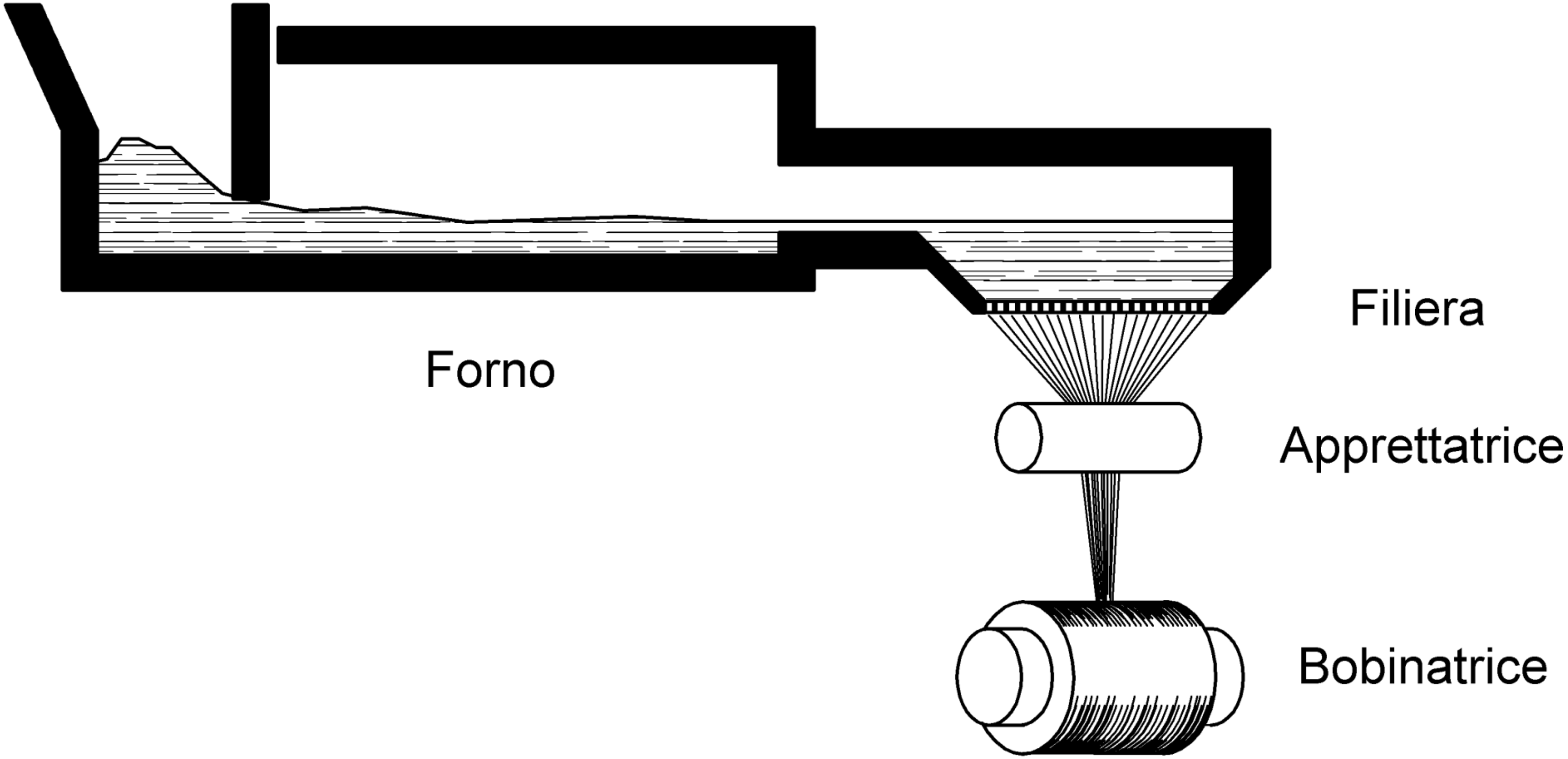
COSTRUZIONI NAVALI II

(materiali compositi: rinforzi - sandwich)

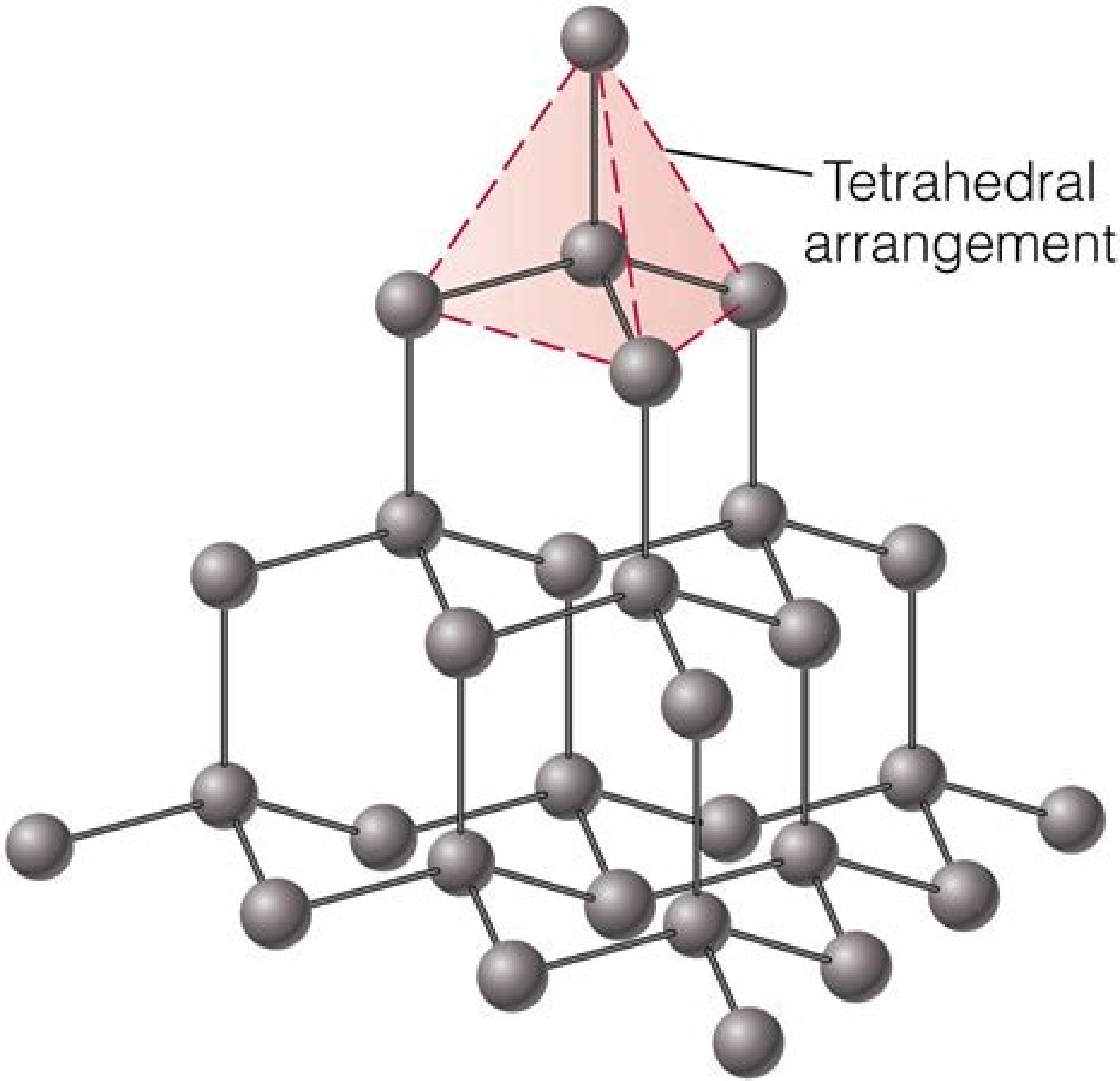
Confronto fra diversi tipi di fibra

TIPO DI FIBRA	ρ [g/cm^3]	E [GPa]	σ_R [MPa]	ε_R [%]
Vetro E	2.55	72	2400	3.0
Vetro S2	2.50	88	3400	3.5
Carbonio SM (Toray, T300)	1.76	230	3530	1.5
Carbonio IM (Toray, T1000G)	1.80	294	6370	2.2
Carbonio HM (Toray, M40)	1.77	377	4410	1.2
Carbonio UHM (Toray, M60J)	1.94	588	3920	0.7
Kevlar 49	1.45	125	2800	2.8

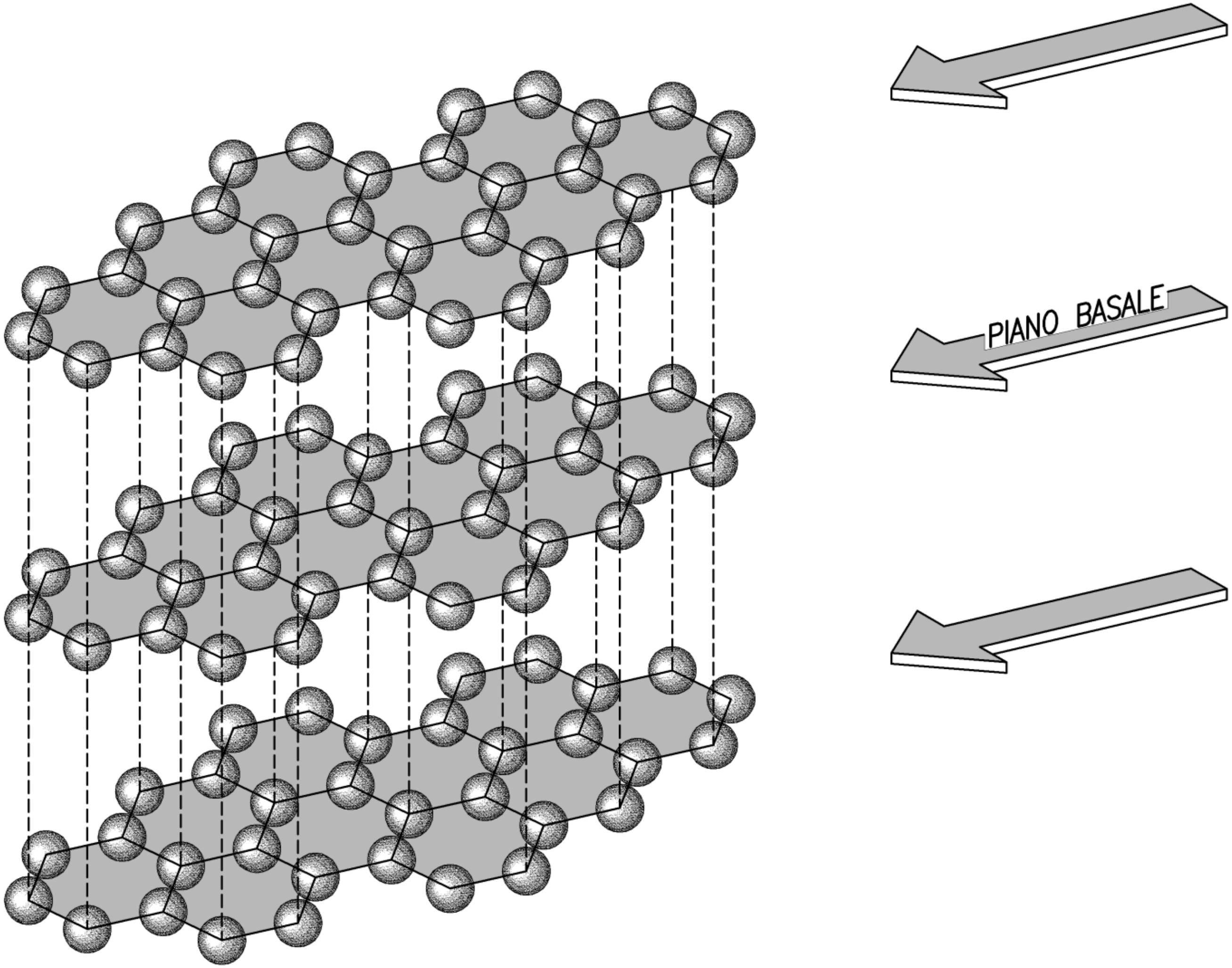
Il processo di produzione delle fibre di vetro



