MODELING IMPACT, DAMAGE, AND PENETRATION OF SANDWICH COMPOSITES

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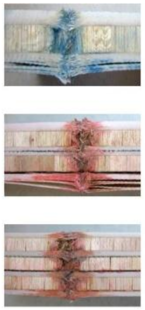
OBJECTIVE

- Evaluate the Impact, Damage, Penetration Resistance Behavior of Sandwich Composites
- METHODOLOGY:
  - Finite Element Analysis to Gain Insight into Failure Modes and Energy Dissipation
  - Compare FEA Results with the Existing Quasi-static Punch Shear and Ballistic Experimental Data
  - FEA to Investigate the Relative Role of Balsa Core in a Sandwich Structure

QS-PS AND BALLISTIC IMPACT TESTS ON DIFFERENT S2-GLASS/SC15 BALSA CORE SANDWICH STRUCTURES

Quasi-Static | Ballistic | Schematic



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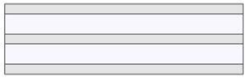

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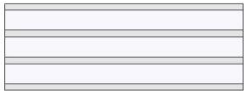

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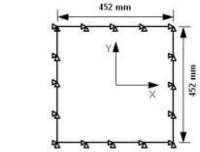
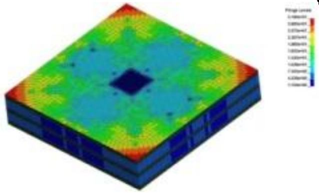
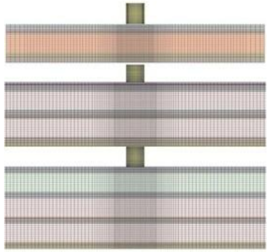
MODEL DESCRIPTION





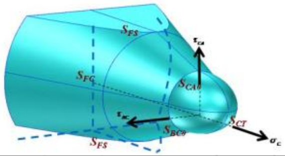


Projectile: 12.7 mm Dia. (0.50cal FSP)

FINITE ELEMENT MODEL

- Composite Face Sheets: 3Elem/2Layer
- Balsa Core: 10 Elem/12.7 (mm) Thickness
- Impact Region:0.5 x 0.5 x 0.275 (mm) with AR 1.04
- Edges: 7.0 x 4.0 x 0.275 (mm) with Max. AR 25.0
- CONTACT_ERODING_SINGLE_SURFACE

MAT 162 PROGRESSIVE COMPOSITE DAMAGE MODEL

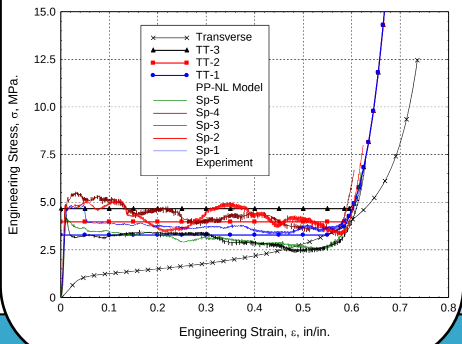


RO (kg/m³)	EA (GPa)	EB (GPa)	EC (GPa)	PRBA	PRCA	PRCB
1.85E+03	27.5	27.5	11.8	0.11	0.18	0.18
GAB (GPa)	GBC (GPa)	GCA (GPa)				
2.9	2.14	2.14				
SAT(MPa)	SAC(MPa)	SBT(MPa)	SBC(MPa)	SCT(MPa)	SFC (MPa)	SFS(MPa)
604	291	604	291	58	850	300
SAB(MPa)	SBC (MPa)	SCA (MPa)	SFFC	AMODEL	PHIC	E_LIMT
75	58	58	0.1	2	10	0.2
OMGMAX	S_DELM	ECRSH	EEXPN	RATE1	AM1	
0.999	1.2	0.001	4	0	2	
AM2	AM3	AM4	RATE2	RATE3	RATE4	
2	0.5	0.2	0	0	0	

MAT 162 FAILURE CRITERIA

Fill Fiber tension/shear	$\left(\frac{E_1\langle\varepsilon_1\rangle}{X_{1T}}\right)^2 + \frac{G_{12}^2\varepsilon_{12}^2 + G_{31}^2\varepsilon_{31}^2}{S_{FS}^2} = r_1^2$
Fill Fiber compression	$\left(\frac{E_1\langle\varepsilon_1'\rangle}{X_{1C}}\right)^2 = r_2^2$, $\varepsilon_1' = -\varepsilon_1 - \langle-\varepsilon_3\rangle\frac{E_3}{E_1}$
Warp Fiber tension/shear	$\left(\frac{E_2\langle\varepsilon_2\rangle}{X_{2T}}\right)^2 + \left(\frac{G_{23}\varepsilon_{23}}{S_{FS}}\right)^2 = r_3^2$
Warp Fiber compression	$\left(\frac{E_2\langle\varepsilon_2'\rangle}{X_{2C}}\right)^2 = r_4^2$, $\varepsilon_2' = -\varepsilon_2 - \langle-\varepsilon_3\rangle\frac{E_3}{E_2}$
Fiber crush	$\left(\frac{E_3 < -\varepsilon_3 >}{S_{FC}}\right)^2 = r_5^2$
Perpendicular matrix crack	$\left(\frac{G_{12}\varepsilon_{12}}{S_{12}}\right)^2 = r_6^2$
Parallel matrix (Delamination)	$S^2\left\{\left(\frac{E_3\langle\varepsilon_3\rangle}{S_{3T}}\right)^2 + \left(\frac{G_{23}\varepsilon_{23}}{S_{23}+S_{SRC}}\right)^2 + \left(\frac{G_{31}\varepsilon_{31}}{S_{31}+S_{SRC}}\right)^2\right\} = r_7^2$

