FCC-ee: Noble-liquid calorimeter
Themo-mechanic properties of the absorbers

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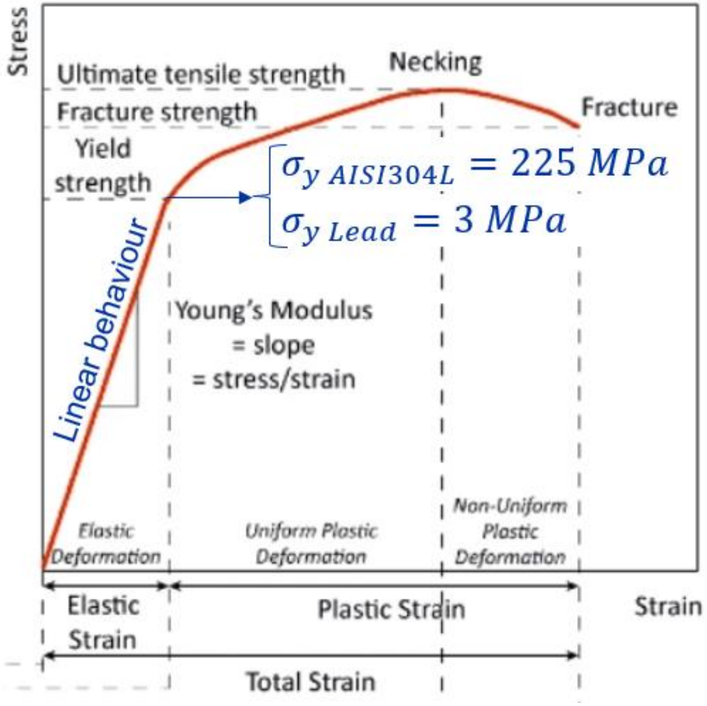
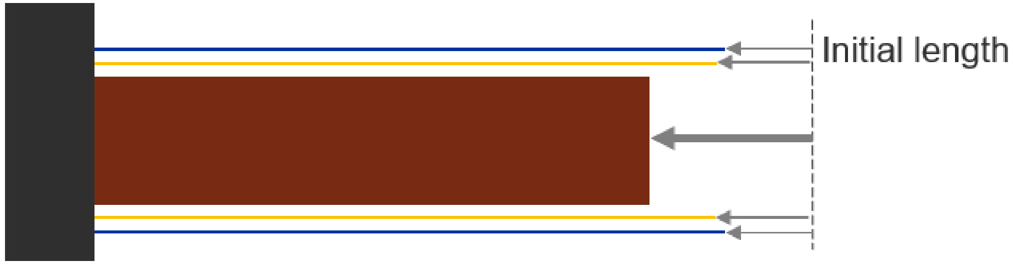


Mechanics of the cooling down of the absorbers

- The first image present the assembly with values of the thickness and thermal contraction from 300 K to 77 K.

- If each wouldn't be stick together, the contraction will be like the sketch below.

A material without constrains do not present stress when is cold down.



- But as they work together, according the laminate theory, should be a compromise between CTE and rigidity.

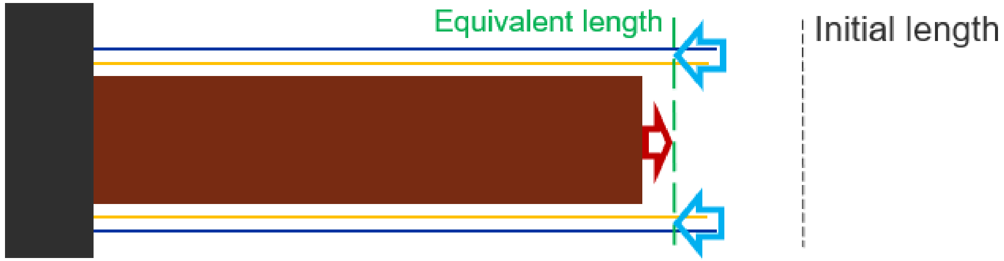
The equivalent Young modulus and CTE are proportional* to the Young modulus (E) multiplied by the thickness (t) of each layer

	Lead	SS304	FR4
E (GPa)	22.2	215.0	24.6
t (mm)	1.8	0.1	0.1
E·t	**40.0**	**21.5**	**2.5**
Contraction	**0.56%**	**0.30%**	**0.33%**