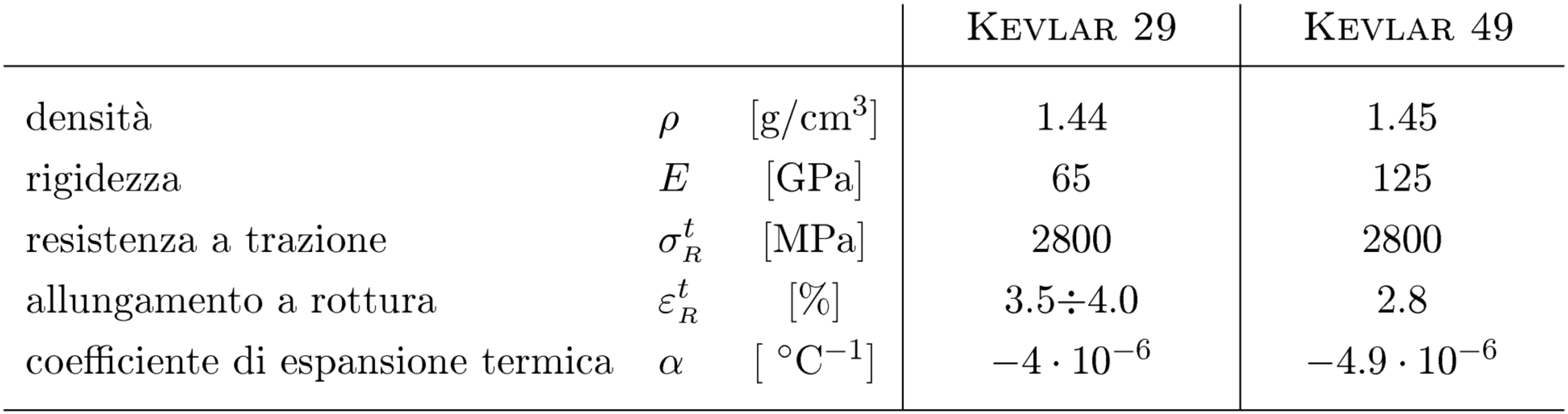
Struttura allotropica del diamante



Cristalliti di grafite

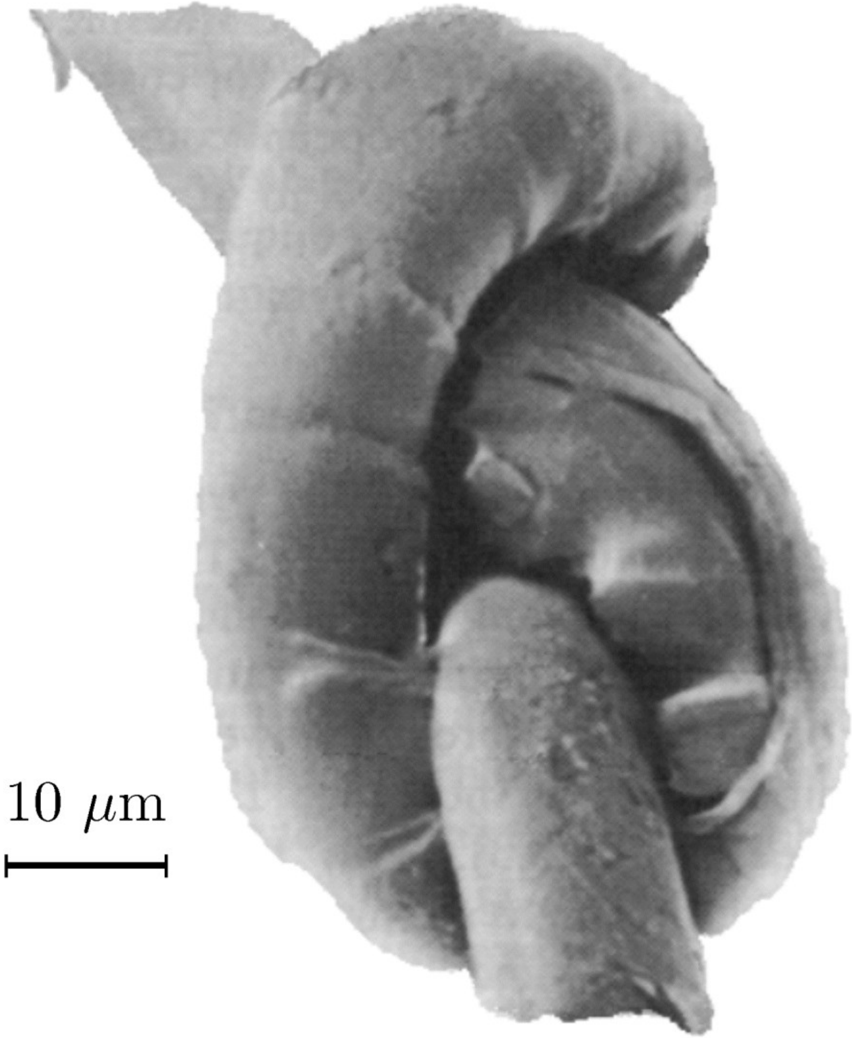


Confronto fra kevlar 29 e kevlar 49

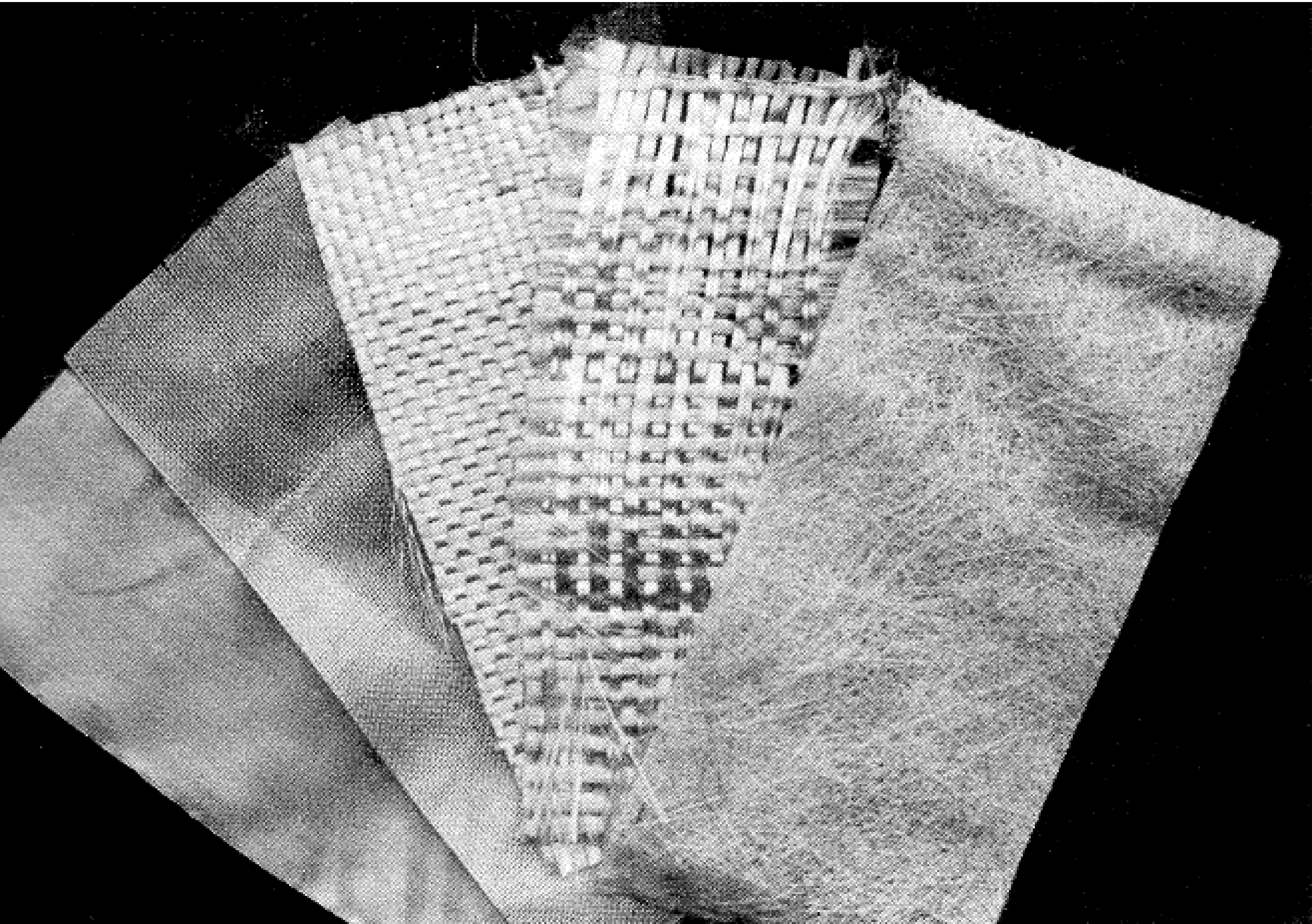


			KEVLAR 29	KEVLAR 49
densità	ρ	[g/cm^3]	1.44	1.45
rigidezza	E	[GPa]	65	125
resistenza a trazione	σ_R^t	[MPa]	2800	2800
allungamento a rottura	ε_R^t	[%]	3.5÷4.0	2.8
coefficiente di espansione termica	α	[°C^{-1}]	$-4 \cdot 10^{-6}$	$-4.9 \cdot 10^{-6}$

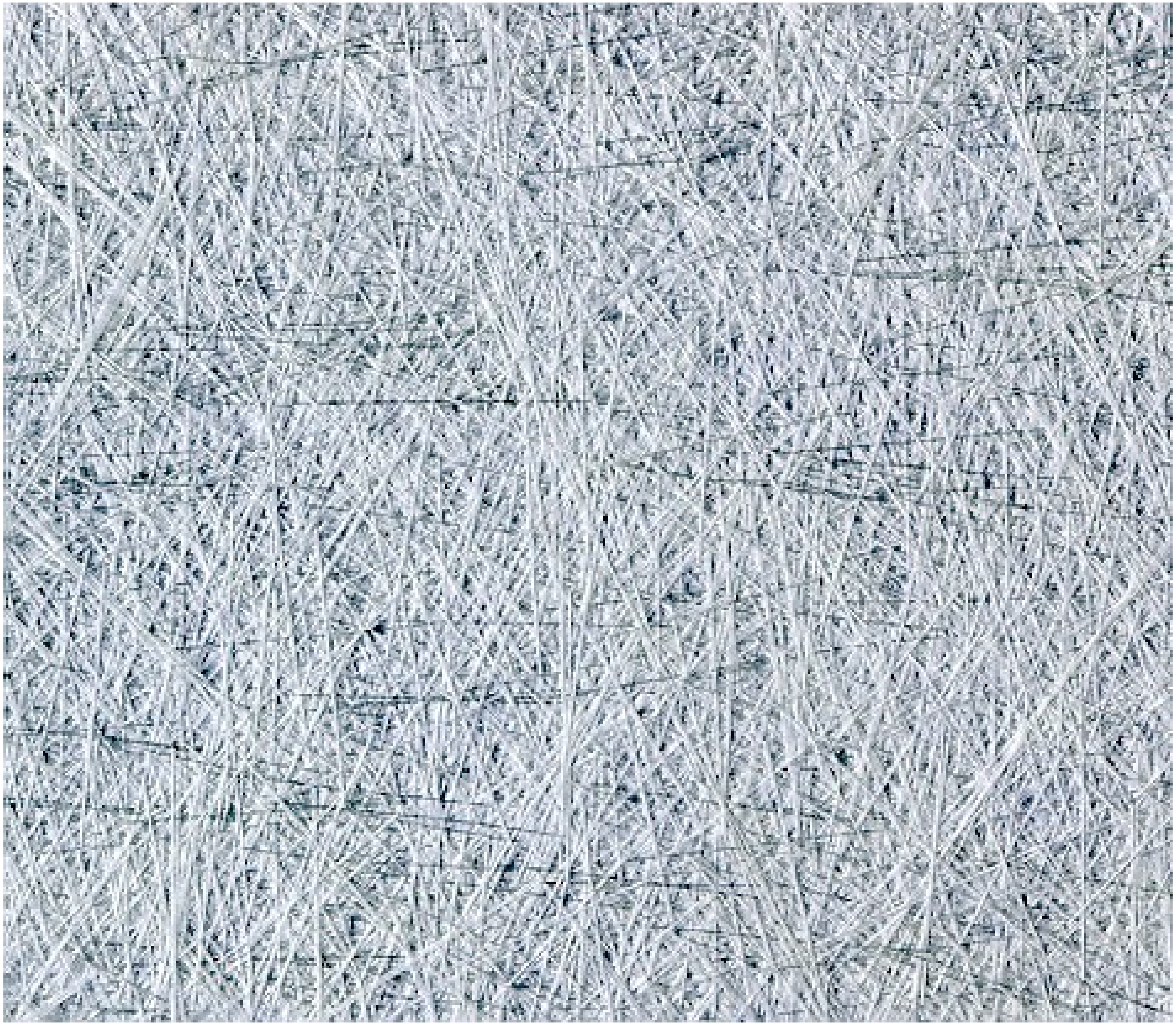
Cedimento per flessione (nelle parti compresse) di una fibra aramidica



