



Università degli Studi di Padova – Dipartimento di Ingegneria Industriale

Corso di Laurea in Ingegneria Chimica e dei Materiali

Relazione per la prova finale

«Validazione tramite analisi ad elementi finiti di un modello analitico per il dimensionamento di inserti per una monoscocca Formula SAE in struttura sandwich CFRP con anima in nido d'ape d'alluminio»

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Prof. Giovanni Meneghetti

Laureando: *Alessandro Brunetta*

Padova, 19/09/2023



formula
ATA

Monoposto SG-e 06



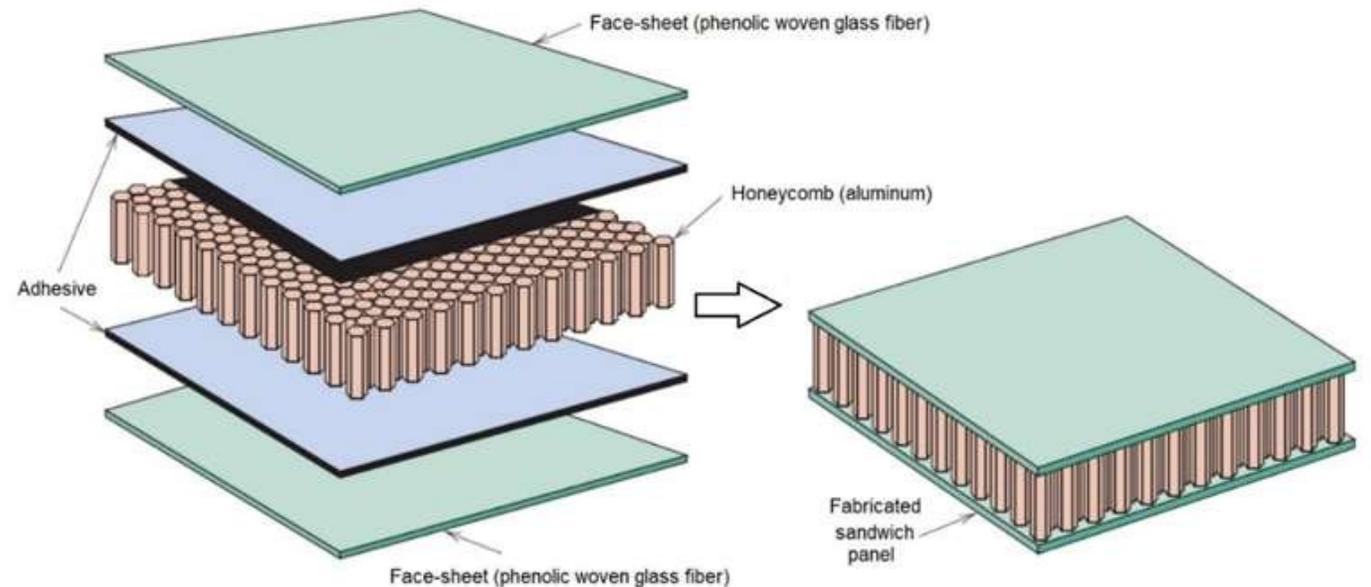
- Monoscocca & Compositi
- Strutture Meccaniche
- Powertrain
- Aerodinamica & Raffreddamento
- Dinamica del Veicolo
- Software
- Driverless
- Elettronica



Elemento costituito da **due strati resistenti**, detti “**pelli**” o “**facce**”, distanziati tra loro e collegati rigidamente ad un **materiale connettivo**, che prende il nome di “**core**”

Comportamento statico incrementato rispetto alle singole parti che lo compongono, specialmente per la rigidità a flessione

Peso relativamente basso



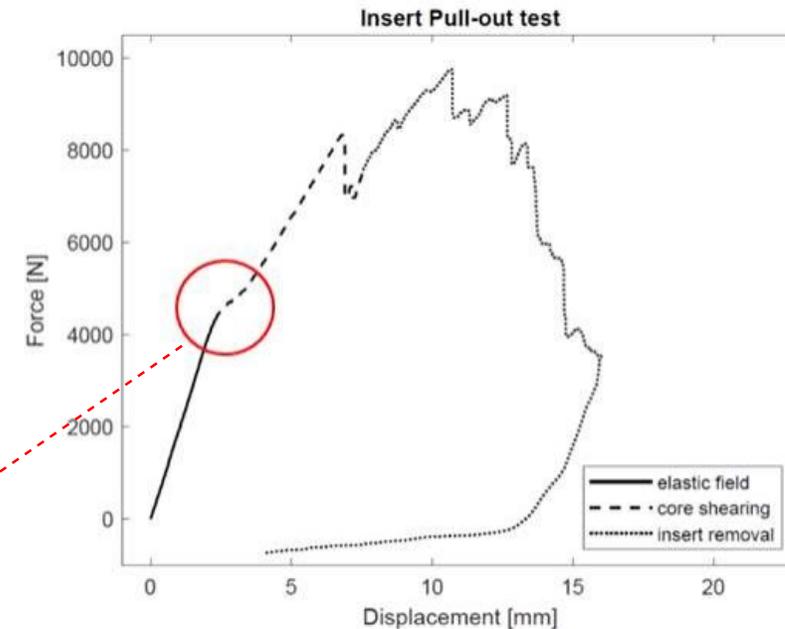
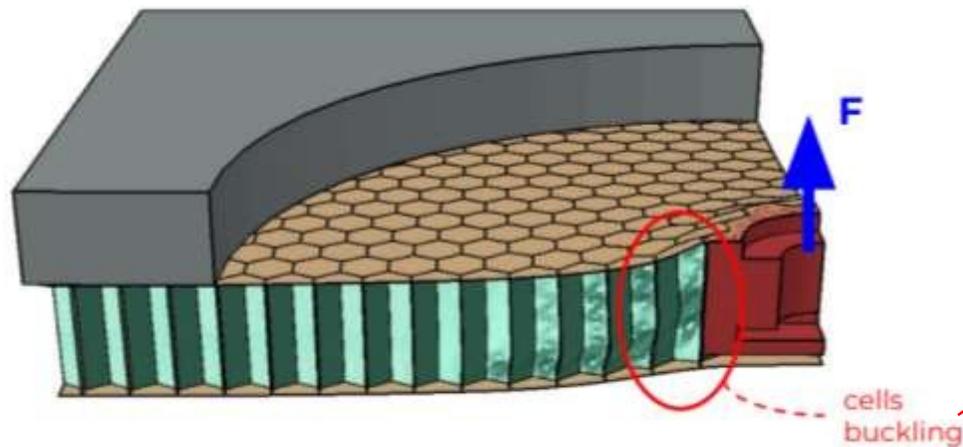
UTILIZZO DI INSERTI NELLA MONOSCOCCA