E eq = 32.0 GPa   Contraction eq = 0.46%

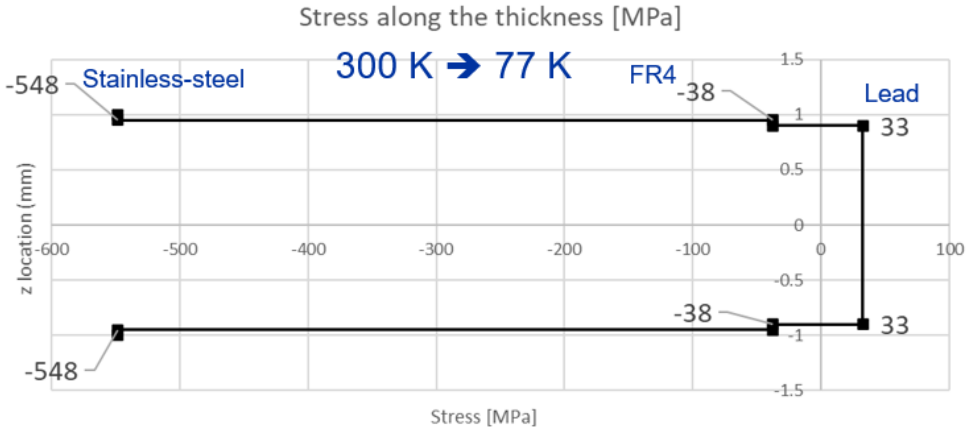
*As the Poisson's ratios of the materials are not the same, according laminate theory E = 32.5GPa and C = 0.48%

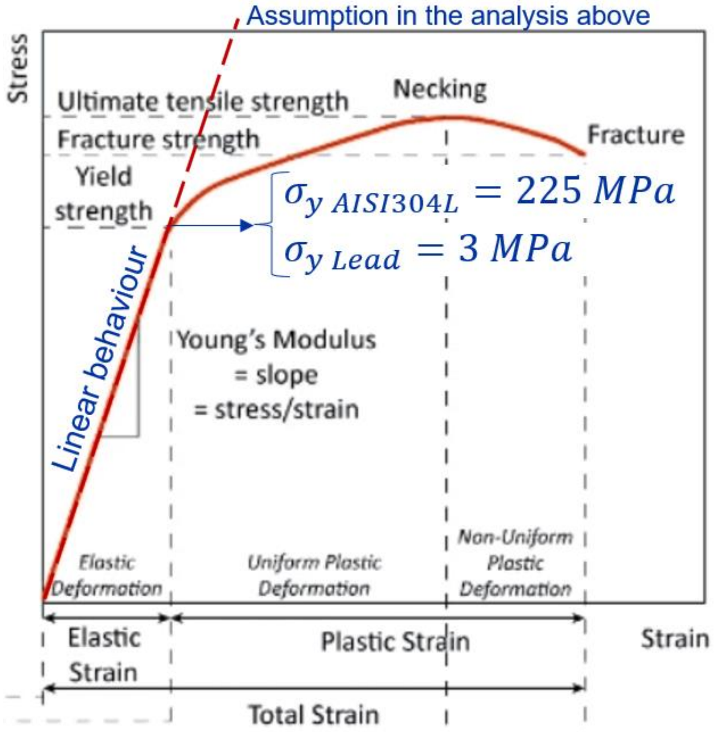
To reach the equivalent length the lead compress the lead and the stainless-steel and they pull the lead.



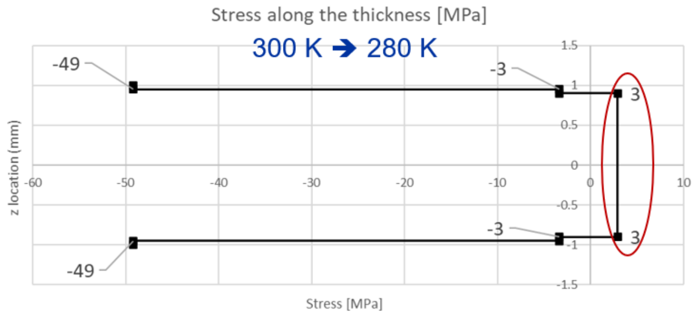
Stress in each layer at 77K

- To reach the equivalent length each layer is working in tension (+) or compression (-).
- The calculated stresses, using the linear approach, are very high in the stainless-steel (-548 MPa) and the lead (33MPa), reaching the yielding points (225 MPa and 3 MPa).





