THERMAL PROPERTIES OF DENTAL MATERIALS

CAN AFFECT THE SENSATION OF COLD AND HOT

AND

CAN CAUSE MECHANICAL FAILURE DUE TO DIFFRENT EXPANSION OR CONTRACTION

THERMAL CONDITIONS IN THE ORAL CAVITY

32°C - 37°C - open or closed

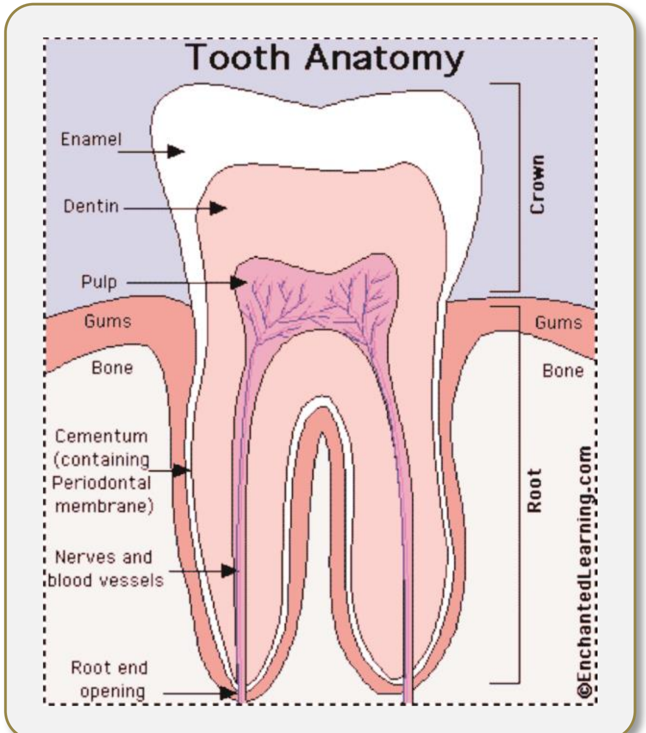
0°C - 70°C - ingestion of hot or cold drink or food

For some dental materials localized temperature increase is observed due to highly exothermic nature of the setting reactions, for instance:

Temperature rise during setting of some selected materials (100 mg sample)	
Material	Temperature rise (°C)
Zinc phosphate cement	1.9
Acrylic resin	9.6!
Glass ionomer cement	1.0

After: Aplied Dental Materials, John F. McCabe and Angus W.G. Walls, 2008

Tooth anatomy



Enamel and dentine – relatively good thermal insulators

Pulp - very sensitive to temperature changes!

<u>THERMAL DEMANDS OF RESTORING MATERIALS:</u>

✓ GOOD THERMAL INSULATION

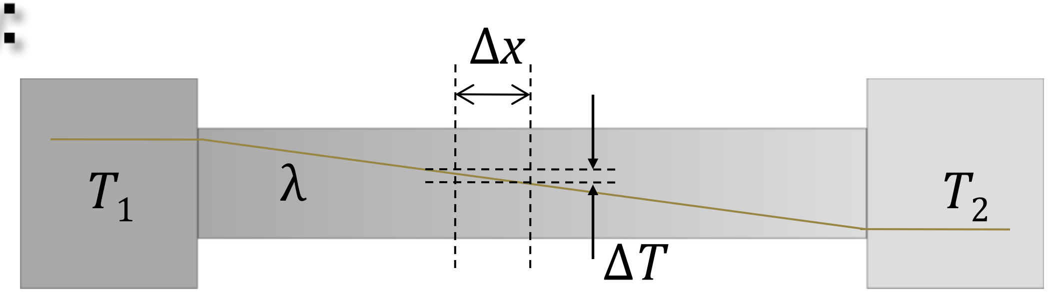
✓ SHOULD NOT UNDERGO A LARGE TEMPERATURE INCREASE WHEN SETTING IN SITU – HEAT LIBERATED AND THE ASSOCIATED RISE IN TEMPERATURE MAY CAUSE CLINICAL PROBLEMS

