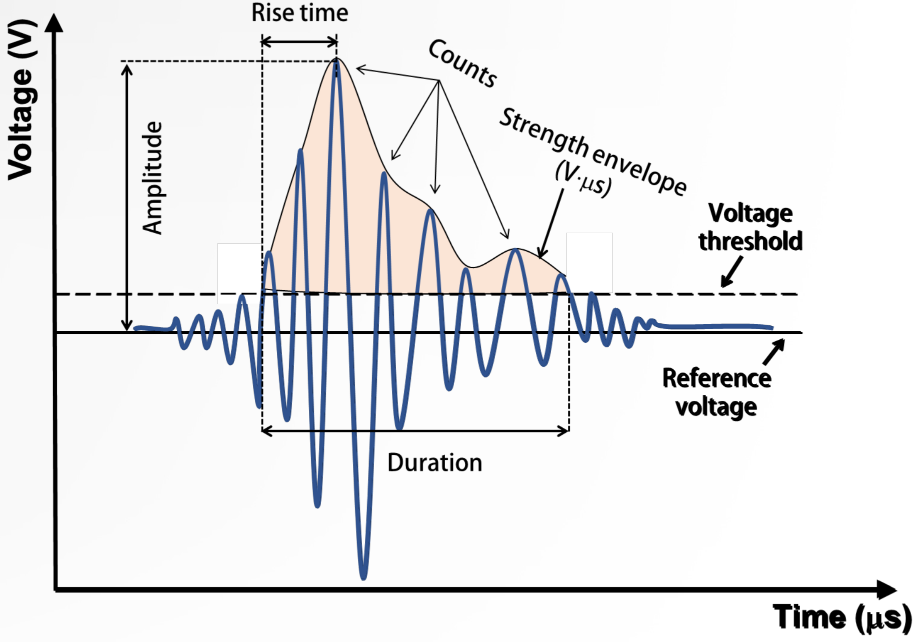
Principles of acoustic emission sensors

- Acoustic emission (AE) sensors detect stress waves.

- **Signal Types**
  Continuous AE → low intensity
  Burst AE → high intensity

- Material separation releases burst-type AE waves.

- Strength envelope → cracking events. [2]



[2]- Van Tittelboom K, et al. (2012) Construction & Building Materials 28 (1)

Introduction

Project goals

- Experimentally investigate coating fracture at hot stamping condition.
- Numerically model coating fracture.
- Minimize coating fracture.
- Optimize the hot stamping process.

Experiments

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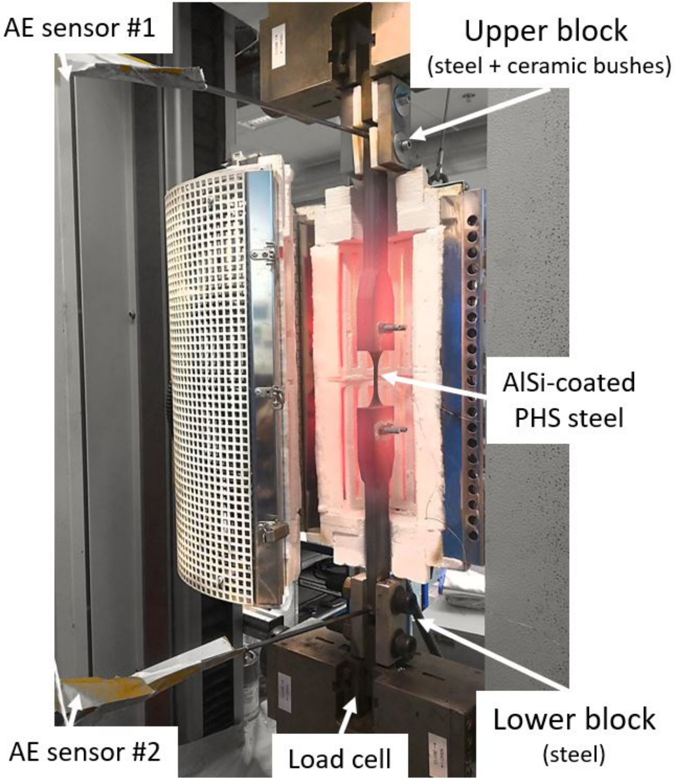
Experimental Approach

AE sensor-integrated hot tensile system

- Additional fixture- holding the sample.
- Ceramic bushes- acting as a thermal barrier.

- Acoustic Emission (AE) sensors- for signal tracing.
- Waveguides- to relay the signal.

- Tube furnace- to reach high temperature.
- Load cell- for tensile straining.



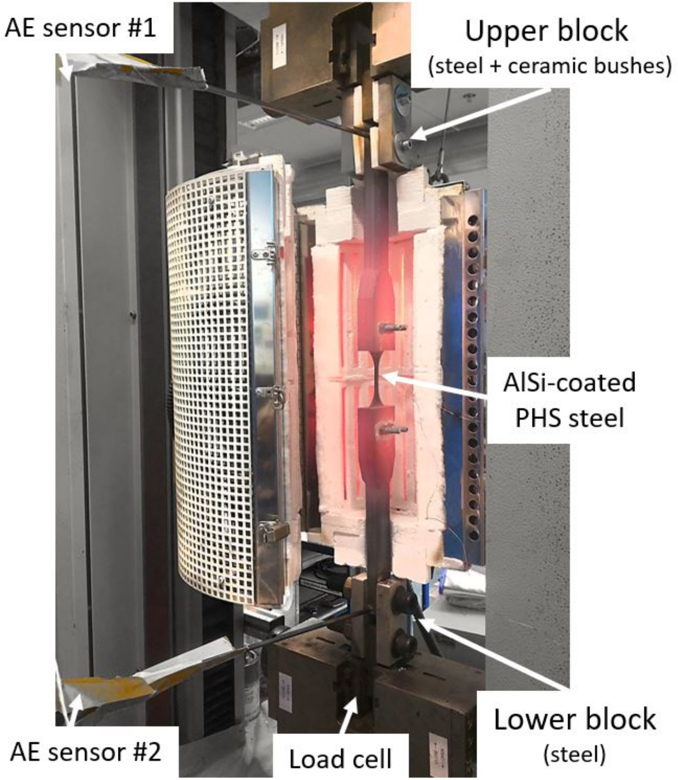
Experiments

Objective

- Detect coating cracks at hot stamping condition via AE sensors.

