Effect of friction stir processing on the damage resistance of 6xxx series aluminium alloys

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Selective formability : A balance between cost and performance

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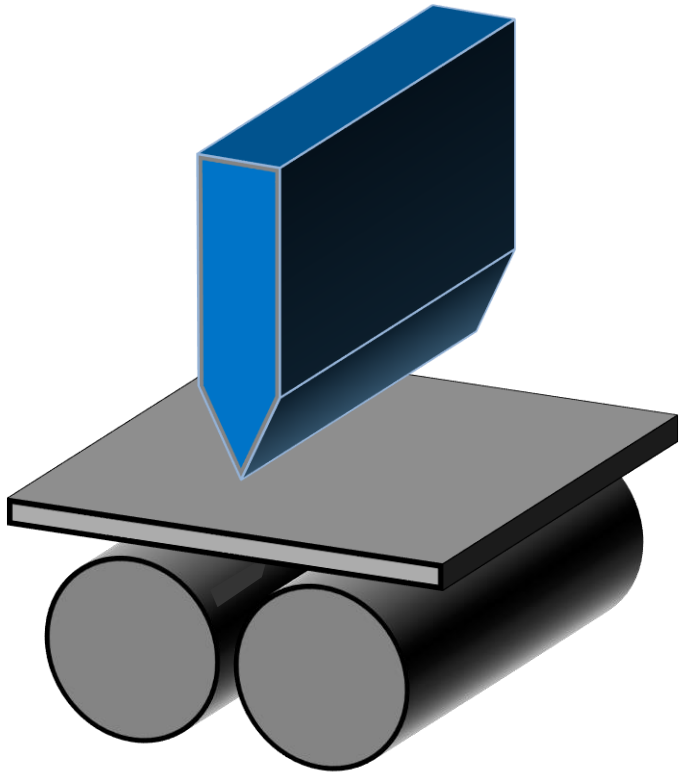
Improve ductility of sheets at locations where **forming** involves **large strains**



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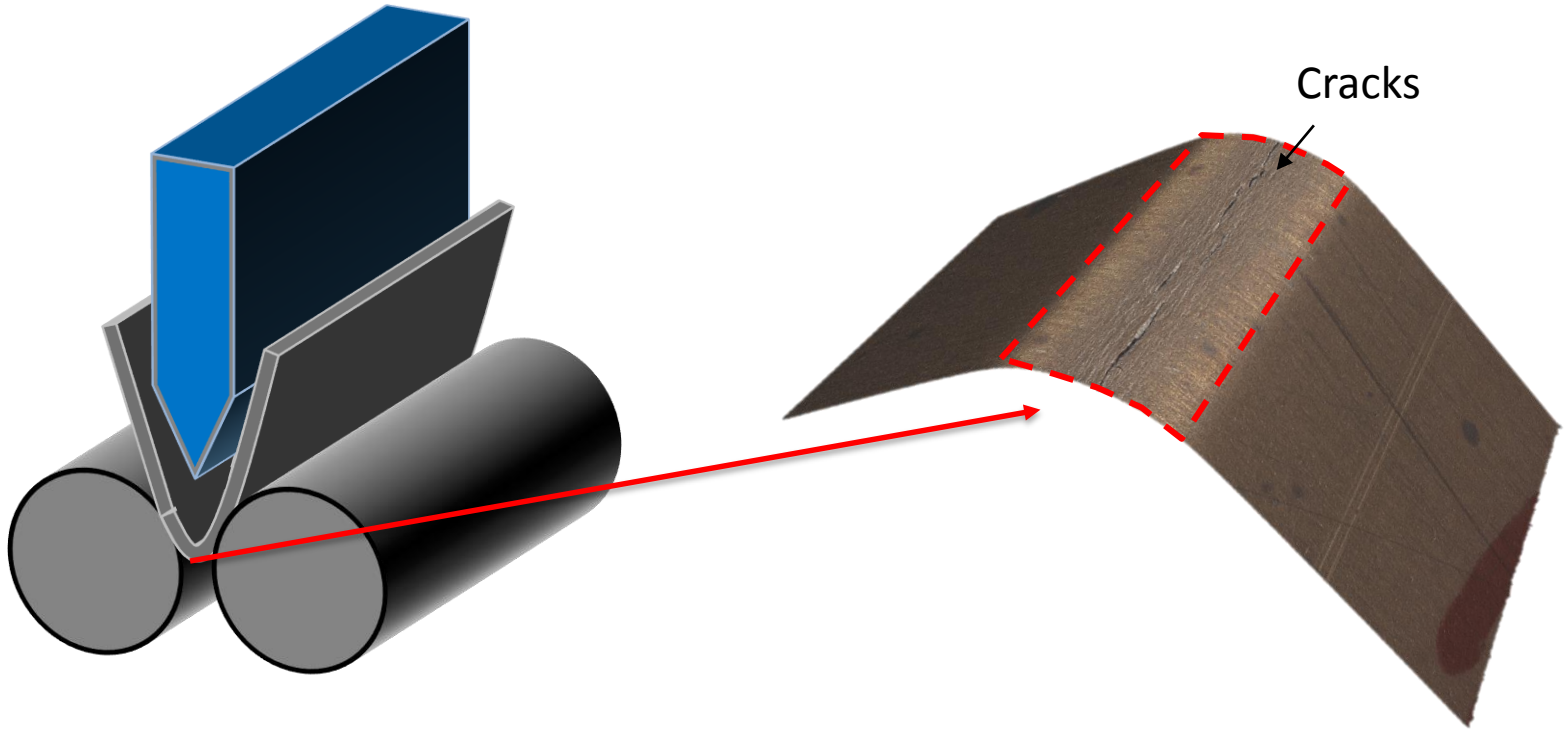

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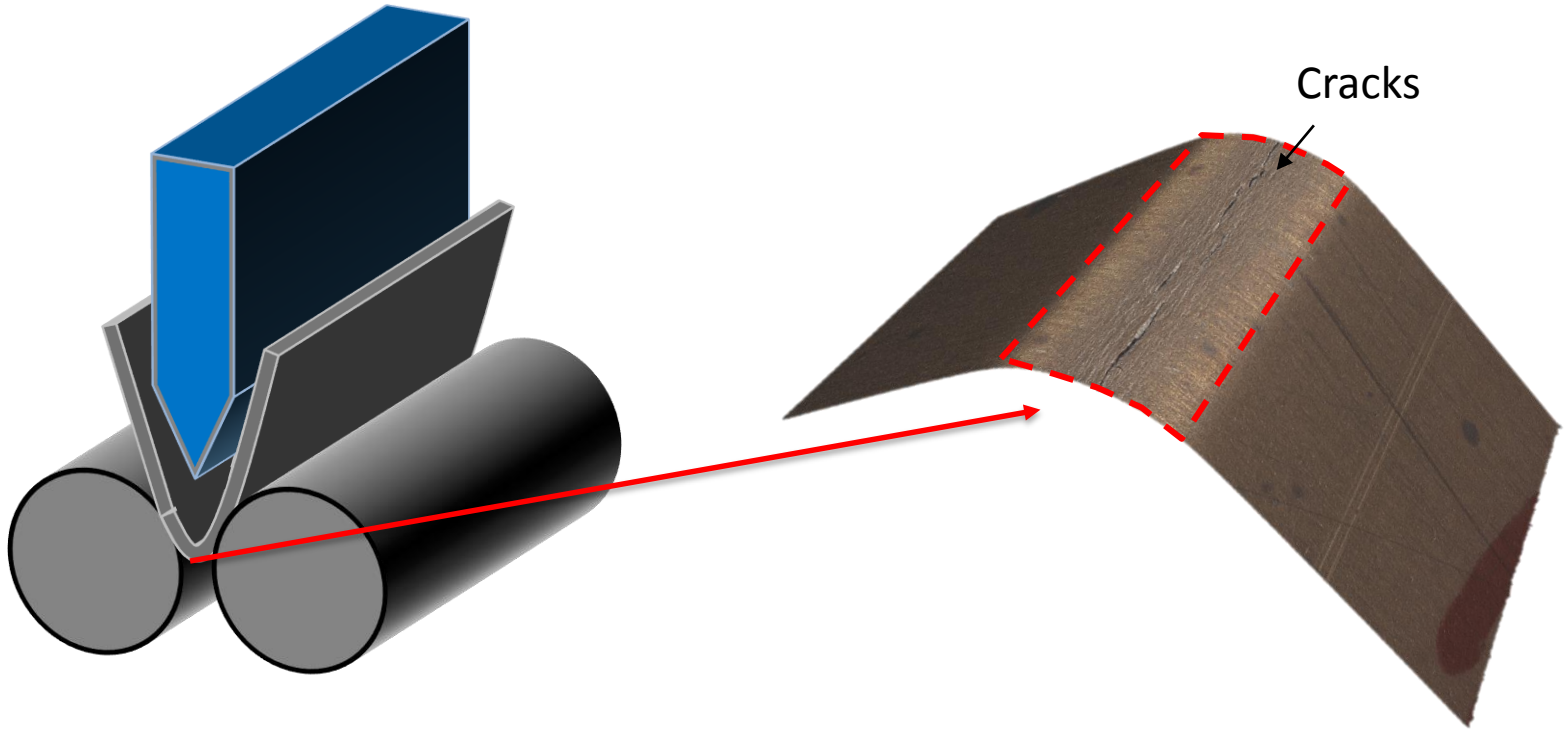
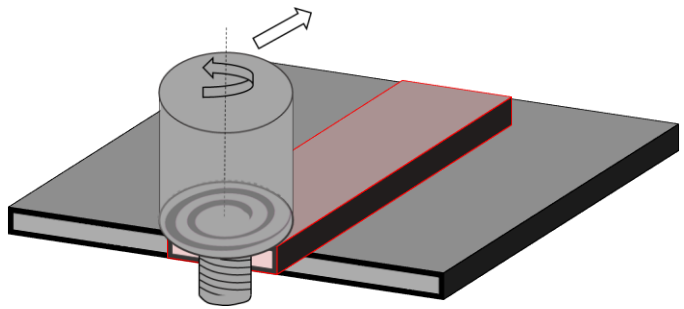
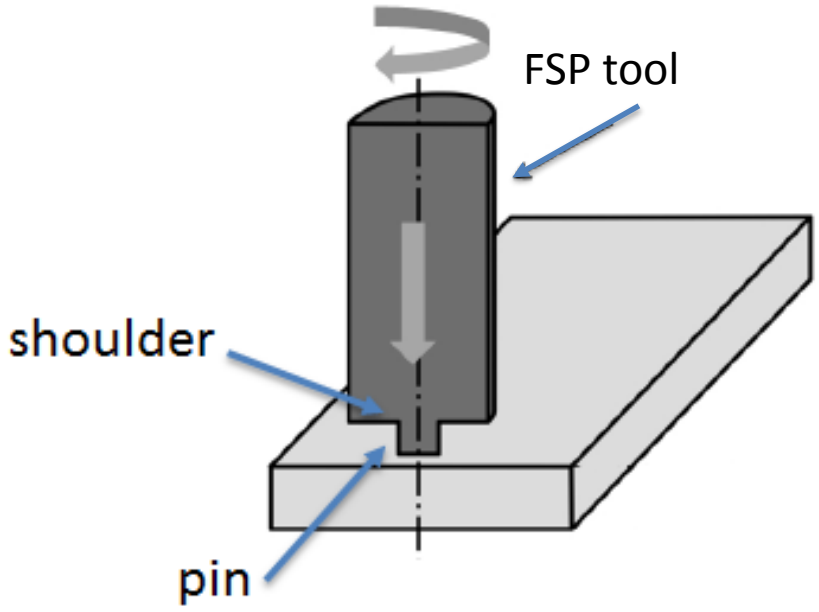


Friction stir processing

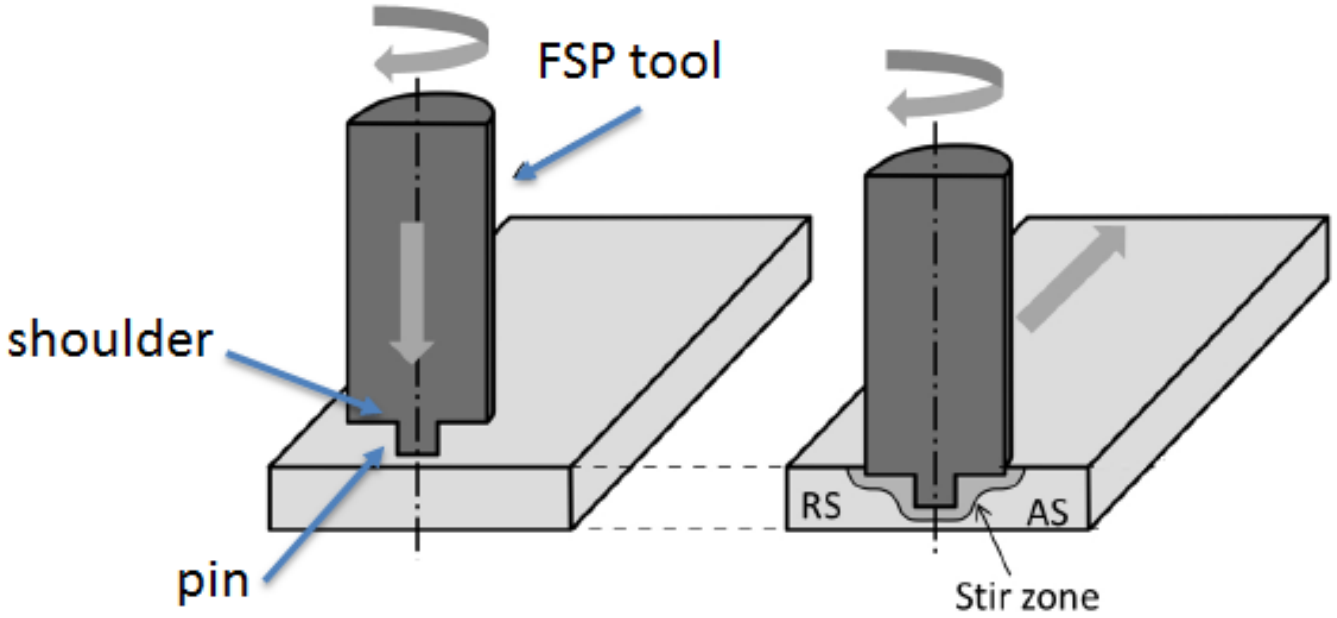


Aim : Improve the damage resistance of Al 6056 alloy by **friction stir processing (FSP)**



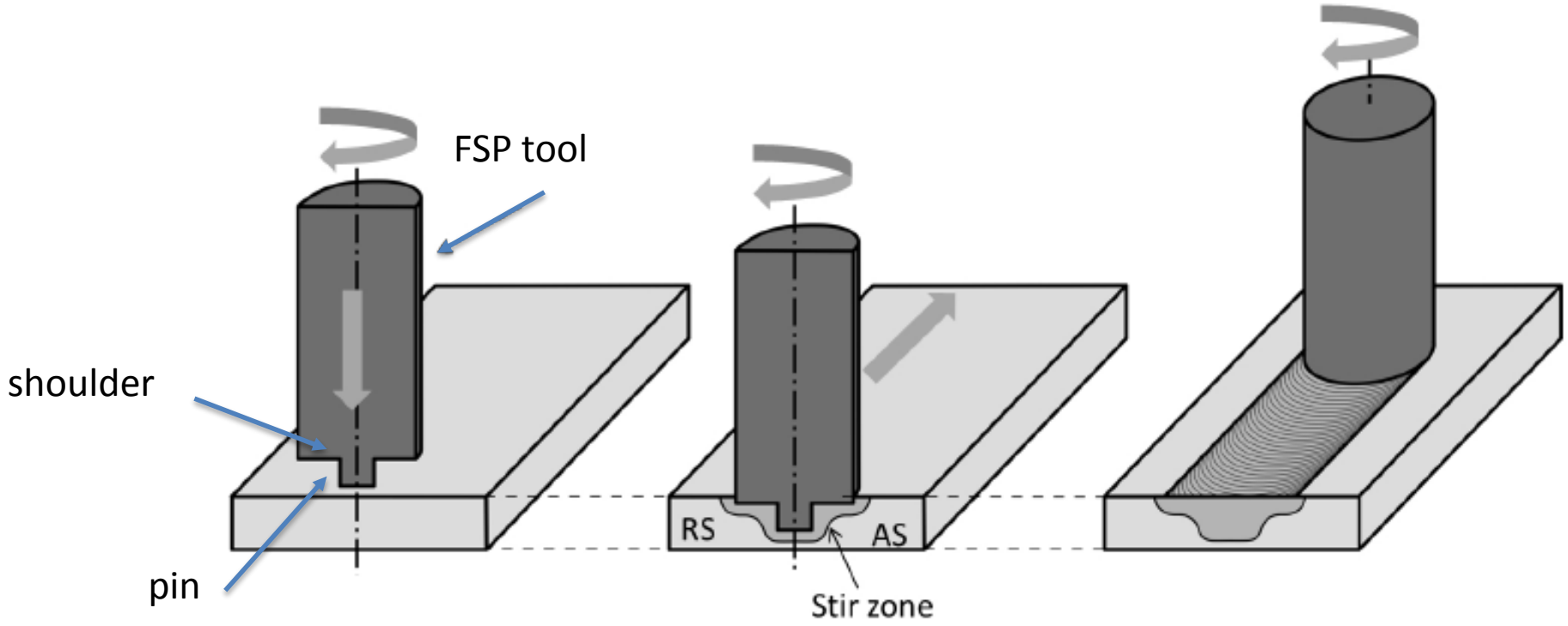
Rotating tool

Aim : Improve the damage resistance of Al 6056 alloy by **friction stir processing (FSP)**



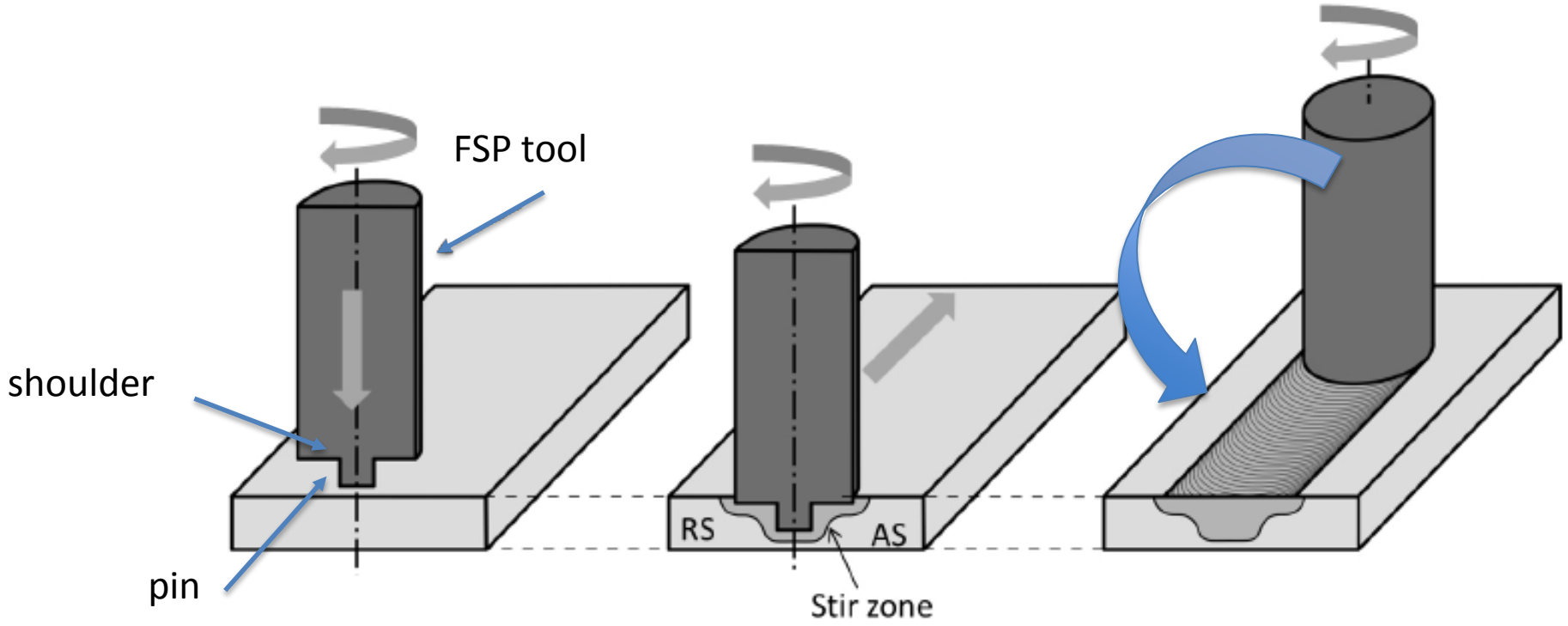
It is introduced into the material.

Aim : Improve the damage resistance of Al 6056 alloy by **friction stir processing (FSP)**



The tool is then travelling forward.

