# Correlation between Microstructure and Residual Stress in Selective Laser Melting

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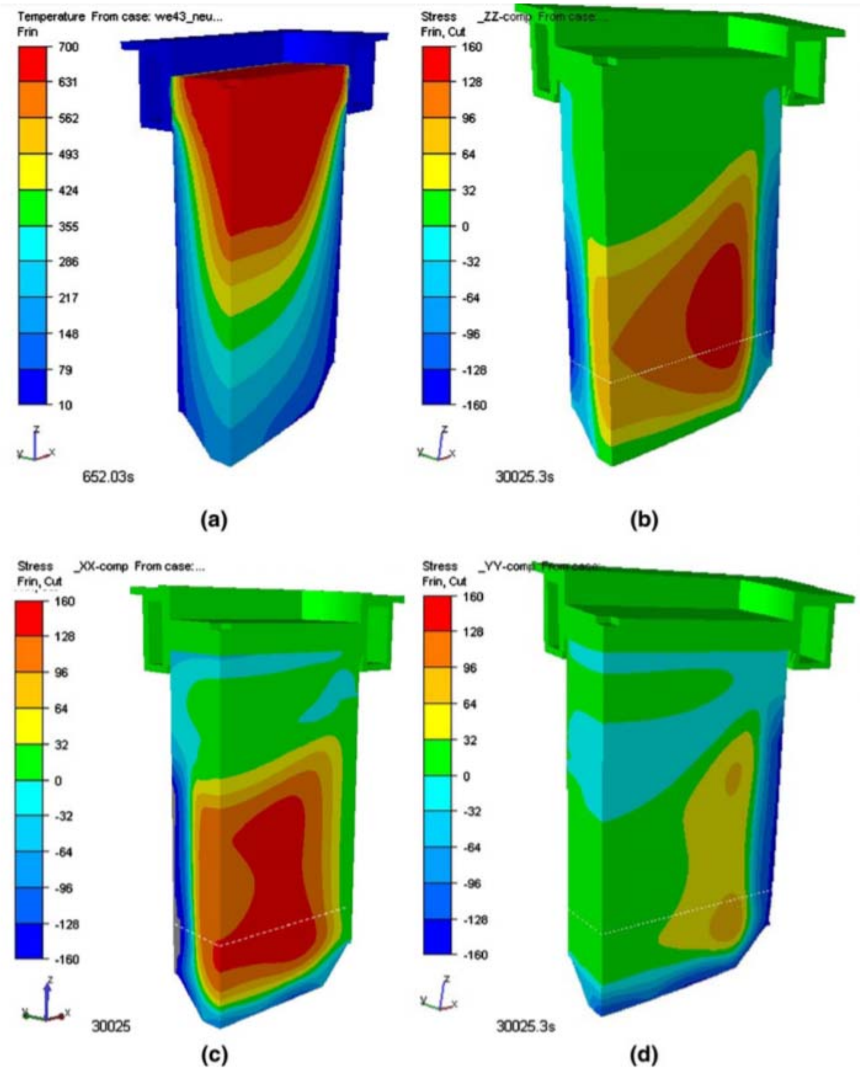
**2019. 05. 20.**