- **Effect of deformation temp.**
  920˚C + 6mins → 400–800˚C → cooling

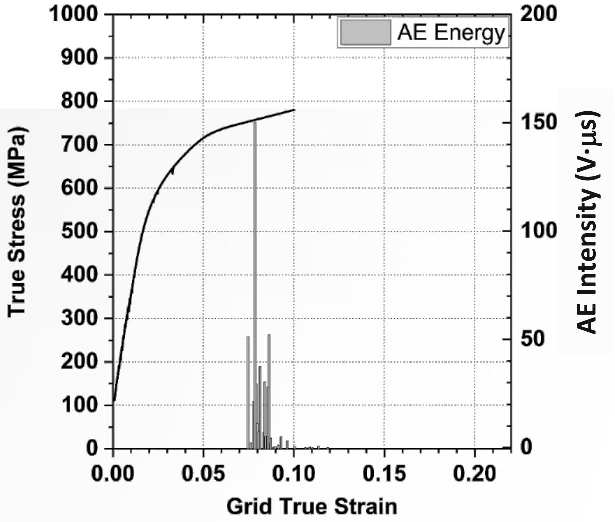
- Correlate AE signals with coating fracture.

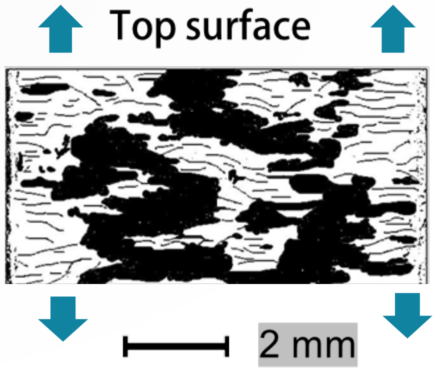


Effect of deformation temp.

Deformation stage- 400°C

- Uniaxial tensile straining → 10% strain.
- Burst AE signal → 8% strain.
- Coating spallation occurs.

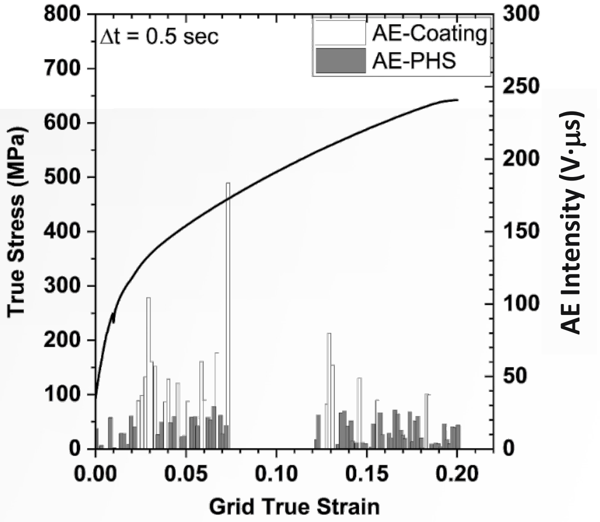




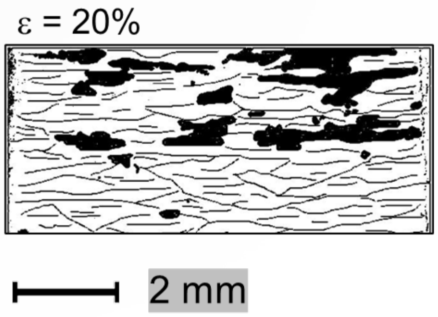
Effect of deformation temp.

Deformation stage- 500°C

- Straining level → 20% strain.
- Burst AE signals → 3, 7% strain.
- Dispersed cracks followed by spallation.