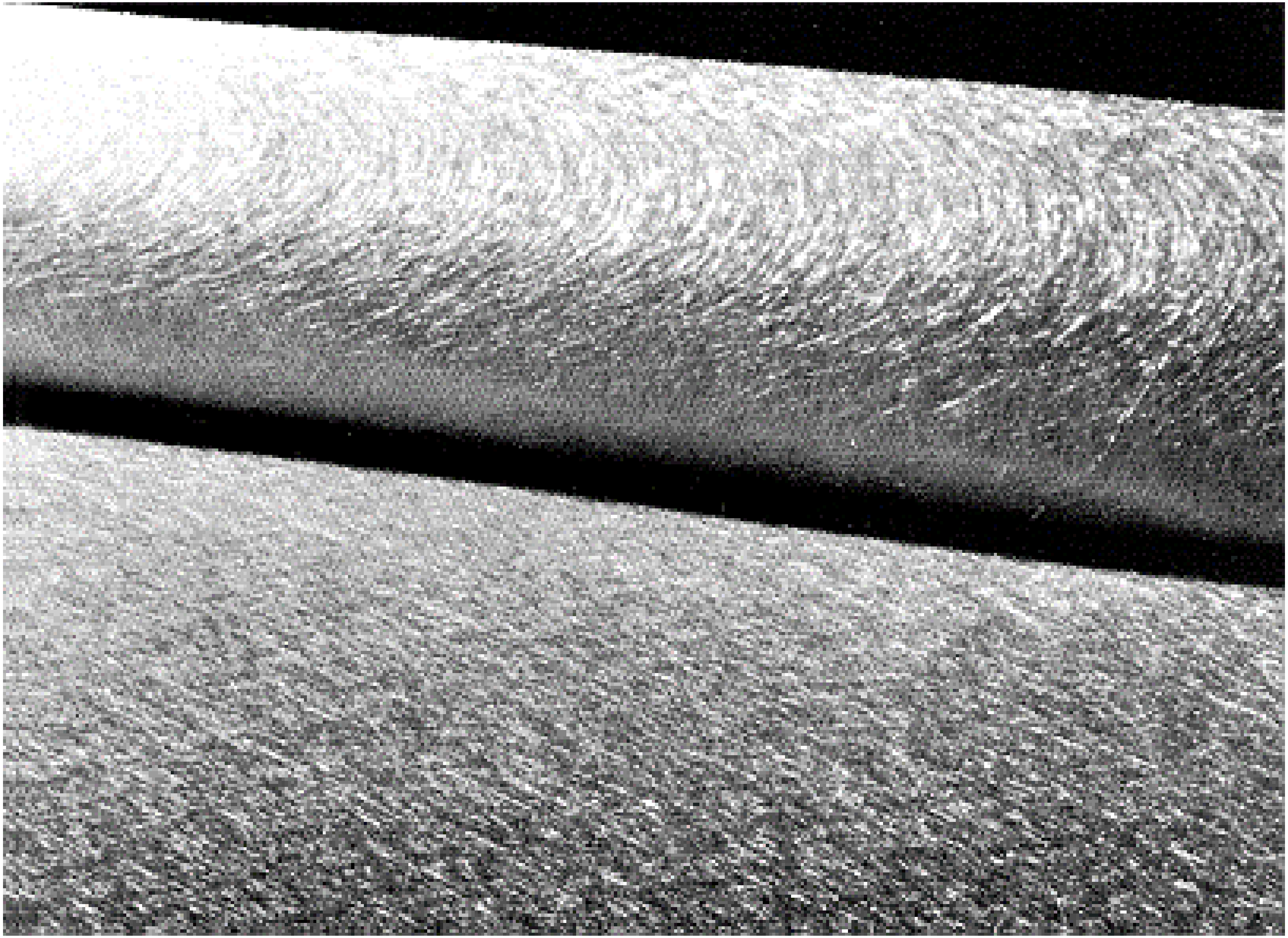
Tipici rinforzi in fibra di vetro



Mat a fili tagliati

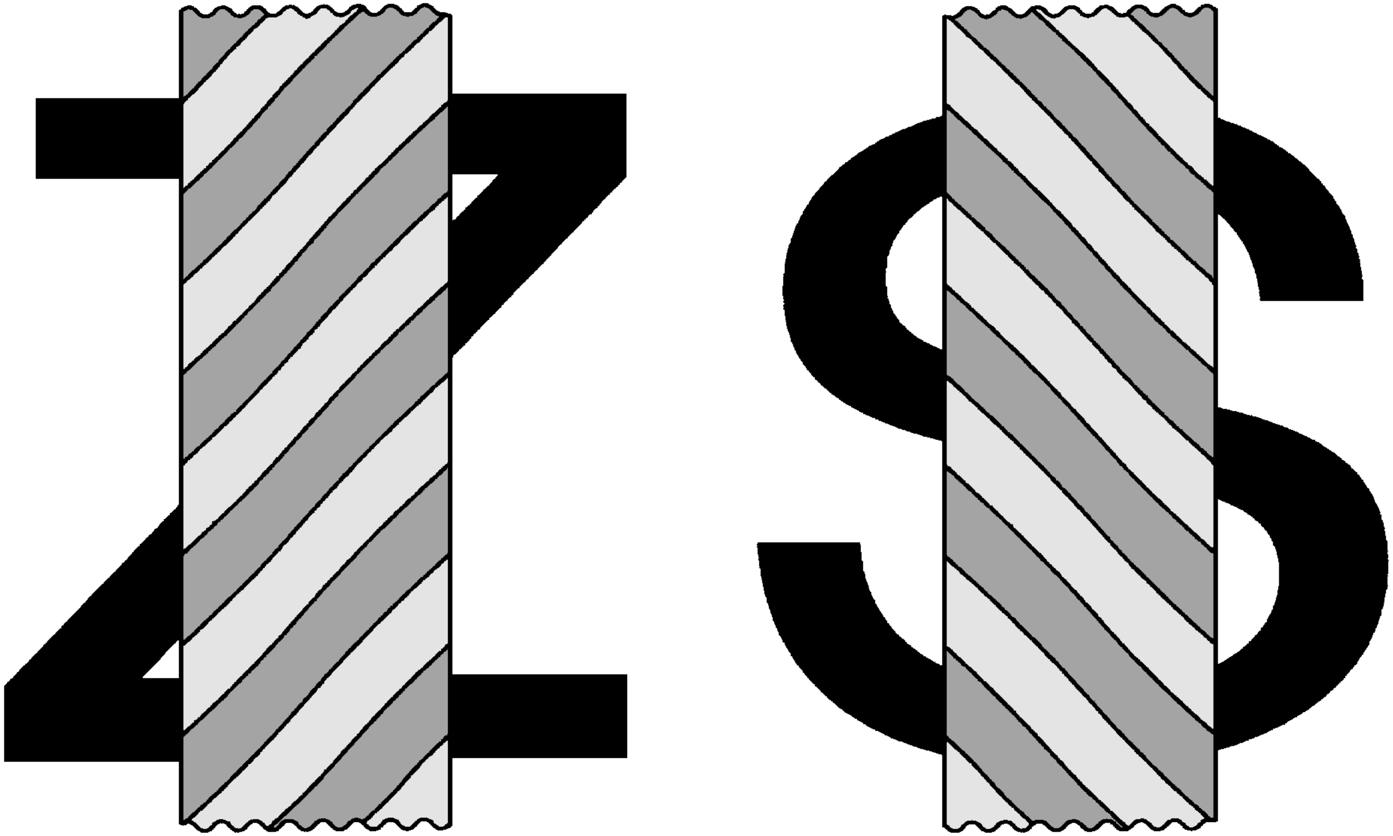


Mat a fili continui

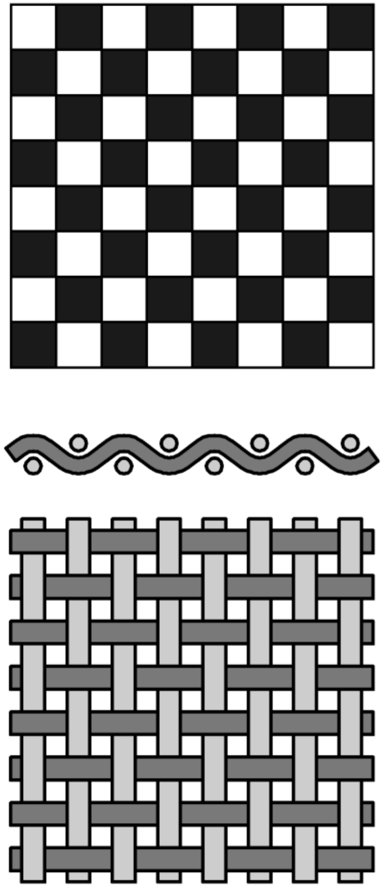


Bobine di roving

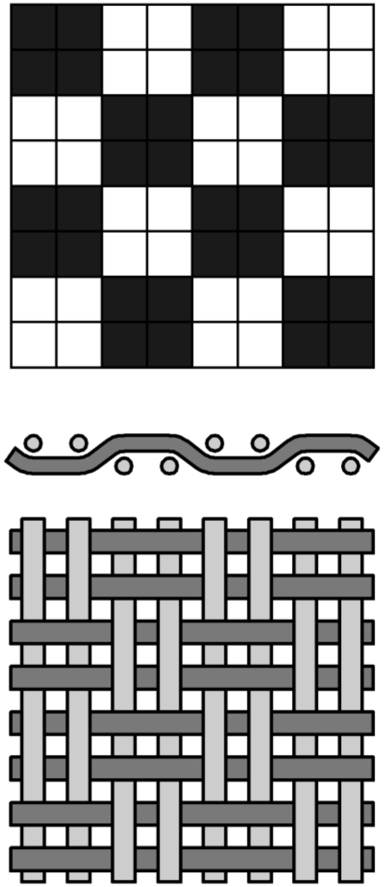
Modalità di torcitura a Z ed a S



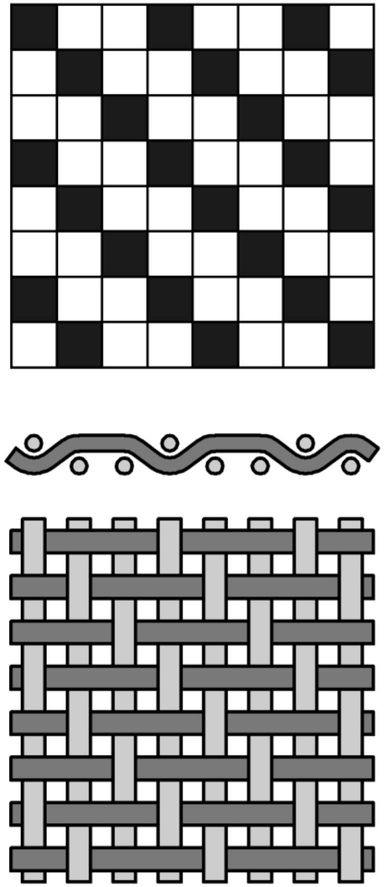
Tipi di armature tessili



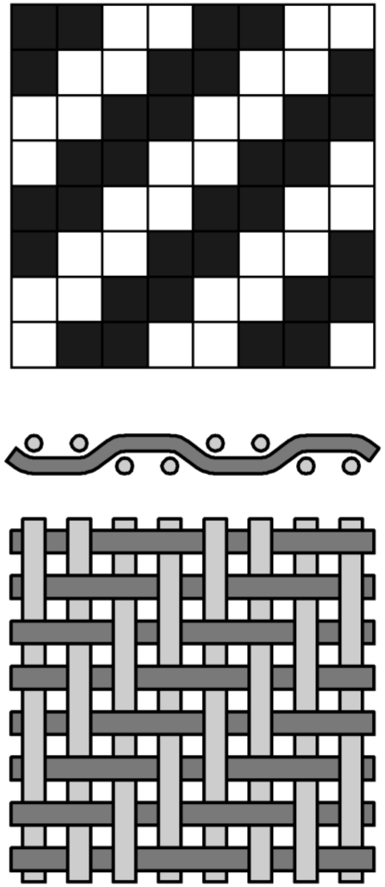
Armatura tela
Plain



Armatura panama
2x2 Basket

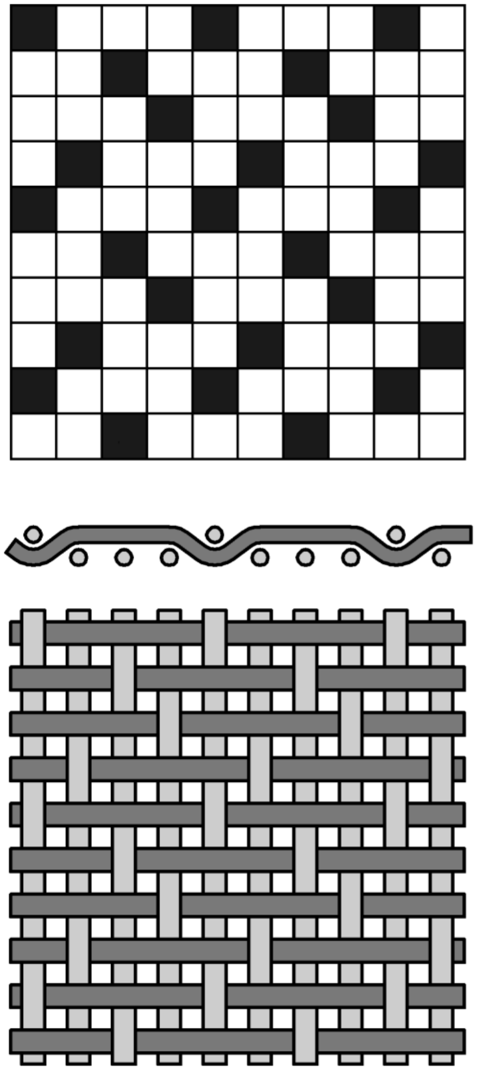


Armatura diagonale
2/1 Twill



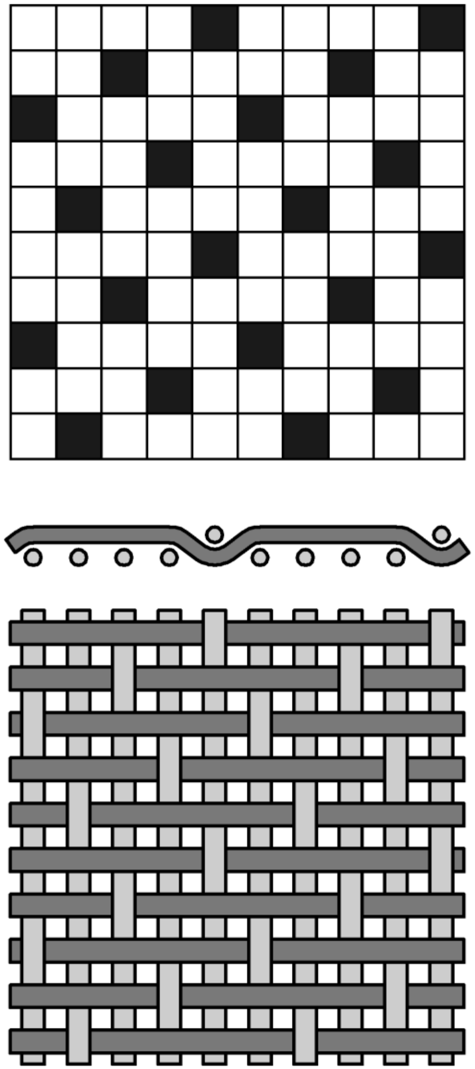
Armatura diagonale
2/2 Twill

Tipi di armature tessili 2/2



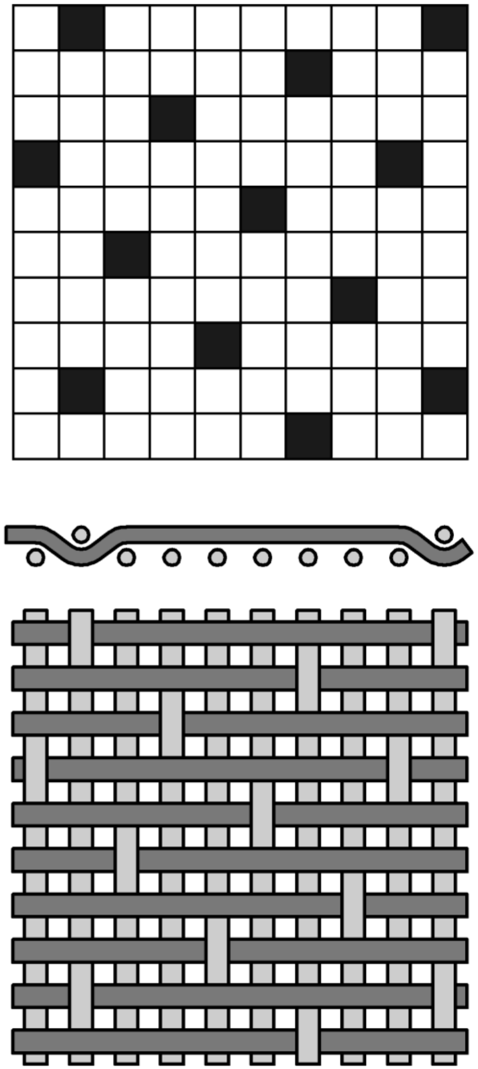
Armatura raso

4–Harness Satin (Crowfoot)



