

Thermal expansion: coefficients of materials and formulas

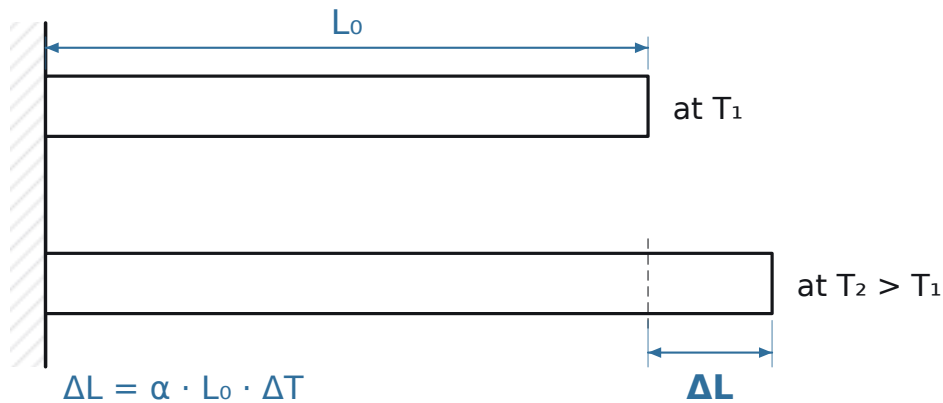
1. Thermal expansion coefficients of materials

Mean linear expansion coefficients between 20 and 100 °C, in 10^{-6} /K (that is, μm per metre per degree). These are common design values: the exact value depends on the grade, condition and temperature range, and the coefficient rises with temperature. For a critical part, use the value from the material's datasheet.

Material	α (10^{-6} /K)	Typical range	α (10^{-6} /°F)	ΔL for 1 m and 100 °C (mm)	Note
Structural and carbon steel (S235 to S355, C45)	12	11 to 13	6.7	1.20	Design value in Eurocode 3
Austenitic stainless 1.4301 (304), 1.4404 (316L)	16	16 to 17	8.9	1.60	About 1.4 times steel
Ferritic stainless 1.4016 (430)	10	10 to 11	5.6	1.00	Close to steel
Grey cast iron (EN-GJL)	11	10 to 12	6.1	1.10	
Aluminium and alloys	23	20 to 24	12.8	2.30	Design value in Eurocode 9; Al-Si casting alloys are lower
Copper	17	16.5 to 17.5	9.4	1.70	
Brass (CuZn)	20	18 to 21	11.1	2.00	
Bronze (CuSn)	18	17 to 19	10	1.80	
Titanium and Ti-6Al-4V	9	8.5 to 9.5	5	0.90	
Invar (Fe-Ni 36%)	1.5	1 to 2	0.8	0.15	For fixtures that must not move
Soda-lime glass (glazing)	9	9	5	0.90	
Borosilicate glass 3.3	3.3	3.3	1.8	0.33	The grade name is its coefficient
Concrete	10	10 to 14	5.6	1.00	Design value in Eurocode 2
Engineering plastics (PA, POM, PC, PMMA, ABS)	—	50 to 120	—	—	5 to 10 times steel: check the grade's datasheet
PE, PP, PTFE	—	100 to 200	—	—	Up to 15 times steel

For the densities of the same materials, see the density chart; for steel grades, S235, S275 and S355.