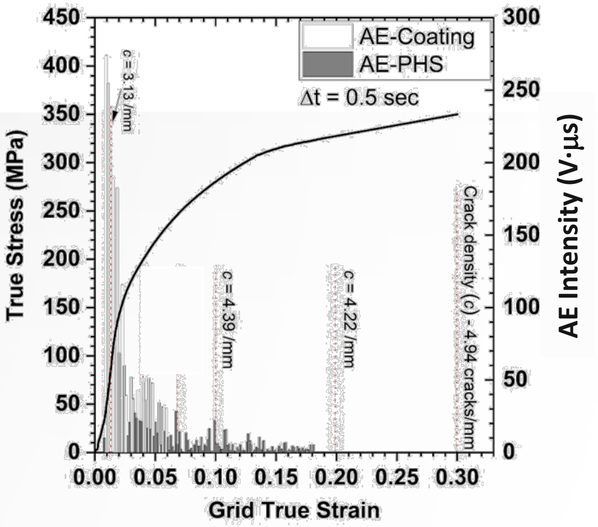
Top surface



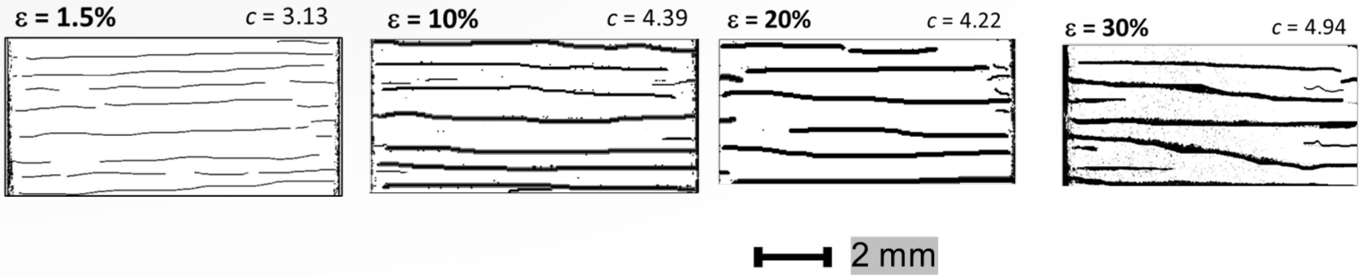
Effect of deformation temp.

Deformation stage- 600°C

- 4 straining levels → 1.5, 10, 20, 30% strain.
- Burst AE signal → 1% strain.
- Cracks observed from 1.5% strain.



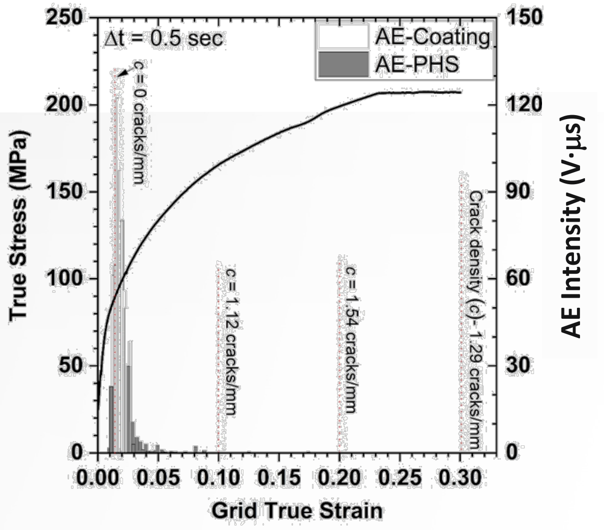
Top surface



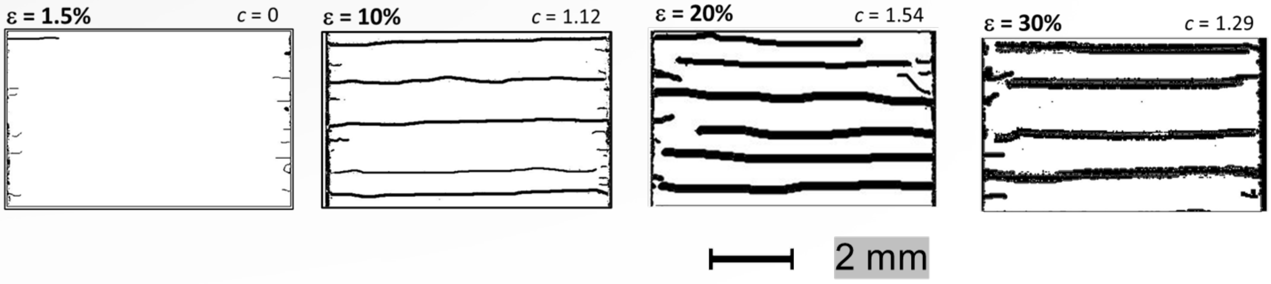
Effect of deformation temp.

Deformation stage- 700°C

- 4 straining levels → 1.5, 10, 20, 30% strain.
- Burst AE signal → 2% strain.
- Cracks observed after 2% strain.



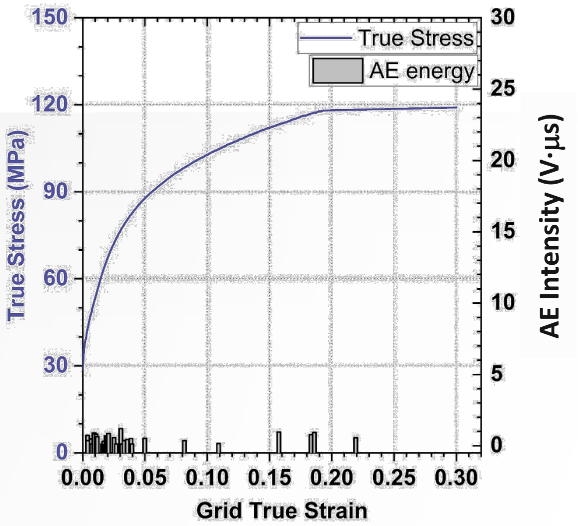
Top surface



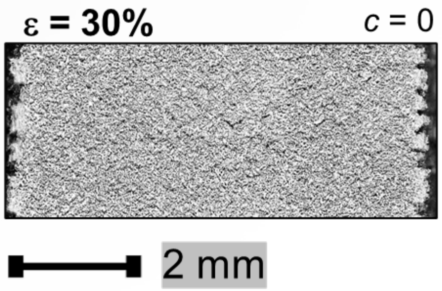
Effect of deformation temp.

Deformation stage- 800°C

- Straining levels → 30% strain.
- NO burst AE signal.
- NO cracks observed.