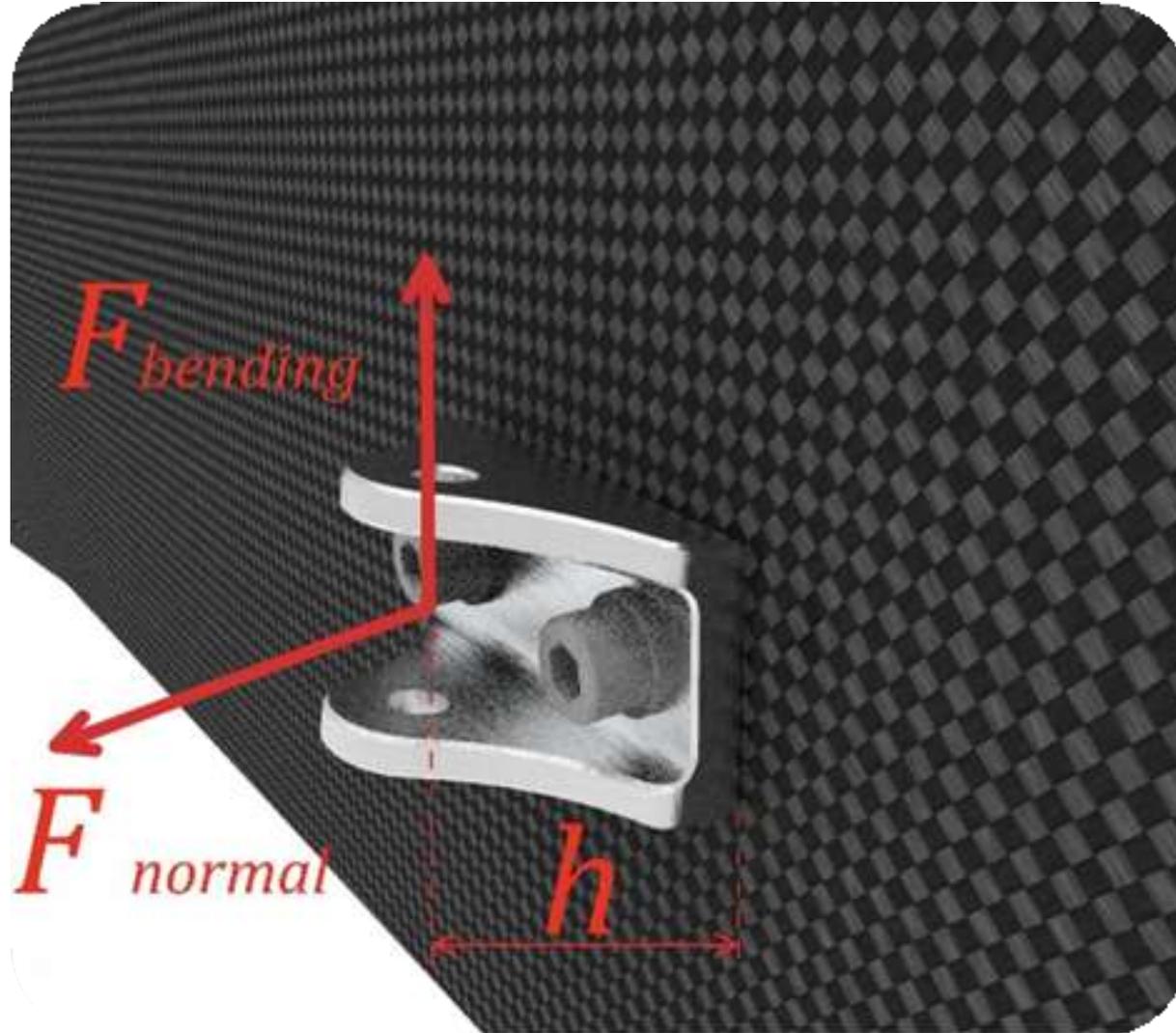
MOTIVI

- Regola **T 3.16.5** (*Regolamento Formula SAE*)
- **Perdita** locale di **rigidezza** della monoscocca in corrispondenza degli **attacchi sospensioni** a telaio

CAUSE

Instabilità localizzata delle **celle** di *honeycomb* dovuta ad uno **sforzo di taglio** agente sul core