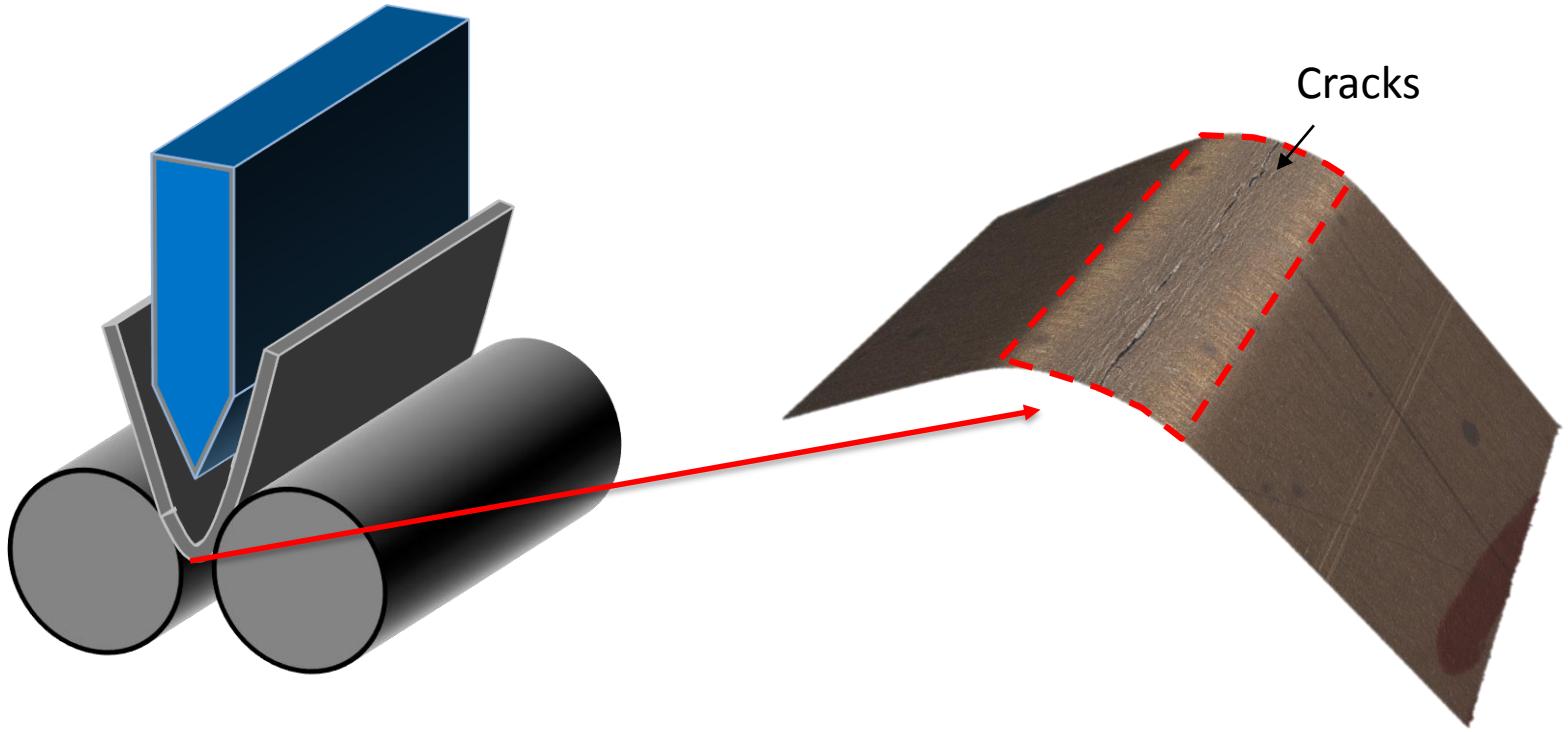
Aim : Improve the damage resistance of Al 6056 alloy by **friction stir processing (FSP)**



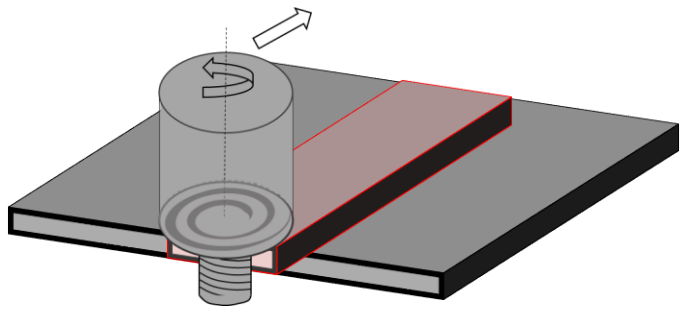
Number of FSP passes

Selective formability : A balance between cost and performance

Improve ductility of sheets at locations where **forming** involves **large strains**

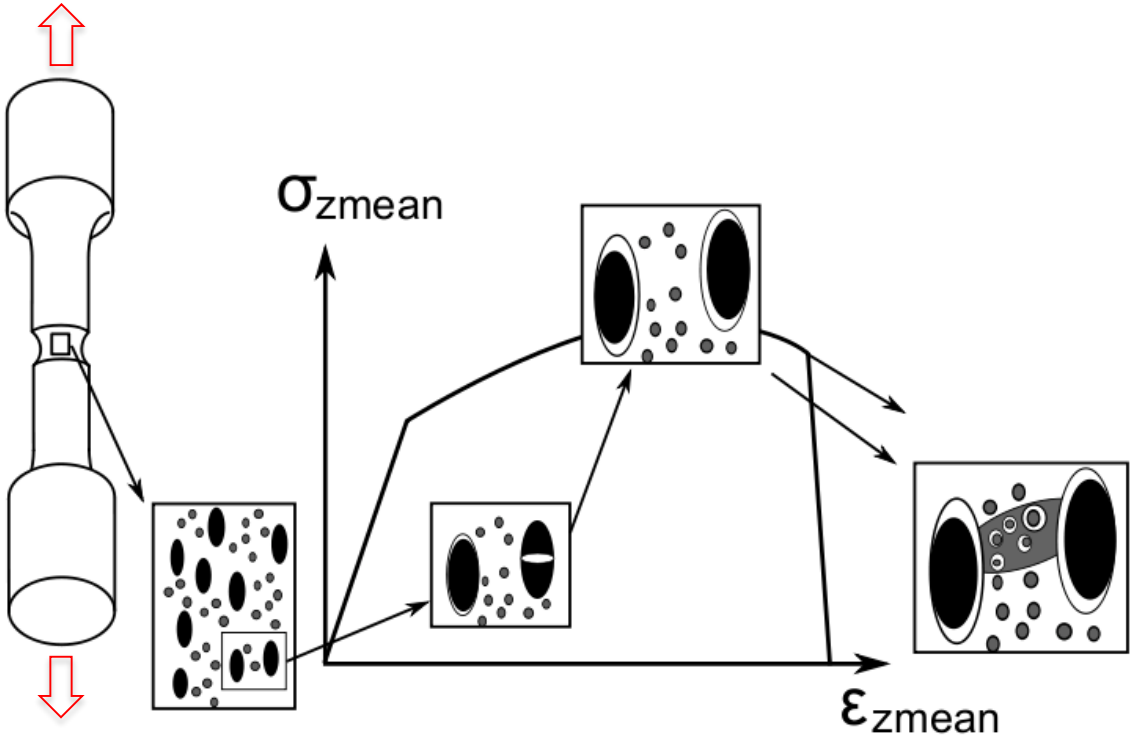


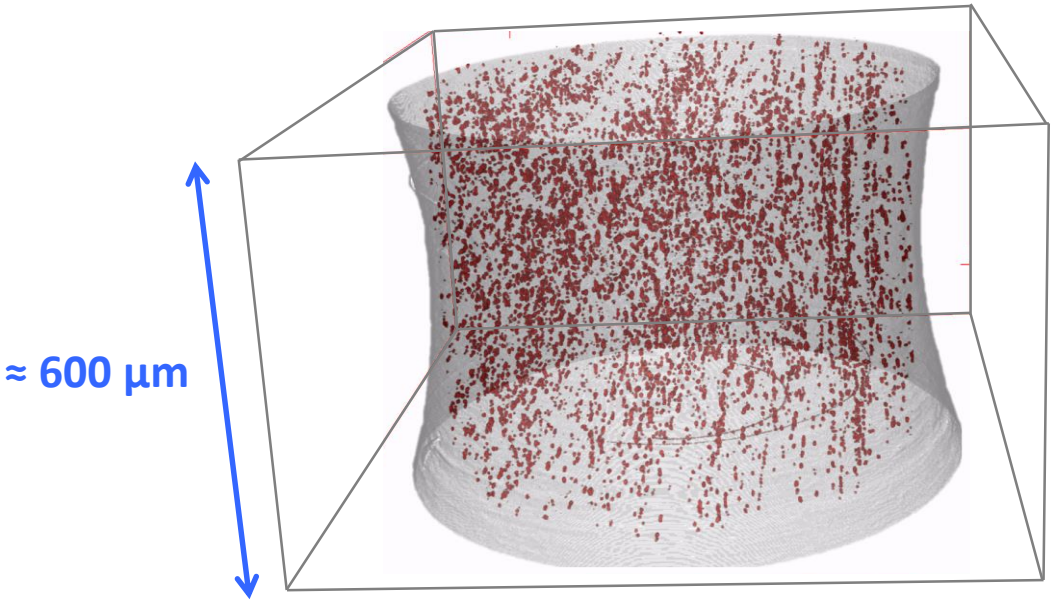
Friction stir processing

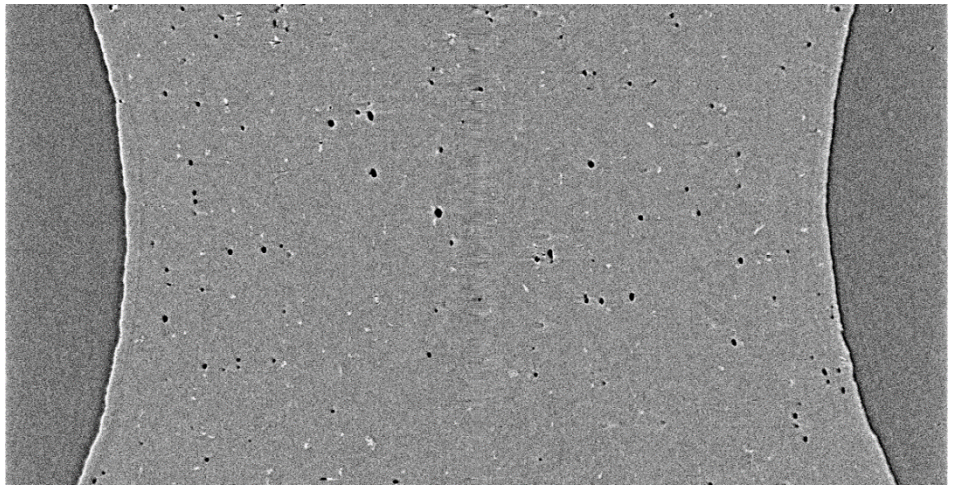


Ductile fracture is led by the damage mechanisms

- Void nucleation
- Void growth
- Coalescence of voids







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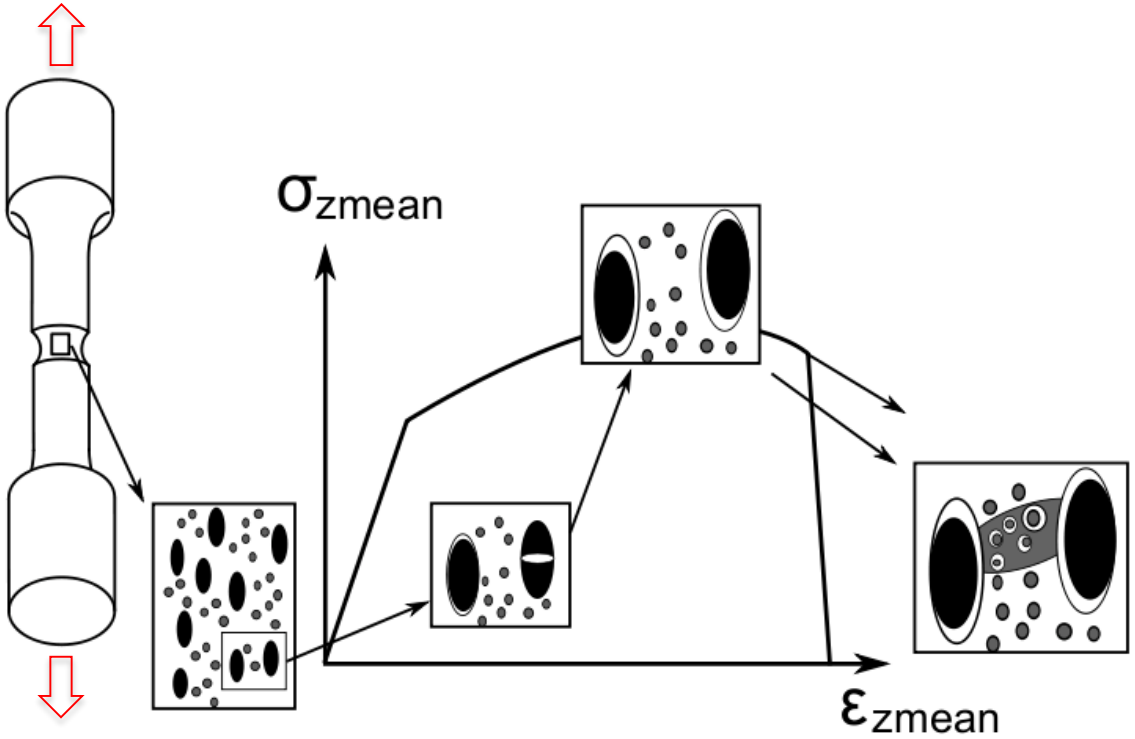

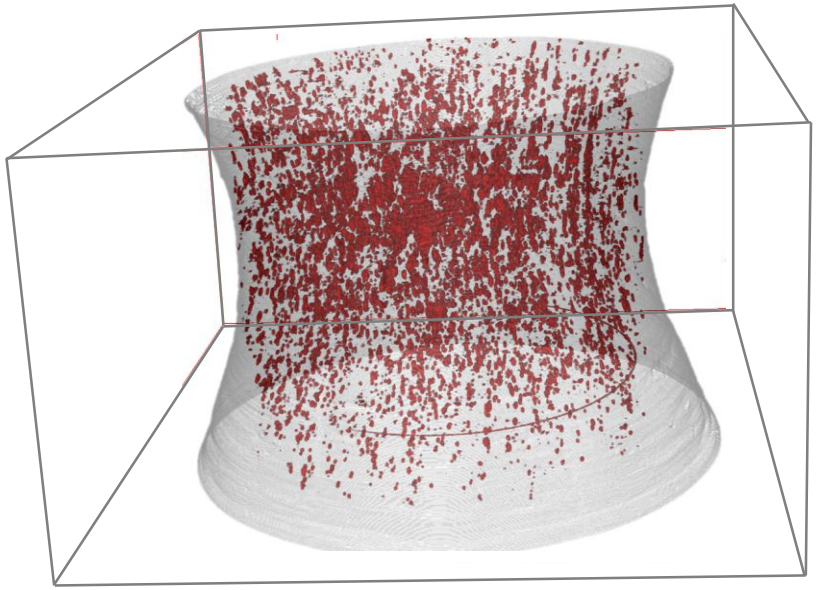

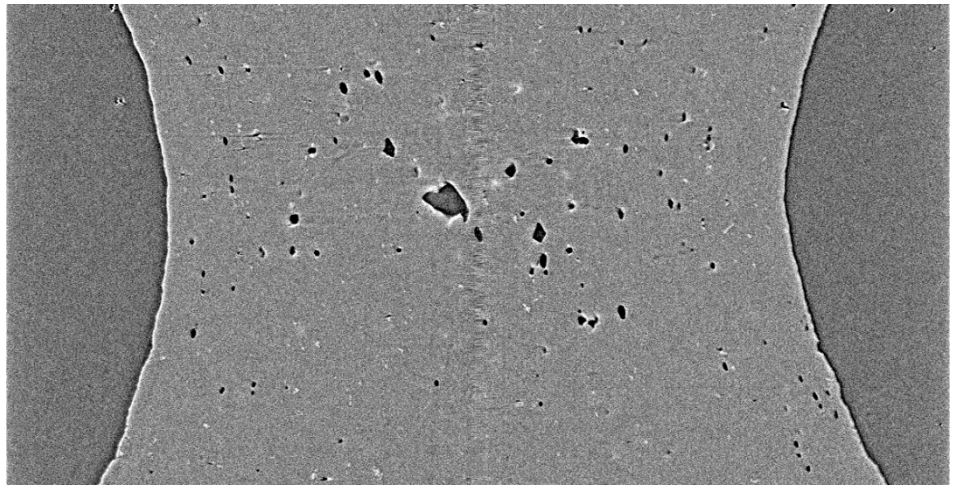

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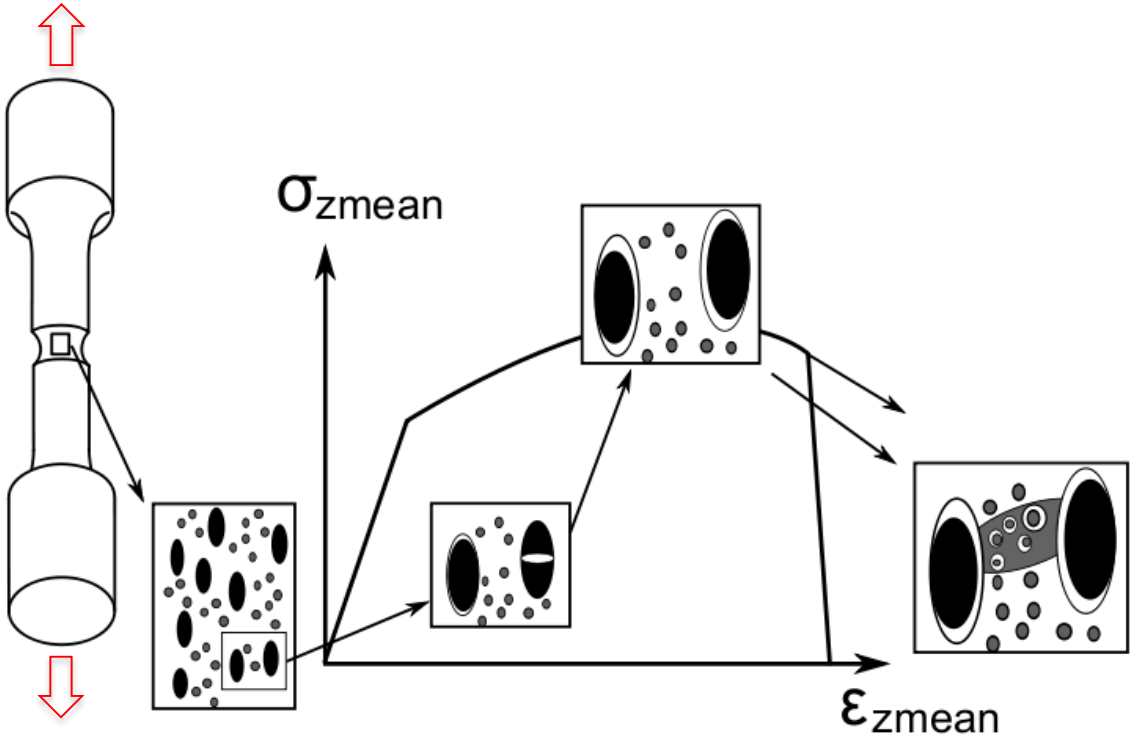