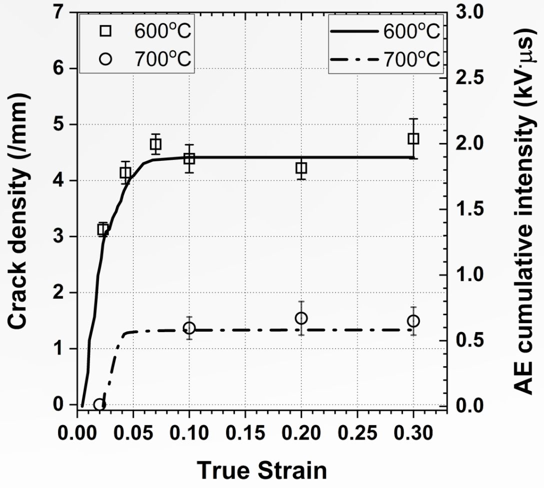
Top surface



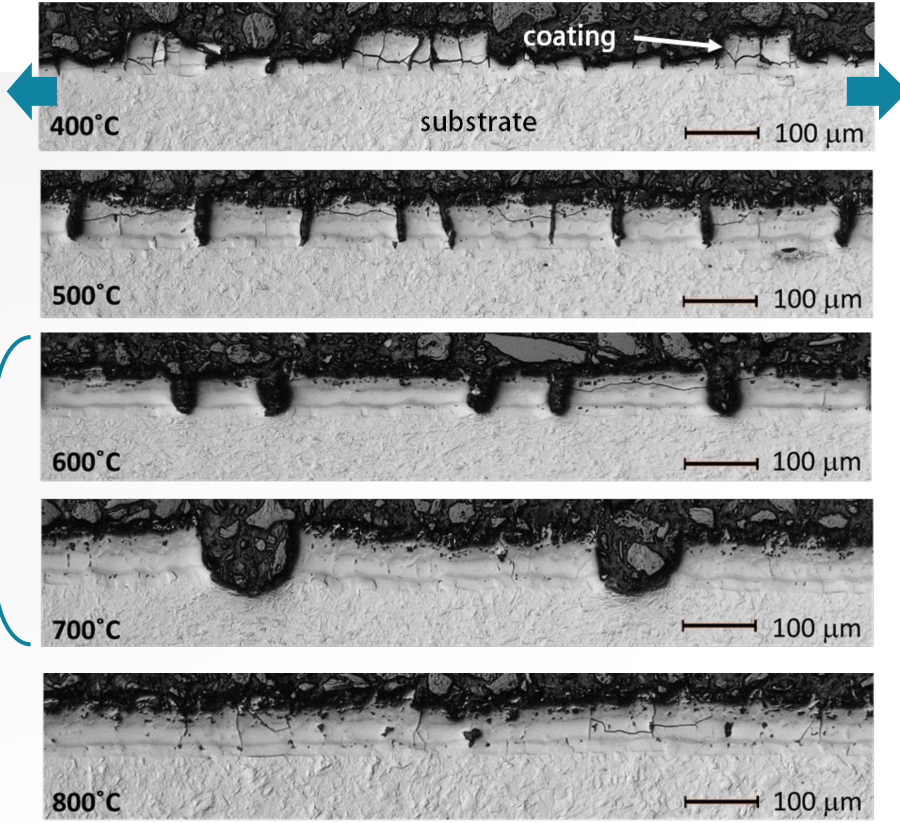
Experimental Results

Effect of deformation temperature

- 3 types of crack evolution:
  - 400-500˚C: Dispersed cracks and spallation.
  - 600-700˚C: Only mode I cracks.
  - 800˚C: No cracks.



Through-thickness inspection



Modeling AlSi coating fracture

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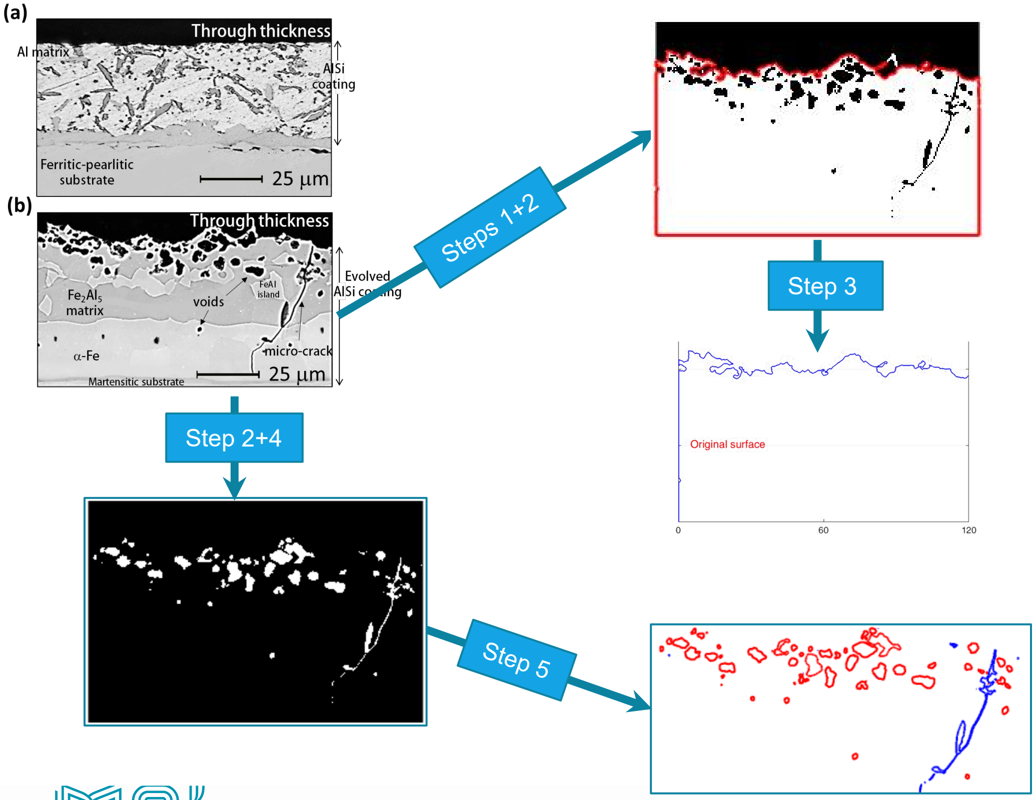
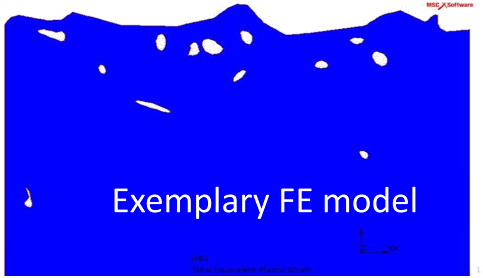
Modeling AlSi coating