**Schema esemplificativo
della condizione
di carico analizzata nel
modello**

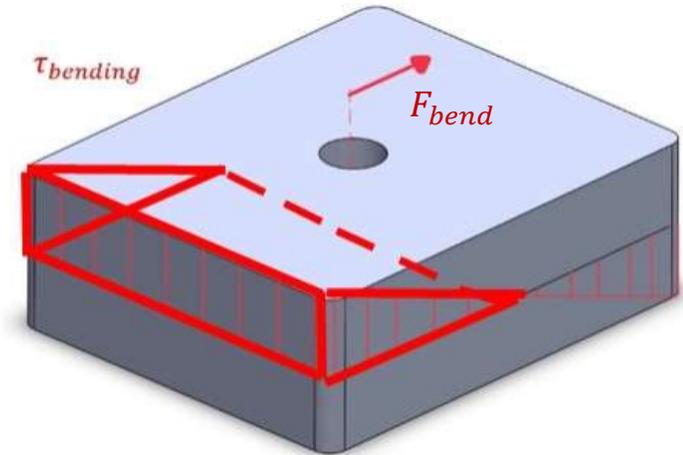
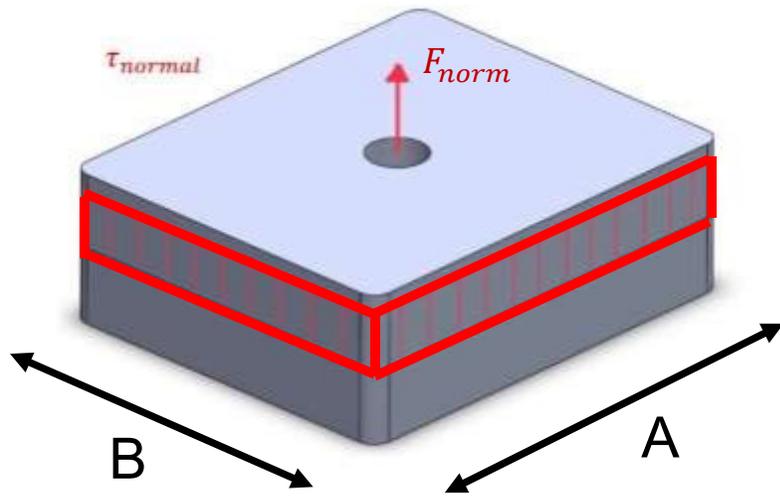
$$\tau_{tot} < \tau_{adm}$$

$$\tau_{adm} = 1,36 \cdot \tau_{w,core} (*)$$

$$\tau_{tot} = \tau_{norm} + \tau_{bend}$$

$$\tau_{norm} = \frac{F_{norm}}{2 \cdot (A + B) \cdot t_{core}} \cdot \frac{1}{K_{ED,N}}$$

$$\tau_{bend} = \frac{F_{bend} \cdot \left(h + \frac{t_{core}}{2} \right)}{2 \cdot t_{core} \cdot \left(\frac{A^2}{6} + \frac{A \cdot B}{2} \right)} \cdot \frac{1}{K_{ED,B}}$$