- For metallic materials, tension and compression behaviour is similar.
- The analysis above is considering always the linear behaviour.
- If one material reaches the yield point, E should be corrected.



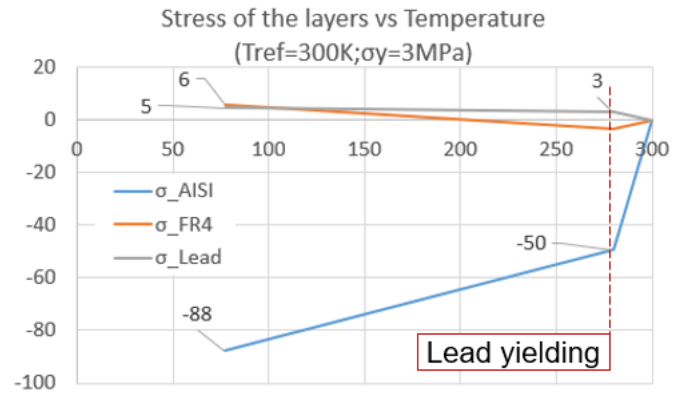
- Lead reach the point after only after a decrease of 20 degrees.
- The new E of the lead is 0.4 GPa instead of 22.2 GPa
- This changes the equivalent contraction of the assembly.

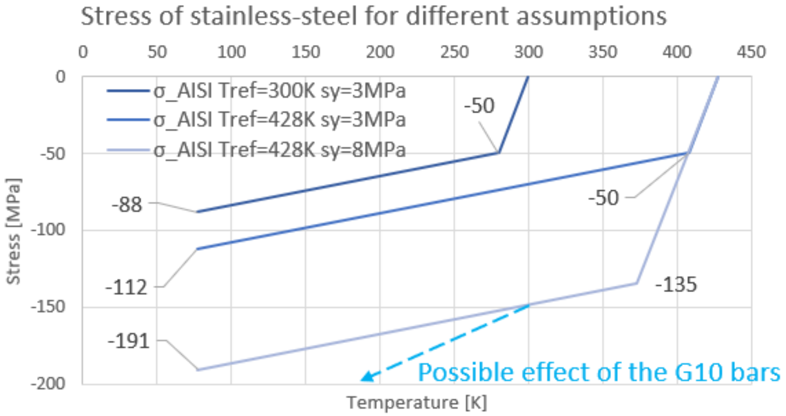
Mechanical properties during cooling down

- Mechanical properties of the assembly after plastic deformation of lead.
  - E equivalent is 60% less.
  - The contraction is almost the same as stainless-steel.
- The maximum compression stress in the stainless-steel is 88 MPa at 77 K. So, below the yield point.
- But if, instead 300 K, the reference temperature is taken in the moment the prepreg (FR4) is polymerised during the heated pressing(428 K), the temperature drop is bigger, being 112 MPa the stress in the steel.
- Yielding point of lead is different depending on the used literature. The higher it is, the higher will be the stress in the stainless-steel. For example, if it's 8 MPa, the stress of the stainless-steel at 77 K will be about 191 MPa.
- If the stress due to gravity and the different CTE of G10 bars is added, stainless-steel will reach its yield point in the last case.

	Lead	SS304	FR4
E (GPa)	0.4	215.0	24.6
t (mm)	1.8	0.1	0.1
E·t	**0.72**	**21.5**	**2.5**
Contraction	**0.56%**	**0.30%**	**0.33%**

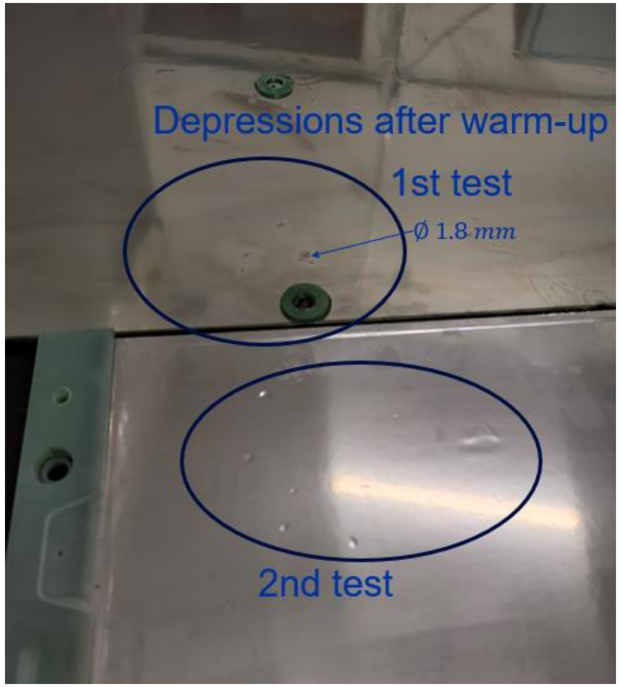
E eq = 12.3 GPa   Contraction eq = 0.31%