Coating reconstruction strategy



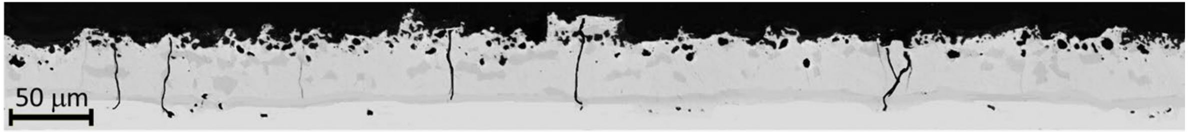
1 Surface & defect detection algorithm

Step 1 → Binarize the Area Of Interest (AOI).
Step 2 → Use *bwboundaries()* to get coordinates of surface and defects.
Step 3 → Store the **surface coordinates**.
Step 4 → Calculate the total number of defects (D_{total}).
Step 5 →
  for $k = 1$ to D_{total} **do**
    ⇒ Measure major ($maj(k)$) and minor ($min(k)$) axes
    ⇒ Calculate ellipticity $\left(\frac{maj(k)}{min(k)}\right)$
    ⇒ **if** $\frac{maj(k)}{min(k)} < 8$
      it is a void i.e., **accepted**.
    else
      it is a micro-crack; i.e., **rejected**.
    end if
  end for
Step 6 → Retrieve all coordinates enclosing voids and surface.
Step 7 → Map voids and surface coordinates into MSC.Marc.