(*) ESA Insert Design Handbook

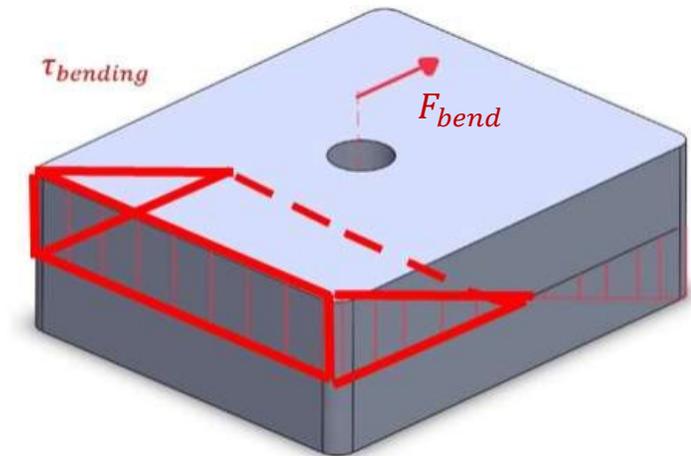
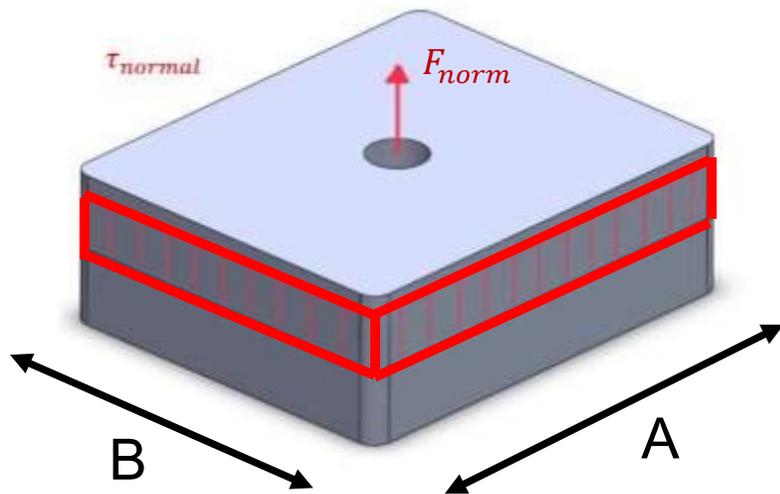
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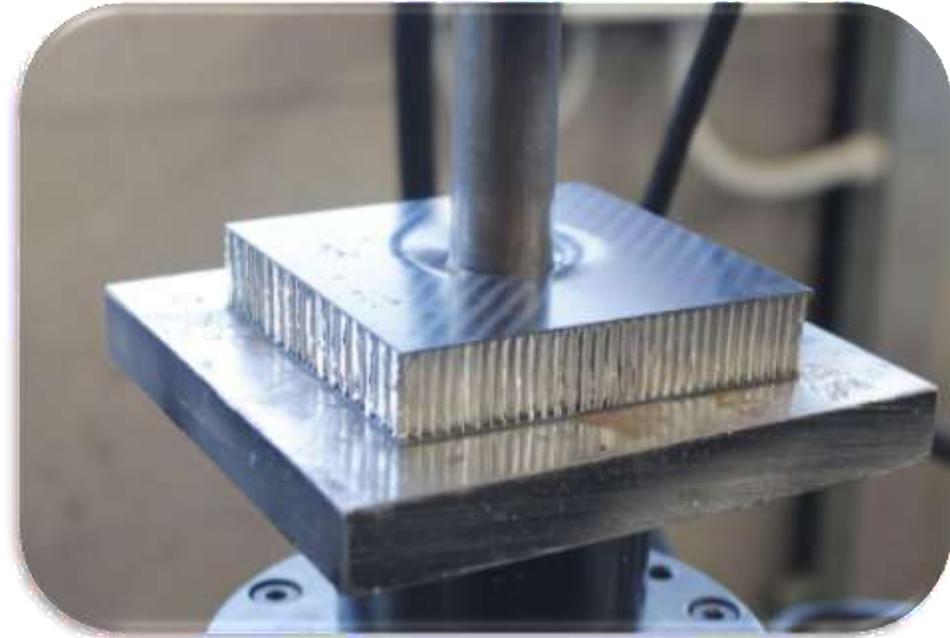
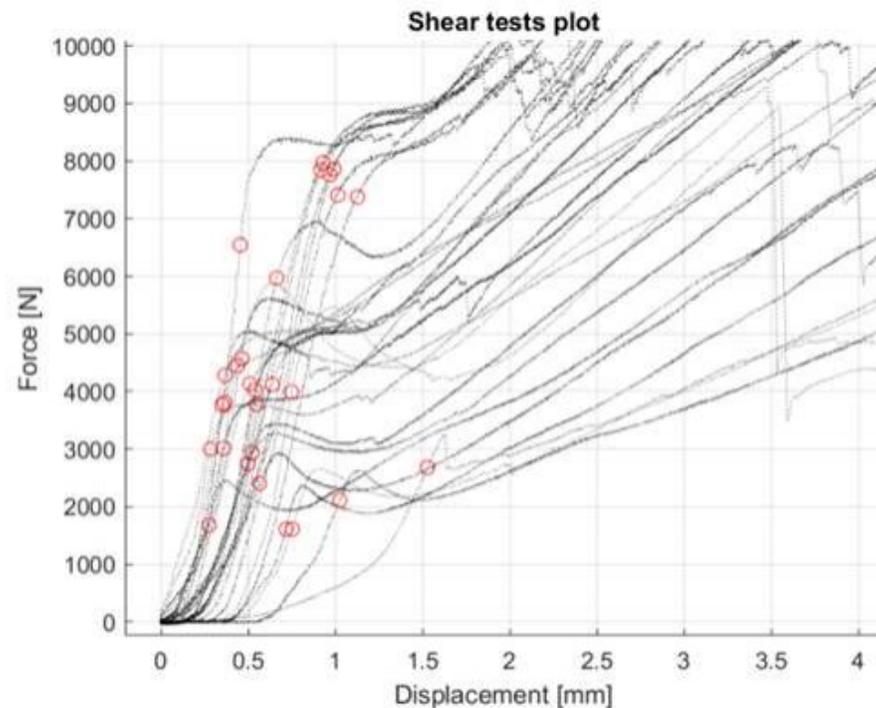
$$\tau_{norm} = \frac{F_{norm}}{2 \cdot (A + B) \cdot t_{core}} \cdot \frac{1}{K_{ED,N}}$$

$$\tau_{bend} = \frac{F_{bend} \cdot \left(h + \frac{t_{core}}{2} \right)}{2 \cdot t_{core} \cdot \left(\frac{A^2}{6} + \frac{A \cdot B}{2} \right)} \cdot \frac{1}{K_{ED,B}}$$



(*) ESA Insert Design Handbook

- Permettono di considerare l'**effetto delle pelli** nel mitigare il carico agente
- **Ottenuti sperimentalmente** sulla base dello storico di *Shear Tests* a disposizione del Team
- Per **ogni provino testato** si determina la **forza limite** che causa la prima **deviazione dalla linearità**