✓ SMALL DIMENSIONAL CHANGES RESULTING AS A CONSEQUENCE OF *THE <u>THERMAL EXPANSION</u>* <u>PHENOMENON!</u>

CONDUCTION OF HEAT

THE FOURIER LAW:

$$\frac{\Delta Q}{\Delta t} = -\lambda S \frac{\Delta T}{\Delta x}$$



THERMAL CONDUCTIVITY

$$\lambda = \frac{\frac{\Delta Q}{\Delta t}}{S \frac{\Delta T}{\Delta x}}$$

$$[\lambda] = \frac{\mathrm{W}}{\mathrm{mK}}$$

	MATERIAL	λ (W/mK)
Good conductors	silver	422
	gold	~300
↓	iron	80
	glass	0.7-1.0
	water	0.6
	wood	0.1-0.2
Poor conductors (good insulators)	air	0.02

COEFFICIENT OF THERMAL CONDUCTIVITY OF SOME SELECTED DENTAL MATERIALS

	λ , W m^{-1} K^{-1}	
Enamel	0.92	
Dentine	0.63	
WATER (37.8°C/100°F)	0.63	
Silicate materials	0.75	
Acrylic resin	0.21	
Zinc phosphate cement	1.2 (!)	cavity lining or base
Dental amalgam	23 (!)	does not provide satisfactory thermal insulation of the pulp
Gold	292	
Silver	422	

After: Applied Dental Materials, John F. McCabe and Angus W.G. Walls, 2008

THE CONDUCTION OF HEAT IS A SLOW PROCESS.
THERMAL STIMULI ARE USUALLY OF BRIEF DURATION!