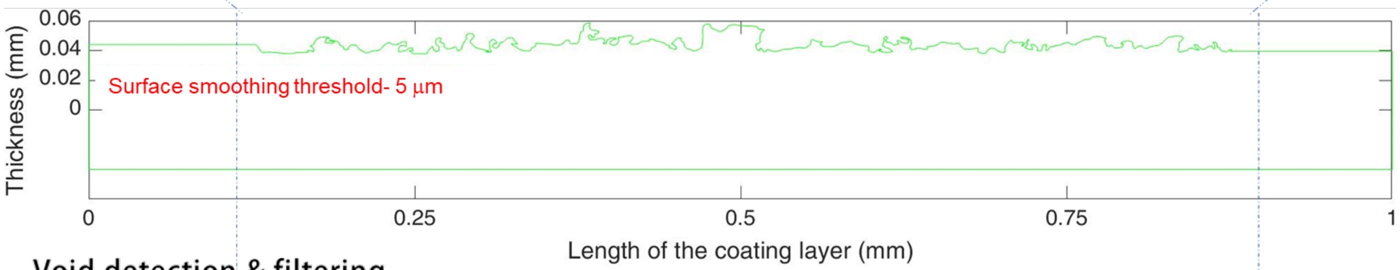


Modeling AlSi coating

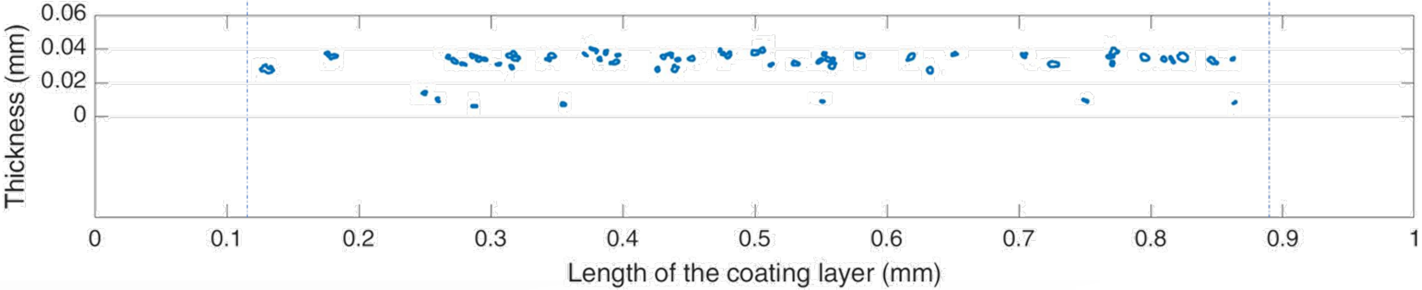
Coating reconstruction strategy



Surface profile detection

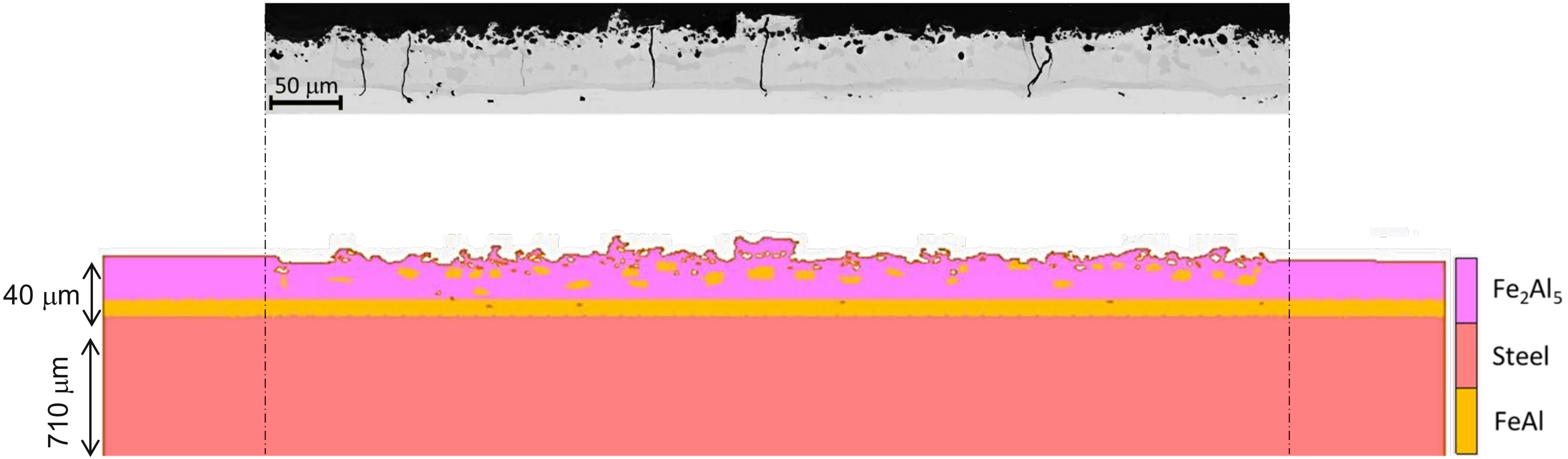


Void detection & filtering



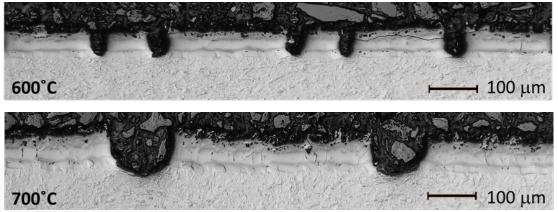
Modeling AlSi coating

Coating reconstruction strategy

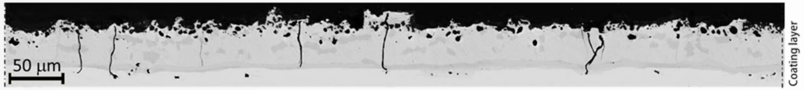


Modeling AlSi coating

Objective

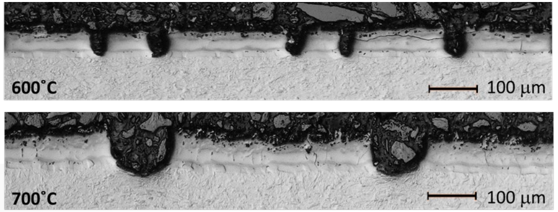


- Replicate the experimental findings.
- Investigate the cause of coating fracture.
- Optimize the process.



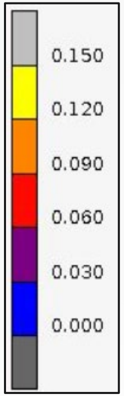
Modeling AlSi coating fracture

Tensile simulation results

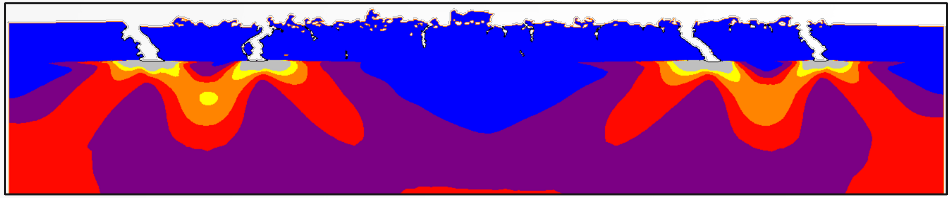


- Calibration of FE model.
- Replicates experimental findings.
- Temperature-dependent fracture pattern.
- A tool to find the cause of coating fracture.

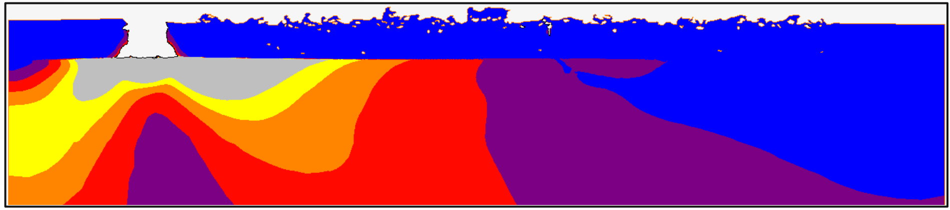
ε_p^{eq} plot



600˚C



700˚C



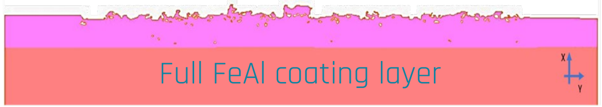
Modeling AlSi coating fracture

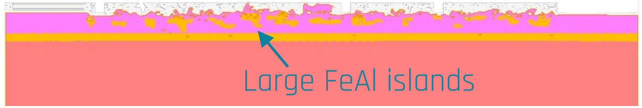
Objective- To reduce coating fracture

Sensitivity Analysis Summary

(#) → no. of cracks

SURFACE	Original Roughness (4)	Increased roughness (4)	Flat surface (3)	
VOIDS	Original voids (4)	No voids (5)	Increased void size (2)	No Kirkendall voids (2)
INTERMETALLICS	Original distribution (4)	Small FeAl islands (3)	Large FeAl islands (2)	Full FeAl (2)





Recommendations

To reduce coating fracture at hot stamping

Sensitivity Analysis Summary				(#) → no. of cracks
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INTERMETALLICS	Original distribution (4)	Small FeAl islands (3)	Large FeAl islands (2)	Full FeAl (2)

- Favorable **heat treatment conditions** for coating layer-
  - Higher austenitization heating temperature.
  - Longer dwell time.