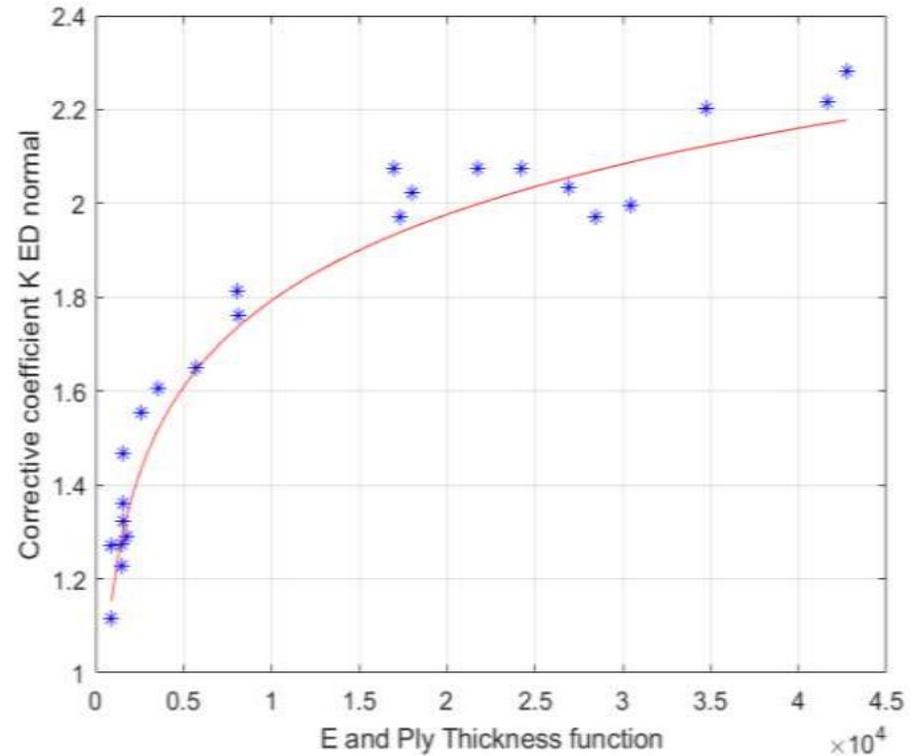
$$K_{ED,N} = 0,481 + 0,217 \cdot \ln(k_{panel})$$

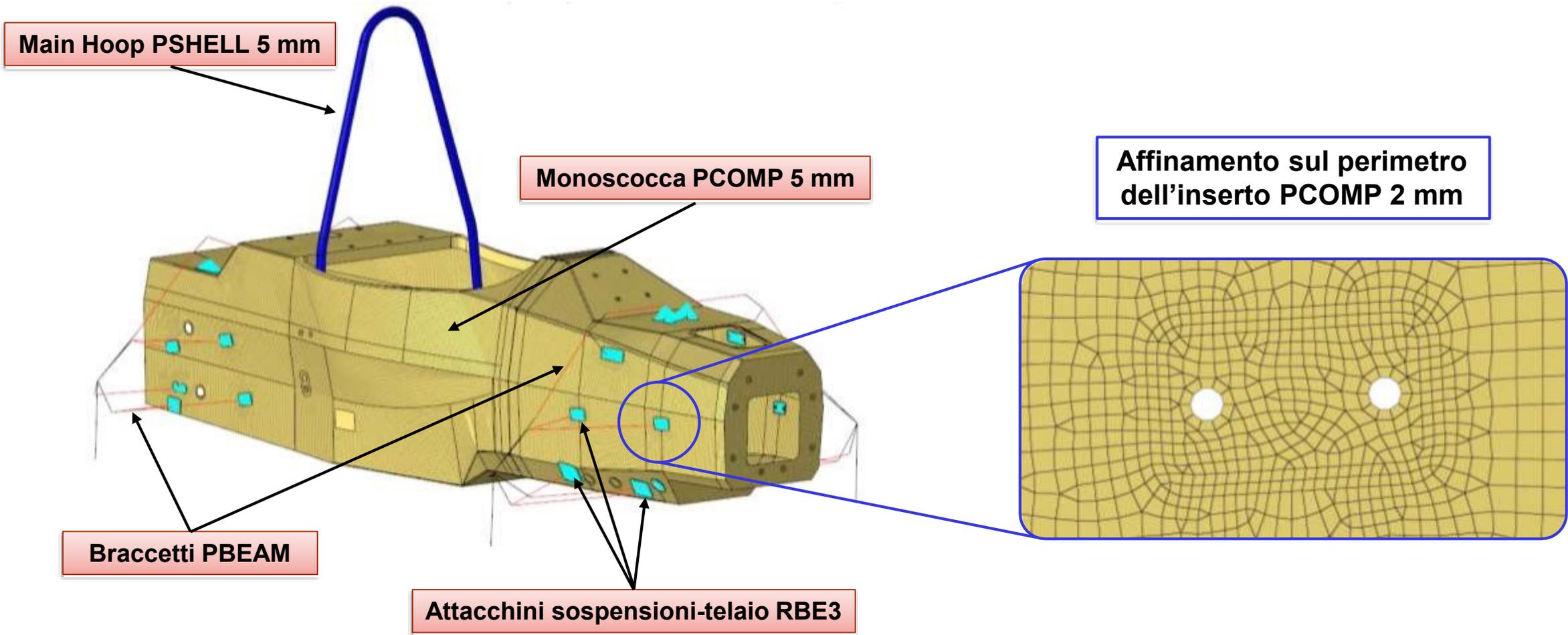
$$K_{ED,B} = 1 + \frac{K_{ED,N} - 1}{3}$$