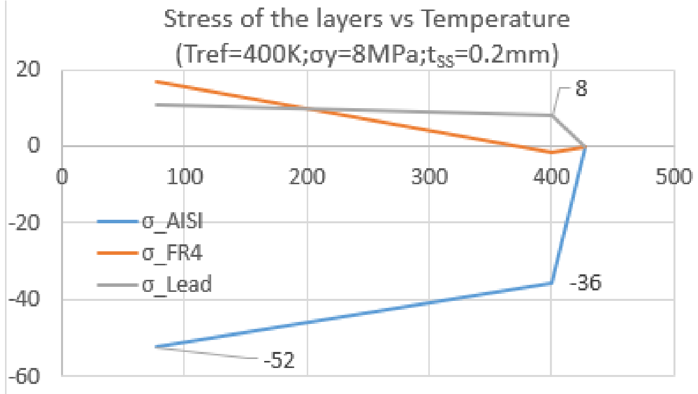




Conclusions

- The aim of the strength tests planned is to know the characteristics of the materials used and to know in which of the situations described the assembly fit.
- Yielding of the stainless steel can be the responsible of the depressions seen in the tests.
- It may will be necessary to use thicker stainless-steel sheets. If the thickness is 0.2 mm, the maximum stress in the worst-case scenario is -52 MPa instead of -191 MPa.
- Which would be the ideal combination of lead and steel to achieve the desired X_0 is thicker sheets of steel are needed?
- Once all the assembly of the sample for the tests is done and no problems are seen tests using thicker steel will be planned.
- The material was received. Assembly will be done the week 6.





Lead plates for the samples

home.cern

Backup 1: Stress-strain curve of lead

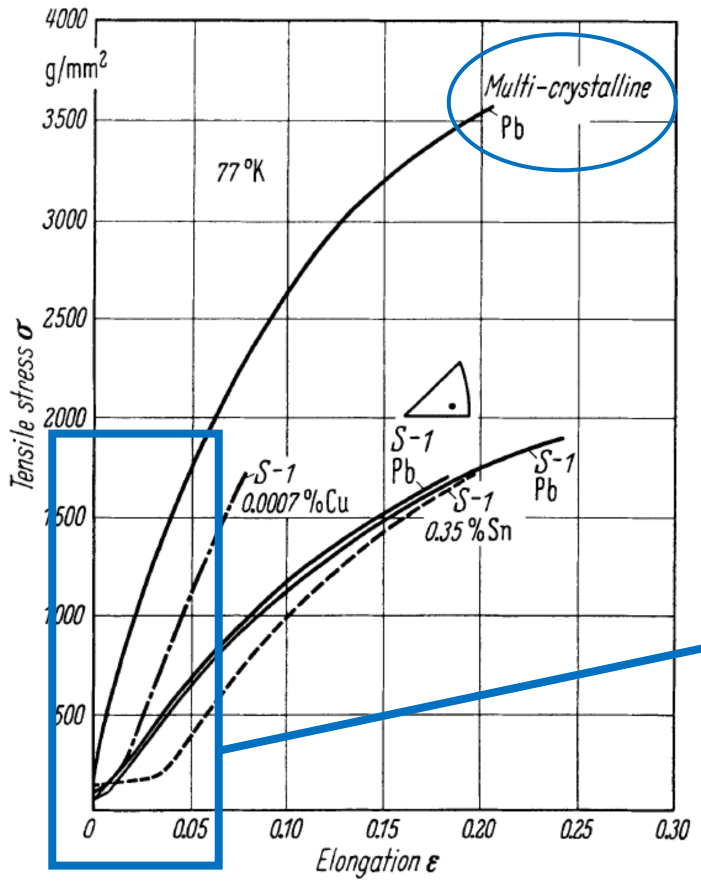
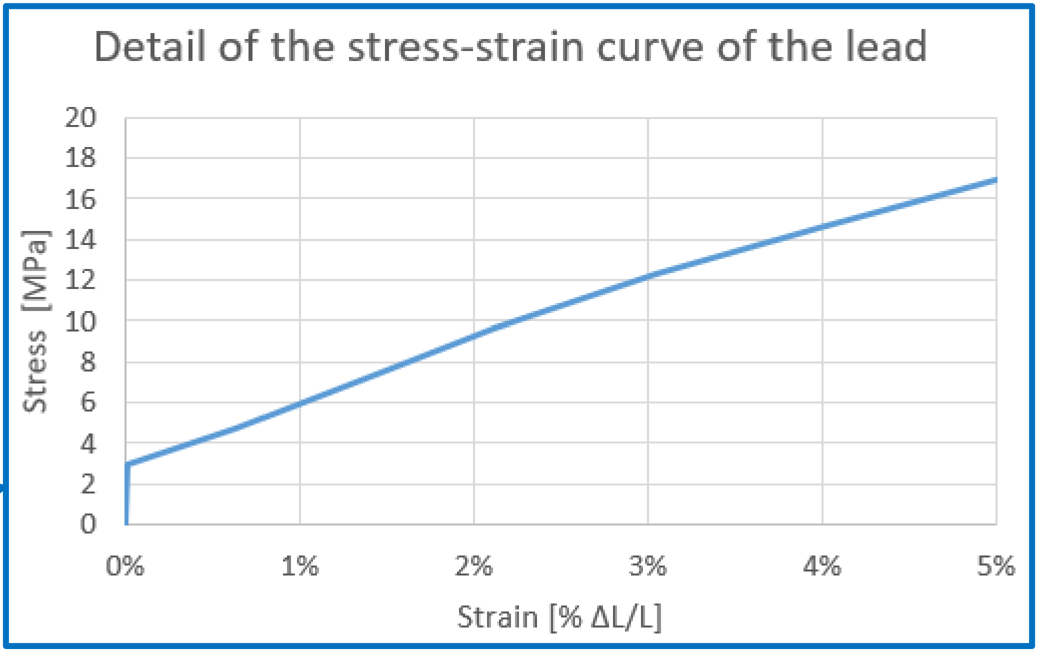