Armatura raso

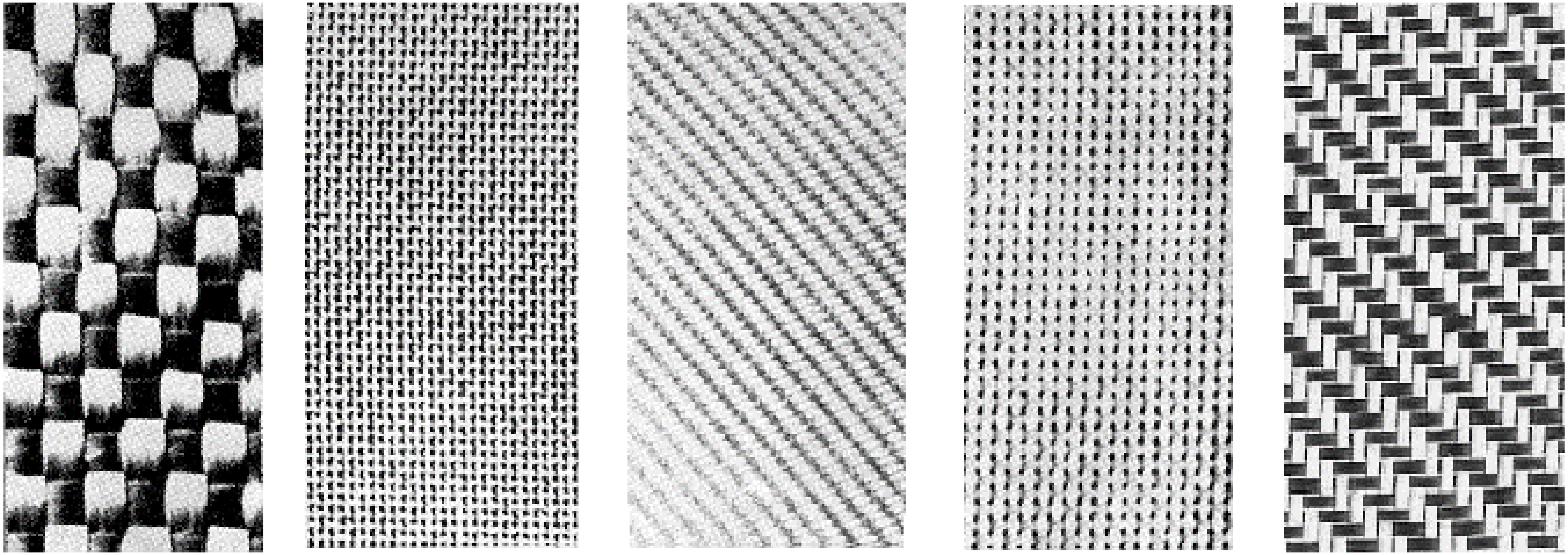
5–Harness Satin



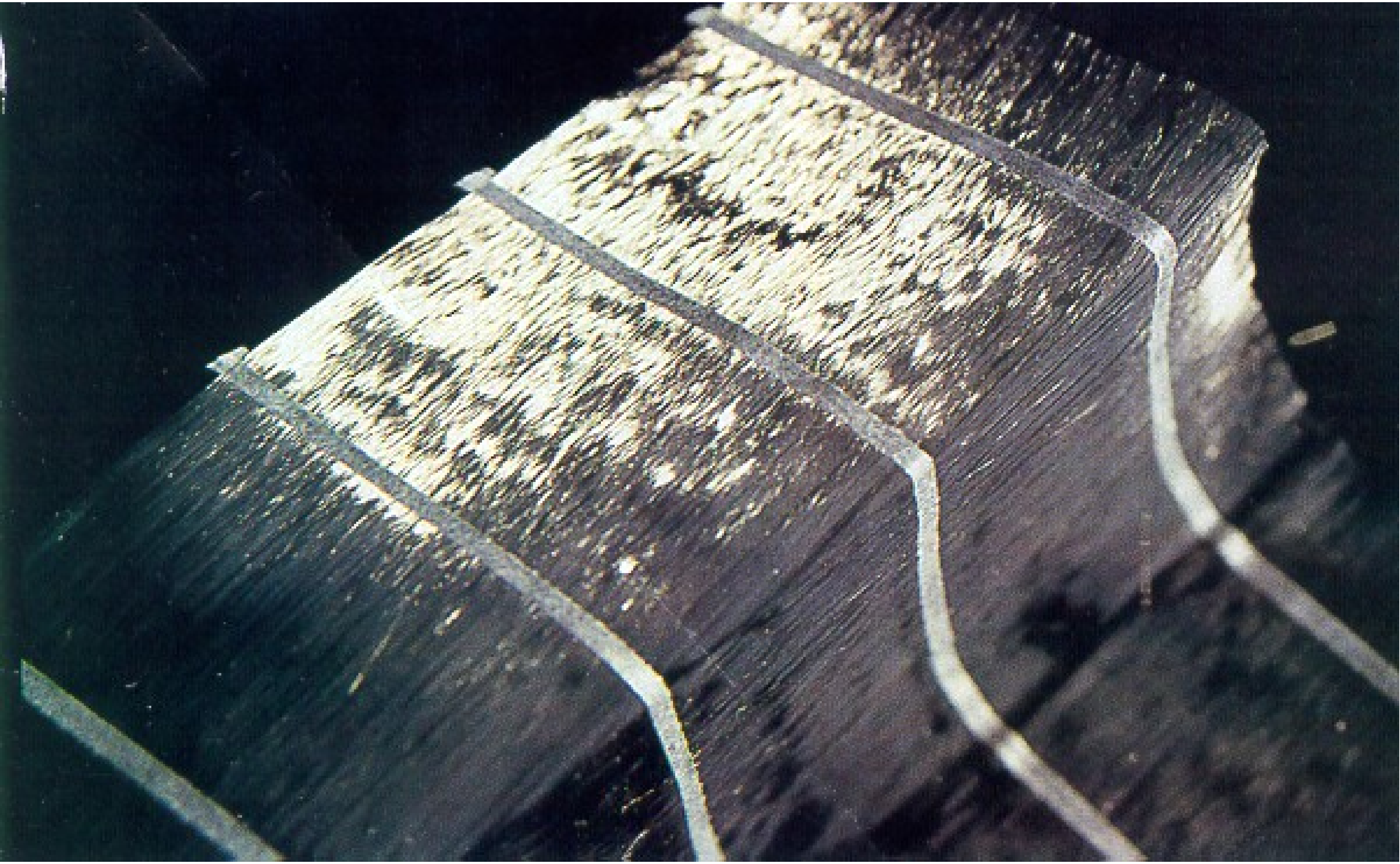
Armatura raso

8–Harness Satin

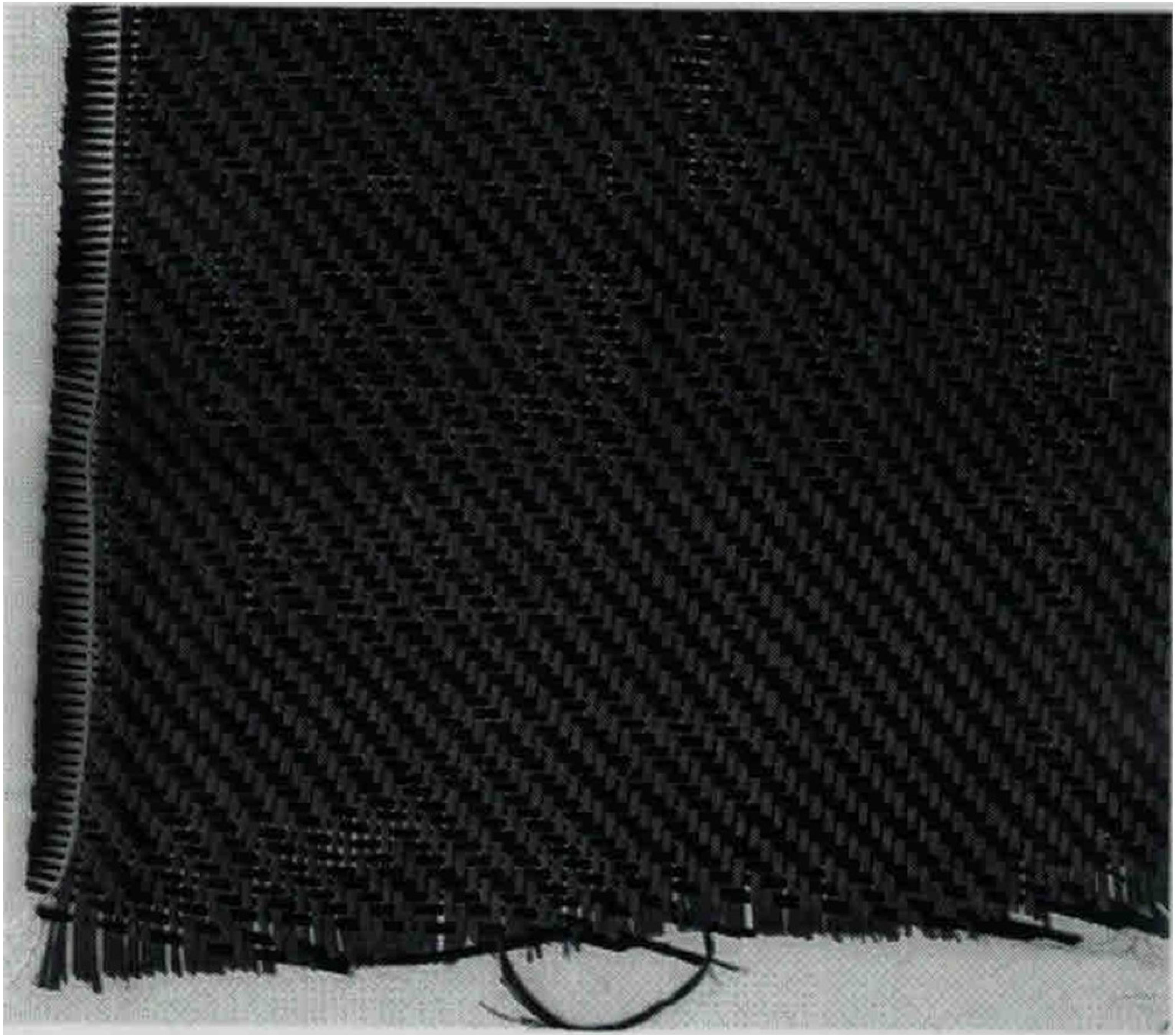
Differenti tipi di stuoie



Unidirezionale in fibre di carbonio

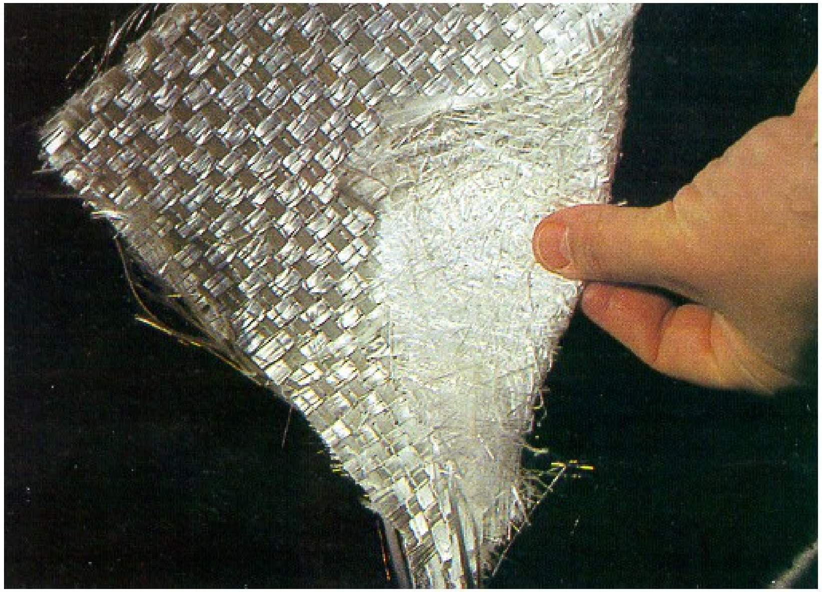


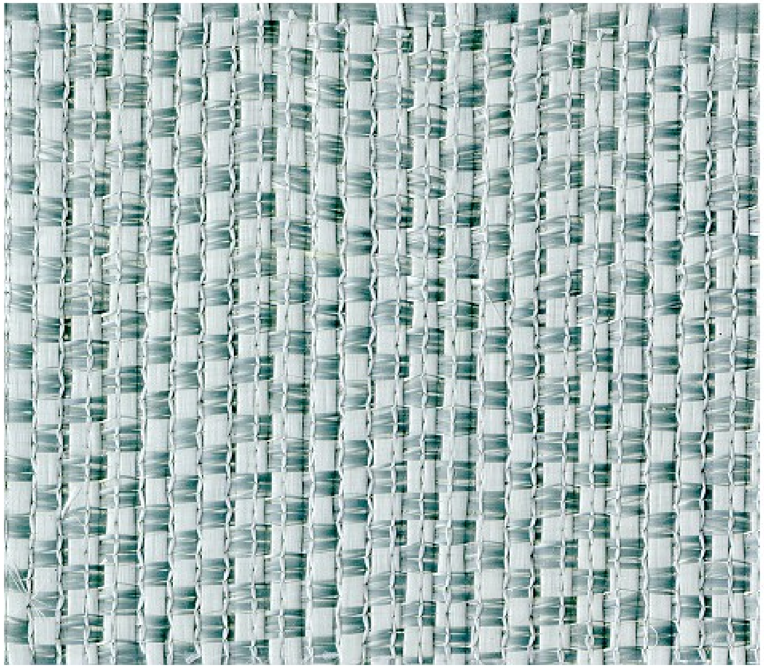
Stuoia in carbonio



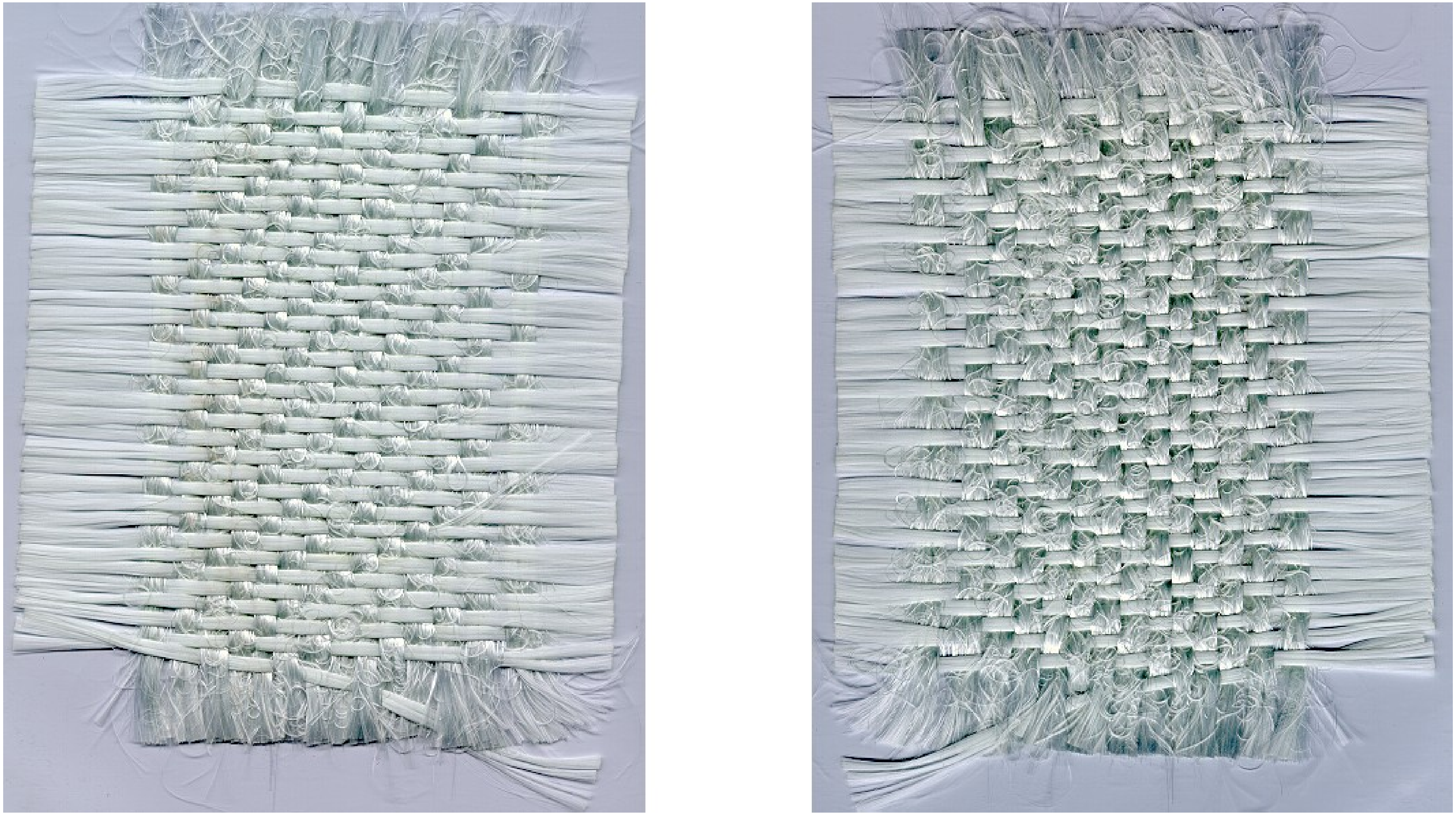
ARAMAT: lato stuoia e lato mat

ROVIMAT

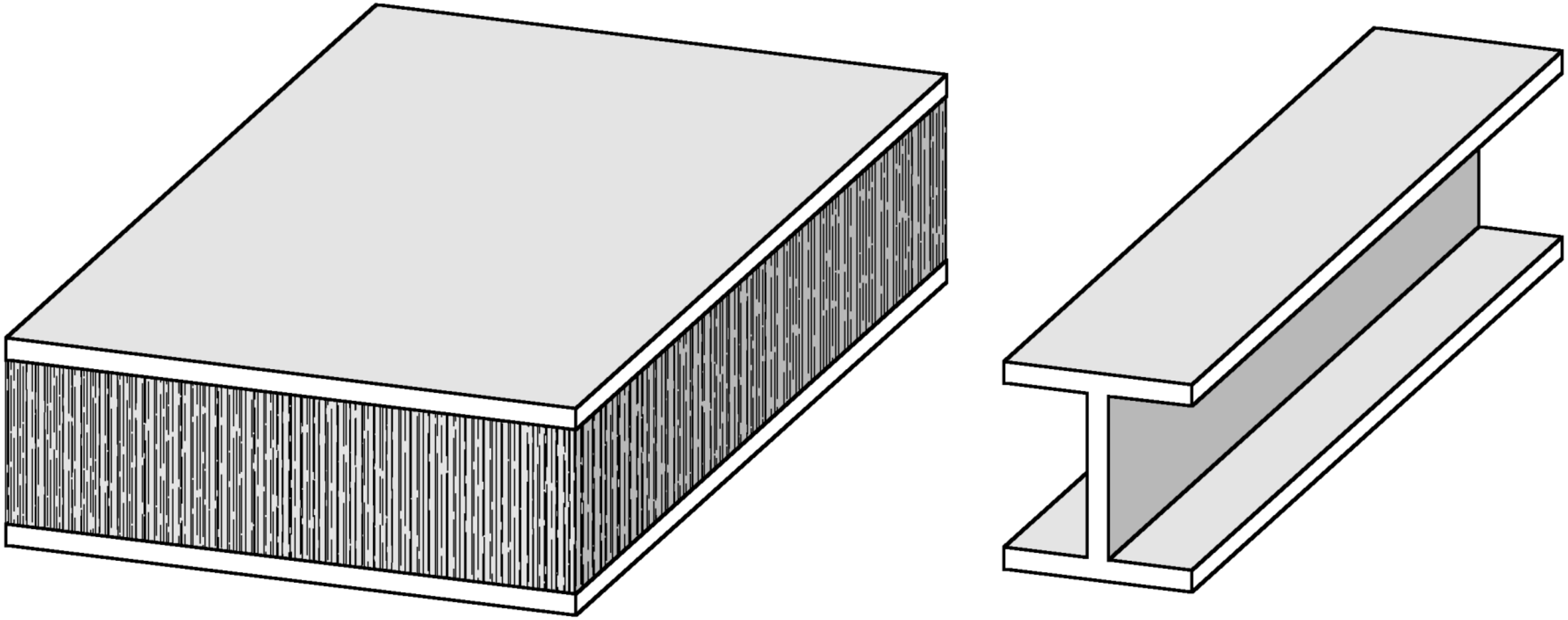




Double Face

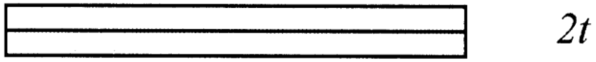


Analogia fra sandwich e putrella



Stiffness to weight ratio of sandwich versus single skin plates

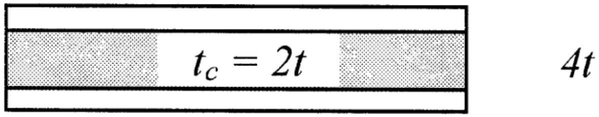
Face thickness = t and $Mass_{face} = 25\ Mass_{core}$



$$I_1 = \frac{1}{12}(2t)^3 = \frac{2}{3}t^3$$

Relative bending stiffness = 1