$$K_{ED,N} = \frac{F_{limite}}{F_{honeycomb}}$$

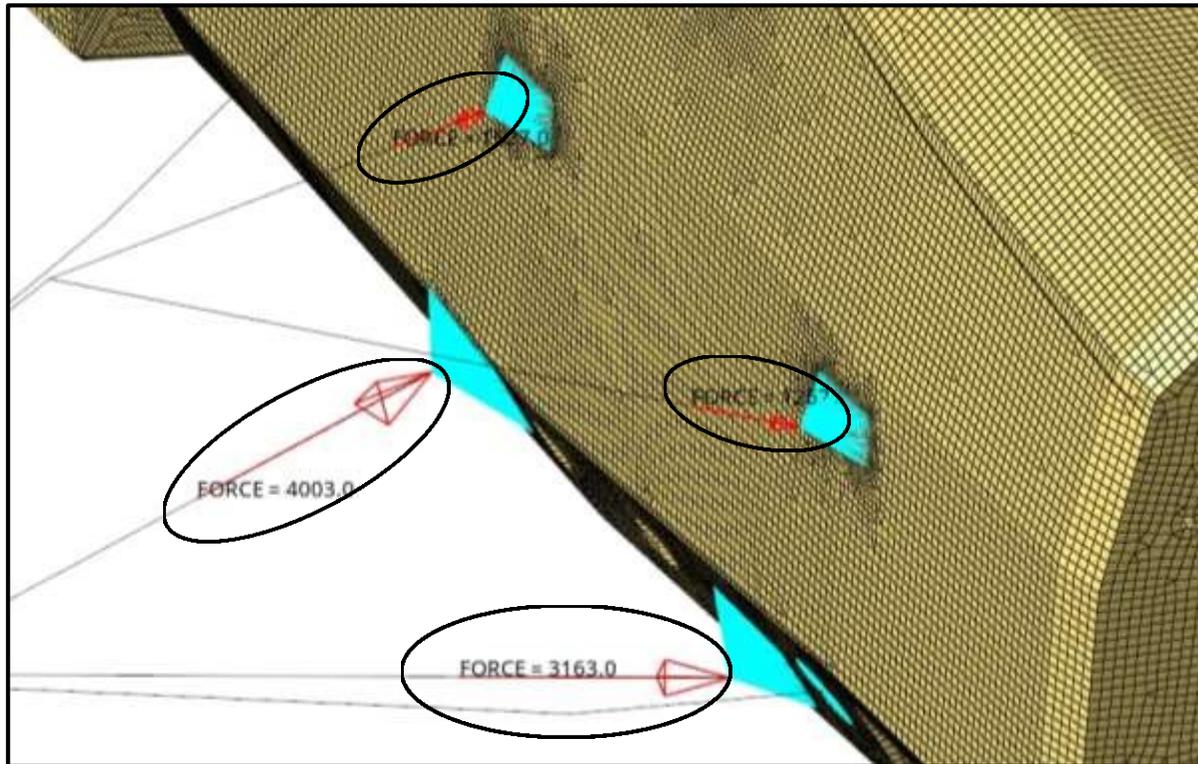
$$F_{honeycomb} = 3450 \text{ N}$$

$$k_{panel} = 1,73 \cdot \sqrt[3]{E_1 * E_2^2 \cdot t_{plies}^{3,48}}$$

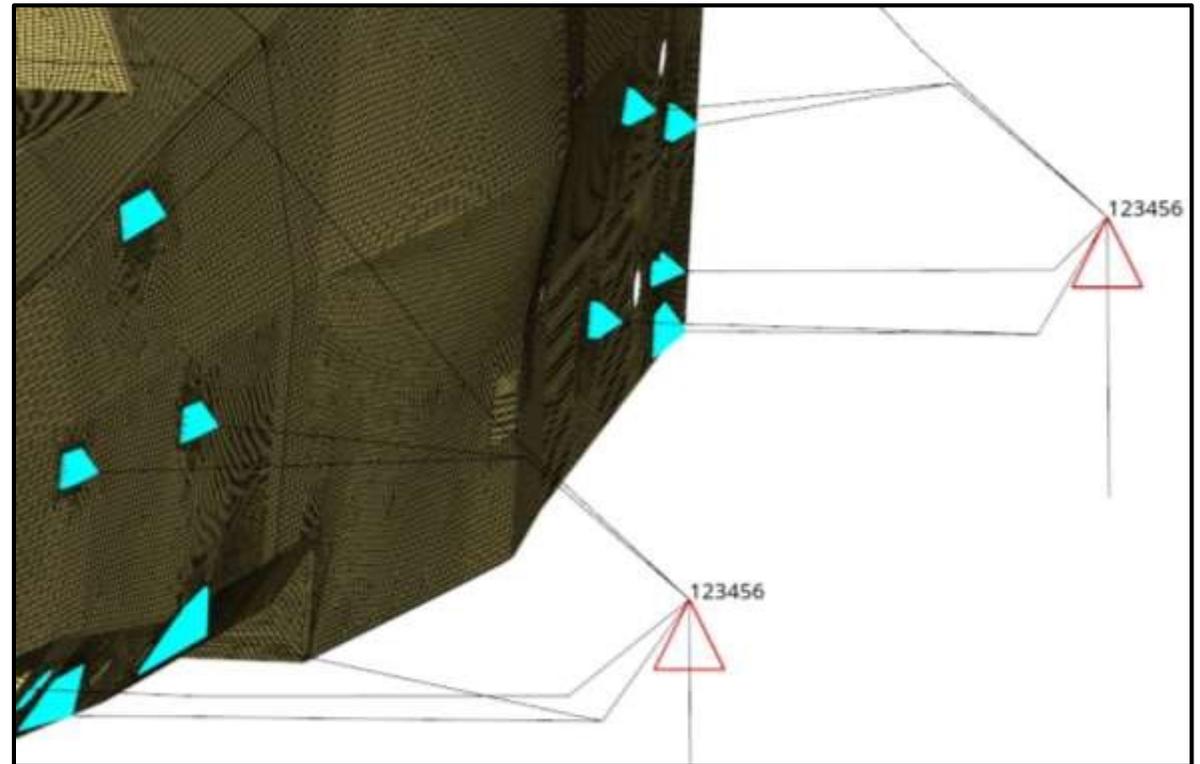




FORZE



VINCOLI



TOTAL ACTING FORCE = 1267 N

ID: [Front - Front Wishbone Upper Triangle](#)