- Favorable **deformation conditions** for coating layer-
  - Higher deformation temperature.

Conclusion

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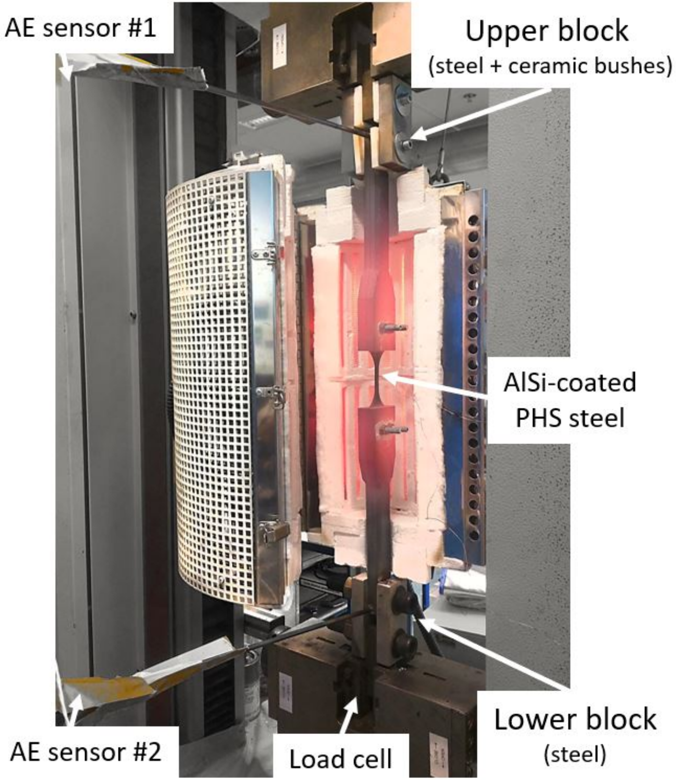
Conclusion

Investigating AlSi coating fracture

- AE sensors is used to detect coating cracks.

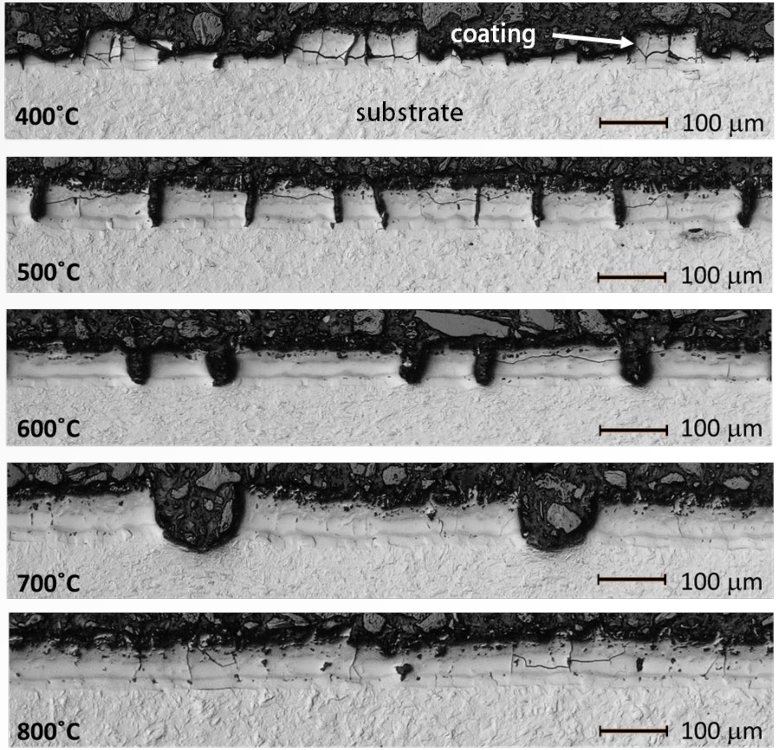


Conclusion

Investigating AlSi coating fracture

- AE sensors is used to detect coating cracks.
- **Effect of deformation temp-**
  - At 800˚C, no cracks.
  - At 600 or 700˚C, mode-I coating fracture.
  - At 400 or 500˚C, dispersed + spallation.