$$Mass_1 = 2\,Mass_{face}$$

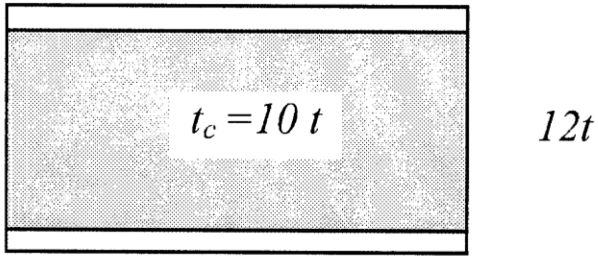


$$I_2 = 2\left(\frac{3}{2}t\right)^2 t + 2\frac{1}{12}t^3 = \frac{14}{3}t^3 = 7I_1$$

$$Mass_2 = 2\,Mass_{face} + \frac{2}{25}Mass_{face} = 1.04\,Mass_1$$

Relative bending stiffness = 6.73

$$\frac{I_2}{Mass_2} = 6.73\frac{I_1}{Mass_1}$$



$$I_3 = 2\left(\frac{11}{2}t\right)^2 t + 2\frac{1}{12}t^3 = \frac{182}{3}t^3 = 91I_1$$

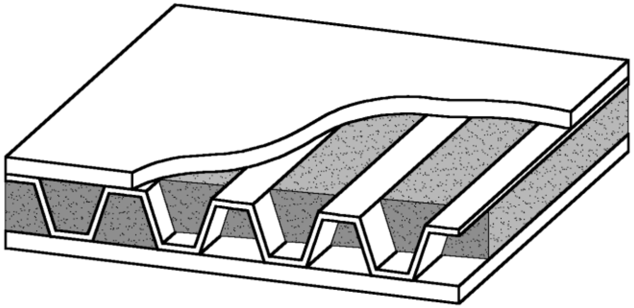
$$Mass_3 = 2\,Mass_{face} + \frac{10}{25}Mass_{face} = 1.2\,Mass_1$$

Relative bending stiffness = 75.8

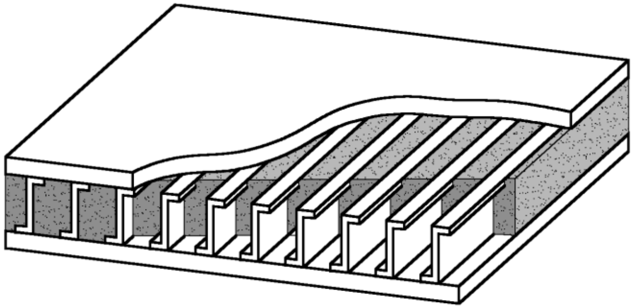
$$\frac{I_3}{Mass_3} = 75.8\frac{I_1}{Mass_1}$$

Bending stiffness to weight ratios for sandwich and single skin cross sections

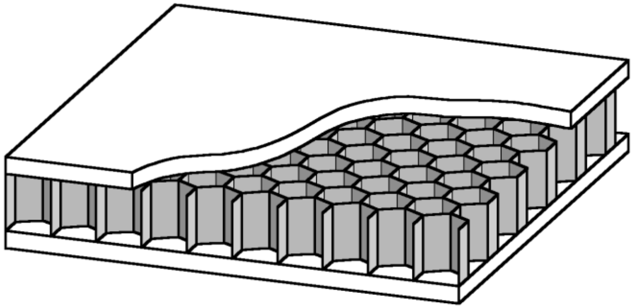
Differenti tipologie di anima per strutture a sandwich