THERMAL DIFFUSIVITY, k

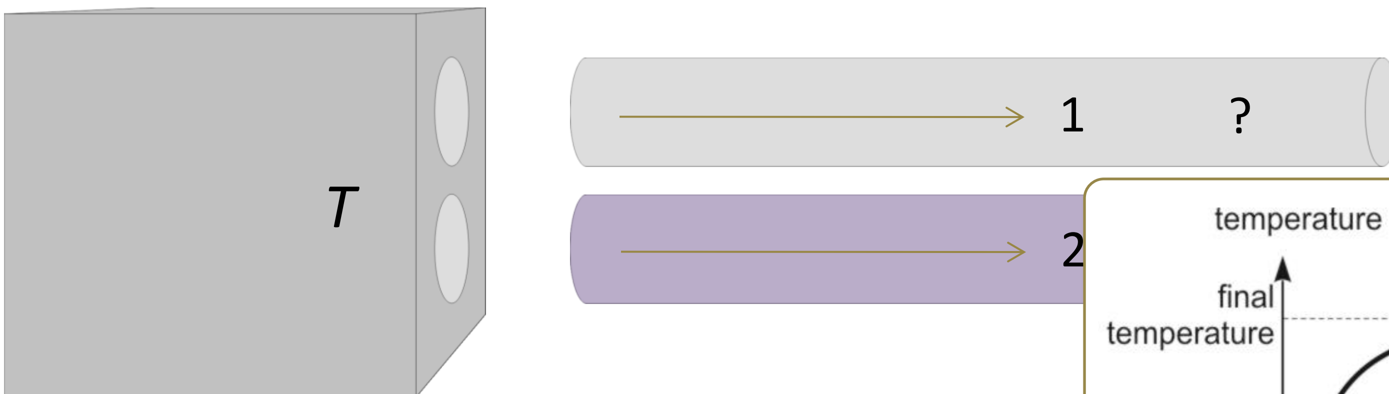
$$k = \frac{\lambda}{C_s \cdot d}$$

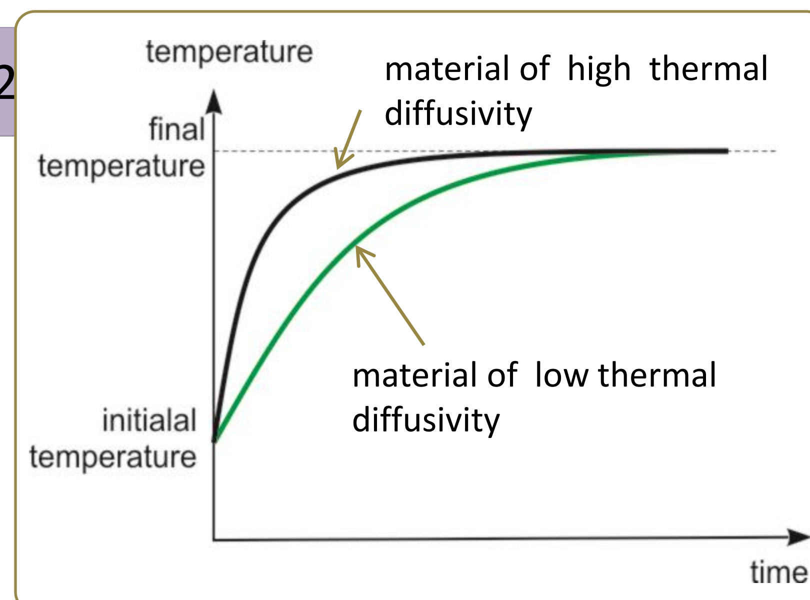
$[k]$ = m^2/s

C_s – specific heat capacity,
d - density,
λ - thermal conductivity

water	1.5
dentine	2.6
enamel	4.2
silver	1690

Thermal diffusivity is a material property which describes the rate at which thermal stimulus travels through a material.



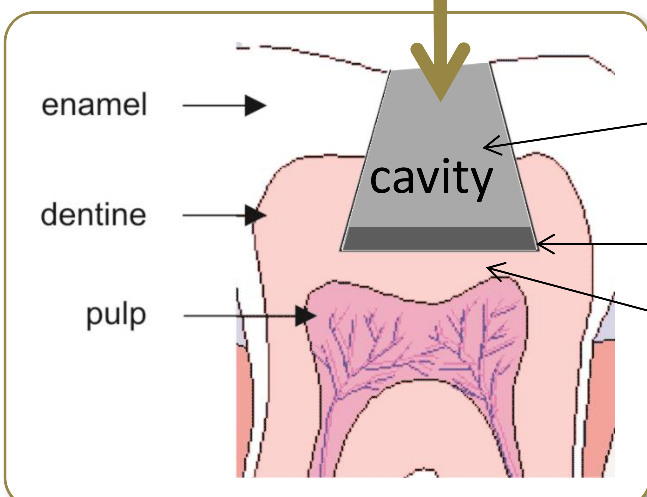


A material insulating properties are characterized by its thermal conductivity and/or thermal diffusivity

In order to protect the pulp from sudden intolerable thermal stimuli a cavity lining or base is often used to form a thermal insulation barrier

	Thermal conductivity $W\ m^{-1} K^{-1}$	**Thermal diffusivity** $\times 10^{-7}\ m^2/s$
Dentine	0.63	2.6
Zinc phosphate cement	1.2 (!) cavity lining or base	
Dental amalgam	23 (!) does not provide satisfactory thermal insulation of the pulp	78

THERMAL STIMULUS
(cold or hot meal or drink)