# Residual Stress in As-cast material

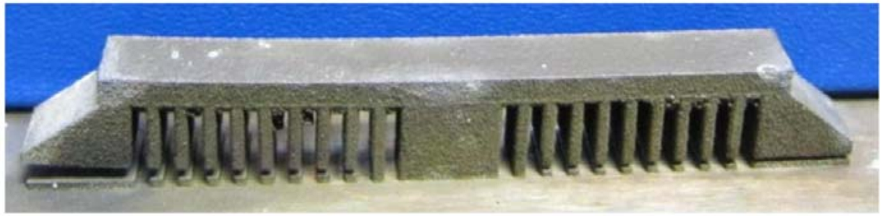
Normal Cast Ingot

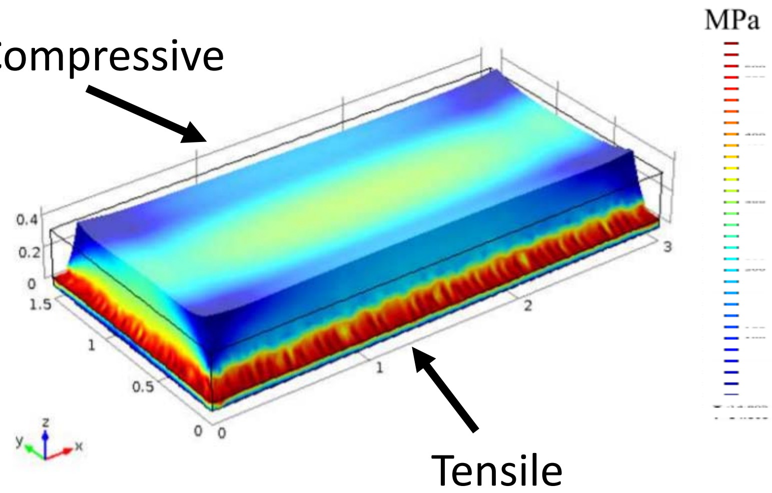


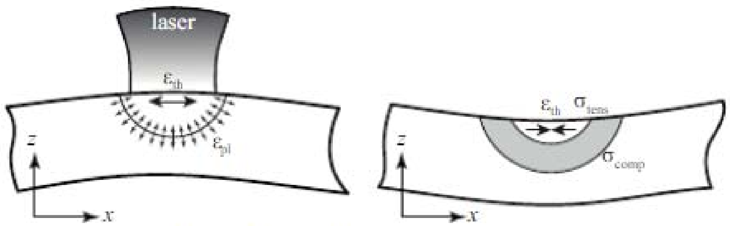

M.Tursky et al., Metallurgical and Materials Transactions A 43(5) · May 2012

# Residual Stress in As-cast material

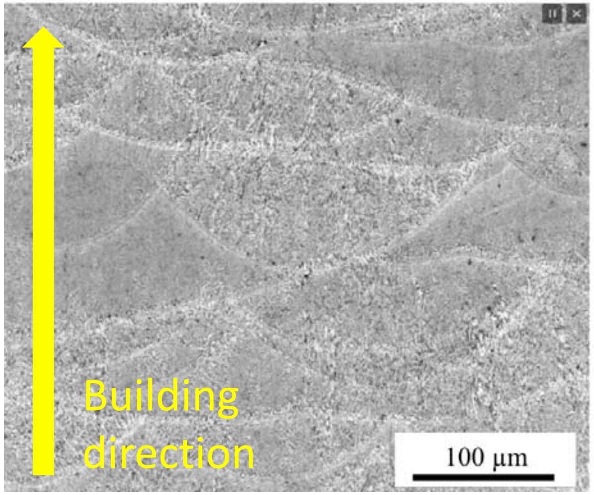