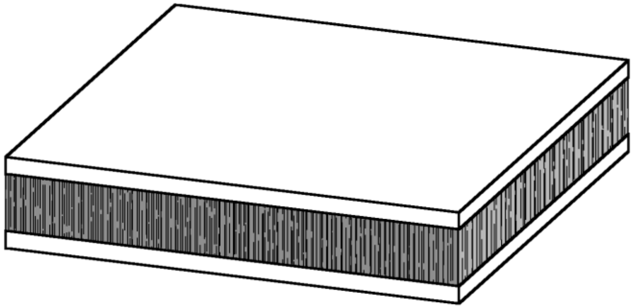
anima corrugata



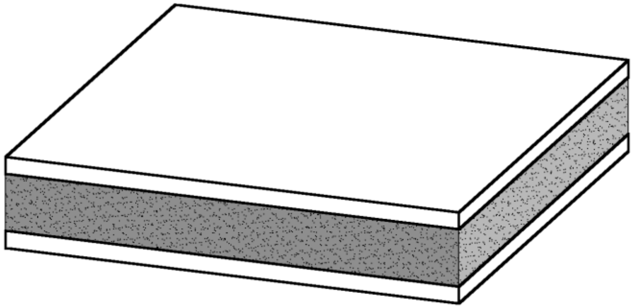
anima a setti verticali



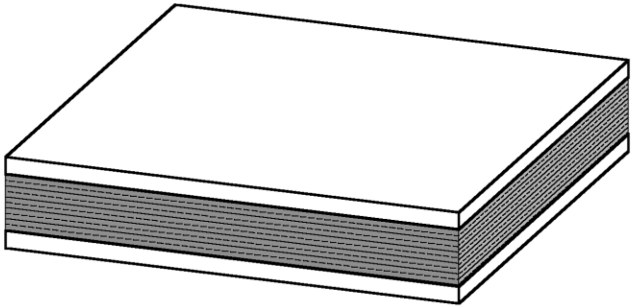
anima a nido d'ape



anima in legno di balsa



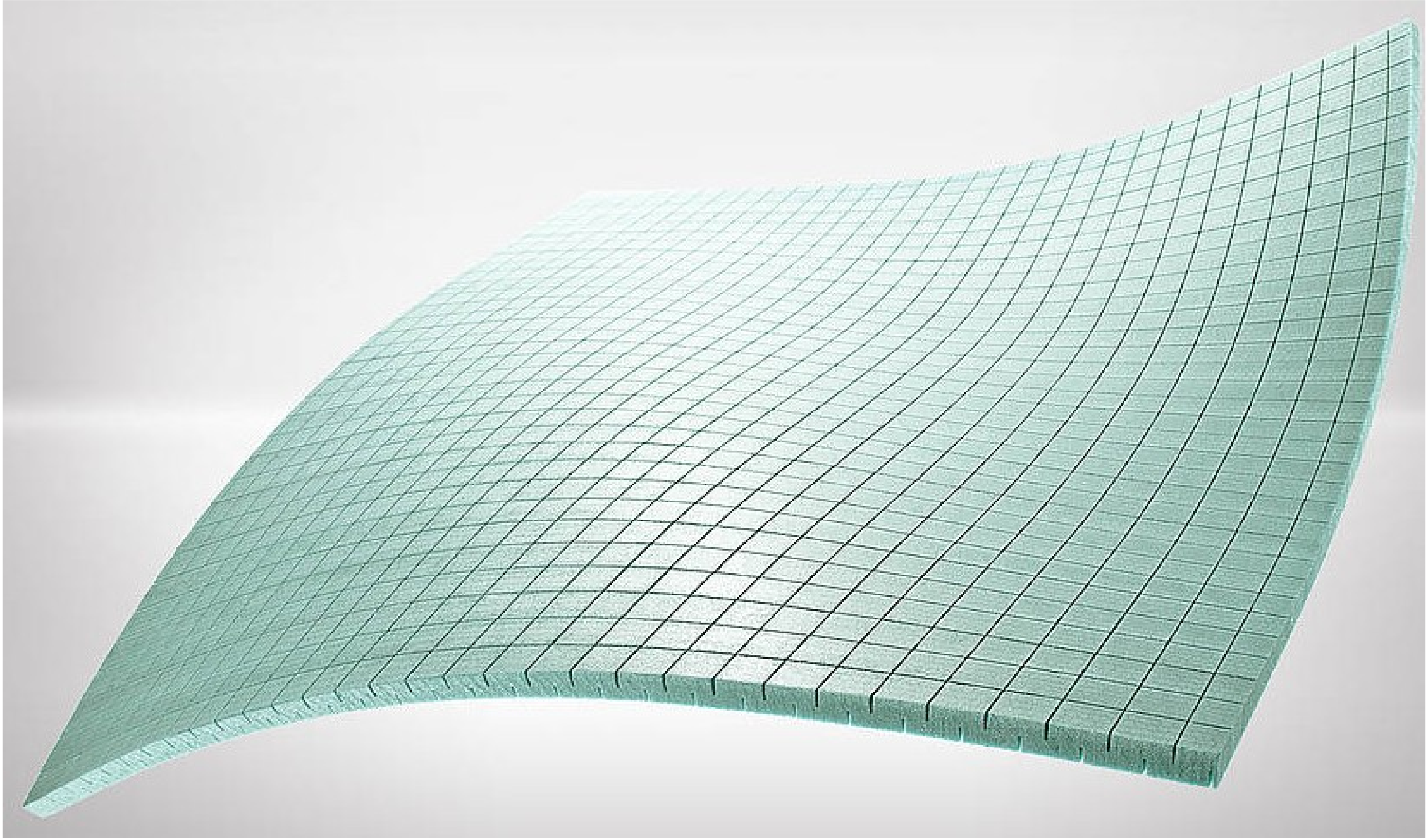
anima in espanso



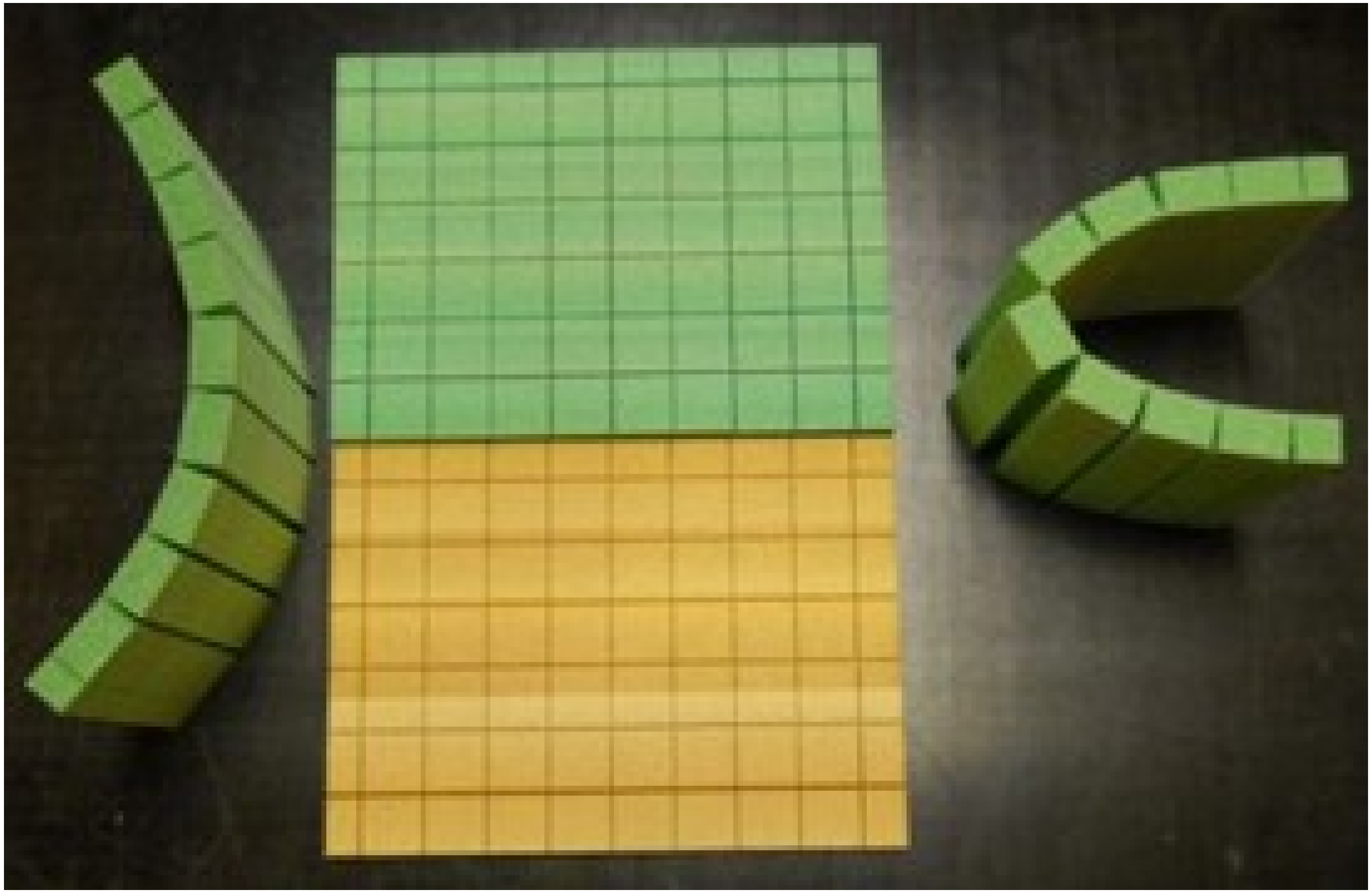
anima in legno compensato

CL-PVC foam (AIREX-C70)

PVC foam

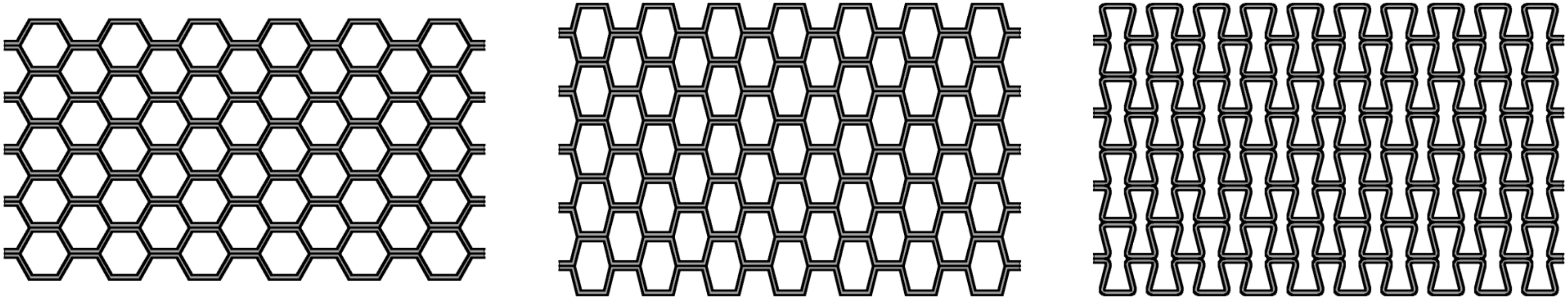


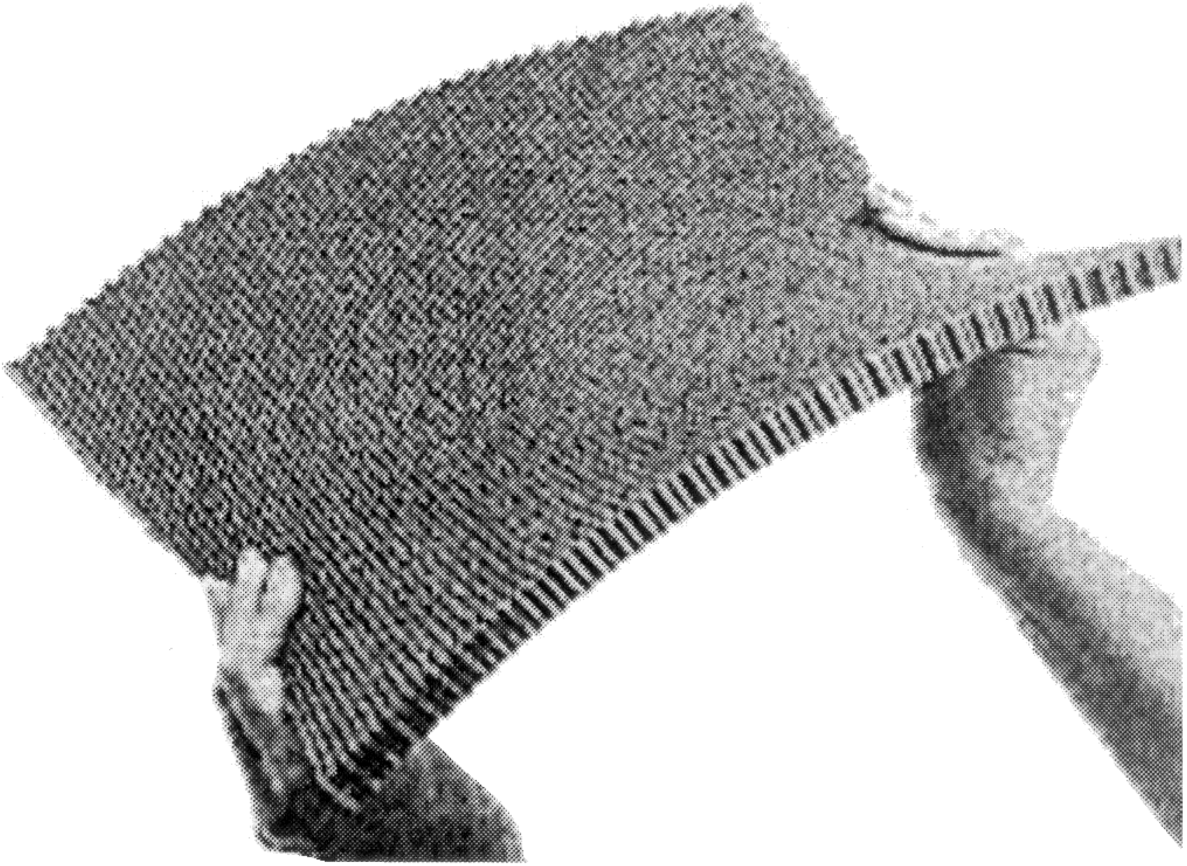
PVC foam



L-PVC foam (AIREX-R63)

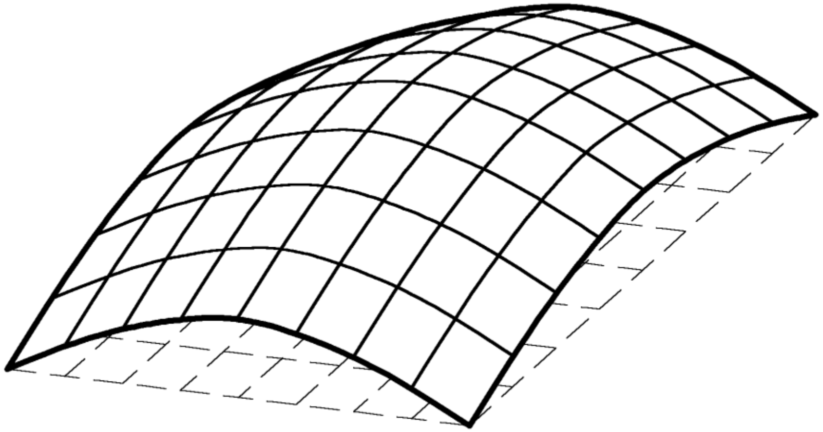
Possibili configurazioni delle celle:
esagonale (sinistra), ultraespansa (centro), con coefficiente di Poisson negativo (destra)