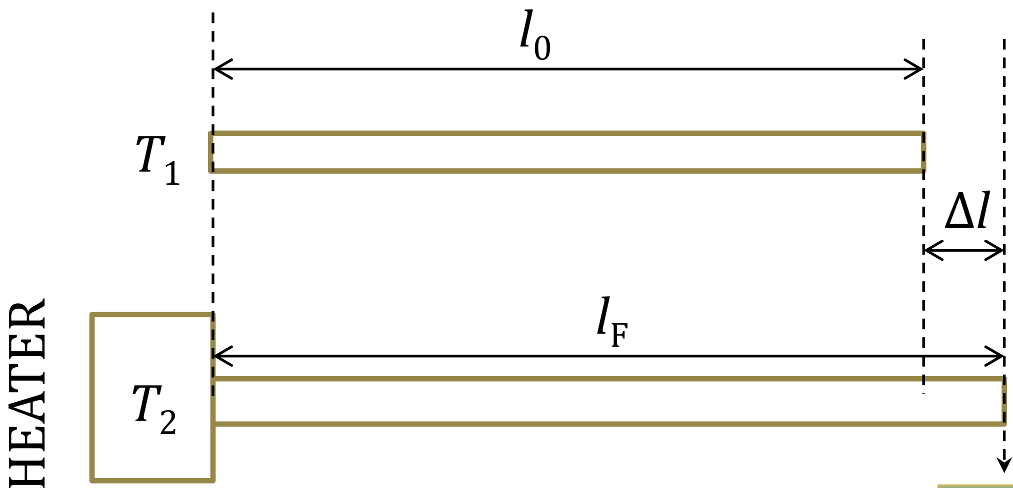


metallic-like filling (AMALGAM) of high thermal conductivity and diffusivity

cavity lining (materials of low value of thermal diffusivity)

residual layer of dentine

THERMAL EXPANSION



$$l_F = l_0 + l_0\alpha(T_2 - T_1)$$

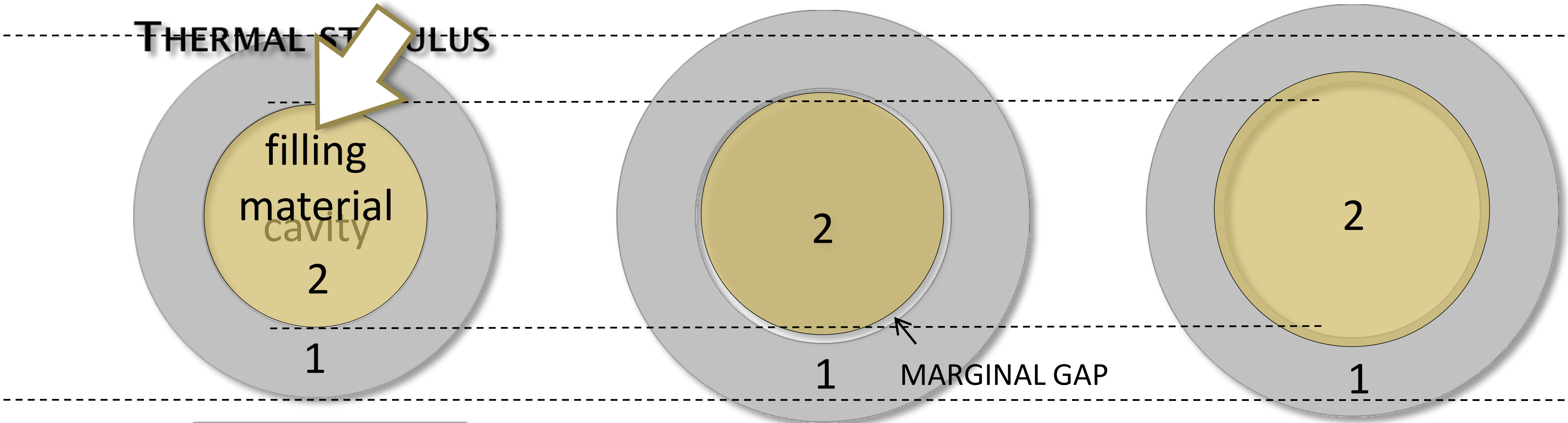
$$\Delta l = l_0 \alpha \Delta T$$

α - the linear coefficient of thermal expansion,
Δl =(l_F-l_0) - change in length,
l_0 - initial length,
ΔT - change in temperature.

$$\alpha = \frac{\frac{\Delta l}{l_0}}{\Delta T}$$

INTERPRETATION:
The linear coefficient of thermal expansion equals the fractional change in length ($\Delta l/l_0$) over unit change in temperature ΔT.