Fig. 193. Strain hardening curves of crystals of very pure lead and of lead with additions of tin and copper at 77 °K. (According to FLEISCHER).

Multi-crystalline Pb



Backup 2: Press cycle of the assembly

Lead-free , Halogen-free Material

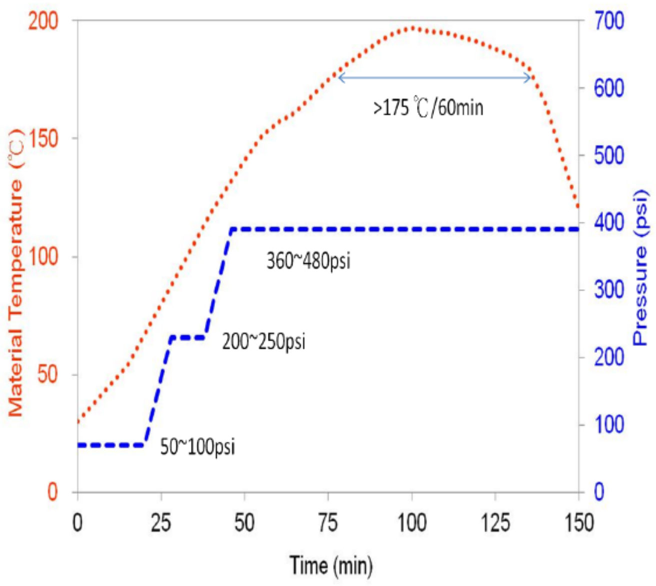
EM-370(5) / EM-37B(5)

Basic Laminate Property

Item	IPC-TM-650	Test condition	Unit	Typical Value
Glass transition temp.	2.4.25	DSC	℃	155

Press Cycle

Basic press cycle for normal construction of multilayer PWB:



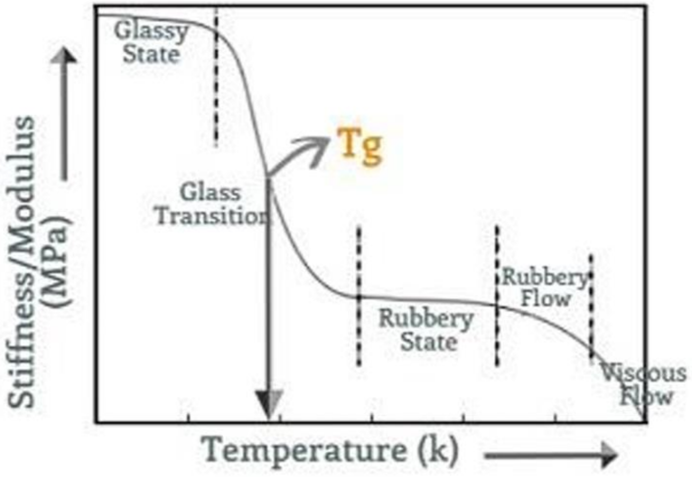
Kiss pressure: 50~100psi(3.5~7kgf/cm²)

Middle pressure:200~250psi(14~18kgf/cm²)
Apply at 70~90°C
Heating rate:1.6~2.5°C/min(70~100°C)

Full pressure:360~480psi(25~34kgf/cm²)
Apply at 105~125°C
Heating rate:1.6~2.5°C/min(100~130°C)

Curing condition: >175°C / 60mins

Peak temperature of material should be preferable achieved at 195°C



https://omnexus.specialchem.com/polymer-properties/properties/glass-transition-temperature

Backup 3: Local buckling

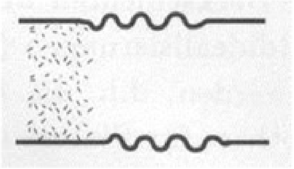
https://www.researchgate.net/publication/267416029_Failure_maps_of_sandwich_panels_with_soft_core

Ep	1349	MPa
Ec	306	MPa
vc	0.44	
Gc	106	MPa
ks	0.794	
sig_CR	280	MPa

Ep	1349	MPa
Ec	306	MPa
vc	0.44	
Gc	106	MPa
ks	0.5	
sig_CR	176	MPa

Wrinkling (1)

Preliminary Assumptions:
- Uni-axial Compression
- Symmetric Lay-Up
- Isotropic Material Behavior



$$\sigma^*_k = k_S . (E_f . E_c . G_c)^{1/3}$$

k_s: Parameter in dependence on the initial imperfection

The lower limit value of $k_s = 0.5$ is assumed for dimensioning.

Sandwich Structures - ETH Zürich STA_ETH_V1/ 117

$$\frac{\sigma_i^w}{f_{swi}} > 1, \quad f_{swi} = 0.794 \cdot E_f^{1/3} \cdot E_C^{1/3} \cdot G_C^{1/3}, \qquad (5)$$

where σ_i^w is wrinkling (compression) stress in the span or at the support, and f_{swi} is defined according to the work of Zenkerts' (1995).

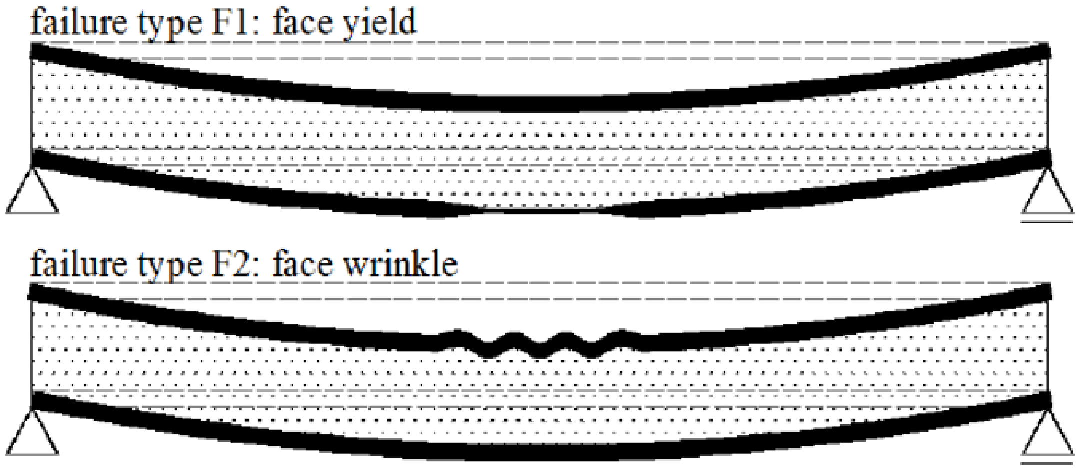


Fig 3. Failure modes in facing.