## Residual stress in SLM





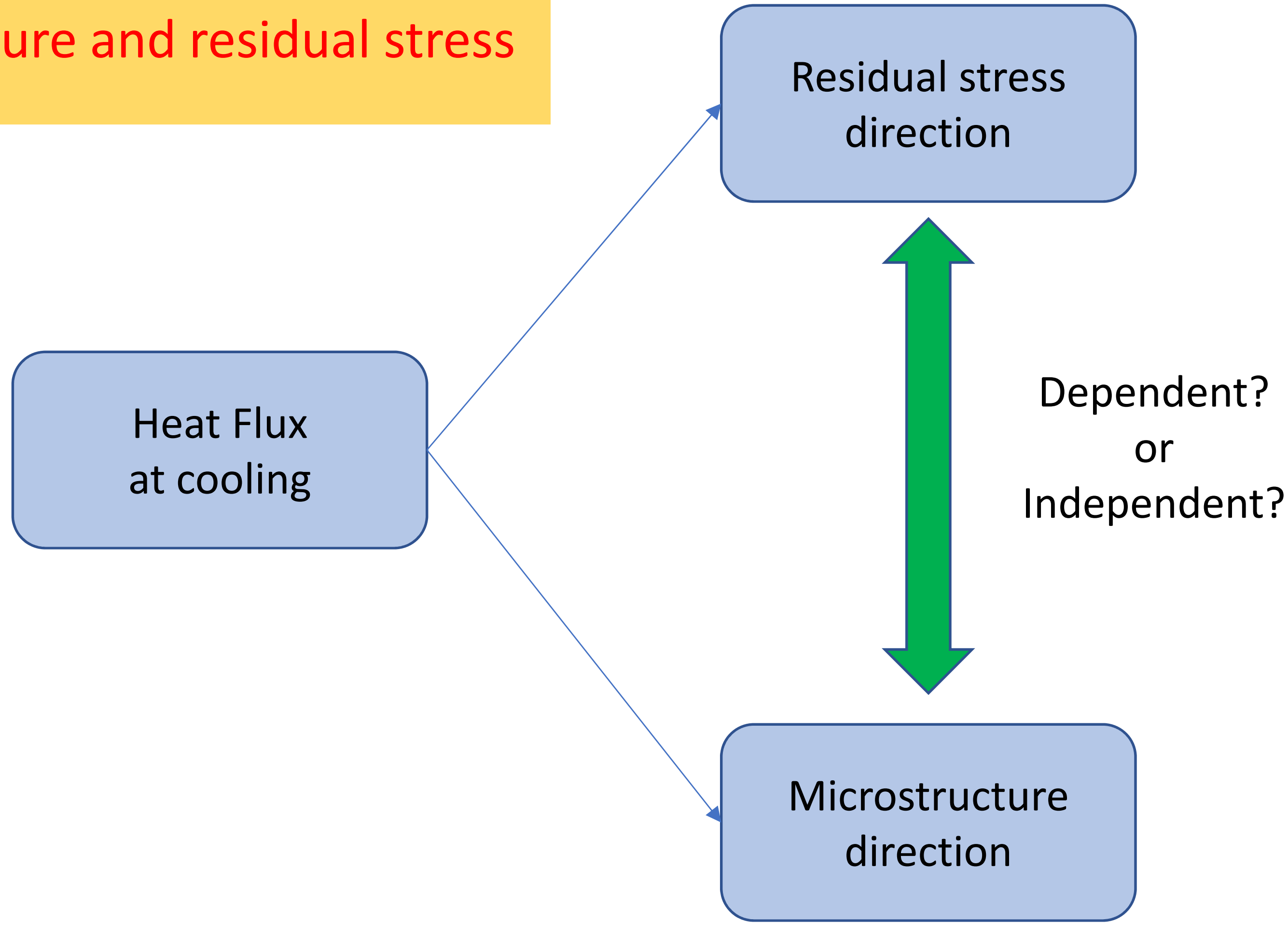

(a) – Heating (b) – Cooling

# Motivation

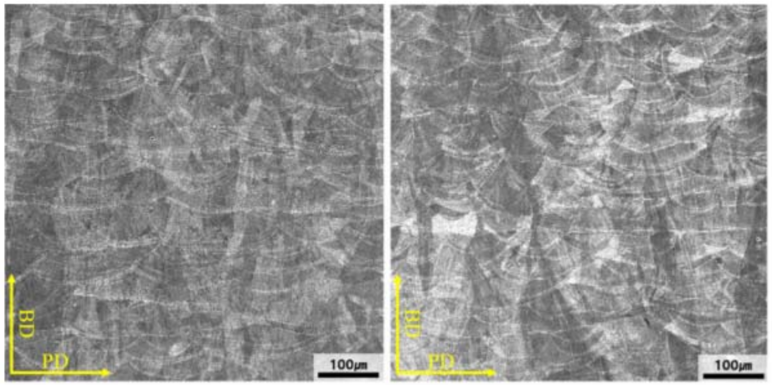


Possible correlation between microstructure and residual stress



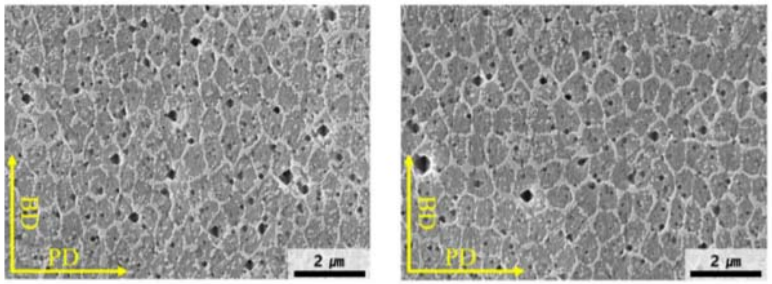