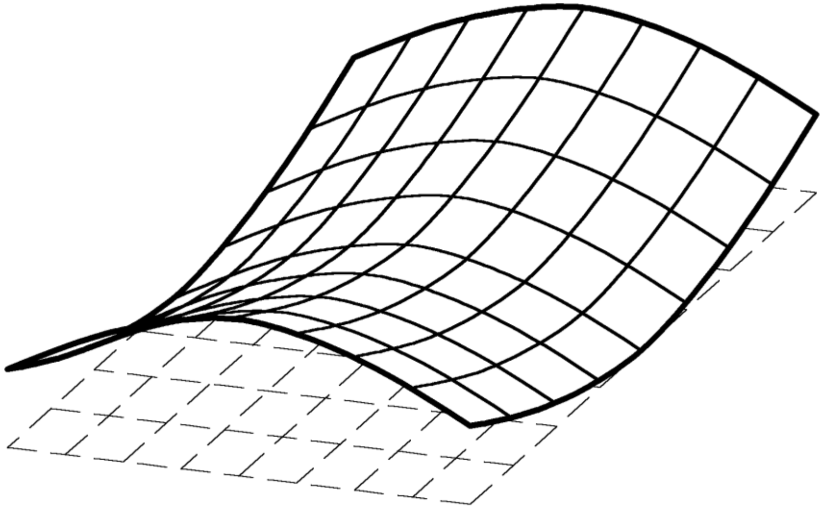


Anticlastic Curvature

Classificazione di superfici a doppia curvature

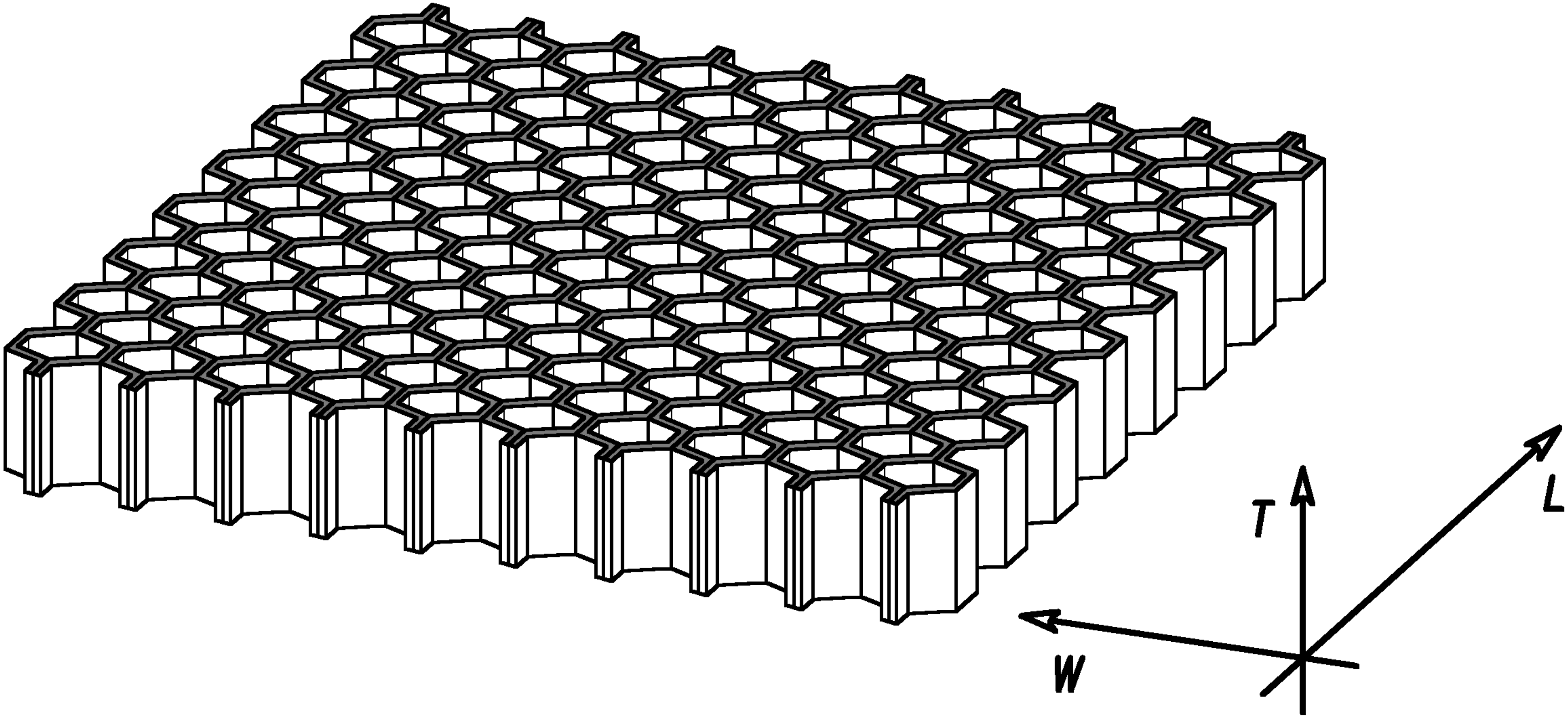


superficie a doppia curvatura sinclastica

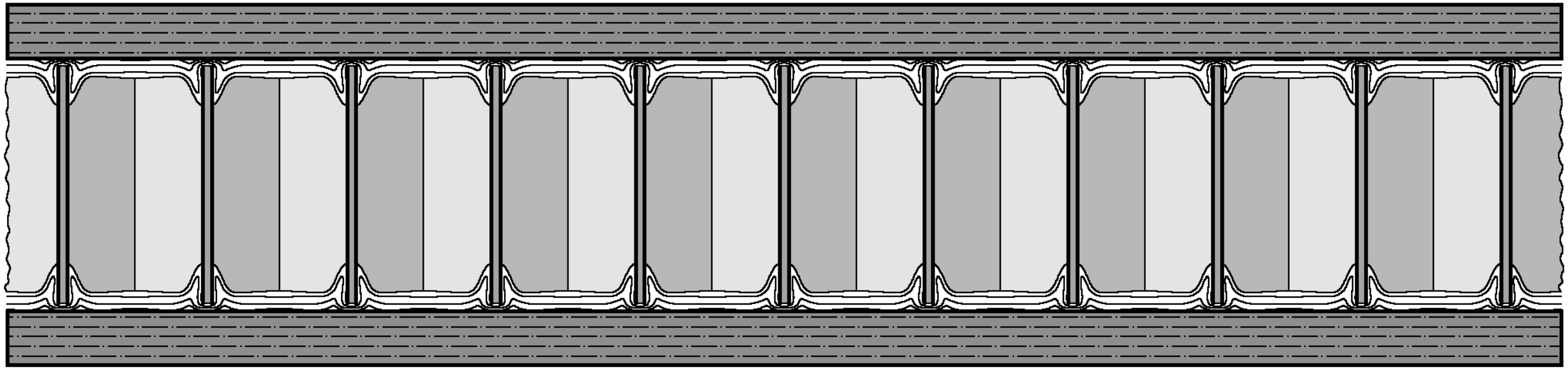


superficie a doppia curvatura anticlastica

Direzioni di riferimento per le anime a nido d'ape



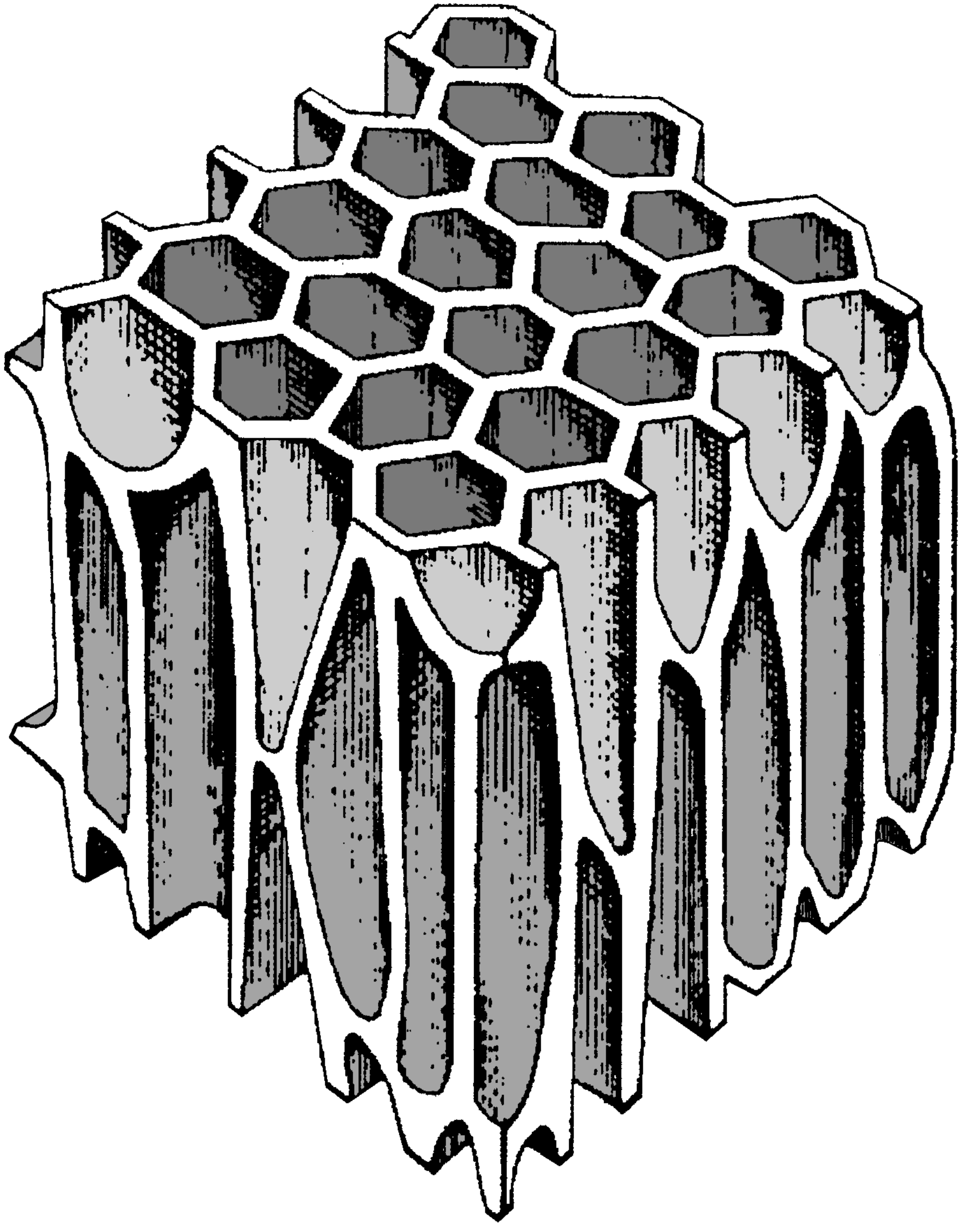
“Fillets” formati con il mat interposto fra pelle e nido d’ape



Albero di balsa (Ochroma pyramidale)

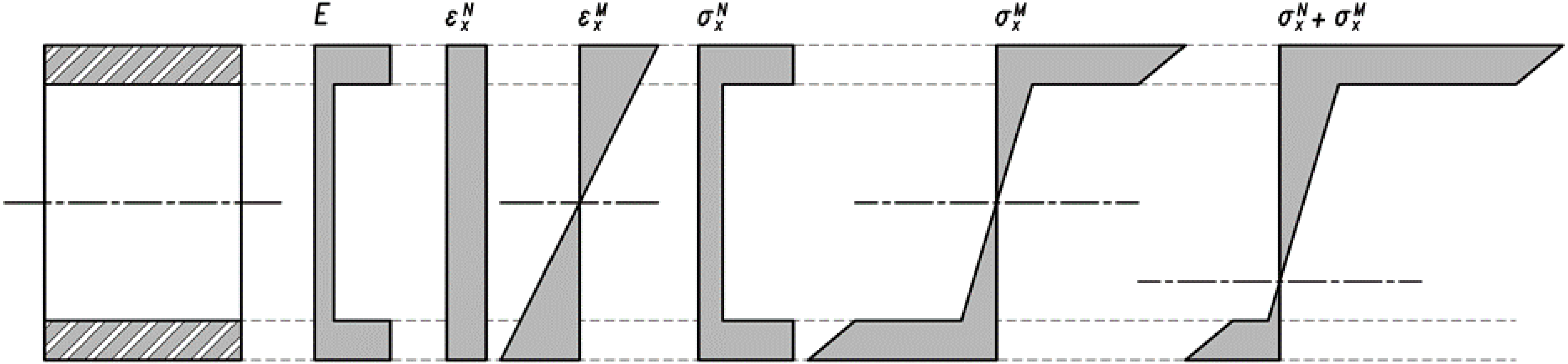
Struttura alveolare naturale del legno di balsa