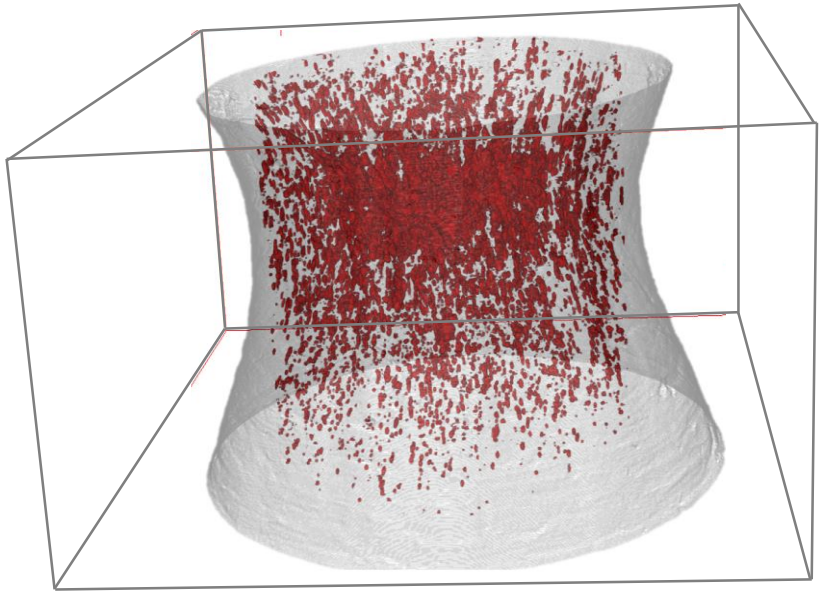

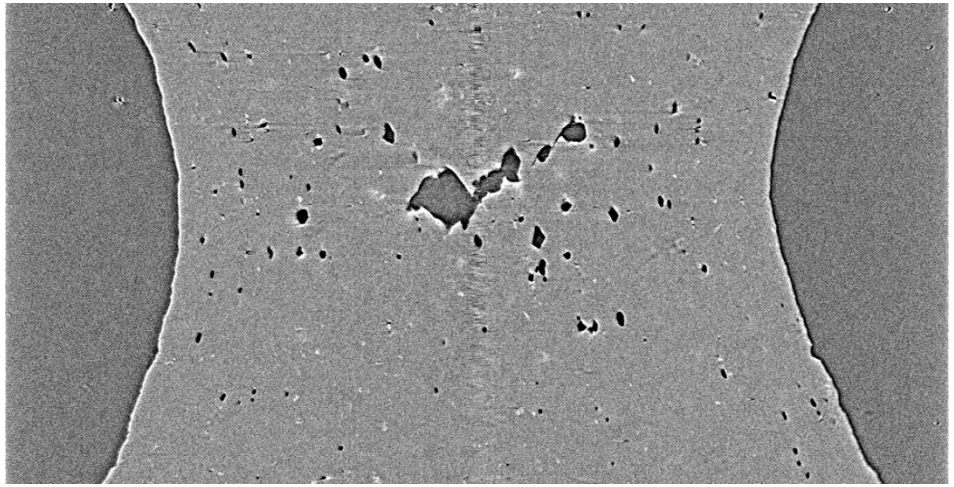

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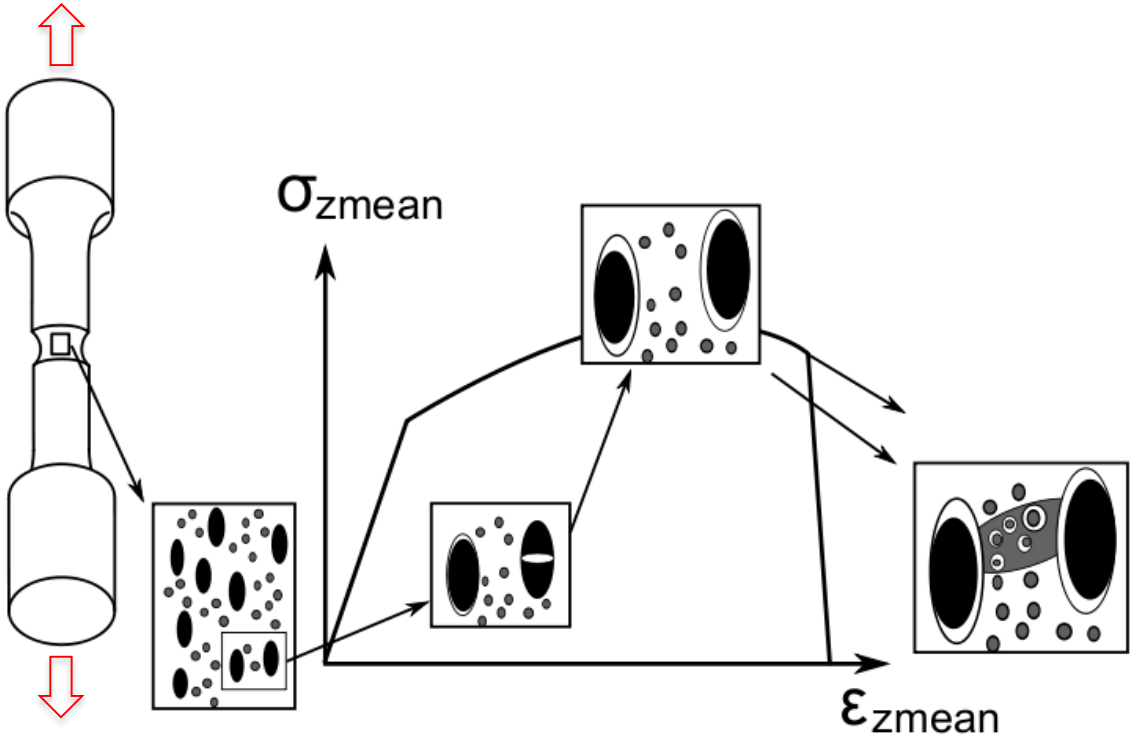

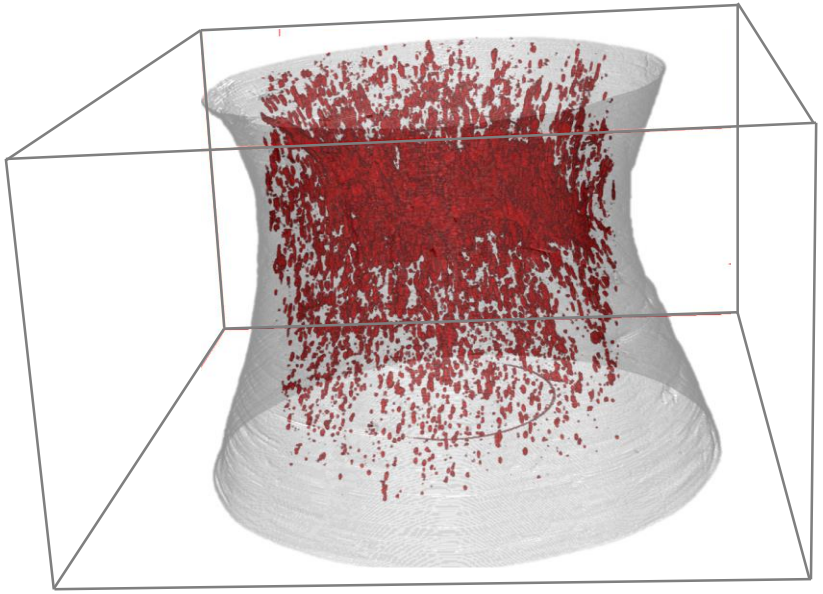

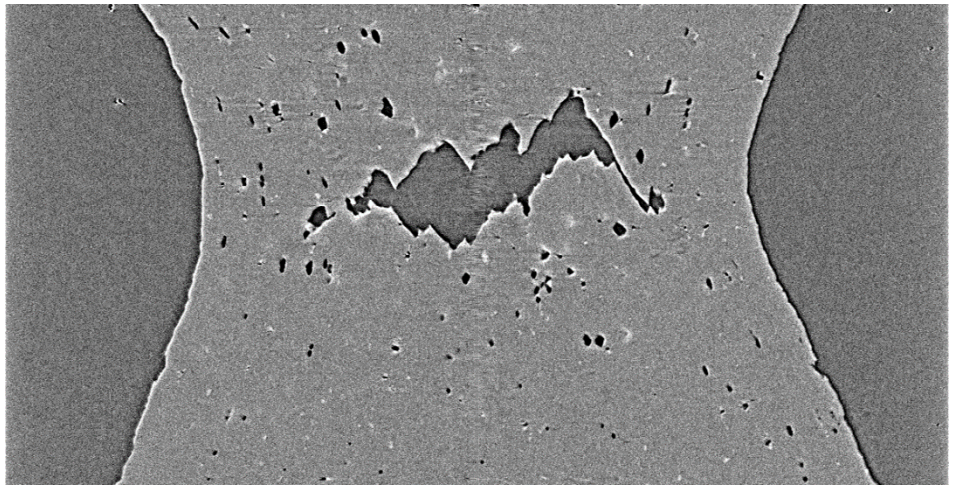

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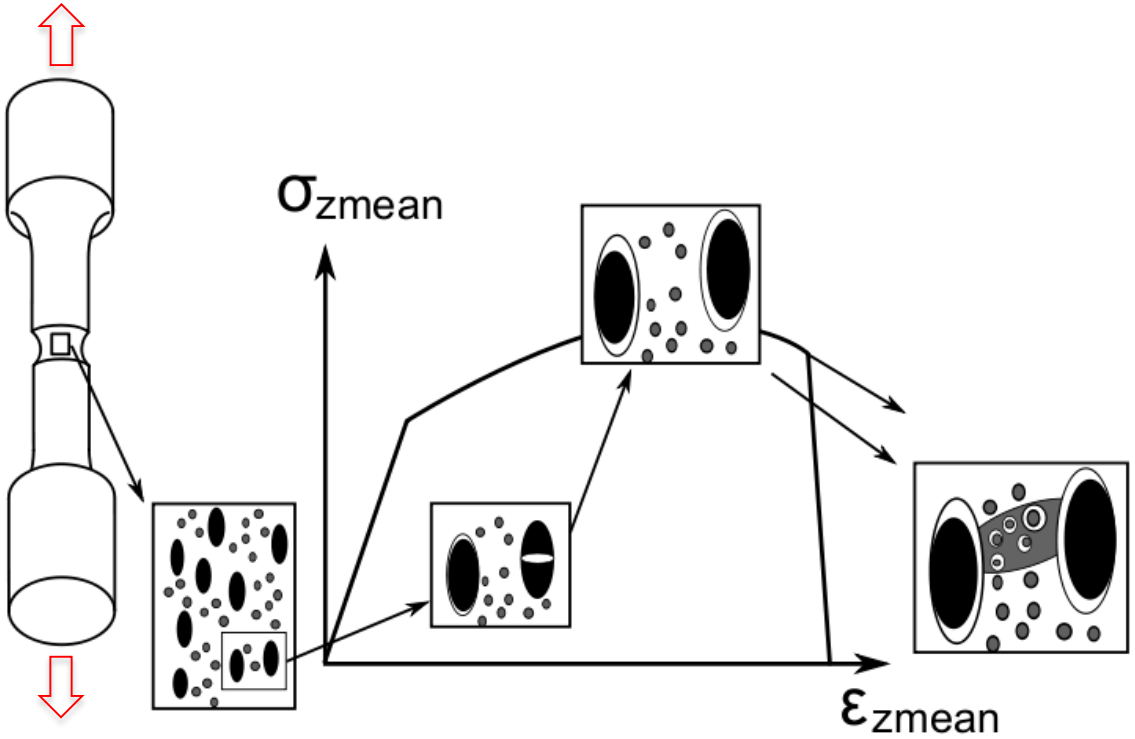

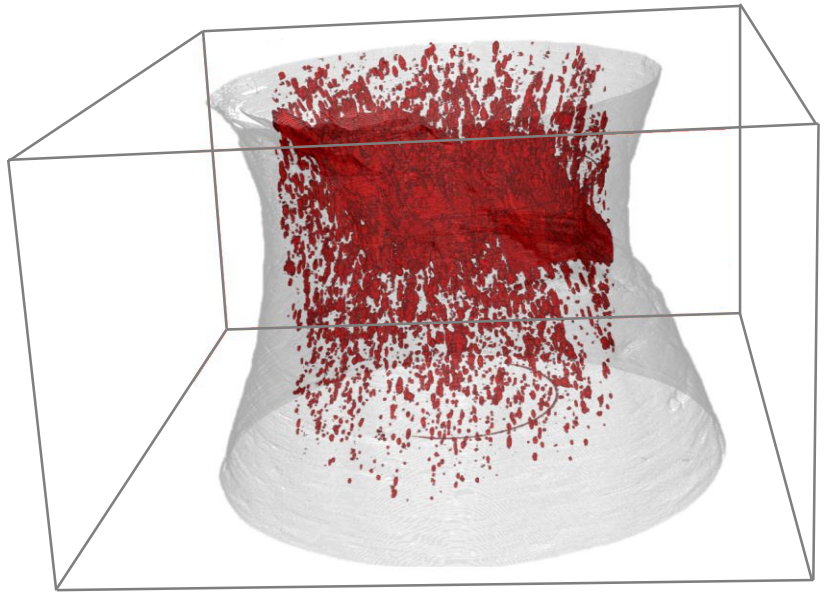

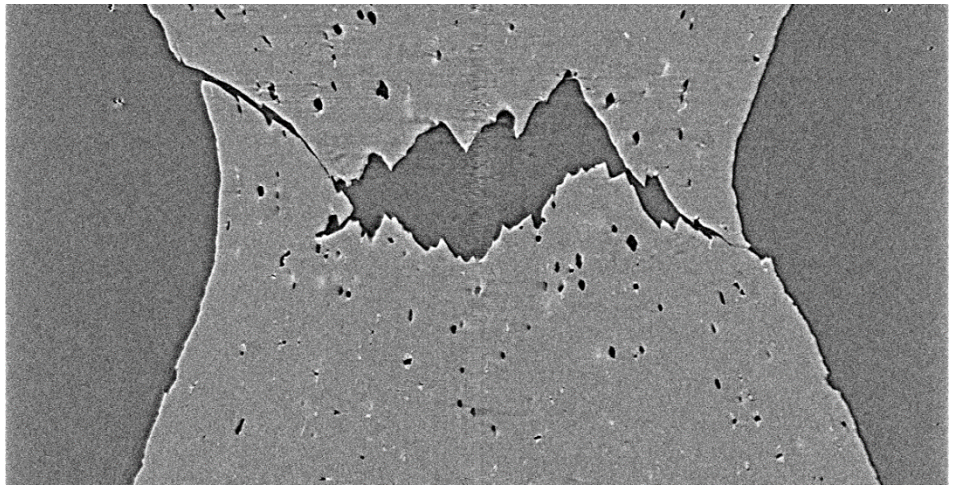

3 main causes limiting the ductility in Al-6xxx Alloys

1 Size of intermetallic particles

FSP → FSP breaks the large particles into smaller fragments

2 Pre-existing porosity

FSP → FSP closes the existing initial porosity

3 Clustering of intermetallic particles

FSP → FSP reduces the degree of clustering

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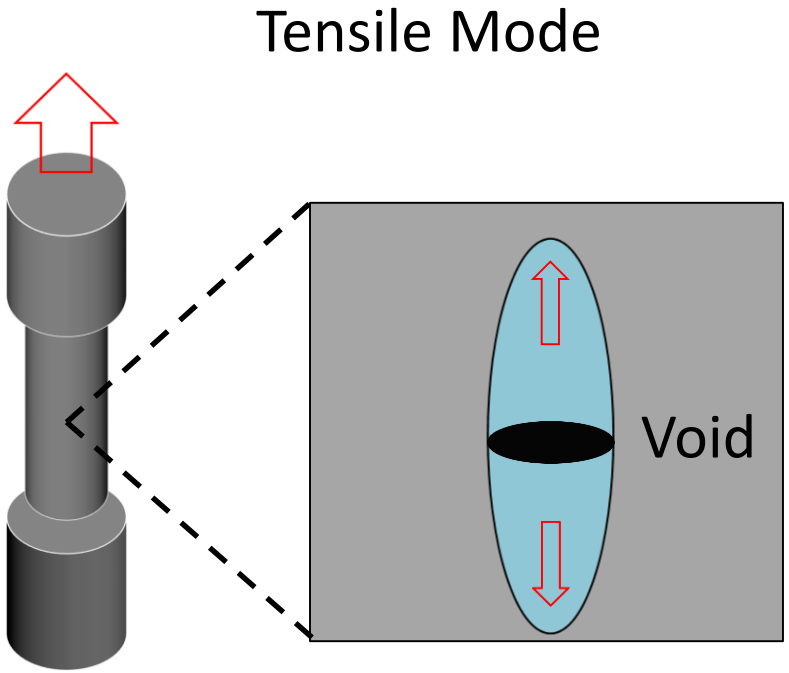
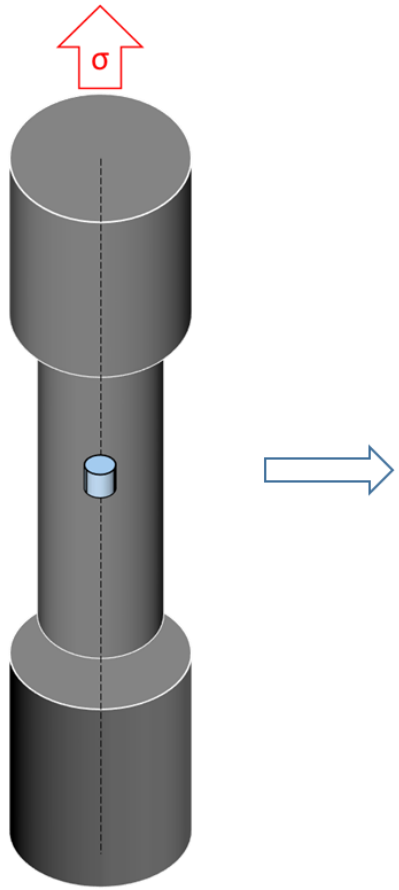
1 The ductility degrades when intermetallic particles are large