EXPANSION – CONTRACTION MISMATCH



$$\Delta l = l_0 \cdot \alpha \cdot \Delta t$$

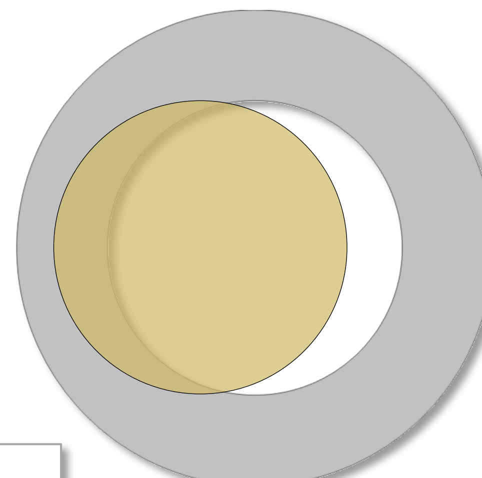
$\alpha_2 < \alpha_1$

$\alpha_2 > \alpha_1$

„THERMAL MISMATCH” LEADS TO CLINICAL PROBLEMS:
MICRO FISSURES - MICRO LEAKAGE - PENETRATION OF BACTERIA CONTAINING FLUIDS :

- ✓ PULP INFLAMMATION
- ✓ SECONDARY CARIES

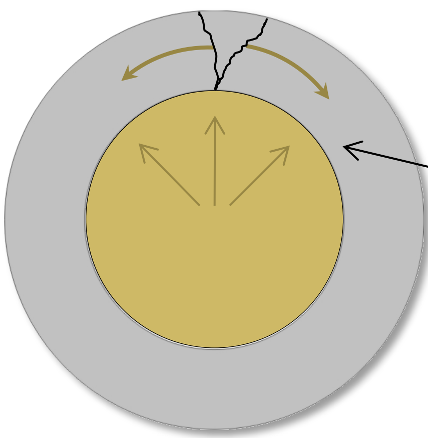
CLINICAL PROBLEM: FRACTURE POSSIBLE



$\alpha_2 = \alpha_1$

DENTINE	8.0
ENAMEL	11.4
AMALGAM	25 !
COMPOSITE RESINS	25-60
CERAMIC	7-9
METAL:	
Nickel	13.3
Silver	19.0
Gold	13.8
SILICATE CEMENTS	10