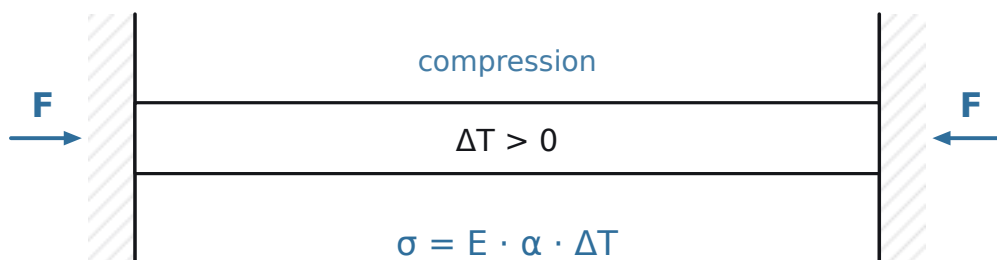
2. Thermal expansion formulas



Quantity	Formula	Note
Change in length	$\Delta L = \alpha \cdot L_0 \cdot \Delta T$	$\Delta T = T_2 - T_1$; same unit for ΔL and L_0
Final length	$L = L_0 \cdot (1 + \alpha \cdot \Delta T)$	Negative ΔT if the part cools
Area	$\Delta A \approx 2\alpha \cdot A_0 \cdot \Delta T$	Isotropic material, moderate ΔT
Volume	$\Delta V \approx 3\alpha \cdot V_0 \cdot \Delta T$	Volumetric coefficient $\beta \approx 3\alpha$
Stress, restrained expansion	$\sigma = E \cdot \alpha \cdot \Delta T$	Part fixed at both ends, elastic range
Change in a clearance	$\Delta j = (\alpha_{\text{bore}} - \alpha_{\text{shaft}}) \cdot D \cdot \Delta T$	Two materials at the same temperature
Heating for a shrink fit	$\Delta T = (s + j_m) / (\alpha \cdot D)$	s : max interference; j_m : assembly clearance

Example: a 1,000 mm steel bar goes from 20 to 70 °C. $\Delta L = 12 \times 10^{-6} \times 1,000 \times 50 = \mathbf{0.6 \text{ mm}}$. The same bar in aluminium grows by $23 \times 10^{-6} \times 1,000 \times 50 = \mathbf{1.15 \text{ mm}}$.

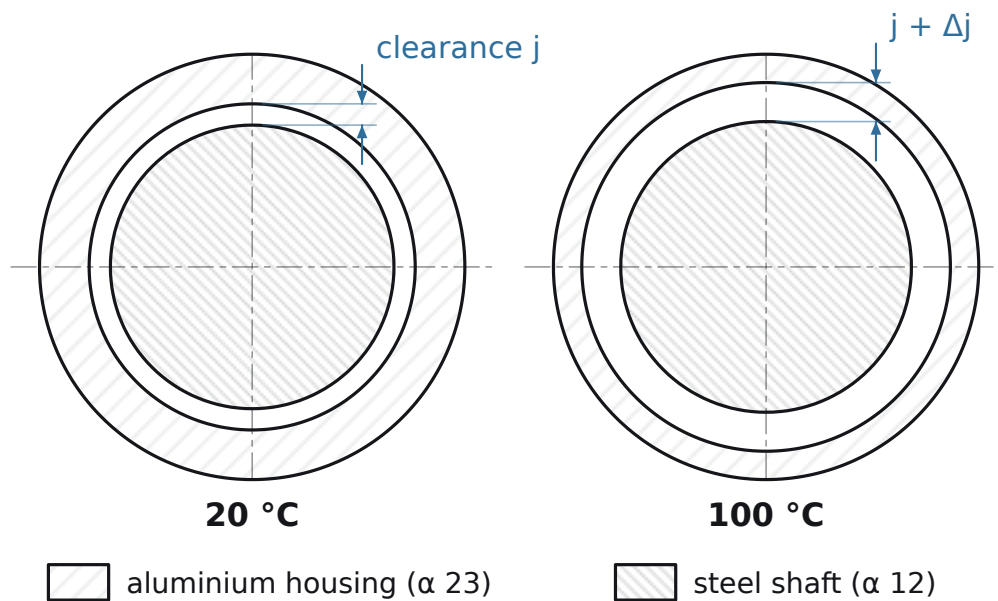
3. Restrained expansion: thermal stress



Stress in a part fixed at both ends, in the elastic range, for a 50 °C change. E : 210 GPa for steel (Eurocode 3), 200 GPa for austenitic stainless, 70 GPa for aluminium (Eurocode 9).

Material	E (GPa)	α (10^{-6} /K)	σ for $\Delta T = 50$ °C (MPa)	σ per degree (MPa/K)
Steel	210	12	126	2.52
Austenitic stainless	200	16	160	3.2
Aluminium	70	23	80.5	1.61

4. Clearances between two materials and shrink fits



Situation	Min clearance	Max clearance
At 20 °C (drawing values)	0.009	0.050
At 100 °C, aluminium housing, steel shaft	0.053	0.094
At 100 °C, steel housing, aluminium shaft	-0.035	0.006

Reference values taken from the article <https://www.baouch.fr/en/blog/dilatation-thermique-coefficient-materiaux/>, which explains the assumptions, formulas and edge cases. For critical use, check the current standard or the manufacturer's documentation. Free to print and share with credit to the source.