# As-cast vs After stress relieving

## Microstructure



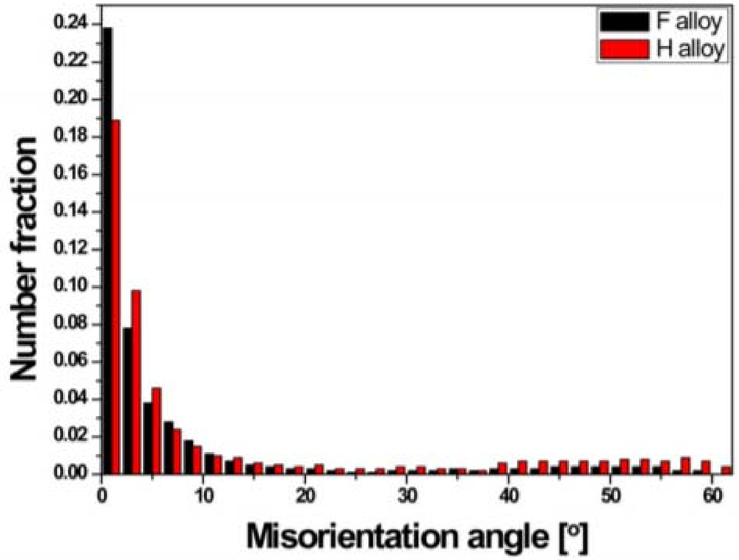

(a) (b)

**Fig. 2.** Microstructures of SLMed AISI 316L alloys; (a) as fabricated (F) and (b) Heat treated (H).




(a) (b)

**Fig. 3.** High magnification microstructures of SLMed AISI 316L alloys; (a) as fabricated (F) and (b) Heat treated (H).