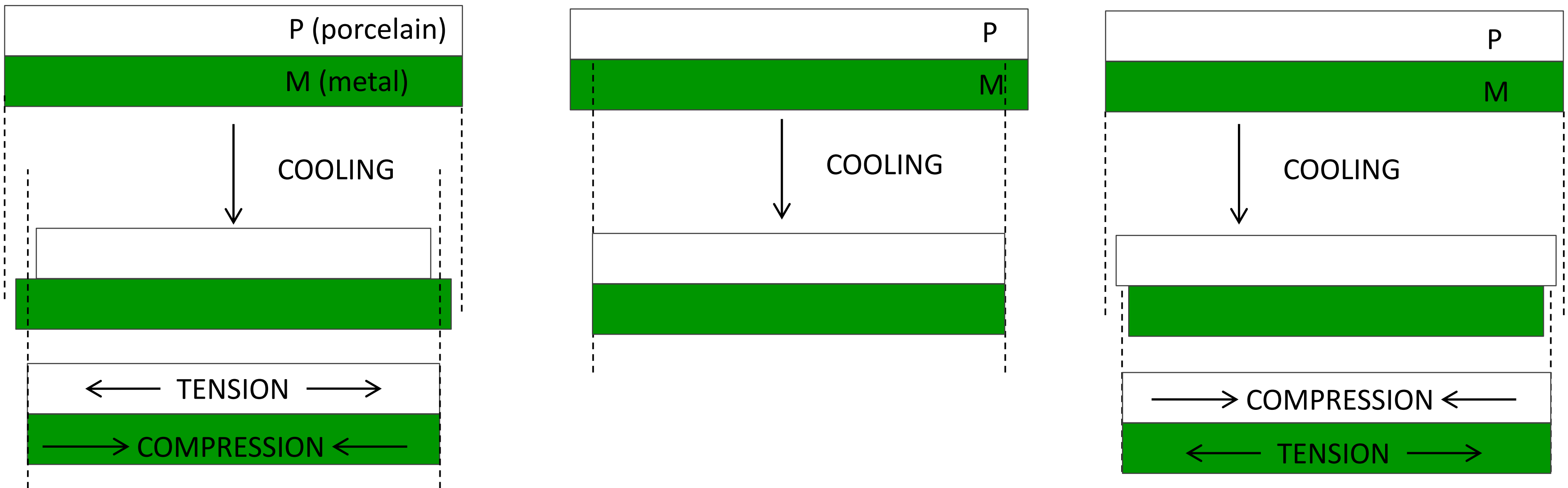
Clinical problem: fracture possible



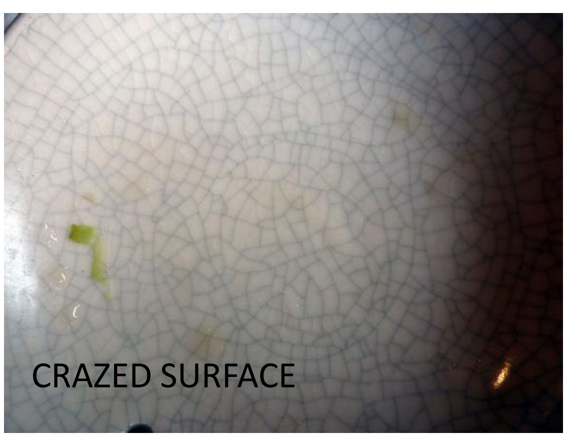
CIRCUMFERENTIAL TENSION IN WALLS DURING HEATING RESULTING STRESS

METAL-BONDED CERAMIC SYTEMS

$\alpha_P > \alpha_M$ | $\alpha_P = \alpha_M$ | $\alpha_P < \alpha_M$

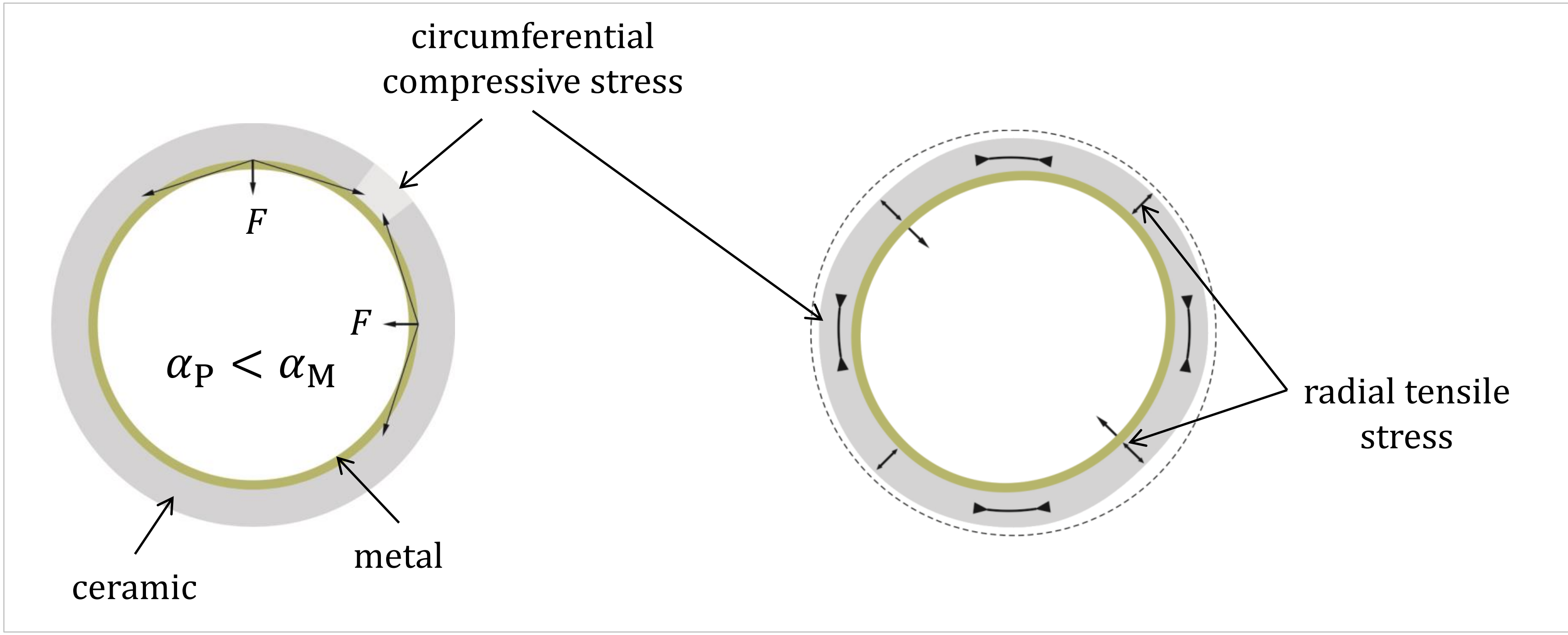


- FORMATION OF SURFACE CRACKS