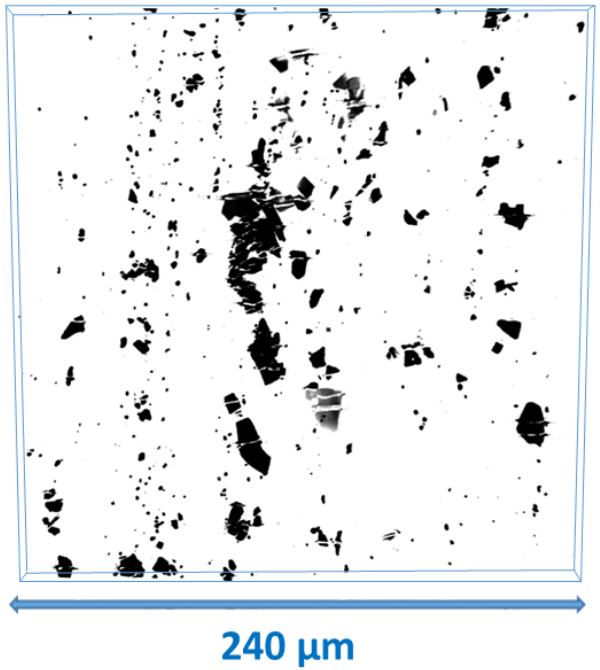


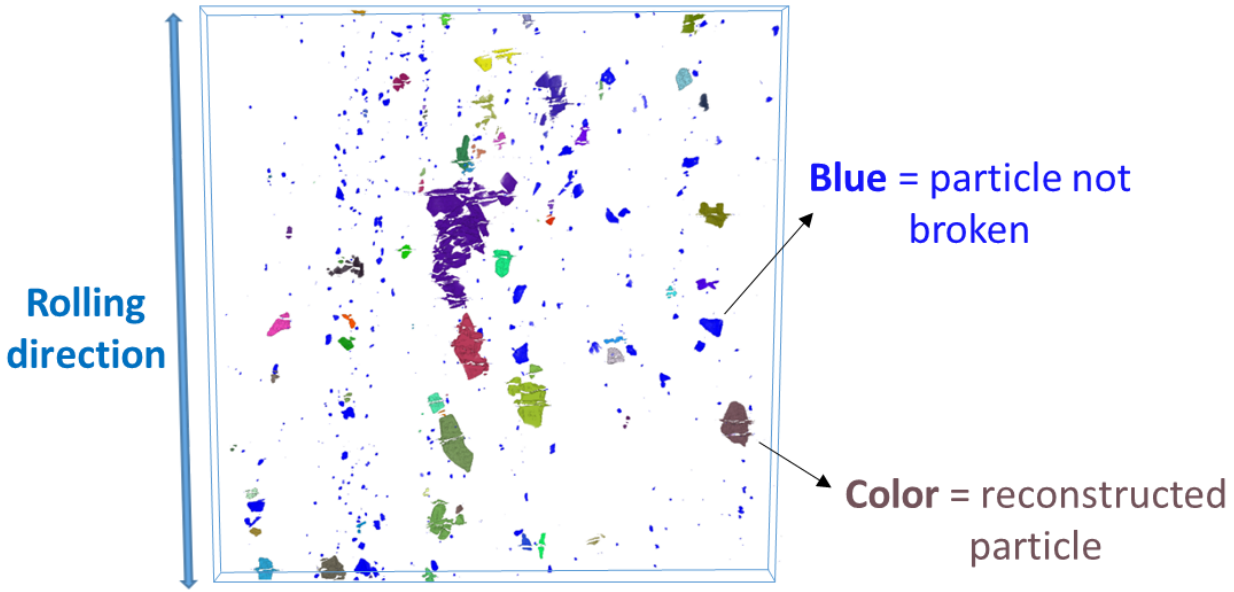
Particle fracture
⇔ Void formation

1 The ductility degrades when intermetallic particles are large

X-ray tomography of ex-situ tensile test





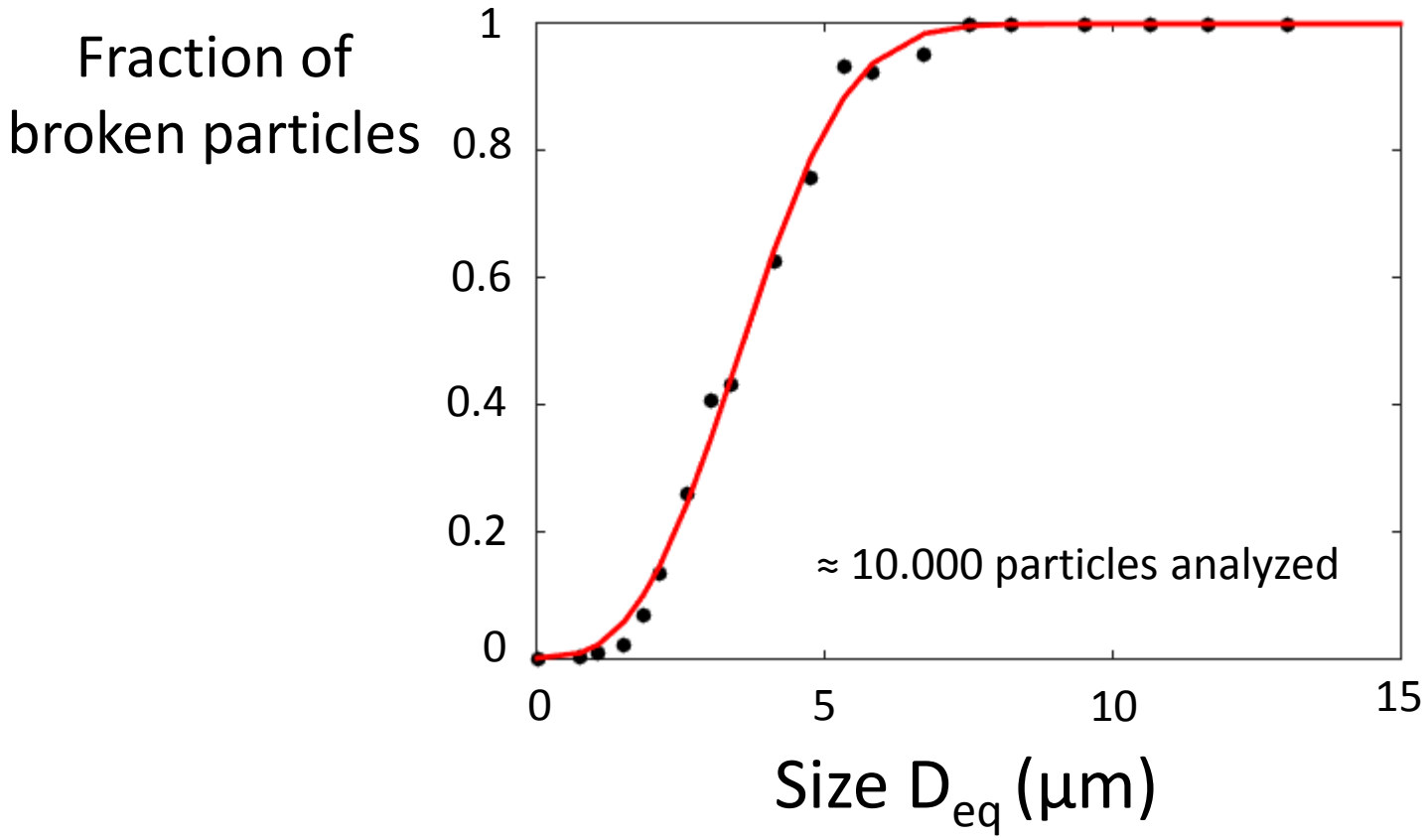


Resolution = 160 nm

1 The ductility degrades when intermetallic particles are large

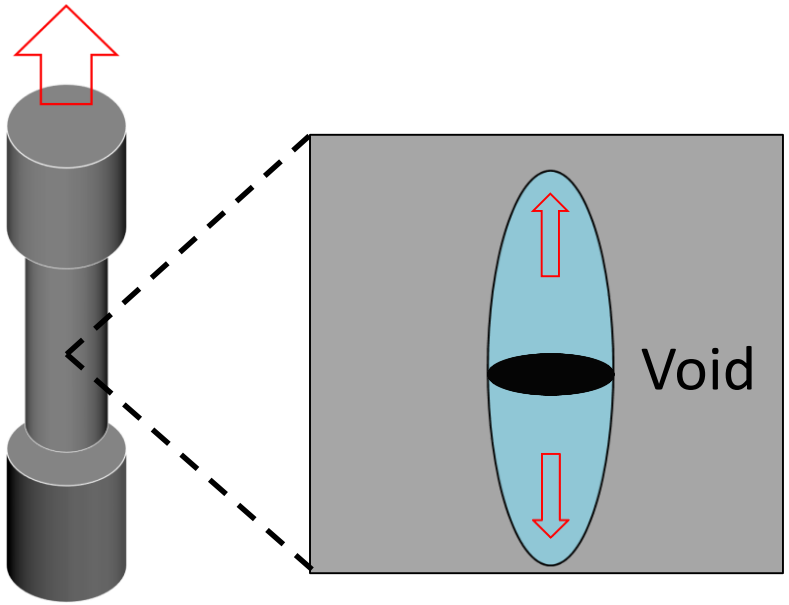
The largest defects are more likely to be found in the largest inclusions.

➔ Void nucleation becomes increasingly difficult with decreasing particle size.

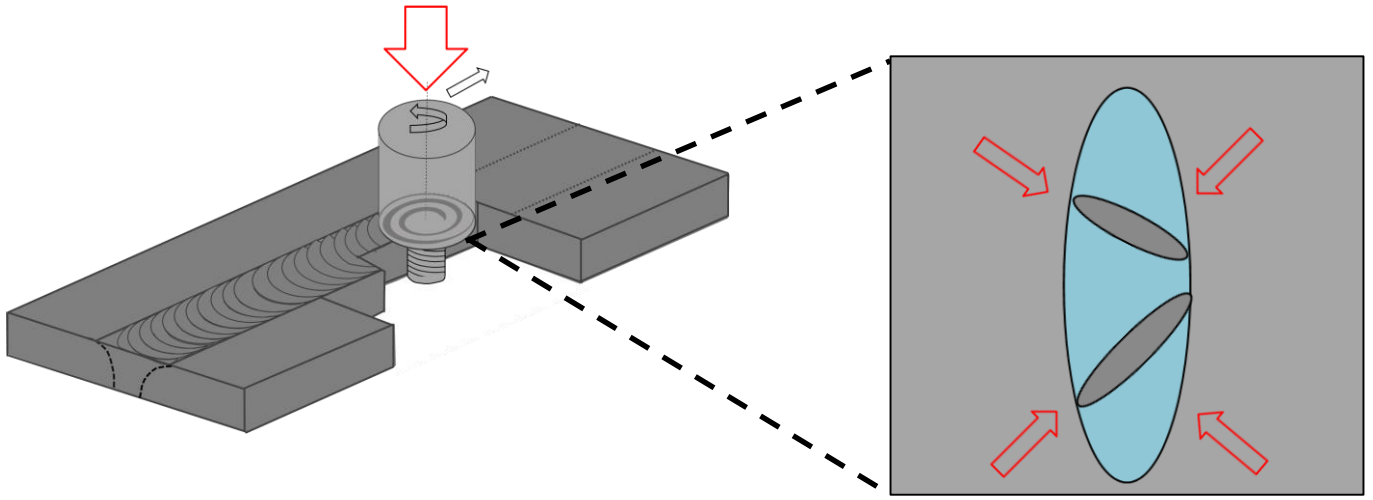


1 FSP breaks the large intermetallic particles into smaller and thus stronger fragments

Tensile Mode



High hydrostatic pressure



Matrix material forced into cracks

Particle fracture ⇔ Void formation

Particle fracture ⇔ Void « healing »

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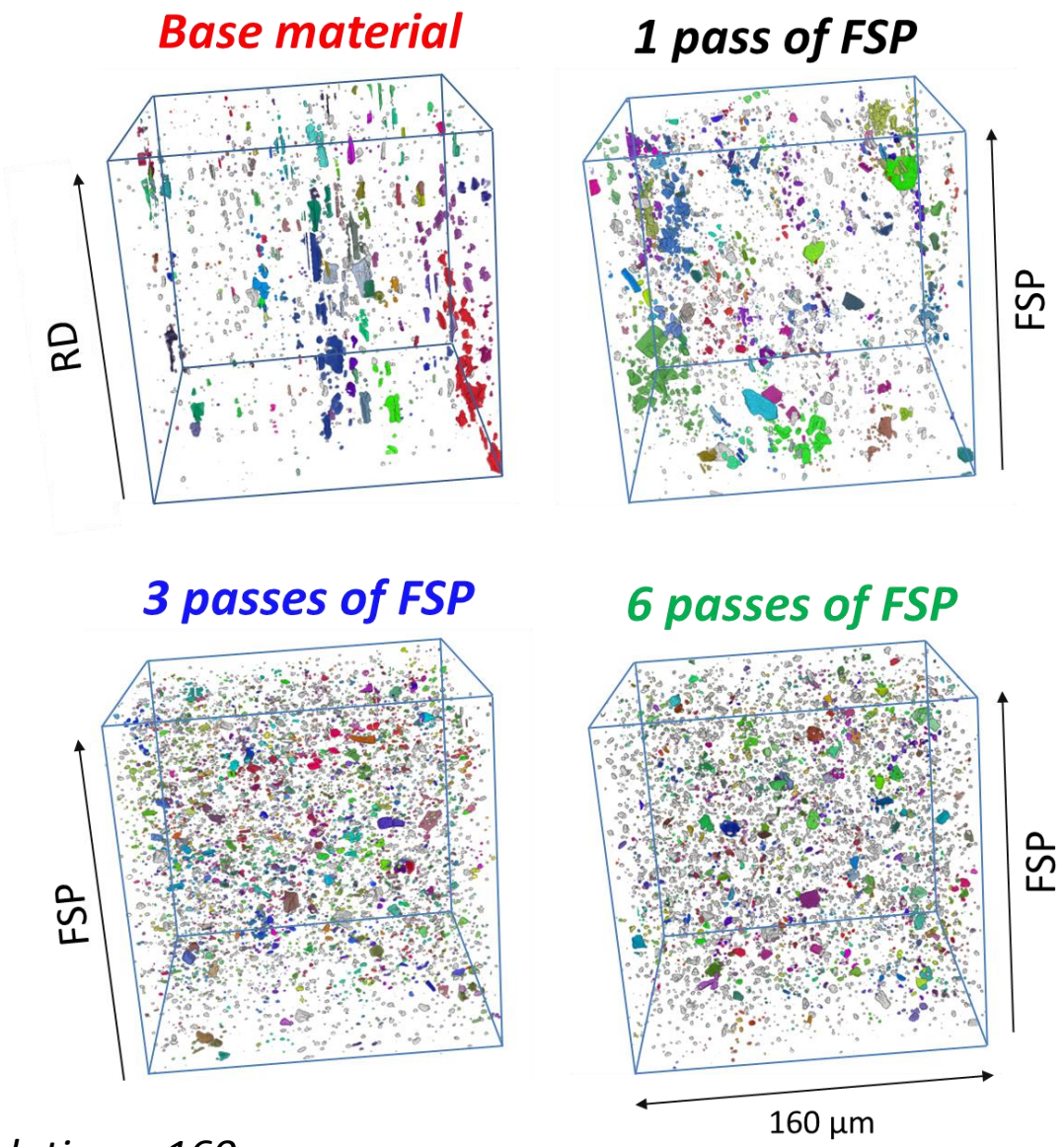

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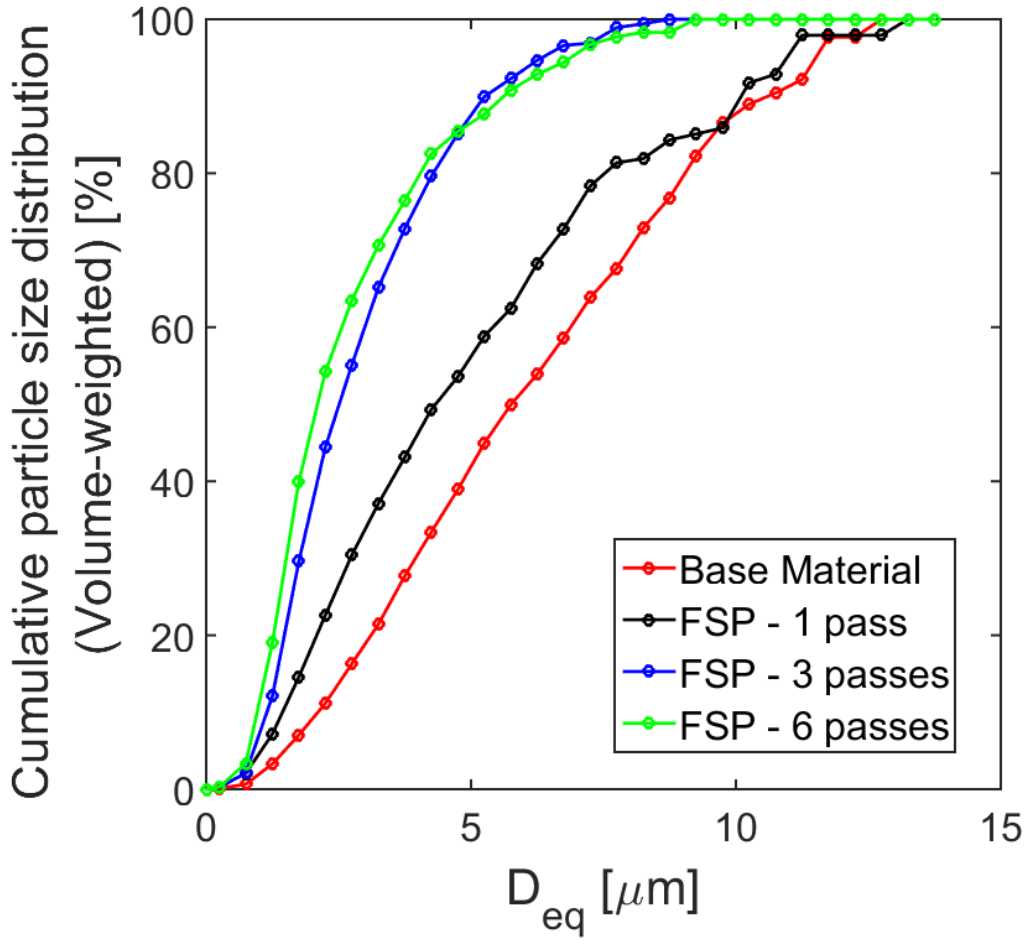

3 main causes limiting the ductility in Al-6xxx Alloys

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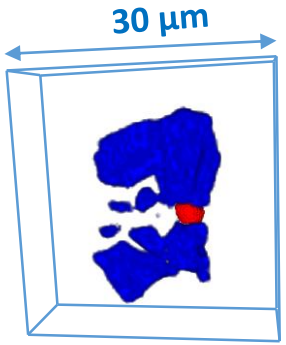
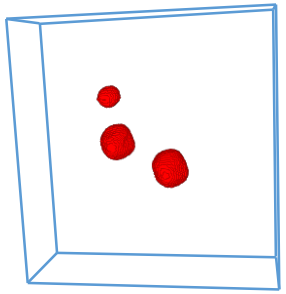
Base Material

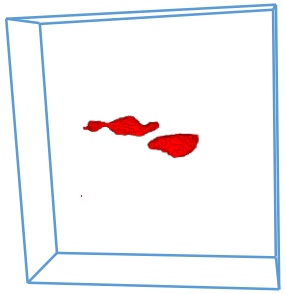


fracture of IM particles
during the rolling process



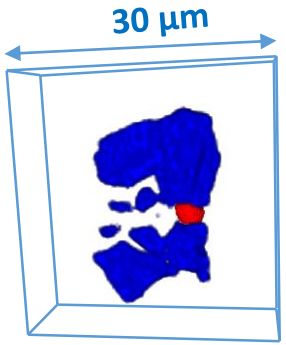
Hydrogen gas porosity
= casting defect

After 1 pass of FSP



2 FSP closes the existing initial porosity

Base Material



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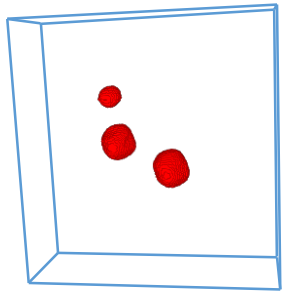

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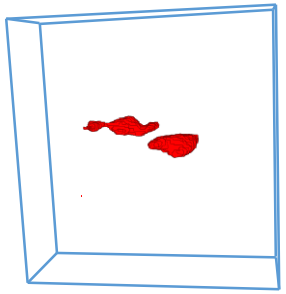
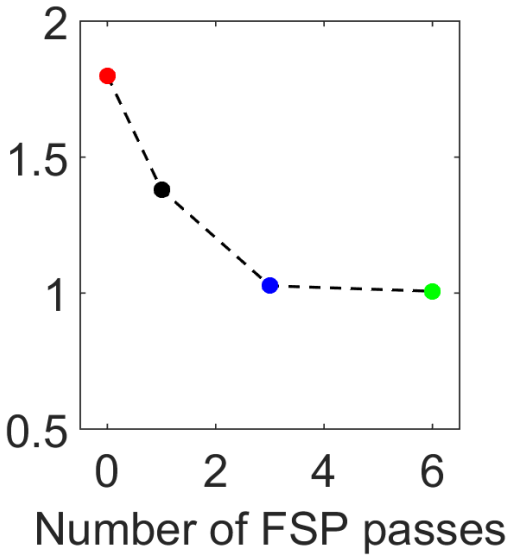
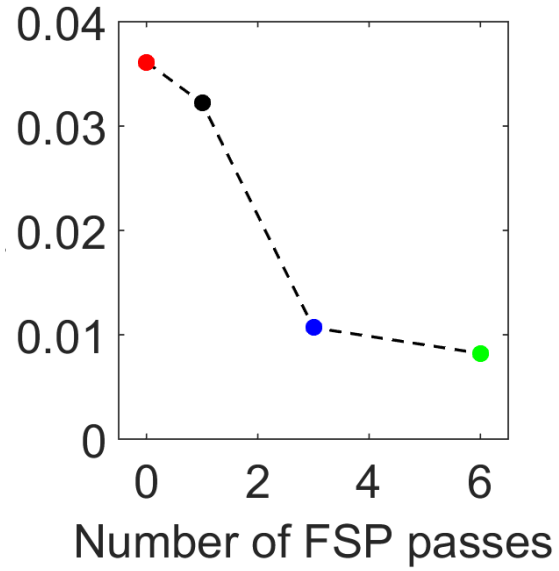


Size [µm]



Initial
porosity [%]



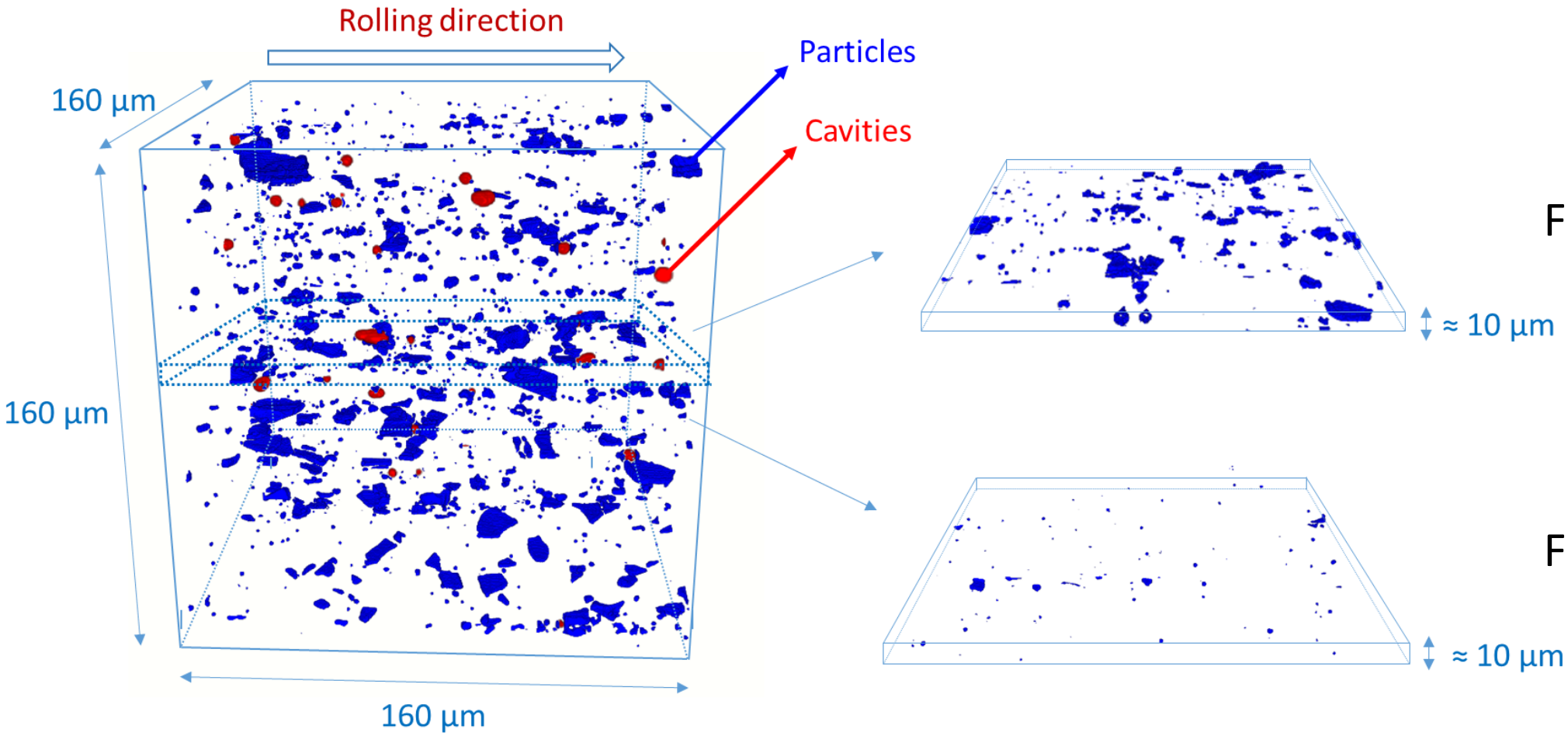
3 main causes limiting the ductility in Al-6xxx Alloys

3 Clustering of intermetallic particles

FSP → FSP reduces the degree of clustering

3 The ductility degrades when intermetallic particles are clustered

Al 6056



$F_p^{local} >> F_p^{global}$

$F_p^{local} << F_p^{global}$

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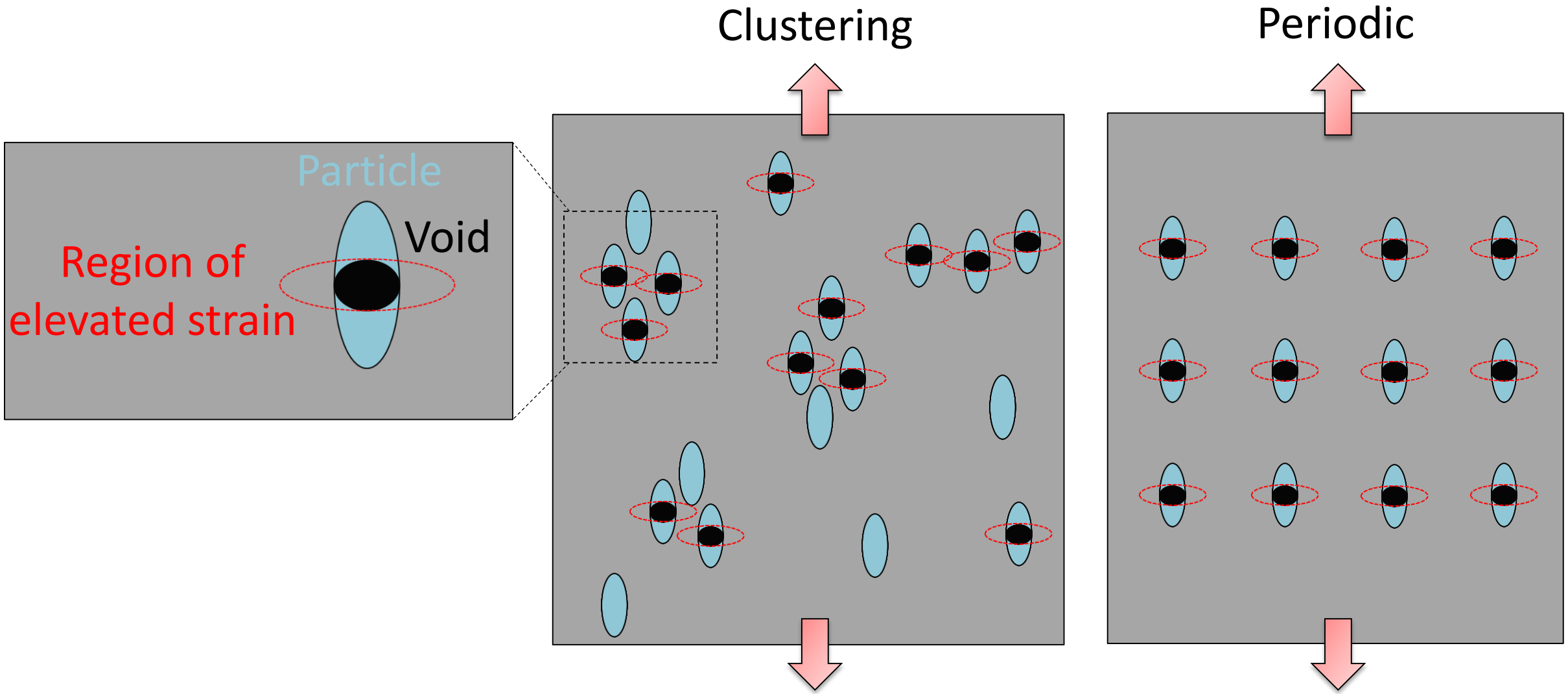

➔ Void clusters favor earlier void coalescence by internal void necking.