Struttura alveolare naturale del legno di balsa

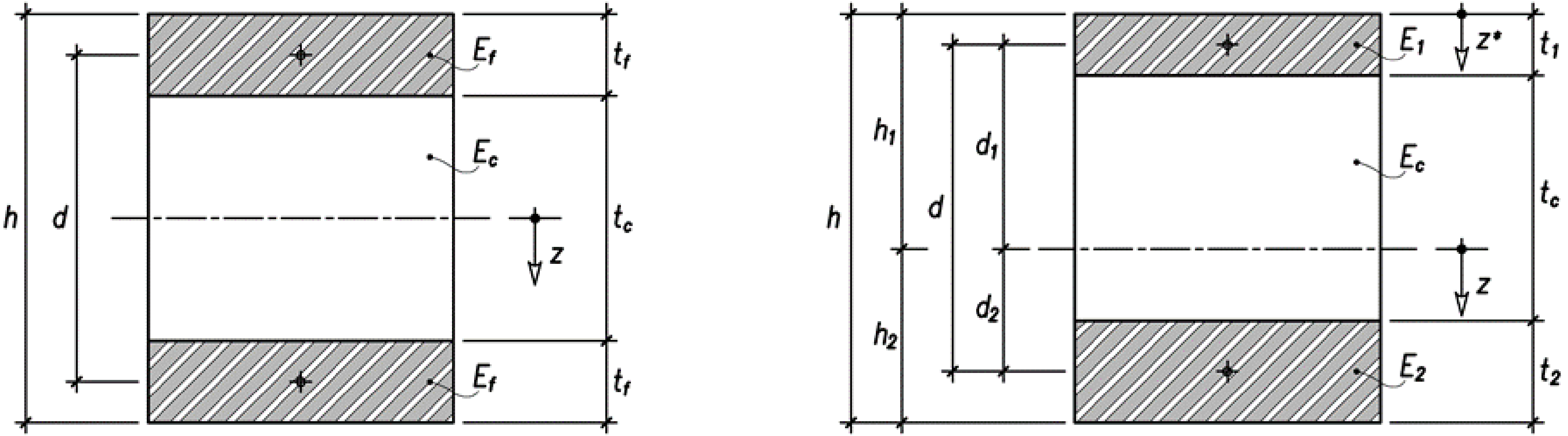


Catasta di legno di balsa

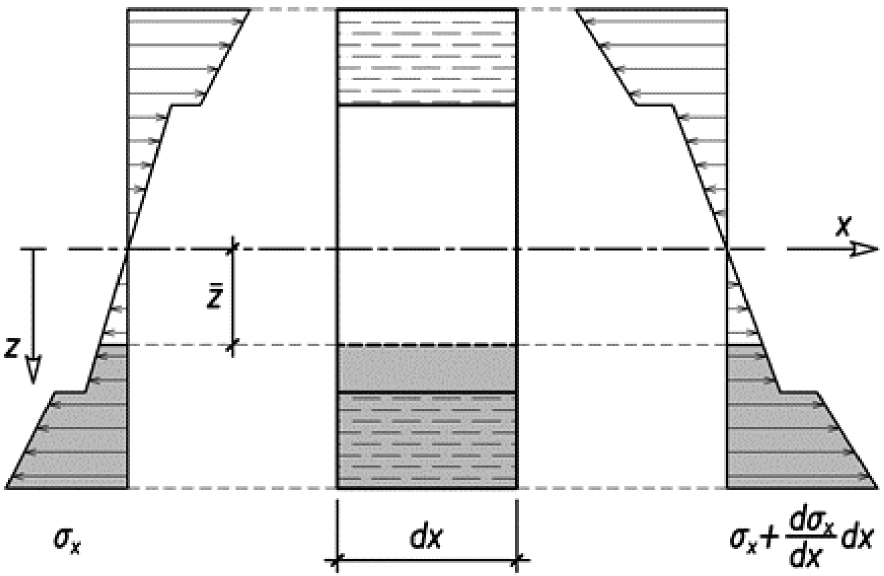
Sollecitazioni dovute forza normale N_x *+ momento flettente* M_x *in un sandwich simmetrico*

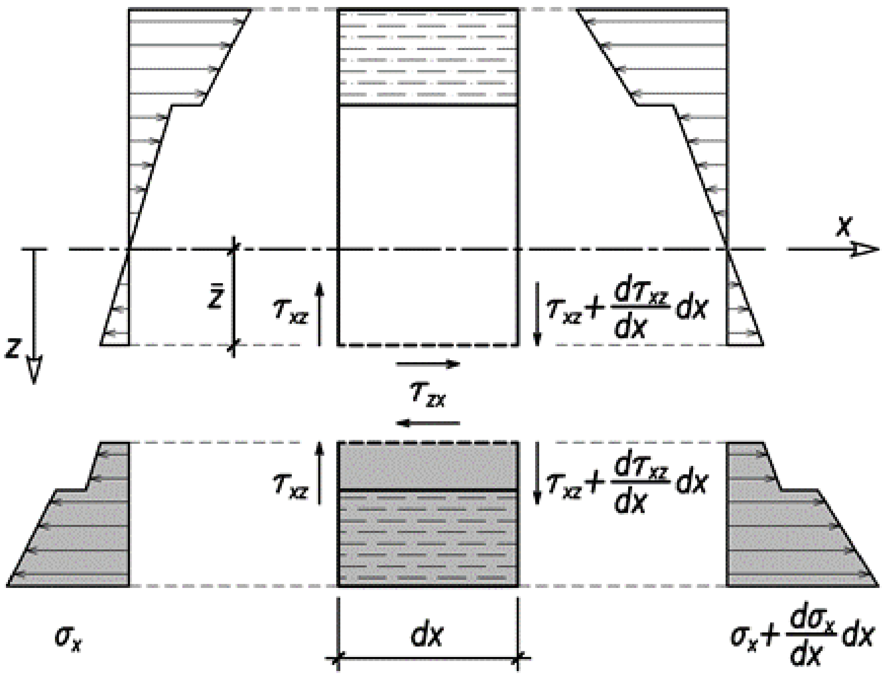


Nomenclatura adottata per un sandwich simmetrico e asimmetrico

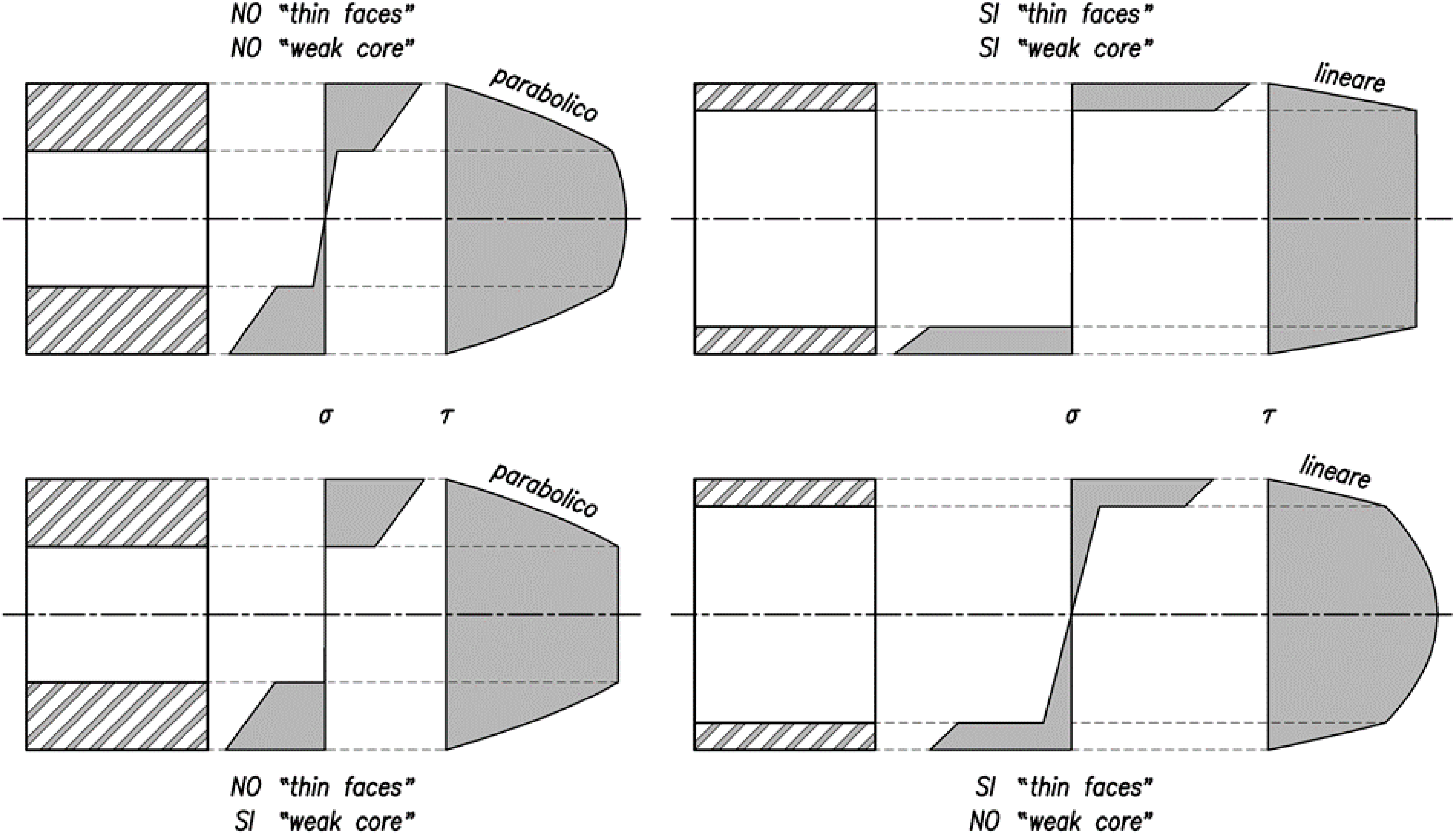


Tensioni tangenziali da taglio equilibranti le tensioni normali da momento flettente variabile





Possibili approssimazioni dovute alle ipotesi «thin faces» e «weak core» per le sollecitazioni da flessione composta in un sandwich



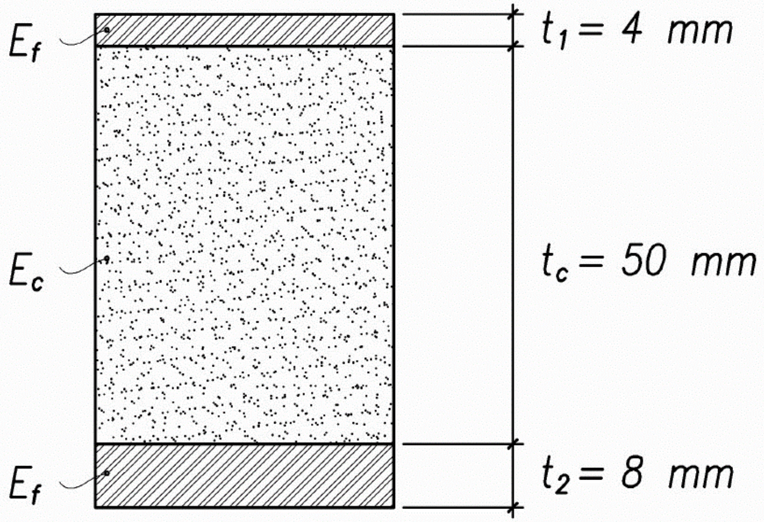
ESERCIZIO-1

Rigidezza flessionale di un sandwich asimmetrico

Sia dato il sandwich asimmetrico di larghezza unitaria rappresentato in figura:

$E_f = 15\ \text{GPa}$ (E–glass/epoxy; $V_f = 50\%$)

$E_c = 0.1\ \text{GPa}$ (PVC–foam; $\rho = 100\ \text{kg/m}^3$)



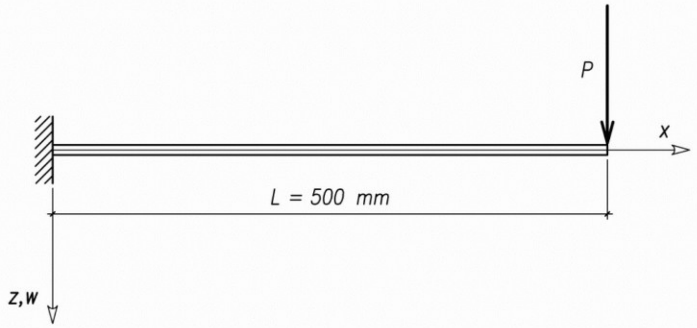
Calcolare la rigidezza flessionale *D*, distinguendo i diversi contributi dati dalle varie parti.

Avvalendosi delle semplificazioni introducibili con le ipotesi *“thin faces”* e *“weak core”*, calcolare il valore della rigidezza flessionale approssimata e valutare il grado di approssimazione percentuale che si realizza.

ESERCIZIO-2

Confronto della freccia massima da flessione e da taglio
per una trave con struttura a sandwich e una con sezione omogenea in acciaio

Sia data la trave a mensola soggetta ad un carico concentrato P = 800 N come rappresentata in figura:

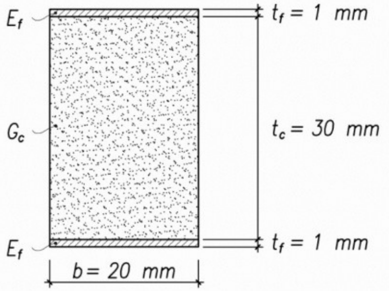


Si considerino i due casi con diverso materiale della trave come qui di seguito indicato:

Sandwich simmetrico:

$E_f = 200$ GPa (steel)

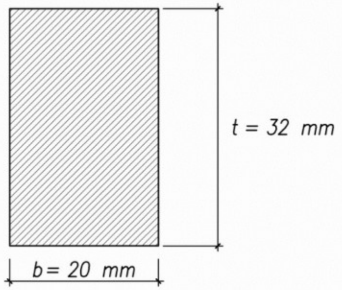
$G_c = 0.030$ GPa (PVC–foam; $\rho = 80$ kg/m^3)



Sezione omogenea (steel):

$E = 200$ GPa

$G = 80$ GPa



Per la struttura a sandwich ci si può avvalere delle semplificazioni introducibili con le ipotesi *"thin faces"* e *"weak core"* nel calcolo della rigidezza flessionale D e della rigidezza tagliante K.

Detta $w_{b,max}$ la freccia massima imputabile al solo momento flettente e $w_{s,max}$ quella imputabile al solo taglio, si valuti per entrambi i casi il rapporto $w_{b,max} / w_{s,max}$