FX	800 N
FY	73 N
FZ	980 N
Eccentricity	20 mm

MECHANICAL PROPERTIES

Laminate EX	93 GPa
Laminate EY	34,5 GPa
Core Shear Strength (W)	1,52 MPa
Honeycomb Cell Size	3,175 mm

INSERT GEOMETRY

Insert shape	Rectangular
Insert A size	45,0 mm
Insert B size	25,0 mm
Typical potted A dimension	54,5 mm
Typical potted B dimension	34,5 mm

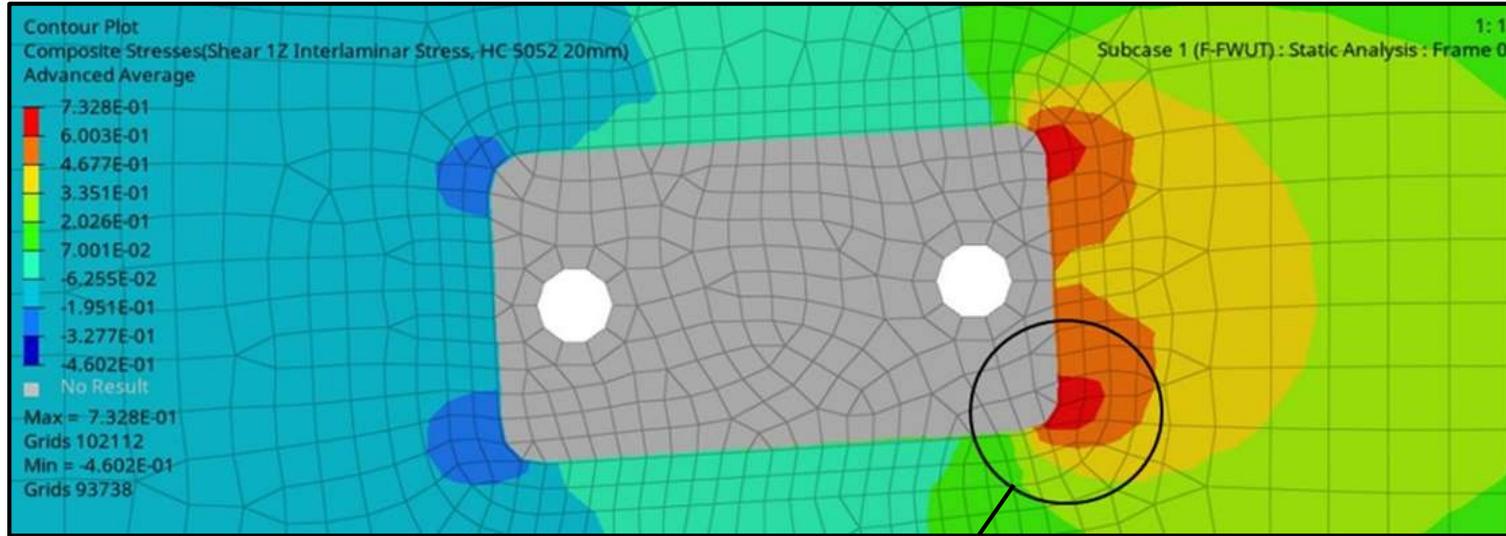
RESULTS

STRESS

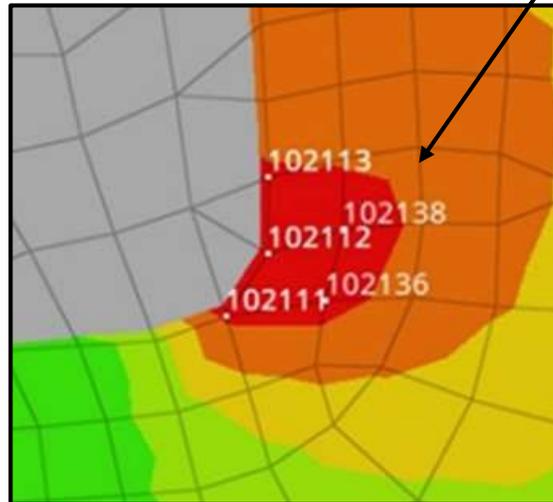
Core Peak Shear Stress ✓	0,66 MPa
Ply Through Thickness Stress ✓	7,61 MPa
Adhesive Plane-Shear Stress ✓	0,71 MPa
Failure load with potting	3991 N
Failure load without potting	2671 N

SAFETY FACTOR

3,15	Effective Shear Buckling Safety Factor vs. Peak Stress
3,94	Punch Through Thickness Safety Factor
25,21	Adhesive Debonding Safety Factor
3,15	Workmanlike manufacturing Safety Factor
2,11	Wrongly done manufacturing Safety Factor