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⇨ Identification of clusters

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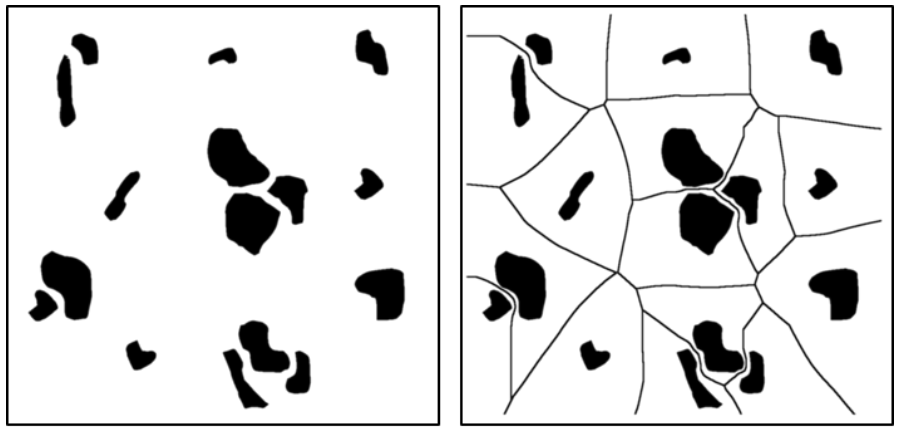
⇨ Identification of clusters

"Finite body" tessellation



Local volume fraction $F_p^{local} = \frac{V_{particle}}{V_{cell}}$

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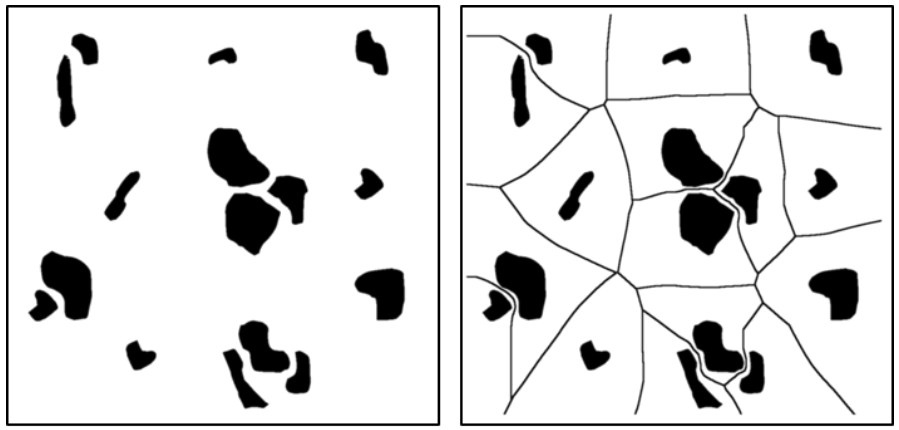
"Finite body" tessellation



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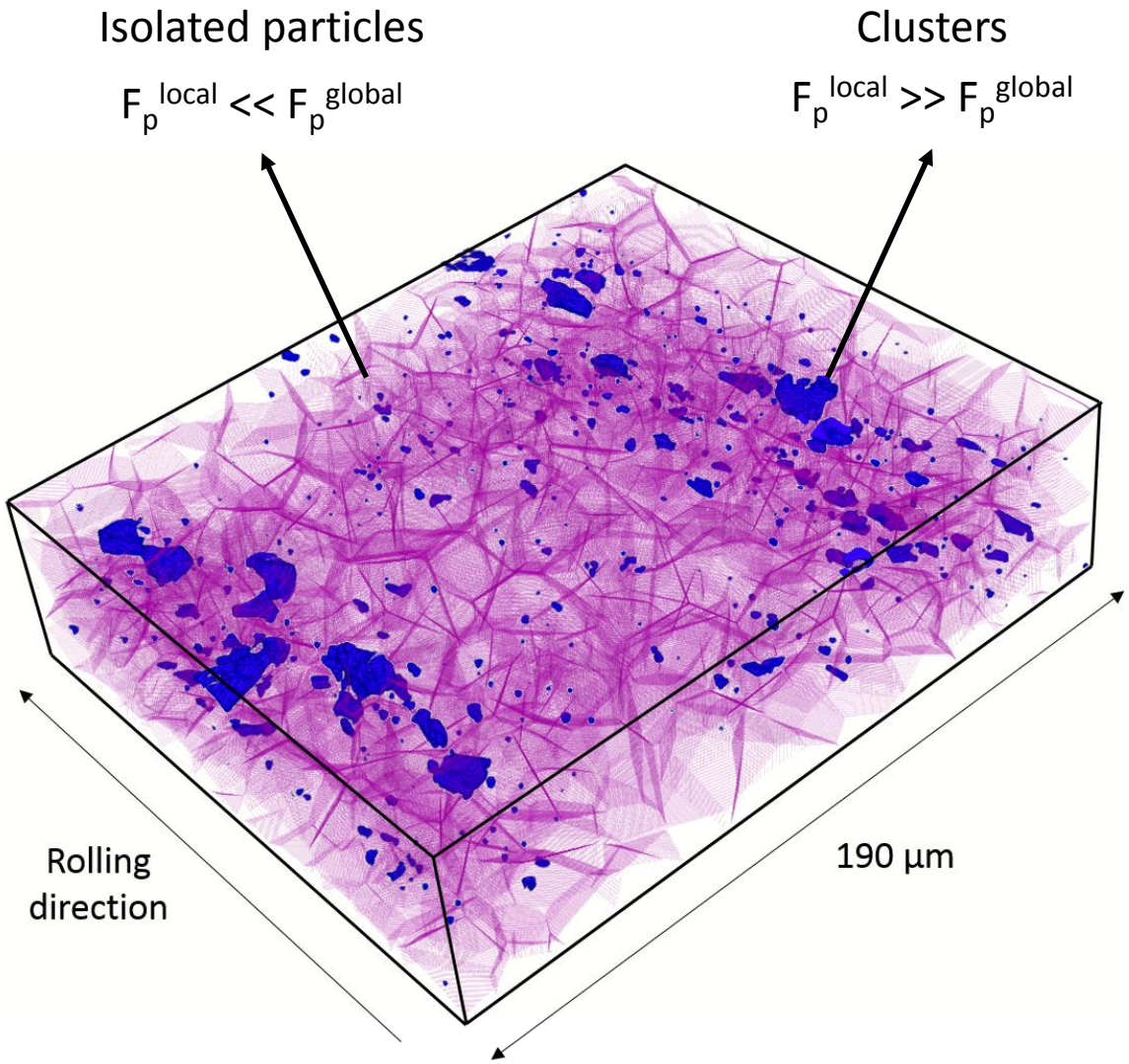
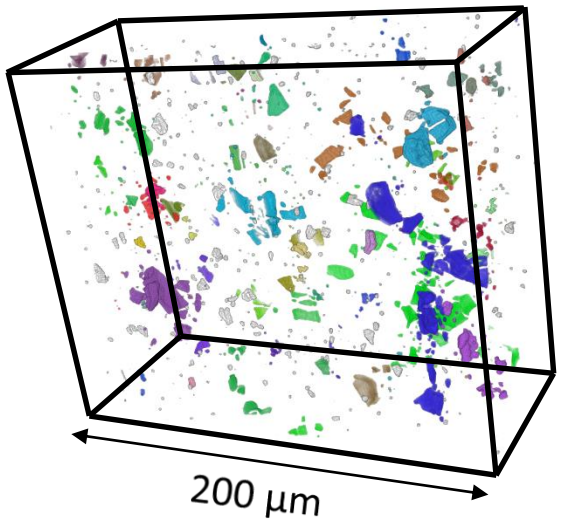
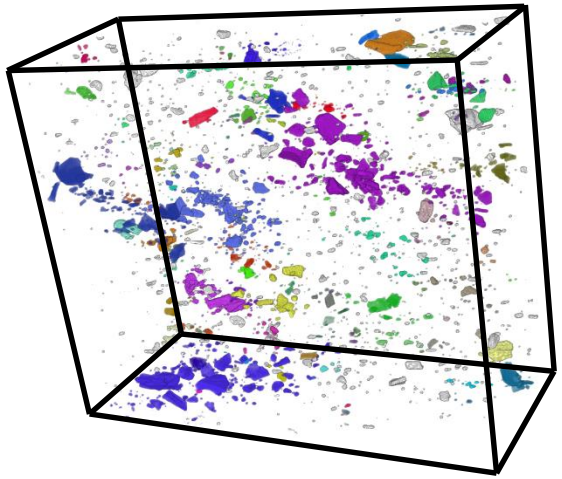


3 FSP reduces the degree of clustering

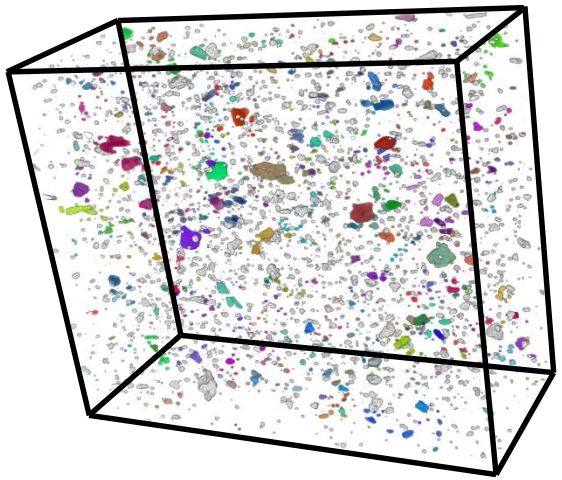
BM



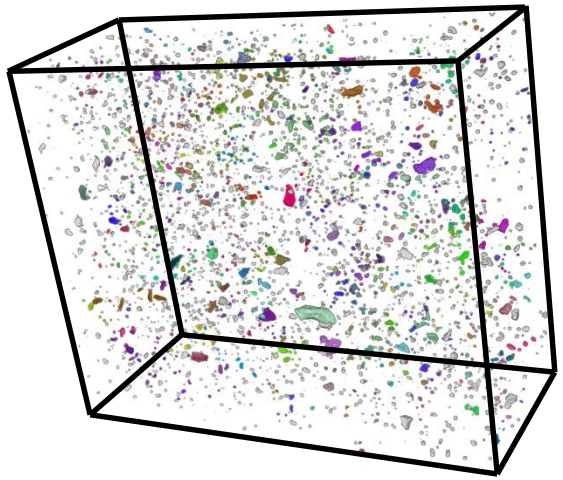
1 pass of FSP

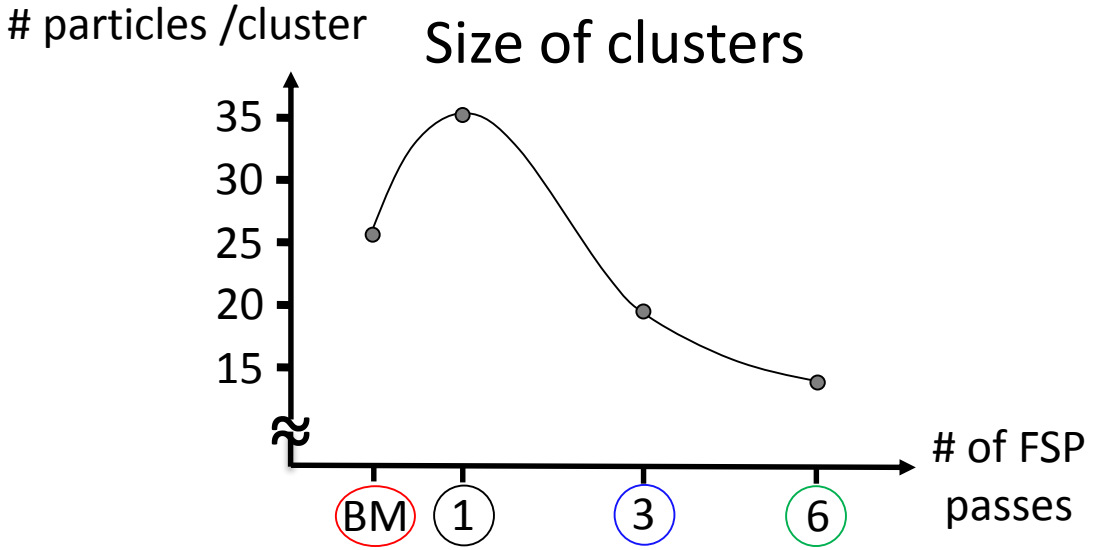


3 passes of FSP



6 passes of FSP





3 main causes limiting the ductility in Al-6xxx Alloys

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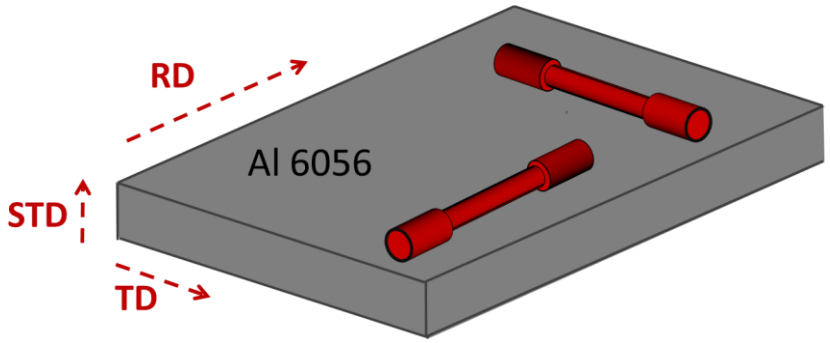
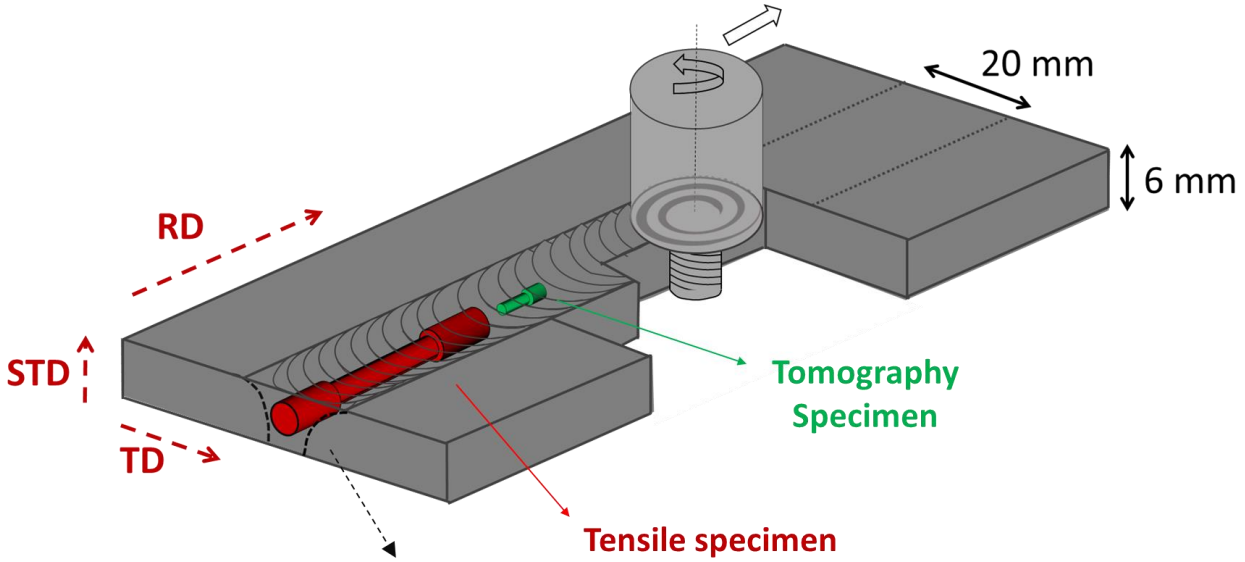
FSP has positive impacts on the damage process

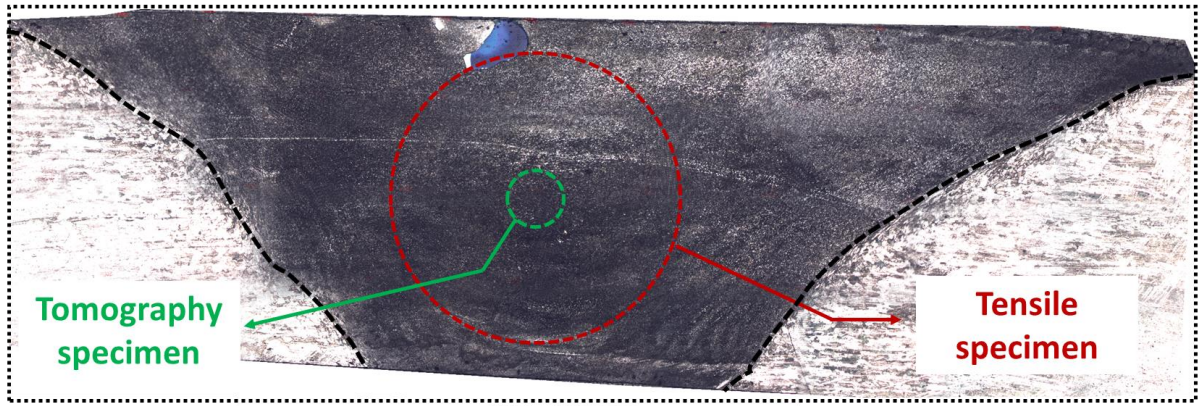
Tensile tests are performed to quantify impact of FSP on the damage process