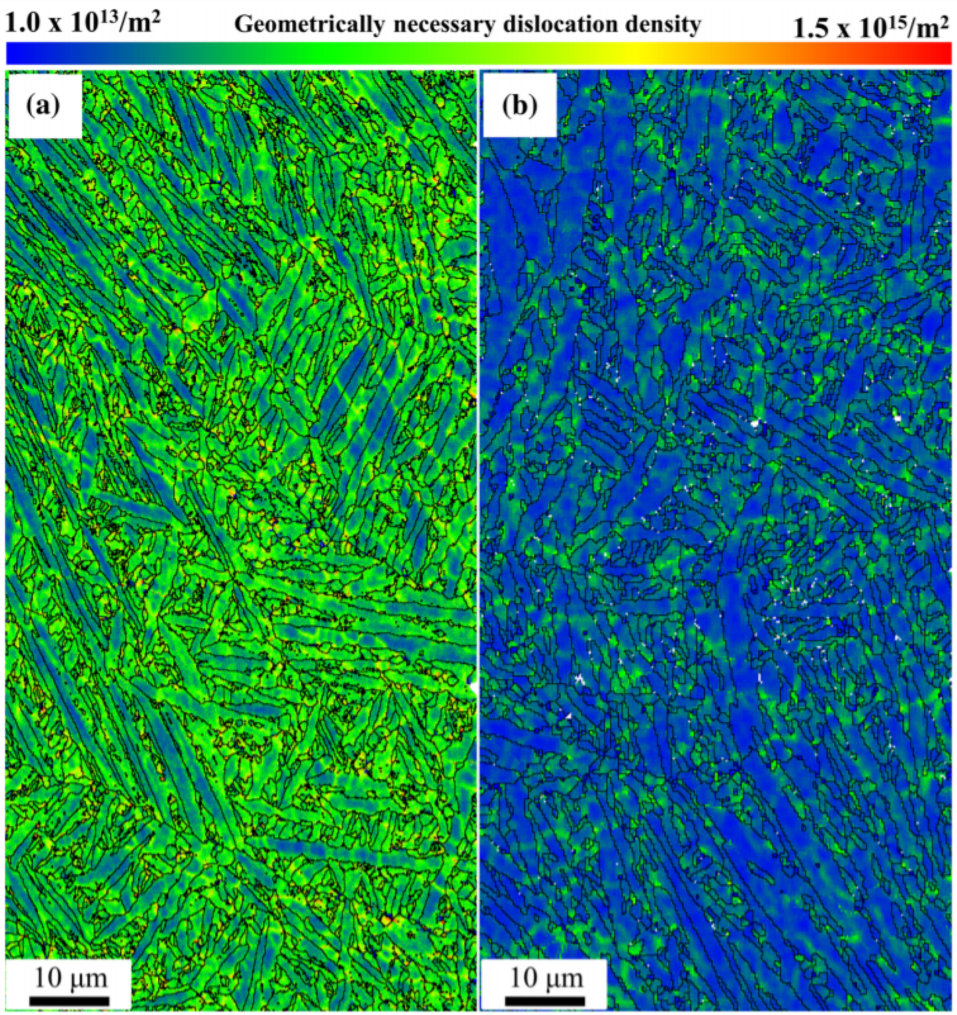


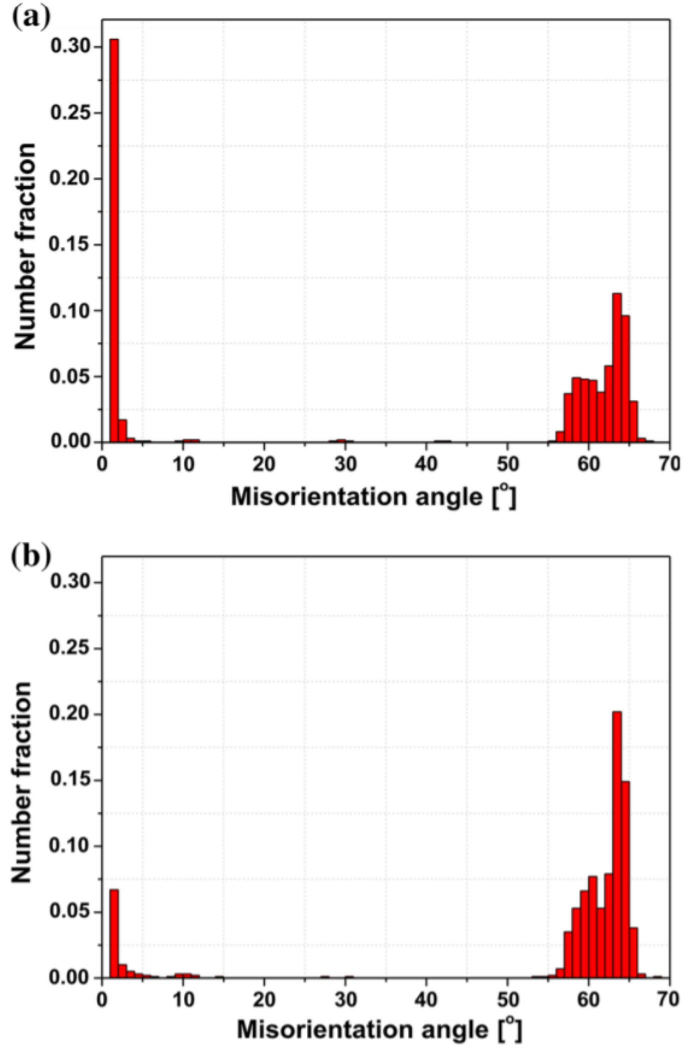

G.S. Ham et al., Korean J. Met. Mater., Vol. 57, No. 5 (2019) pp.295-303

# As-cast vs After stress relieving



## Microstructure

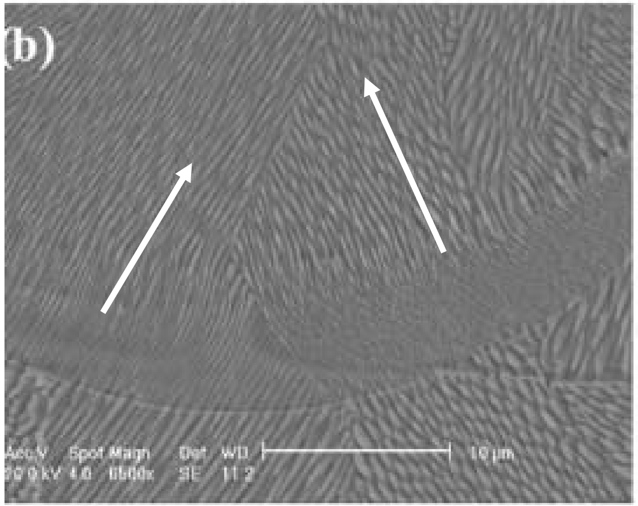


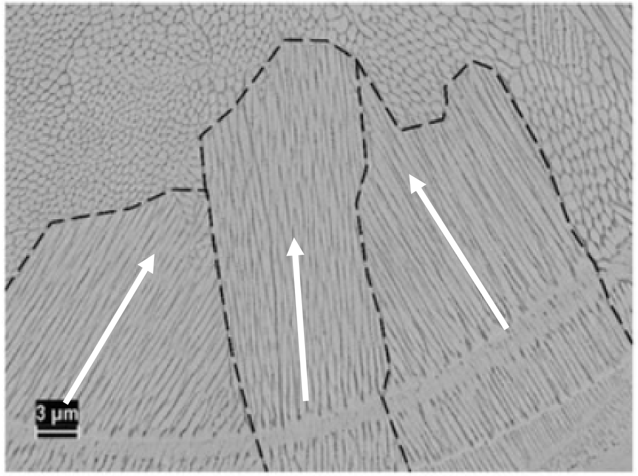

Y.K. Kim et al., Metallurgical and Materials Transactions A 49(11) · Nov 2018

# Presumption

**Cellular Microstructure in SLM**




A lot of interfaces




As-SLMed

- Production of many interfaces
- Directional growth

After stress relief heat treatment

- Reducing interfacial area
- Decreasing directionality

Presumption

- Directional interfaces induce the residual stress

# Surface Stress



Definition of surface free energy is seemly the amount of reversible work $dw$ performed to create new area $dA$ of surface,

$$dw = \gamma dA$$

Surface free energy (Surface tension)

Gibbs was the first to define another surface quantity, different from the surface tension $\gamma$,

that is associated with the reversible work per unit area needed to elastically stretch a pre-existing surface.

$$d(\gamma A) = A f_{ij} d\epsilon_{ij}$$

$$\rightarrow f_{ij} = \gamma \delta_{ij} + \partial\gamma/\partial e_{ij} \quad \rightarrow \quad f = \gamma + \partial\gamma/\partial e$$

