Coating Thermal Mismatch Stress and Substrate Curvature

Stress in a thin coating from the expansion mismatch with its substrate over a temperature change, and the substrate curvature by Stoney's equation.

Method: Thin-film thermal stress and Stoney's equation

Input parameters

Unit system: SI

Parameter	Value	Unit
Coating elastic modulus	200.00	GPa
Coating Poisson's ratio	0.25000	
Coating expansion coefficient	8.0000	µm/(m·K)
Substrate expansion coefficient	12.000	µm/(m·K)
Cooling from stress-free (deposition) temperature	800.00	K
Coating thickness	5.0000	µm
Substrate elastic modulus	200.00	GPa
Substrate Poisson's ratio	0.30000	
Substrate thickness	1.0000	mm

Calculated results

Parameter	Value	Unit
Mismatch strain	3,200.0	µε
Coating stress (compression negative)	-853.33	MPa
Substrate curvature	0.089600	1/m
Radius of curvature	11.161	m

Notes for this case

• A thin coating bonded to a thick substrate is forced to follow the substrate: on cooling by ΔT its biaxial stress is σ = −E_c(α_s − α_c)ΔT/(1 − ν_c). A coating with a lower expansion than its substrate (ceramics on metals) ends up in compression after cooling. Stoney: κ = 6σ_ct_c(1 − ν_s)/(E_st_s²), valid while t_c ⍰ t_s; intrinsic (growth) stresses add to this.

Formula and method

$$\sigma_c = -\frac{E_c(\alpha_s - \alpha_c)\Delta T}{1-\nu_c}, \quad \kappa = \frac{6\sigma_c t_c(1-\nu_s)}{E_s t_s^2}$$

Variables

E_c	Coating elastic modulus	Pa
ν_c	Coating Poisson's ratio	-
α_c	Coating expansion coefficient	1/K
α_s	Substrate expansion coefficient	1/K
ΔT	Cooling from stress-free (deposition) temperature	K
t_c	Coating thickness	m
E_s	Substrate elastic modulus	Pa
ν_s	Substrate Poisson's ratio	-
t_s	Substrate thickness	m
$\Delta\varepsilon$	Mismatch strain	-
σ_c	Coating stress (compression negative)	Pa

κ	Substrate curvature	1/m
R	Radius of curvature	m

Method and standards

Coating stress.

Assumptions and limits

- Thin elastic coating; uniform temperature; constant properties.

References

Thin-film thermal stress and Stoney's equation

Report details

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Release checks	3 reference cases of this calculator, computed independently, are checked on every release

Results are for engineering estimation. Verify critical designs against the referenced standards and your own data.

This calculator online

https://calc.firecad.com/materials/properties/coating-thermal-mismatch-stress

Open this case on calc.firecad.com →

Reopens the calculator with the inputs of this report.