Base Material



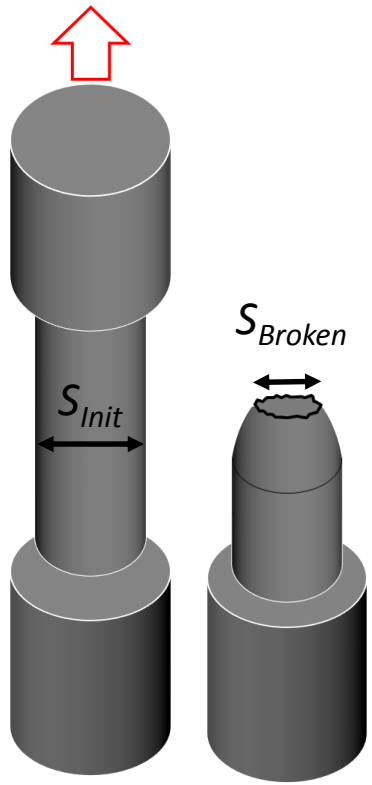
FSPed Material

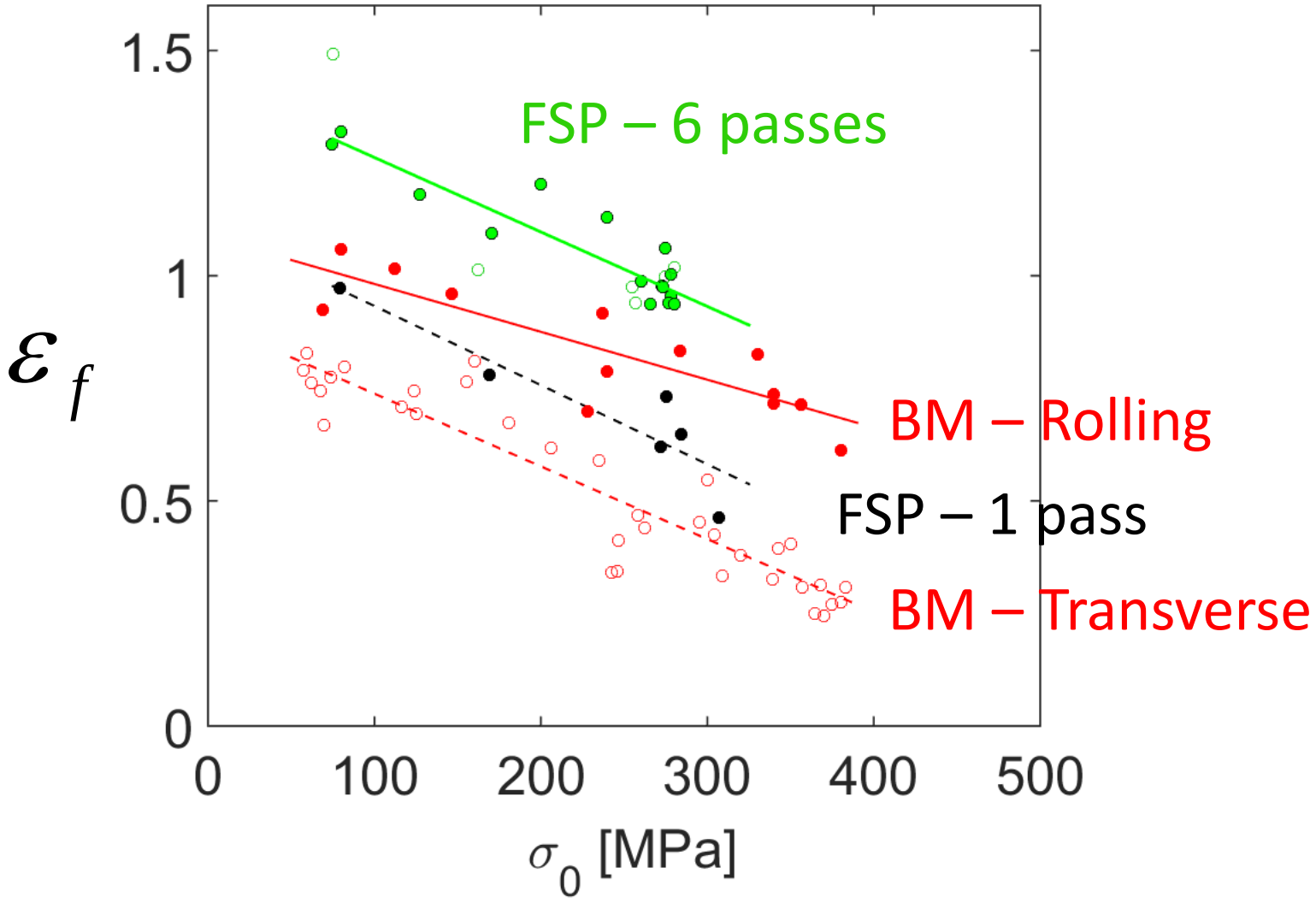




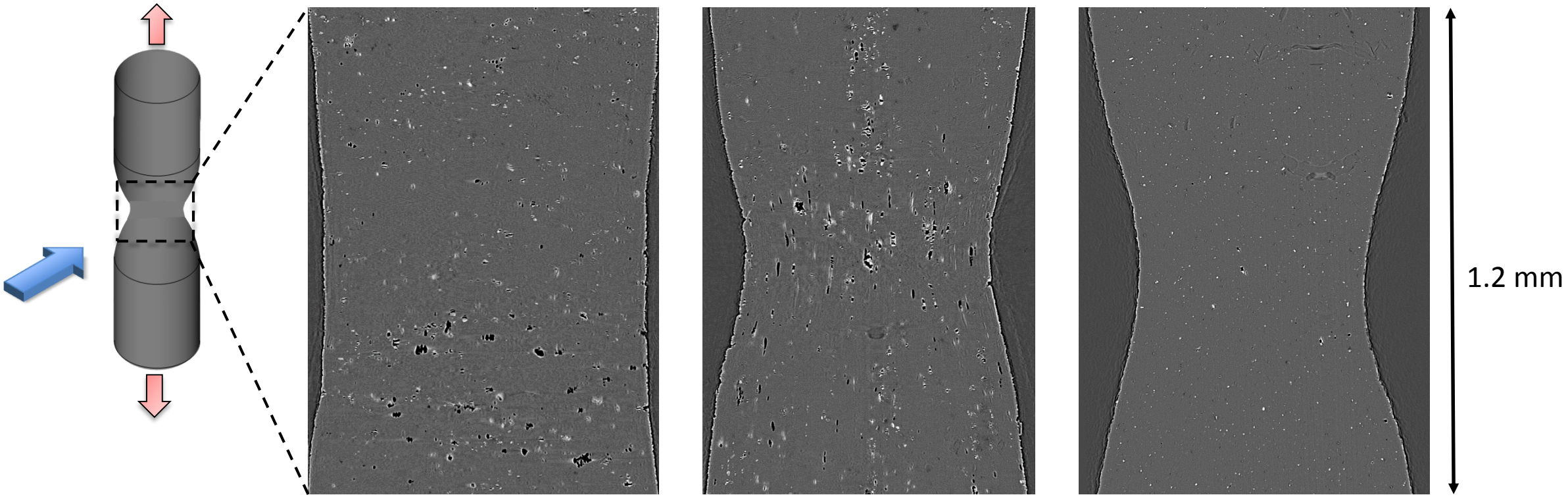
FSP increases very significantly the fracture strain of the Al alloy 6056

$$\varepsilon_f = \ln\left(\frac{S_{init}}{S_{broken}}\right)$$





FSP improves significantly the damage resistance of the Al 6056 alloy

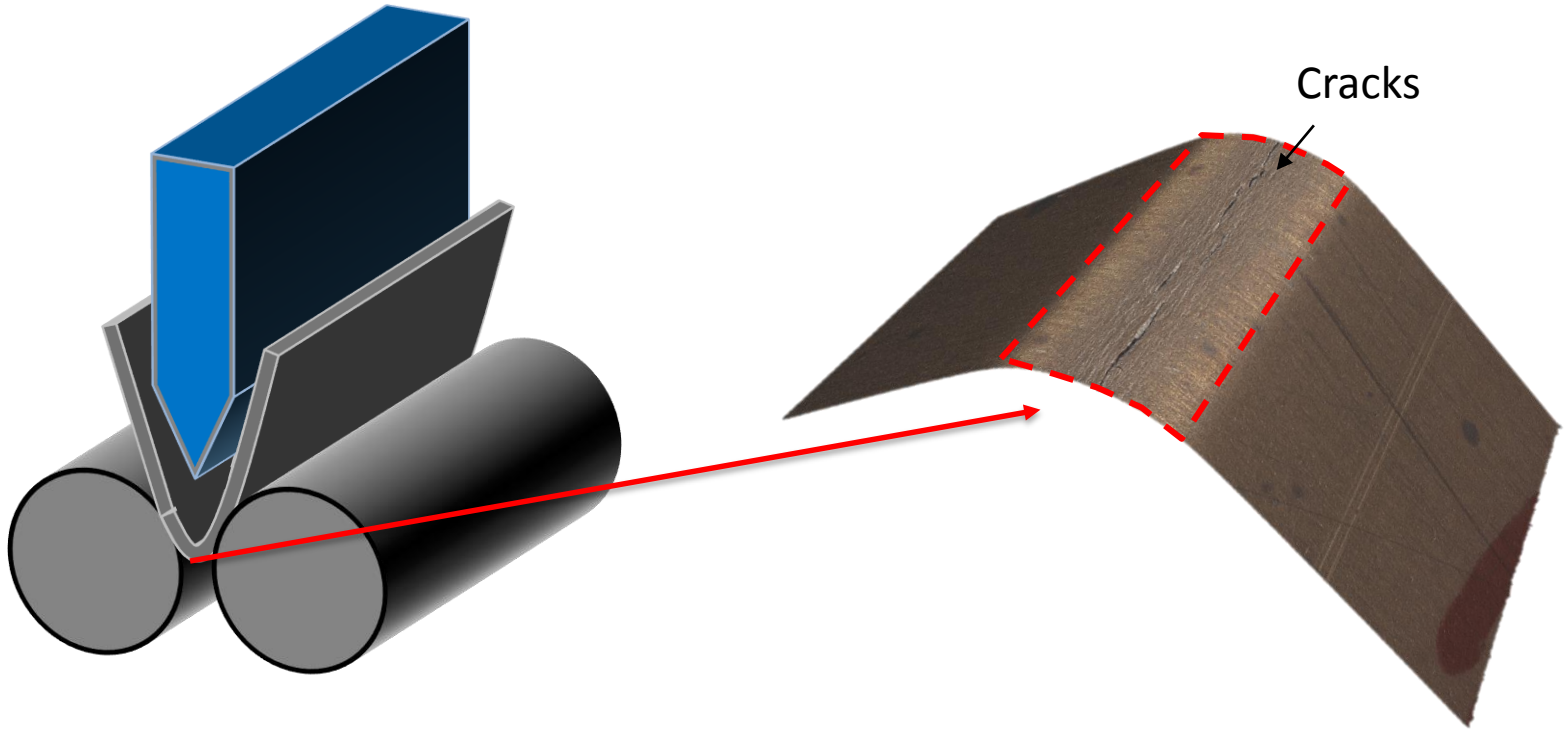


X-ray tomography of in-situ tensile test

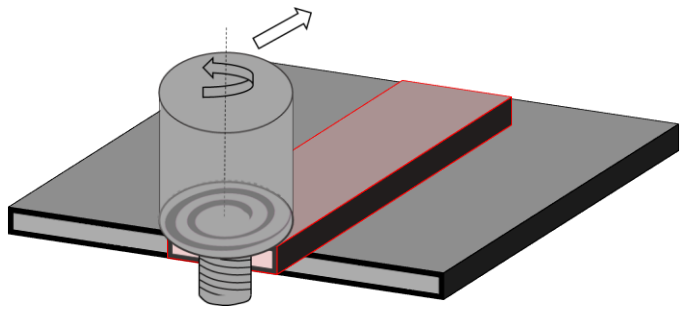
Thank you for your attention !

Selective formability : A balance between cost and performance

Improve ductility of sheets at locations where **forming** involves **large strains**