Surface stress (Same unit with γ)

$$\rightarrow h_{ij} = \sigma\delta_{ij} + \partial\sigma/\partial e_{ij}.$$

Interface stress

**FCC Metal surfaces (111)** [ edit ]

| Metal | γ [J/m^2] | f [J/m^2] |
|---|---|---|
| Al | 0.96 | 1.25 |
| Ir | 3.26 | 5.30 |
| Pt | 2.19 | 5.60 |
| Au | 1.25 | 2.77 |
| Pb | 0.50 | 0.82 |

| Bilayer A/B | $h$ for (100) interface ($J/m^2$) | $h$ for (111) interface ($J/m^2$) |
|---|---|---|
| Ag/Ni | 0.83 | 0.32 |
| Au/Ni | 0.71 | −0.08 |
| Ag/Cu | 0.53 | 0.32 |
| Au/Cu | 0.33 | 0.01 |
| Pt/Ni | 0.04 | −0.57 |

Positive: Tensile , Negative:Compressive

# Research design

a hydrostatic pressure acting on this sphere equal to $\Delta P = 2f/r$

Hooke's Law is $\Delta P = -3K\varepsilon$, where K is the bulk modulus

$f = -3K\varepsilon r/2.$

## Modeling

Integrating Interface stress → Dividing by Surface area → Comparing Residual stress value

## Experimental method

SLM with Different Cooling rate → Difference in total Interface area → Measuring Residual stress

Cell spacing, Aspect ratio of the cell, etc.

Thank you for listening!