- CRAZED SURFACE

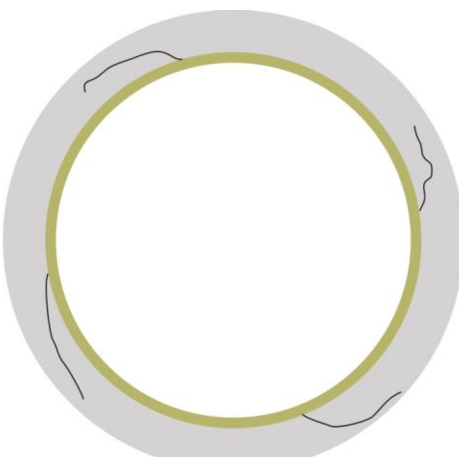


- ➢ MODERATE MISMATCH: REDUCED TENDENCY TO CRACKING
- ➢ TOO LARGE MISMATCH (!):
  - CRAZING
  - FRACTURE
  - DE-BONDING

METAL-BONDED CERAMIC SYSTEM - COOLING



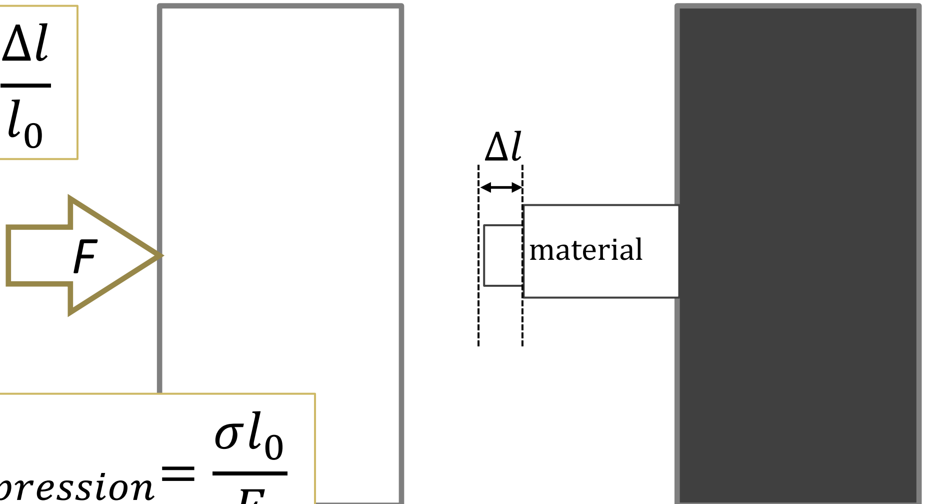
Too large mismatch ($\alpha_p \ll \alpha_M$) : the ceramic fractures circumferentially