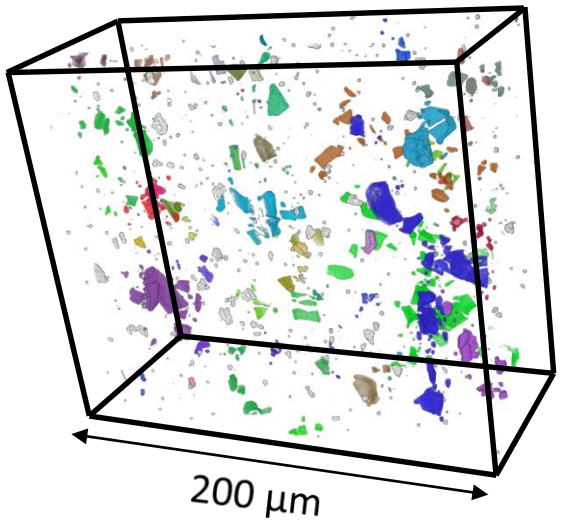


Friction stir processing

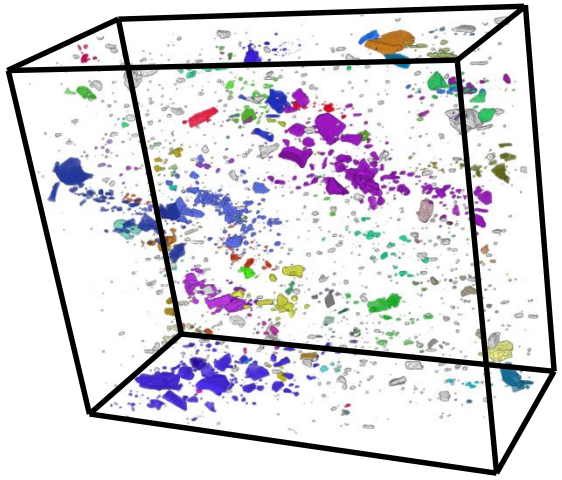


3 FSP reduces the degree of clustering

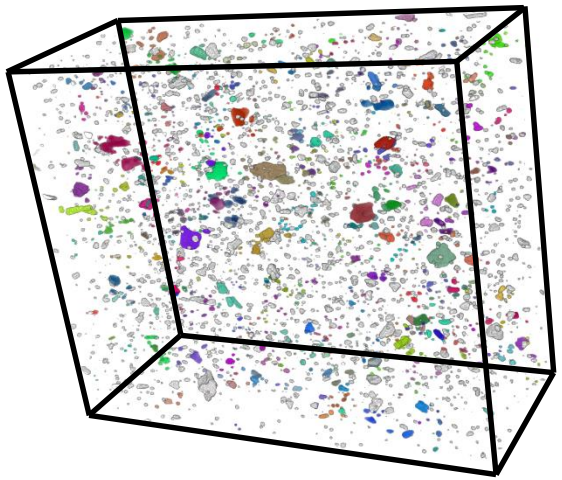
BM



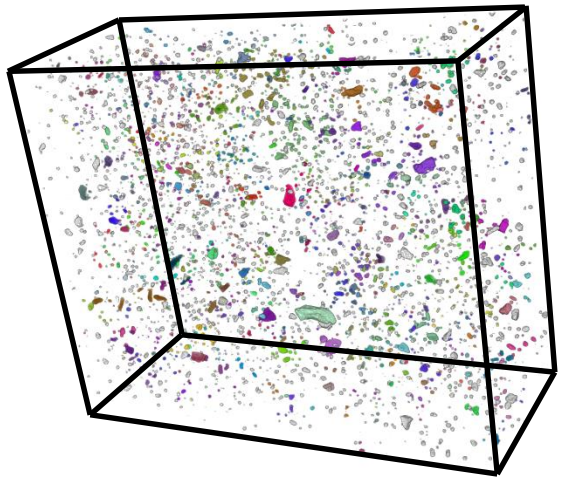
1 pass of FSP



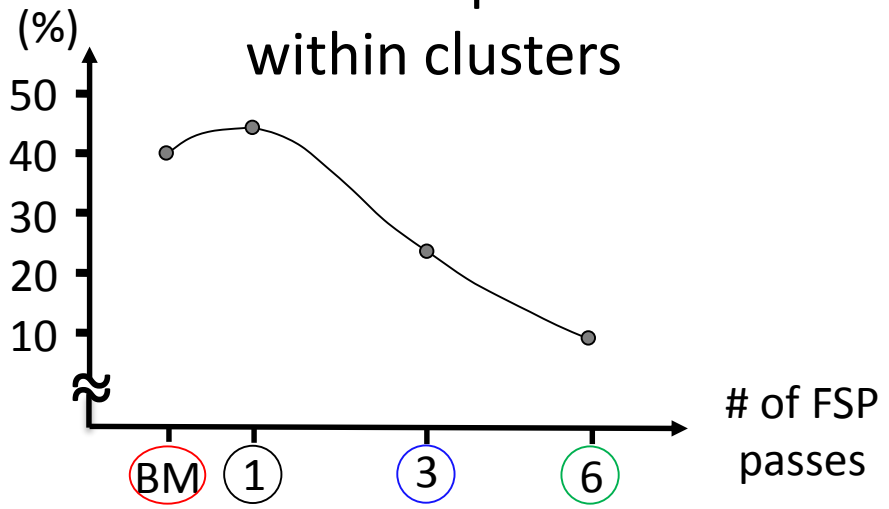
3 passes of FSP



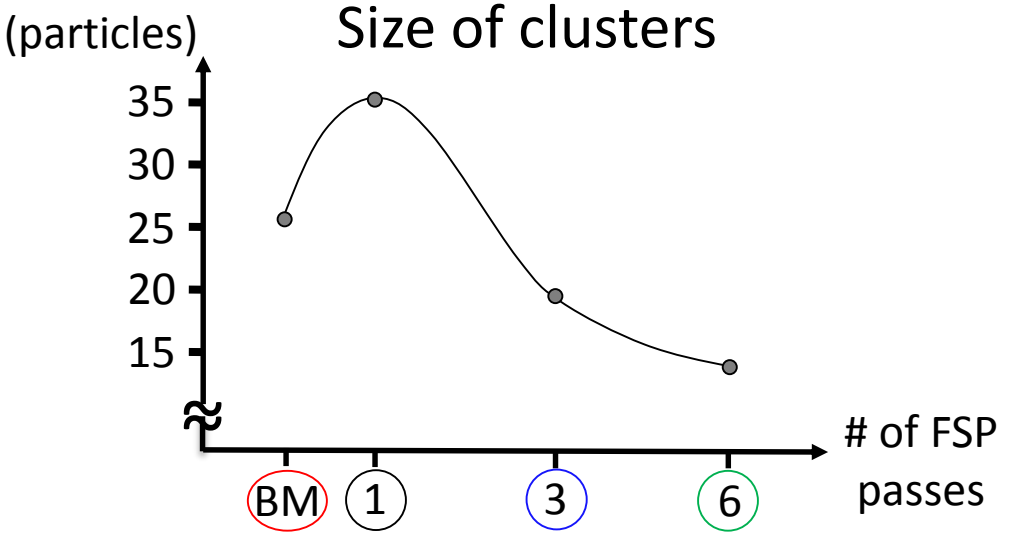
6 passes of FSP



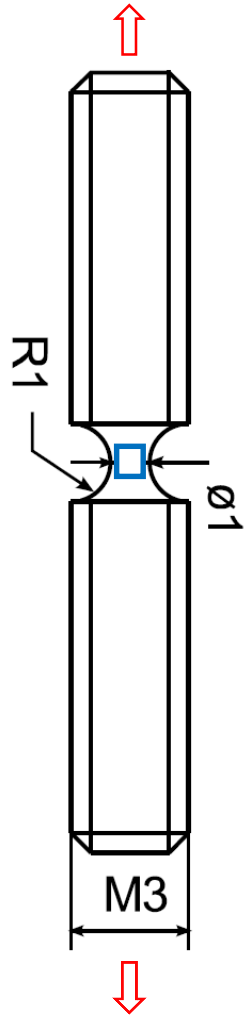
Fraction of particles within clusters

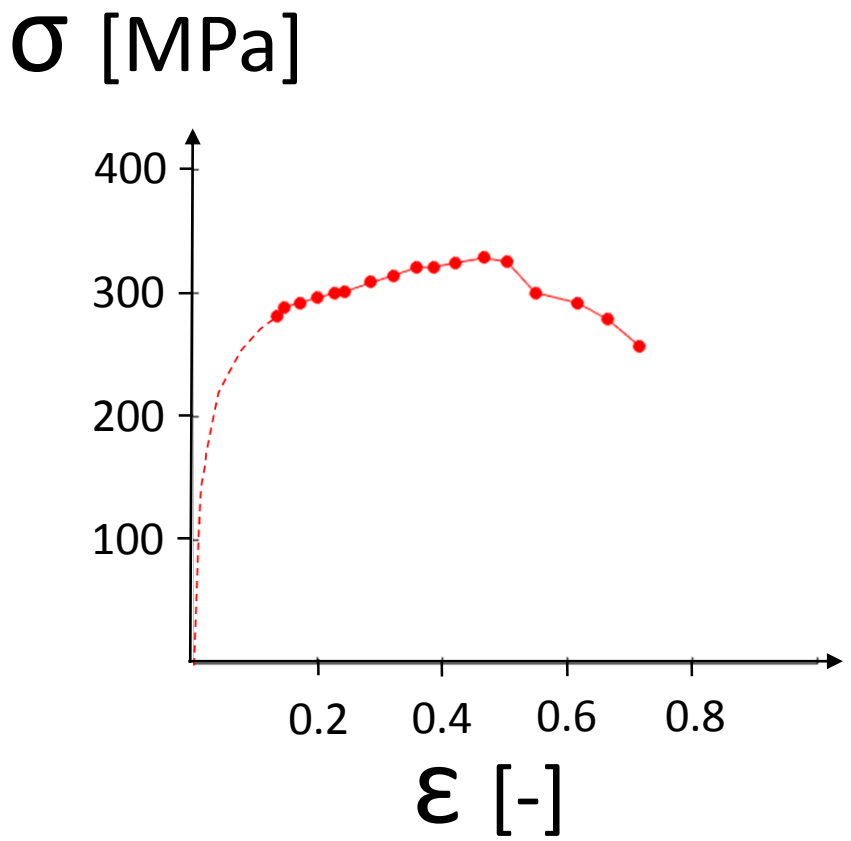


Size of clusters



2 Pre-existing porosity decreases the ductility





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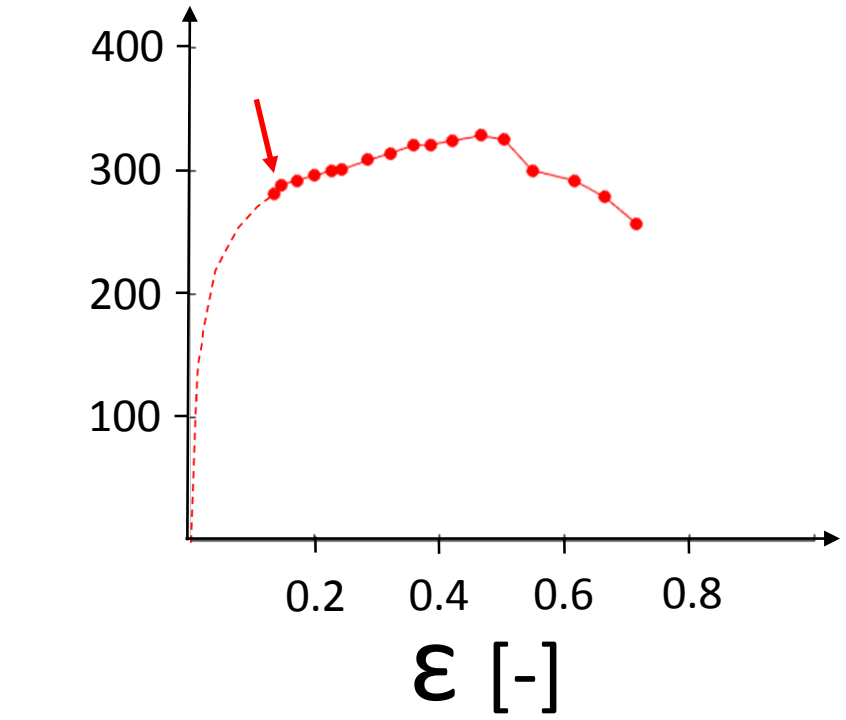
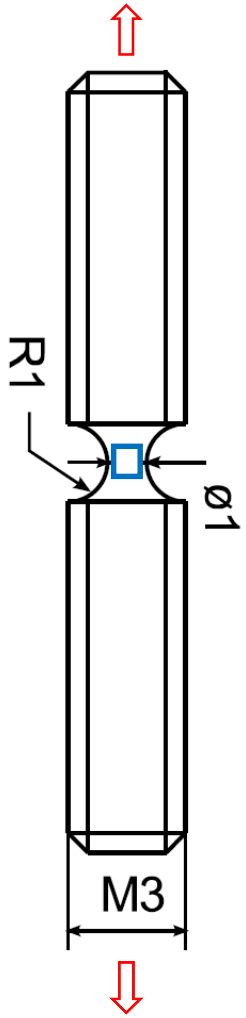
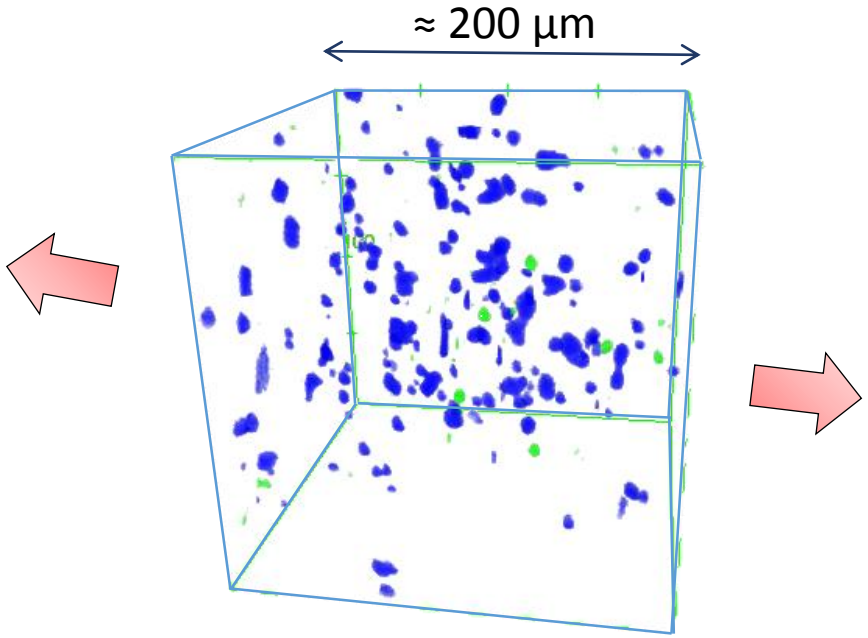




Initial voids

Nucleated voids



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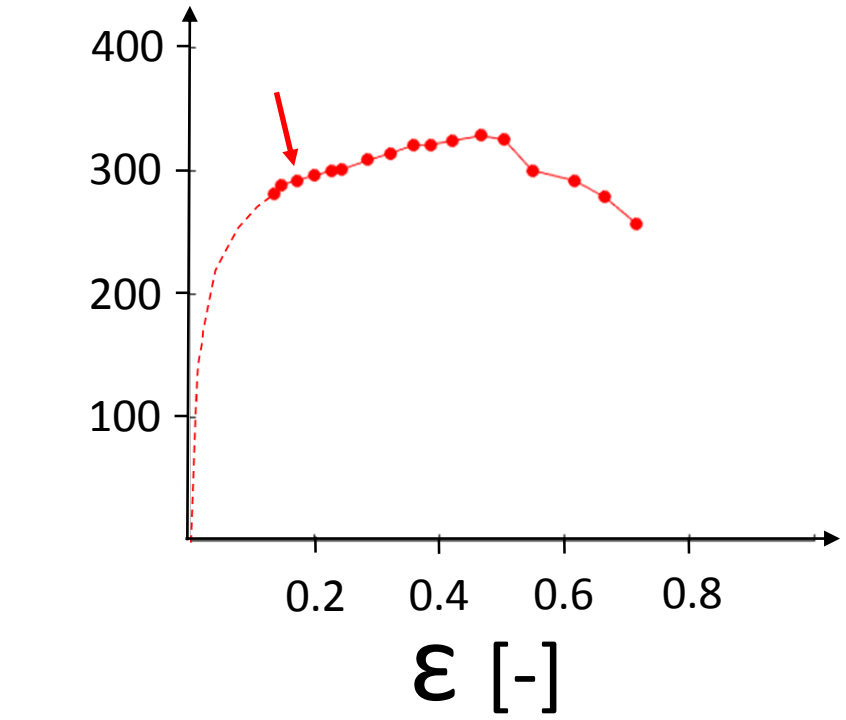

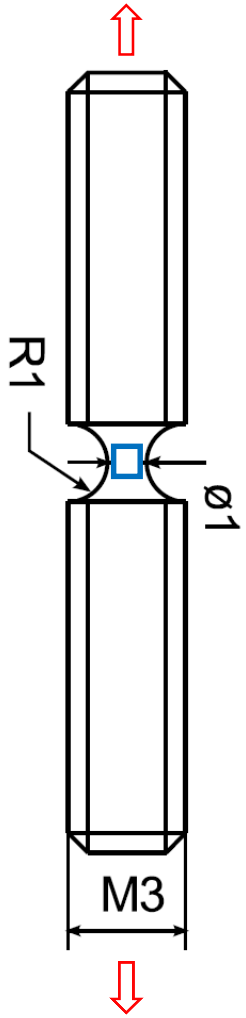

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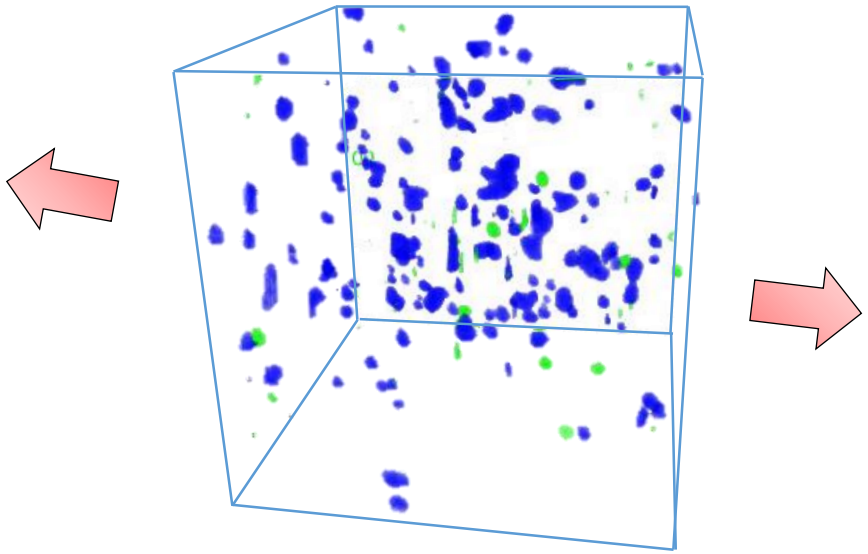

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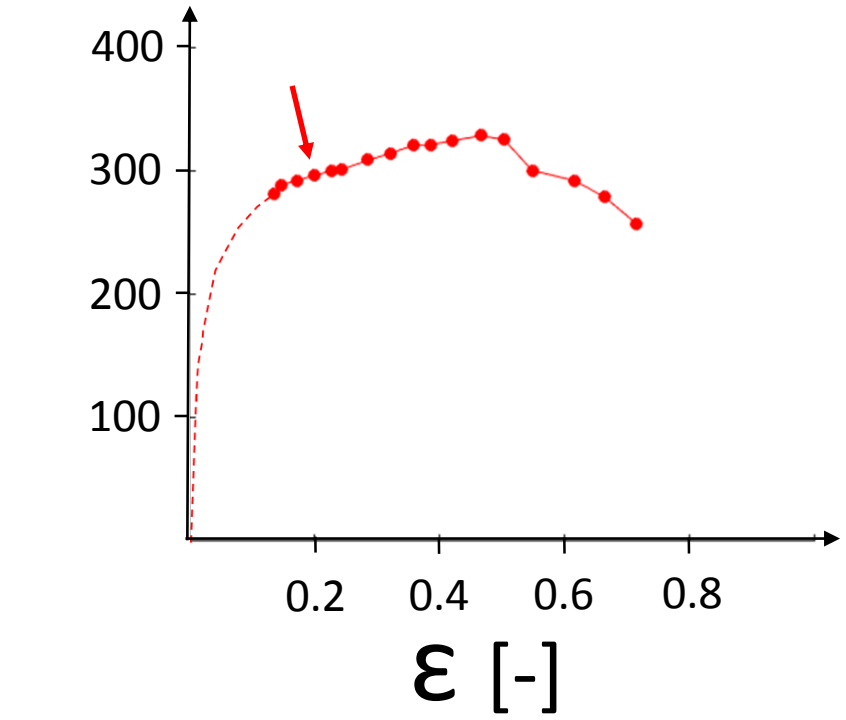

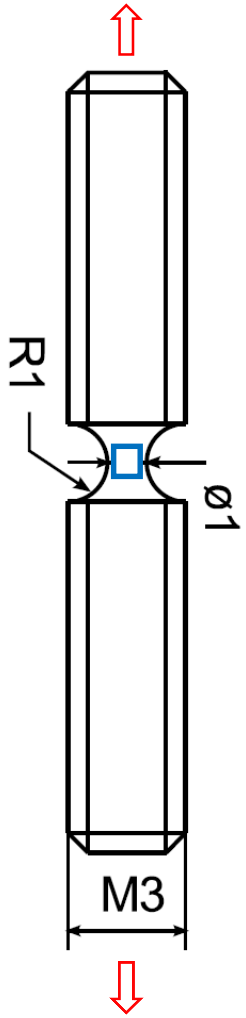

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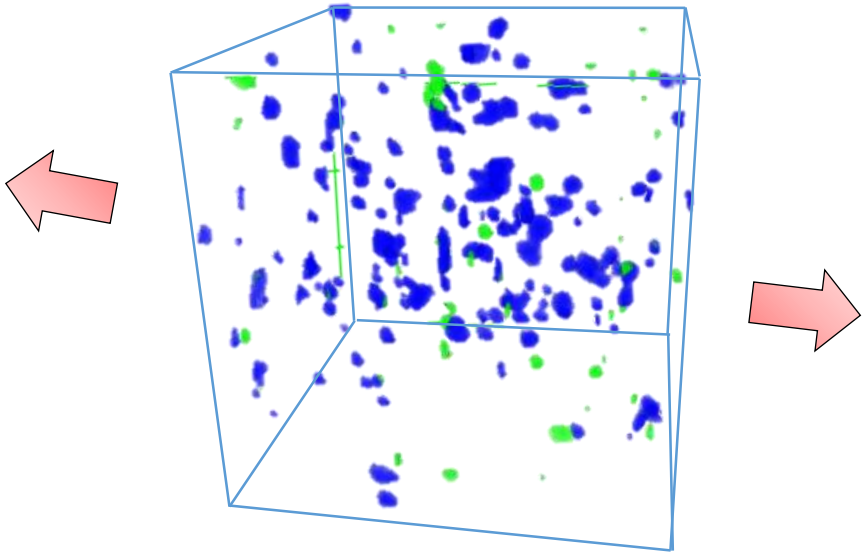

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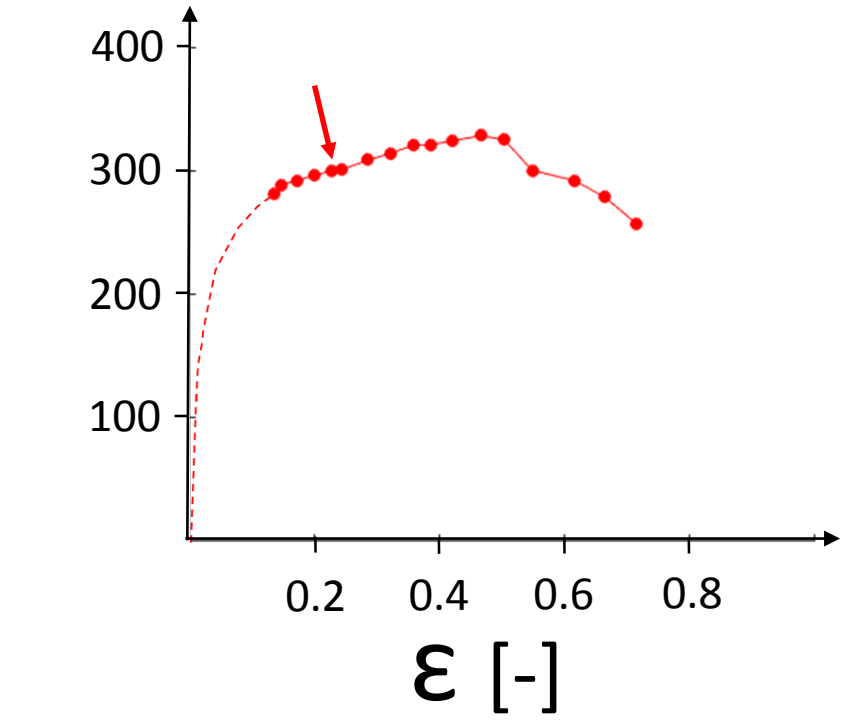

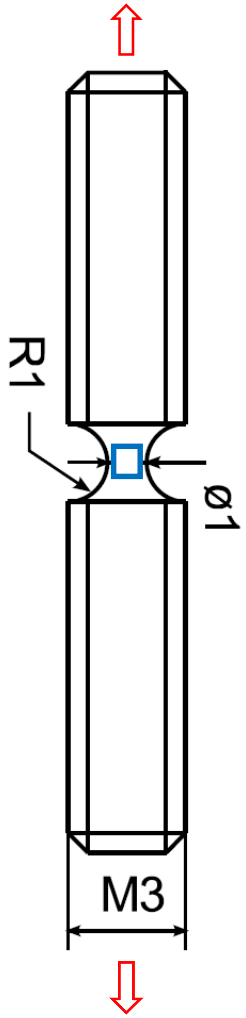

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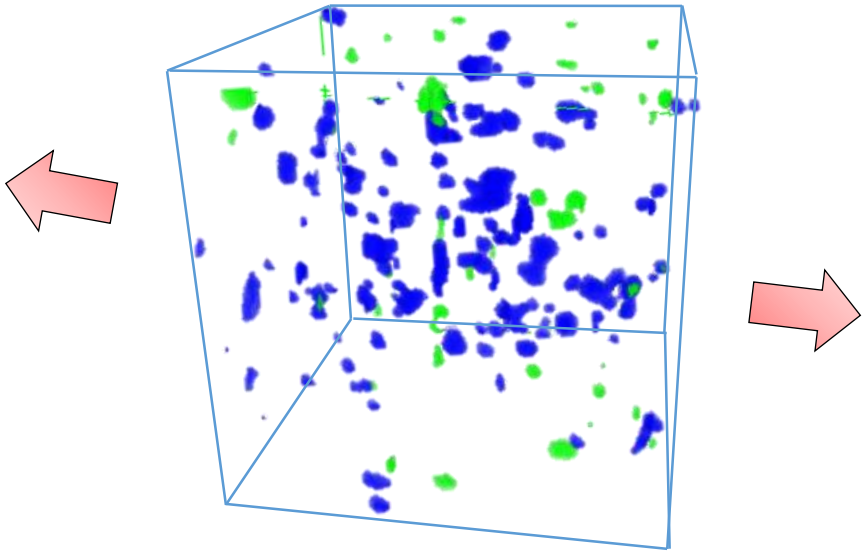

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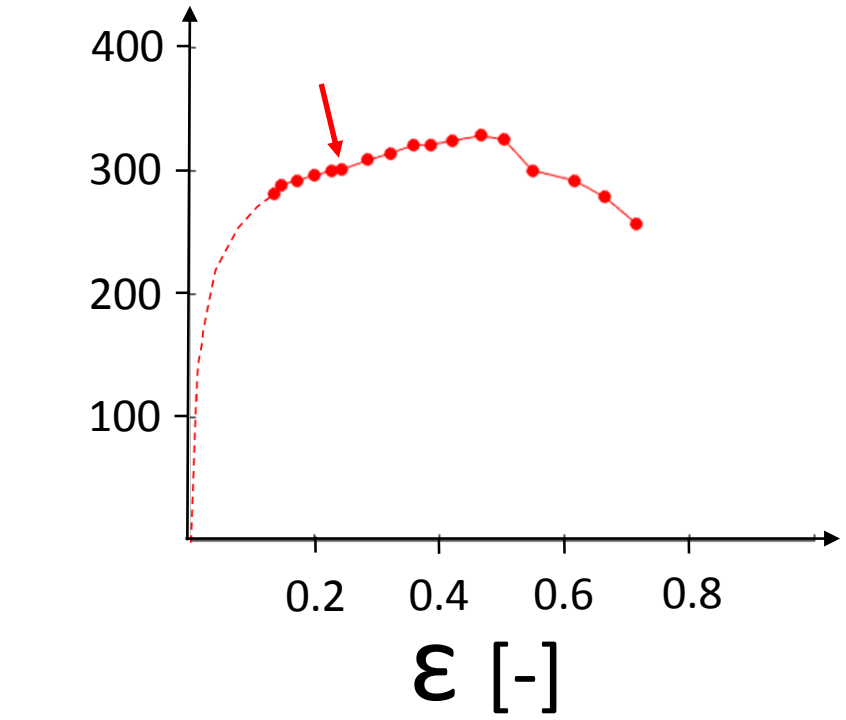

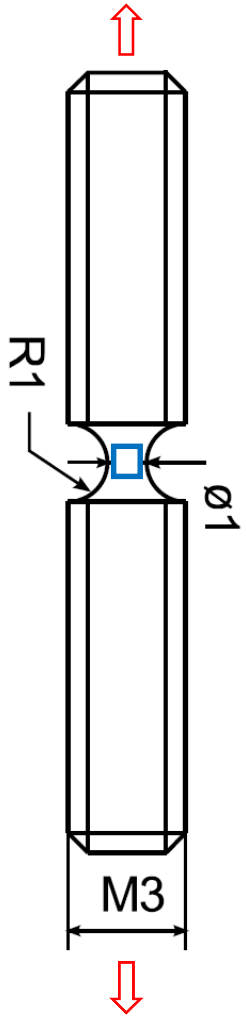

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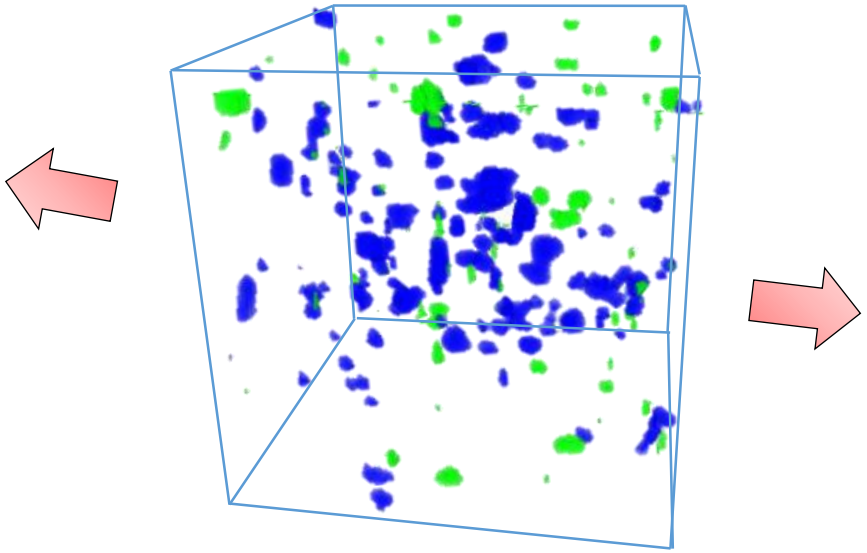