# Surface Stress



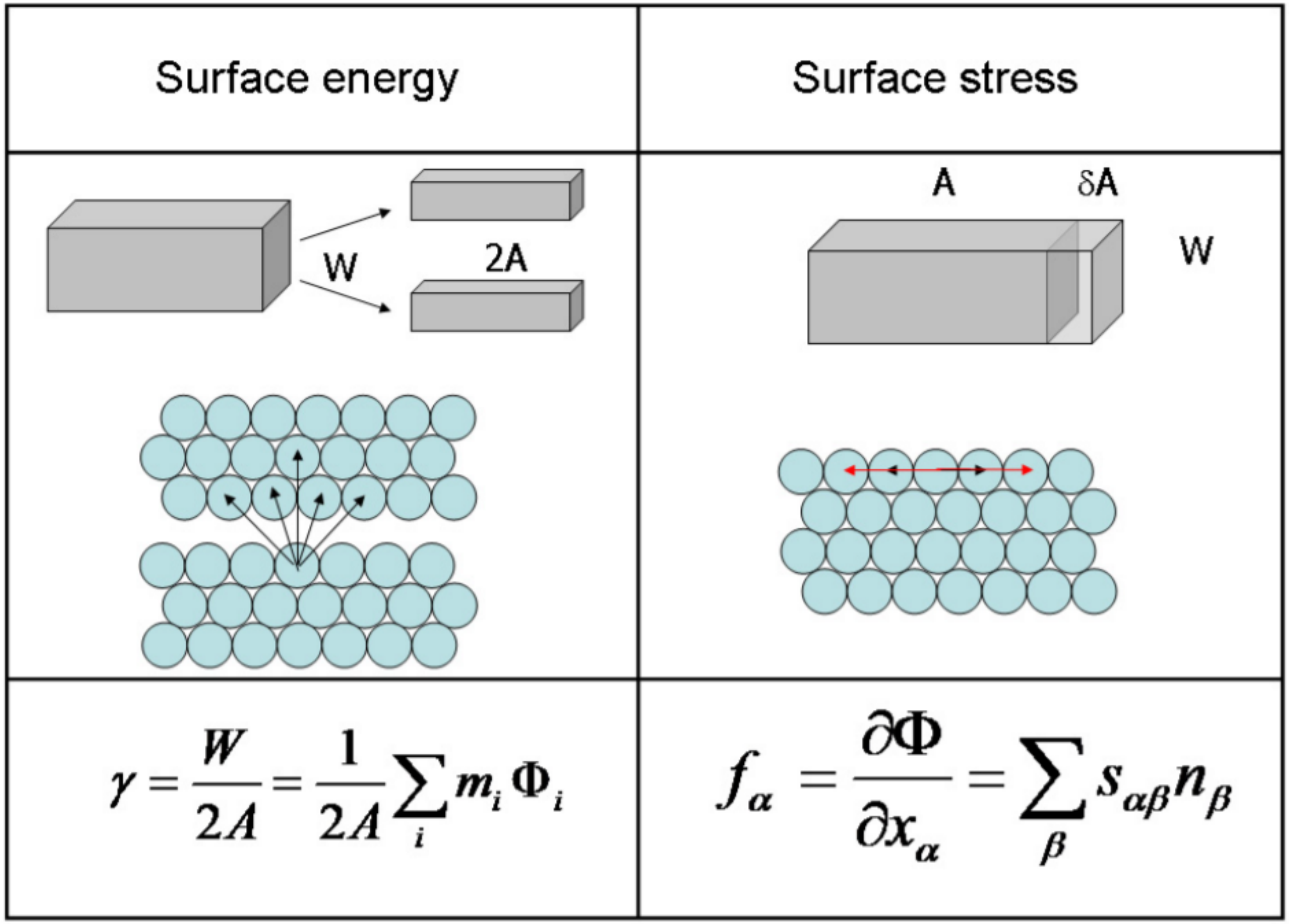



**Figure 3.** Sketch of the difference between surface stress and surface energy. The surface stress originates from an elastic deformation and thus from bonds stretching. It is an excess of stress in the surface (double arrows). Surface energy originates from a cleaving process and thus from breaking bonds. It is thus calculated as the sum of bonds ($A$ is the surface area, $n_i$ the number of $i$th neighbours whose bonding energy $\Phi$ are sketched by the arrows).

# Surface Stress

**Table 1.** Basic thermodynamics equations valid for isotropic solid and liquid spheres of radius $R$ illustrating the deep difference between surface energy and surface stress.

| | Excess of pressure | Excess of chemical potential |
|---|---|---|
| Solid | $\sigma_{33} = \frac{2s}{R}$ | $\Delta\mu = \frac{2\gamma}{R}$ |
| Liquid | $\Delta P = \frac{2\gamma}{R}$ | $\Delta P = \frac{2\gamma}{R}$ |

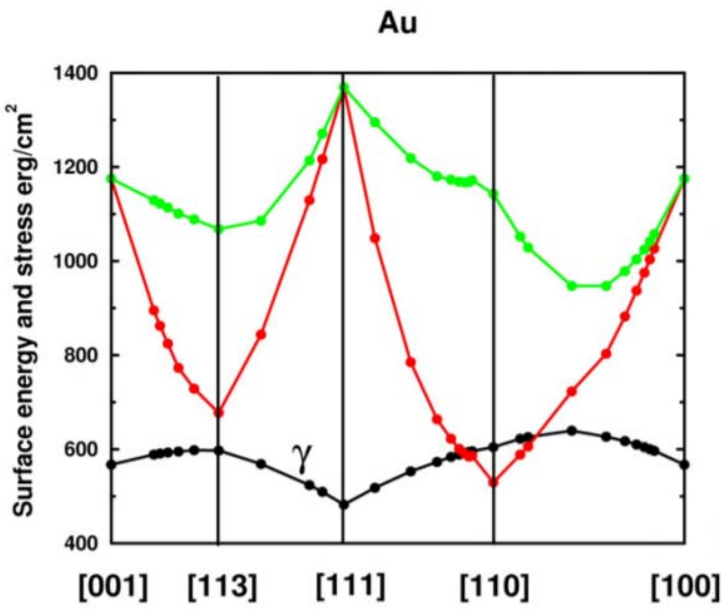



**Figure 4.** Cu surface energy and surface stress anisotropy calculated using a semi-empirical SMA potential. The two branches of surface stress (green and red) correspond to the two principal components of surface stress. For high symmetry directions the two branches merge in a single value (isotropic surface stress).