Through-thickness inspection



Conclusion

Modeling AlSi coating fracture

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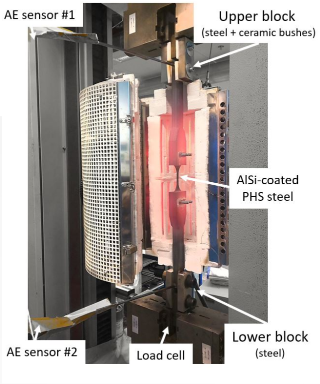
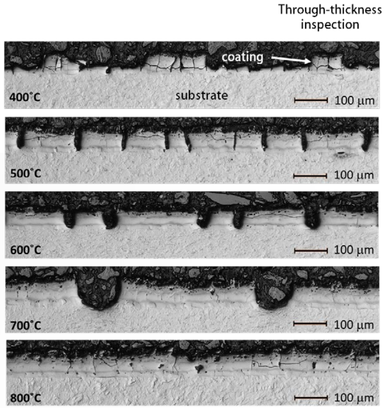
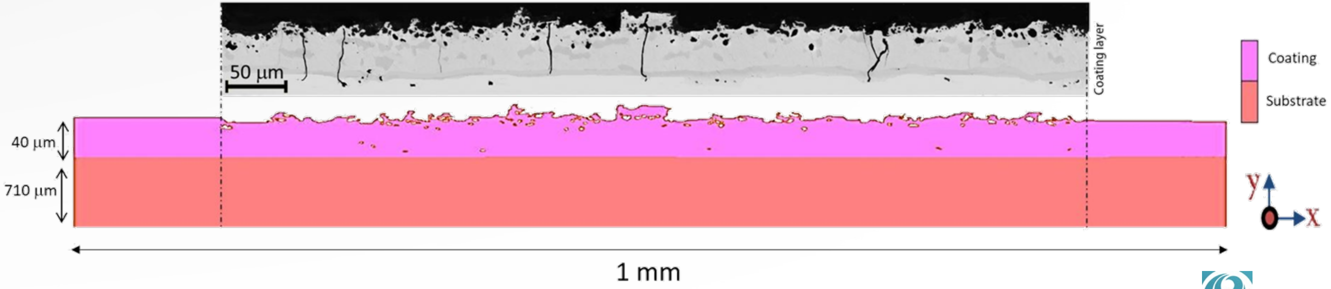




- Model built from 1 mm long coating micrograph.
- Surface profile and void coordinates mapped.



Conclusion

Modeling AlSi coating fracture

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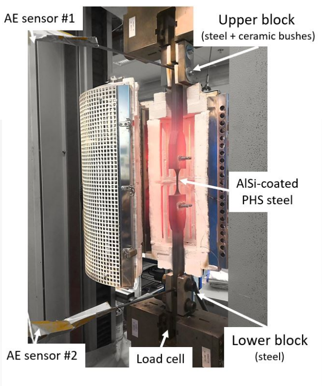
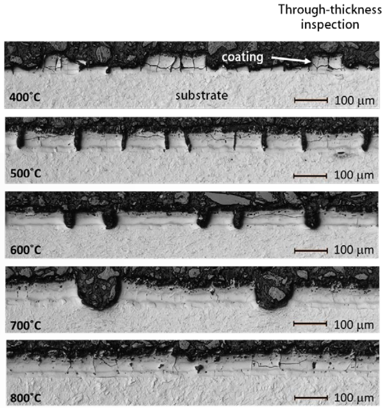
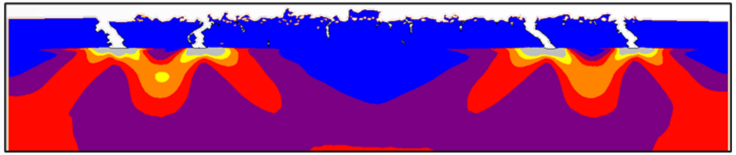


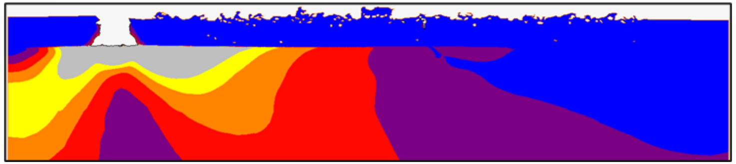


- Model built from 1 mm long coating micrograph.
- Surface profile and void coordinates mapped.
- Numerically replicated the experimental results.

600˚C



700˚C



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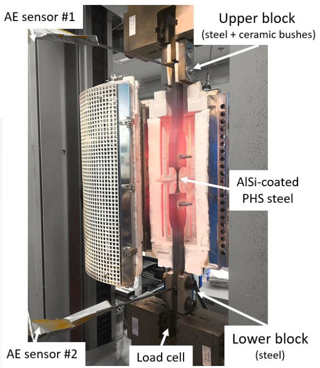
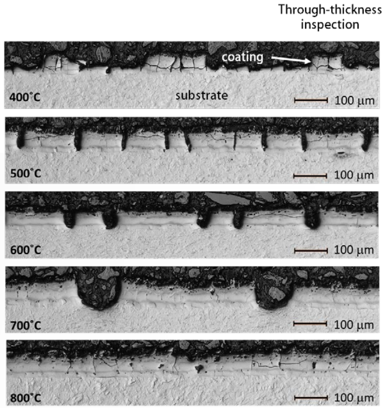
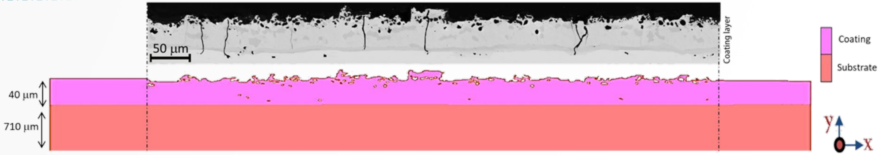
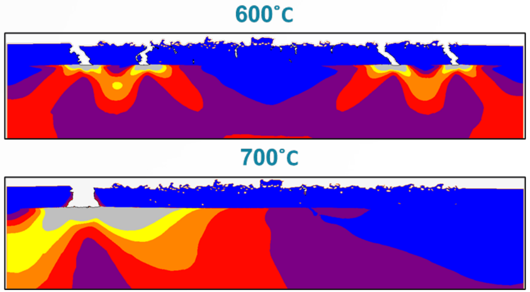




- Model built from 1 mm long coating micrograph.
- Surface profile and void coordinates mapped.
- Numerically replicated the experimental results.
- Coating fracture can be minimized.





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Thank you

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