THERMAL EXPANSION VS. MECHANICAL STRENGTH

Compressive stress – vs. Thermal expansion

$$\sigma = E\frac{\Delta l}{l_0}$$

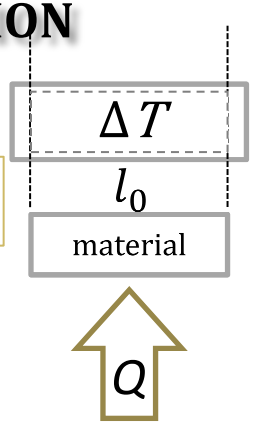


$$\Delta l_{compression} = \frac{\sigma l_0}{E}$$

$$\Delta l_{compression} = \Delta l_{th.exp.}$$

$$\frac{\sigma l_0}{E} = l_0 \alpha \Delta T$$

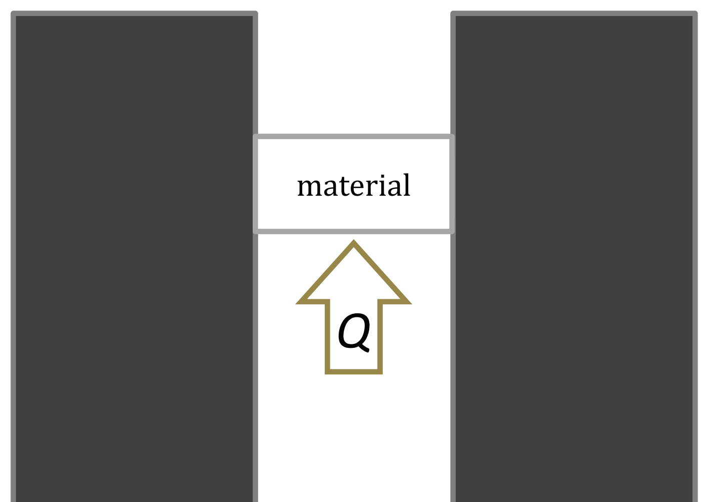
Thermal expansion



$$\Delta l_{th.exp.} = l_0 \alpha \Delta T$$

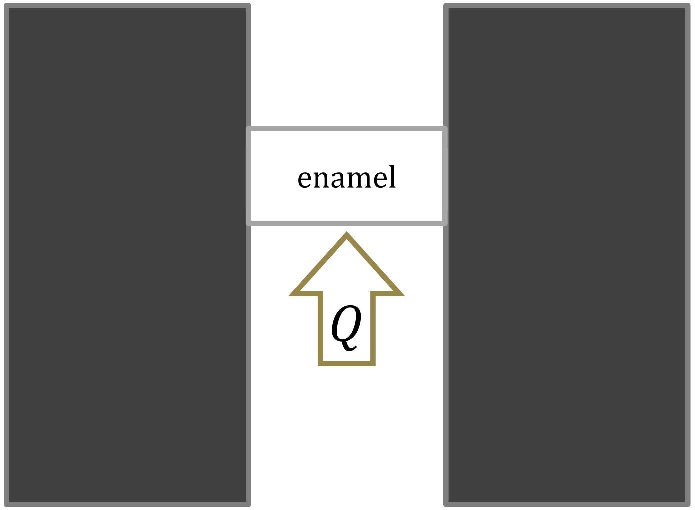
l_0 - initial length,
Δl_0 - elongation,
α - coefficient of thermal expansion,
Δt - change in temperature.

$$\sigma = E \alpha \Delta T$$



A sample on enamel was placed between two rigid, unmovable supports. Calculate how large must be the increase of temperature of the enamel sample to cause its damage as a result of compressive stress.

Given:
compressive strength (σ): 190 MPa
Young's modulus (E): 84 GPa
coefficient of thermal expansion (α): 11×10^{-6} K^{-1}



$$\sigma = E\alpha\Delta T$$

$$\Delta T = \frac{\sigma}{E\alpha}$$

$$\Delta T = \frac{190 \times 10^6}{84 \times 10^9 \cdot 11 \times 10^{-6}} \sim 200 \text{ K}$$

Conclusions:

for filling materials the most ideal combination of physical properties are:

- Low value of thermal diffusivity
- Thermal expansion similar to that for tooth
- Hardness similar to that of tooth