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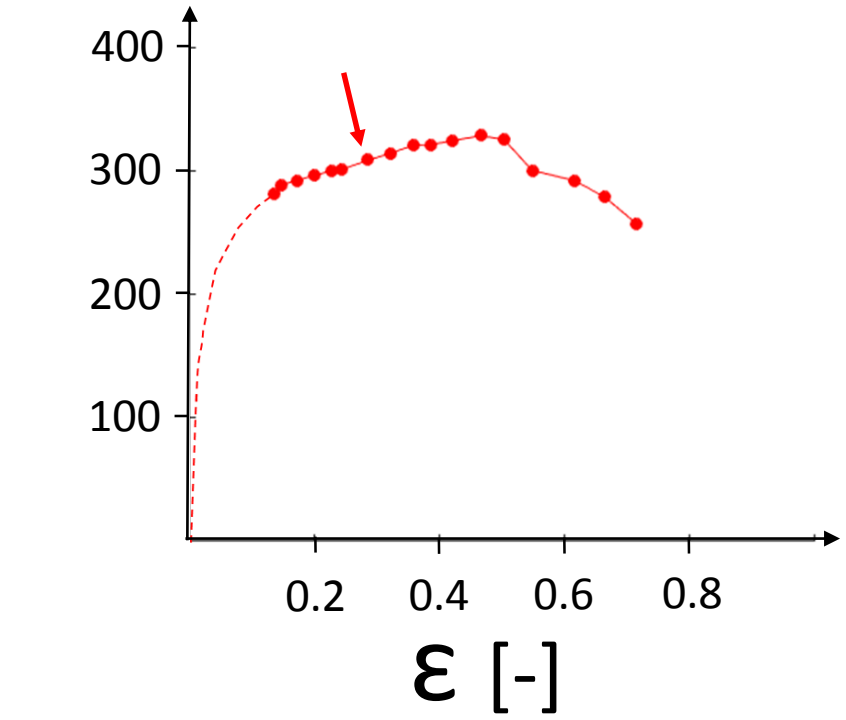

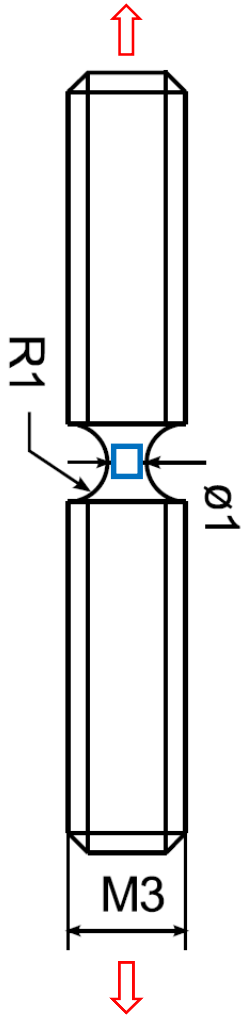

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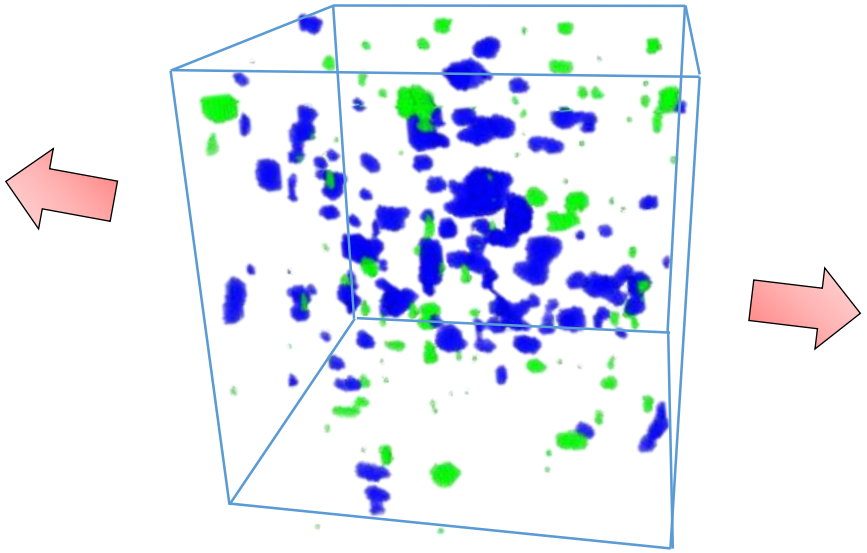

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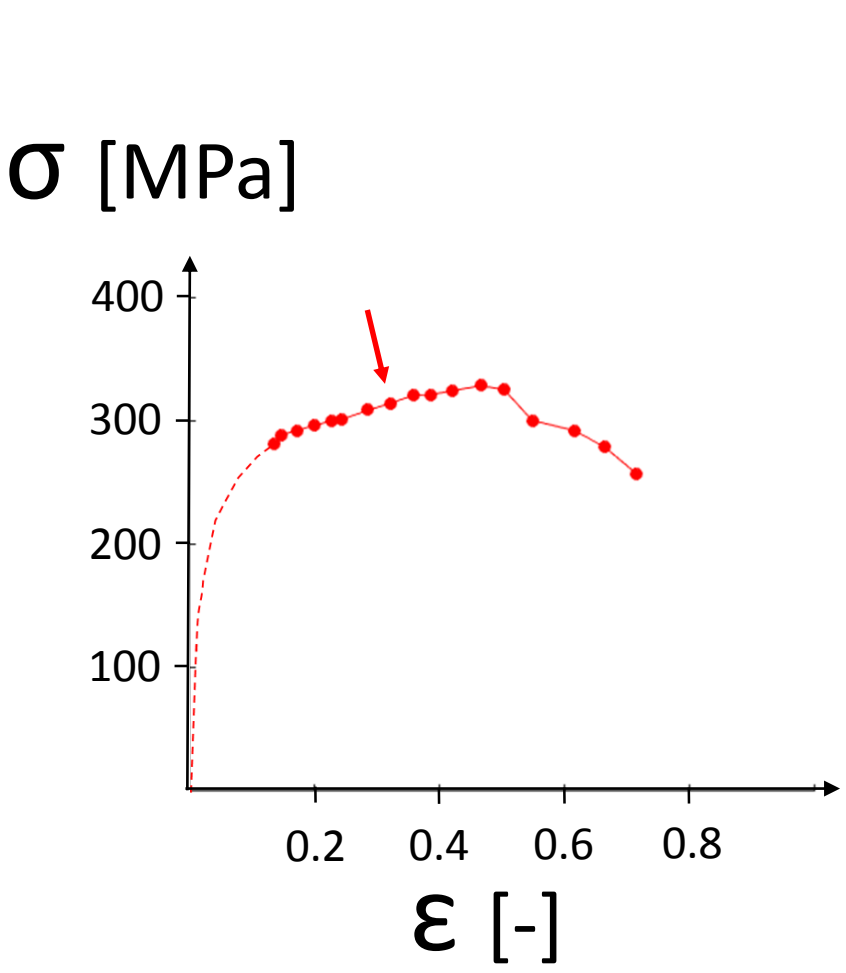

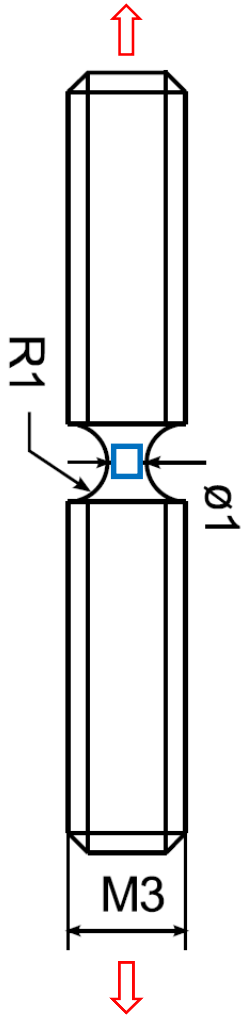

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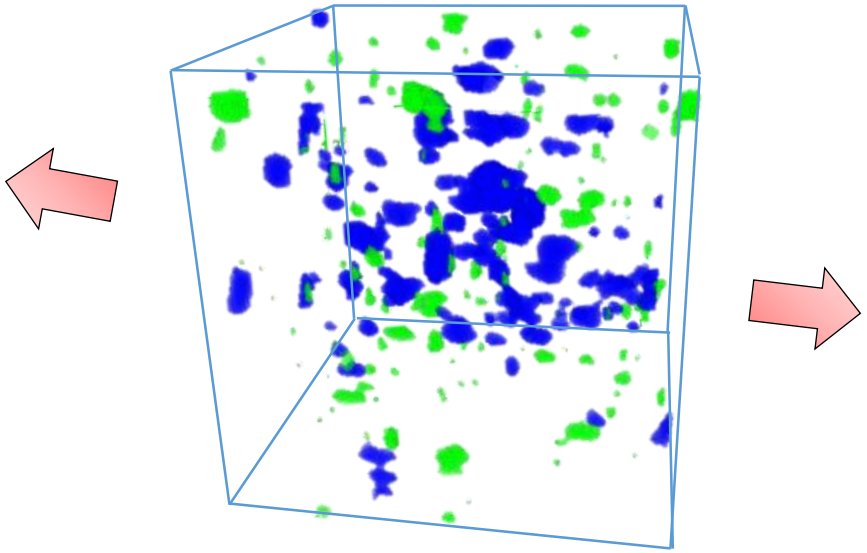
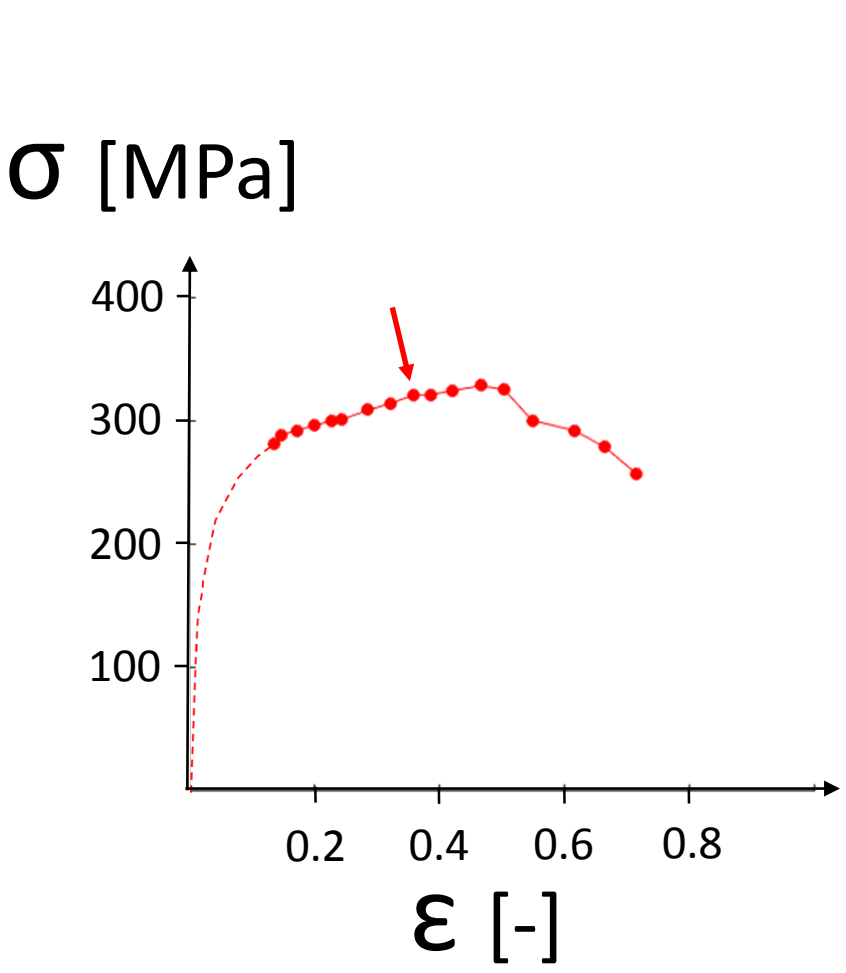
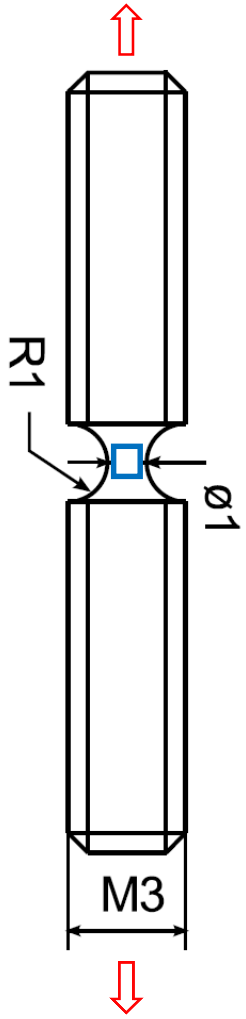
Nucleated voids



2 Pre-existing porosity decreases the ductility





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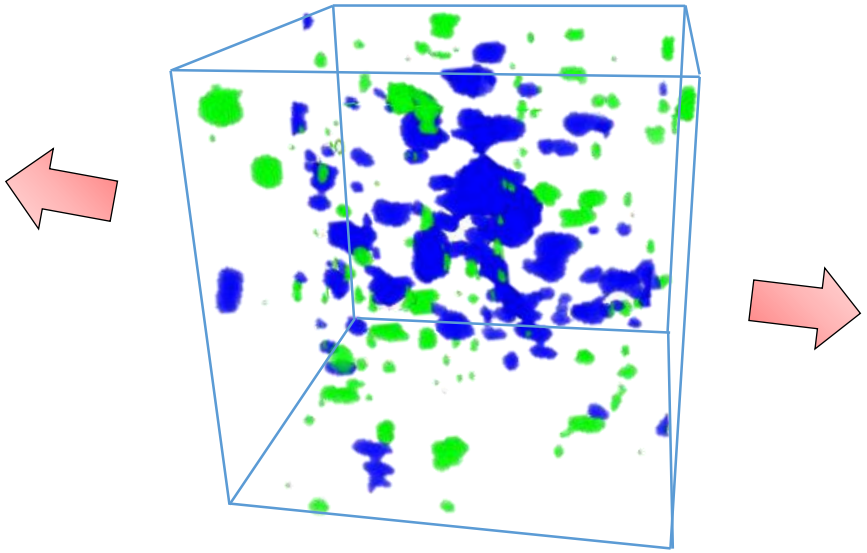

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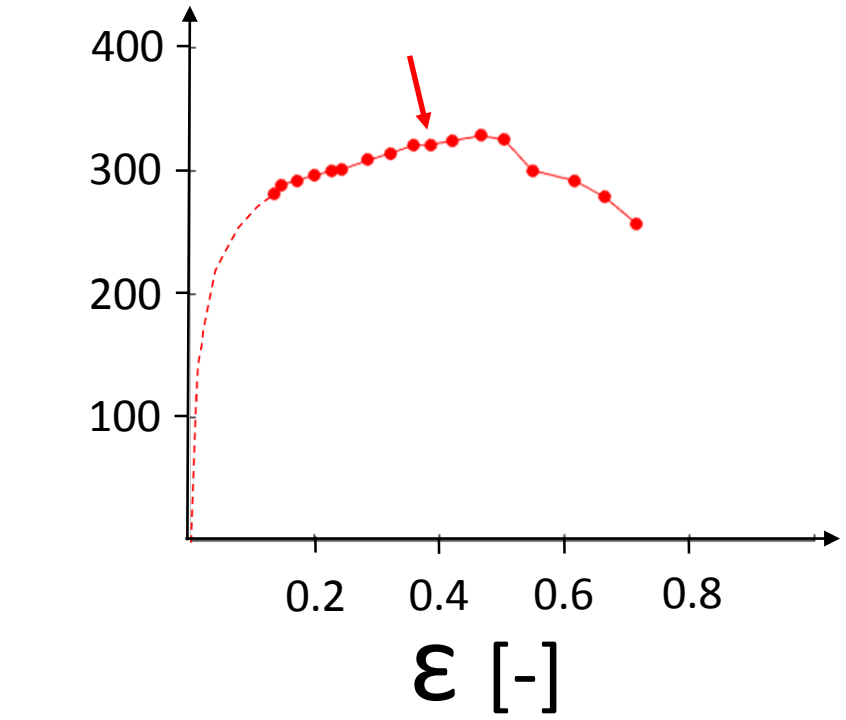

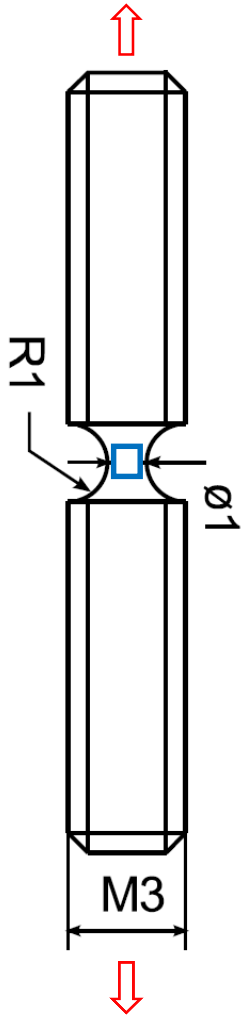

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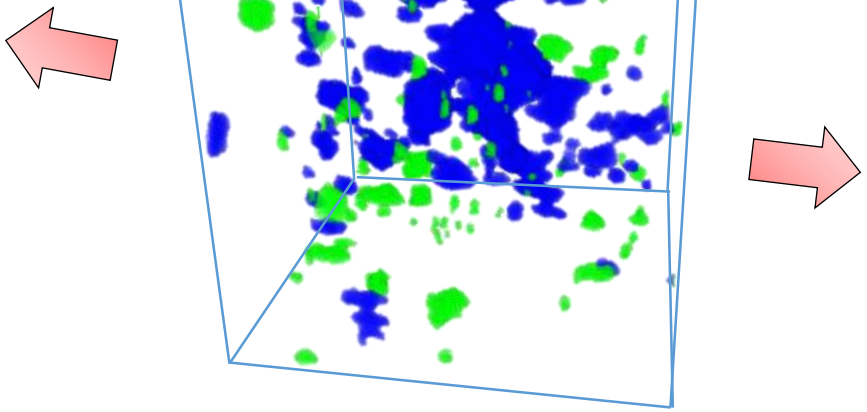

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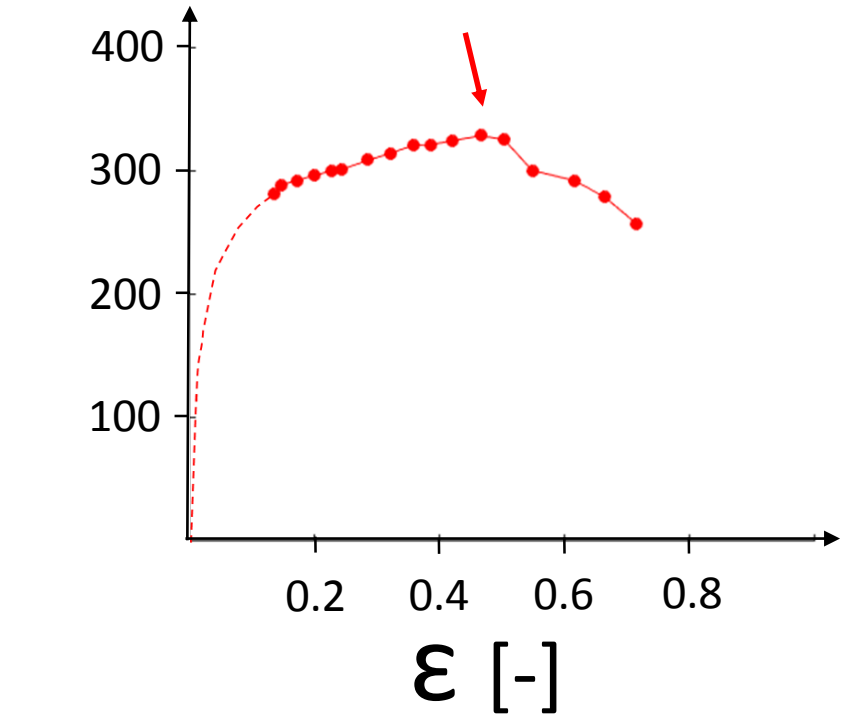

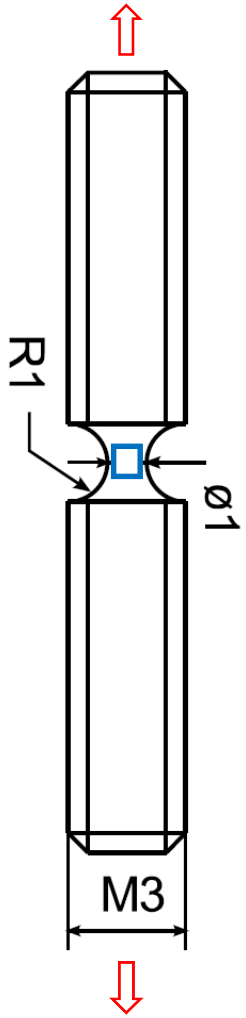

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