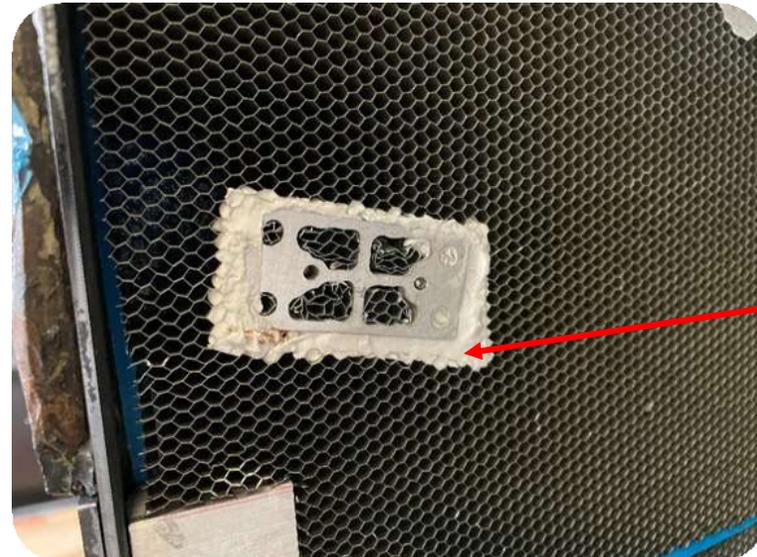
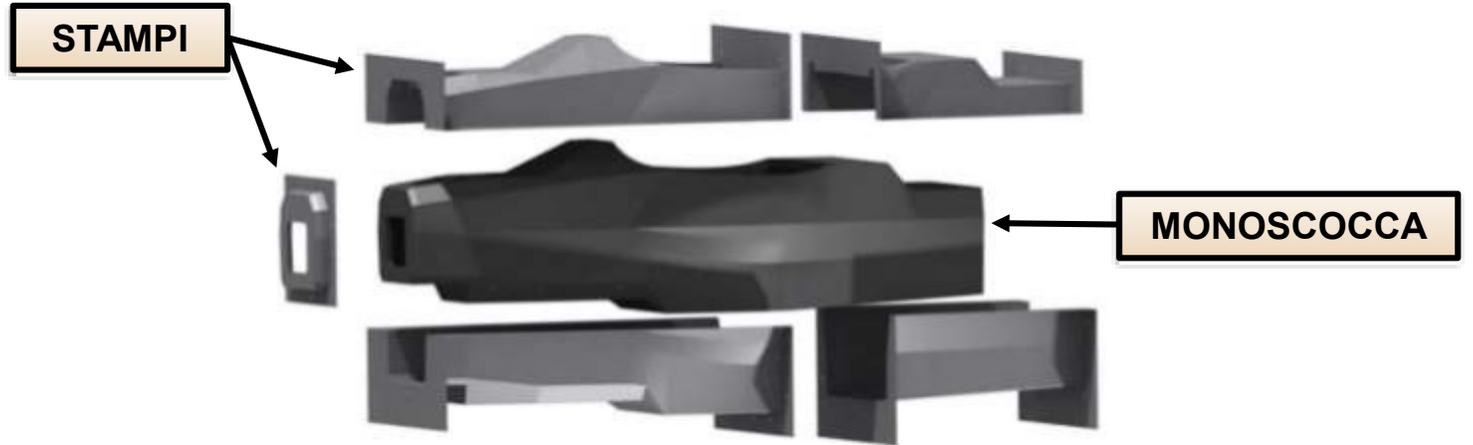
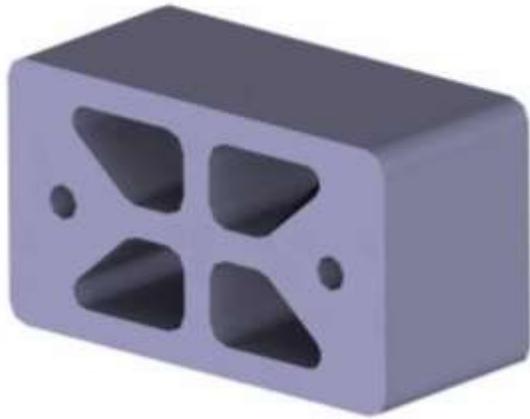


$$Err_{\%} = \frac{\tau_{tot,analitico} - \tau_{simulazione}}{\tau_{simulazione}} \cdot 100$$



NODE ID	CORE SHEAR STRESS [MPa]
102112	0,73
122138	0,67
102136	0,66
102111	0,62
102113	0,61
AVERAGE STRESS [MPa]	
	0,66

FRONT			
Nome inserto	Previsione modello [Mpa]	Simulazione [Mpa]	Errore relativo [%]
Braccetto anteriore triangolo superiore	0,66	0,66	0,0
Braccetto posteriore triangolo superiore	0,63	0,80	21,3
Braccetto anteriore triangolo inferiore	1,29	1,43	9,7
Braccetto posteriore triangolo inferiore	1,37	1,35	1,5
Rocker	0,47	0,33	29,8
REAR			
Nome inserto	Previsione modello [Mpa]	Simulazione [Mpa]	Errore relativo [%]
Braccetto anteriore triangolo superiore	0,76	0,72	5,5
Braccetto posteriore triangolo superiore	0,77	0,84	8,3
Braccetto anteriore triangolo inferiore	1,26	1,50	16,0
Braccetto posteriore triangolo inferiore	1,16	1,51	23,2
Rocker	0,53	0,71	25,4
ERRORE MEDIO DEL MODELLO ANALITICO [%]			12,8



POTTING

CONCLUSIONI

- [1] Samuele Libralato, Diego Della Ragione, Race Up Team (2021), ***Inserts Design in Sandwich Structures***, Team Google Drive
- [2] Alaa Al-Fatlawi, Károly Jármai, György Kovács (2021), ***Optimal Design of a Fiber-Reinforced Plastic Composite Sandwich Structure for the Base Plate of Aircraft Pallets In Order to Reduce Weight***
- [3] Monocoque & Composite Department, Race Up Team (2022), ***Monocoque Design Presentation***, Team Google Drive
- [4] www.abbottaerospace.com, ***ESA Inset Design Handbook*** (2016)
- [5] Samuele Libralato, Diego Della Ragione, Race Up Team (2021), ***Inserts Design Spreadsheet.xlsx***, Team Google Drive
- [6] ***Formula Student Rules v1.1*** (2023), Team Google Drive
- [7] William Callister Jr, David Rethwisch, ***Scienza ed Ingegneria dei Materiali*** (2019)