CONSTITUTIVE MODEL FOR BALSA WOOD



BALSA WOOD PROPERTIES

*MAT_HONEYCOMB_TITLE			
Density, , gm/cc	0.71	Elastic Modulus E_{aau} in uncompressed Configuration, GPa	0.20
Young's Modulus for compacted honeycomb, GPa	6.9	Elastic Modulus E_{bbu} in uncompressed Configuration, GPa	0.20
Yield stress for compacted honeycomb, GPa	0.0265	Elastic Modulus E_{ccu} in uncompressed Configuration, GPa	0.20
Poisson's Ratio	0.285	Shear Modulus G_{abu} in uncompressed configuration, GPa	0.08
Shear Modulus G_{bcu} in uncompressed configuration, GPa	0.08	Shear Modulus G_{acu} in uncompressed configuration, GPa	0.08

- Under Static or Low Strain Rate Conditions, Wood can be Treated as Linearly Elastic
- With Increasing Loading Rate, Cell Walls Buckle Locally and Wood Behavior Becomes Non-Linear
- MAT_HONEYCOMB was Used to Model the Wood Behavior

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(Continued)

MODELING BALLISTIC DAMAGE OF MULTI-LAYER SANDWICH STRUCTURES

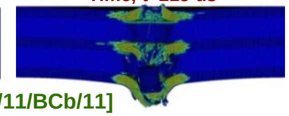
Time, t=45 us

Time, t=215 us

[11/BCb/11]

Time, t=45 us

Time, t=215 us



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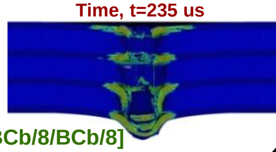
Time, t=66 us

Time, t=235 us



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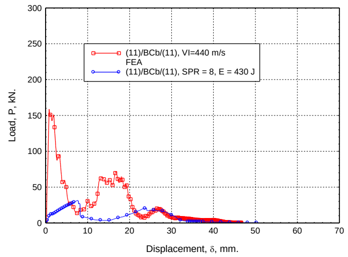
IMPACT RESPONSES



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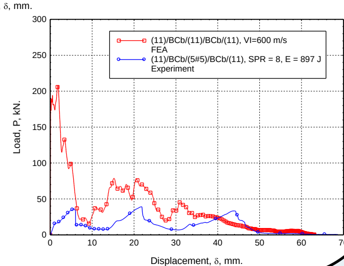
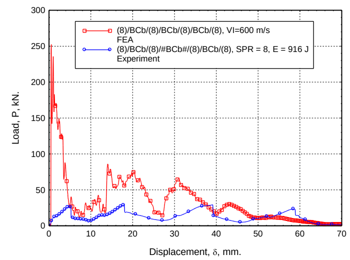


IMPACT RESPONSE (CONT.)



[8/BCb/8/BCb/8/BCb/8]

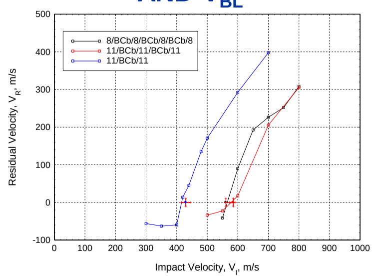
- The Force-Displacement Responses from Quasi-Static Experiments and FEA have been Compared
- The Ballistic Penetration Resistance Force from FEA was an Order of Magnitude Higher than QS-Penetration Resistance Force, hence, QS-Penetration Model may not Work for Sandwich Structures

EXPERIMENTAL BALLISTIC RESULTS

EXPERIMENTAL, QS	AD, kg/m2	H, mm	V_{BL}, m/s	High Partial, m/s	Low Complete, m/s
S11	12.0	6.60	0.0	0.0	0.0
S22	24.0	13.2	0.0	0.0	0.0
S33	36.0	19.8	540.7	530.4	543.5
11/BCa/11	27.5	38.6	421.5	417.3	425.2
11/BCb/11	27.8	25.9	429.8	415.1	444.4
11/BCb/5#5/BCb/11	44.9	45.2	585.2	591.0	585.5
8/BCb/8/#BCb#/8/BCb/8	48.9	58.5	560.5	558.4	573.0

- Experimental Ballistic Limit Velocity (V_{BL} for which V_R=0) was Determined Without Measuring Residual Velocities

FEA PREDICTION OF V_I~V_R, AND V_{BL}



- FEA was Used to Predict the Residual Velocity as a Function of Impact Velocity
- Good Correlation Between Experimental V_{50} and FEA was Observed

CONCLUSIONS

CONFIGURATION	AD, kg/m²	H, mm	V_{BL} [Exp] m/s	V_{BL} [FEA] m/s	E_{BL}/AD [Exp] (J/(kg/m²))	E_{BL}/AD [FEA] (J/(kg/m²))
22	24.83	13.4	370	-	36.97	-
33	37.25	20.1	541		52.68	-
11/BCb/11	27.05	25.9	429	417	45.62	43.10
11/BCb/5#5/BCb/11	39.53	44.5	580	579	57.06	56.86
8/BCb/8/#BCb#/8/BCb/8	45.96	57.5	563	567	46.24	46.90

- The Ballistic Impact on S-2 Glass/Balsa Core/SC15 Sandwich with Three Different Configuration have been Evaluated
- Sandwich Construction did not Decrease the Engergy/AD for 11/BCb/11 and 11/BCb/11BCb/11 Architecture as Compared to 22 and 33 Layer Monolithic Composites

CONCLUSIONS (CONT.)

- Whereas, Thinner Facesheets in 8/BCb/8/BCb/8/BCb/8 Sandwich Construction Reduced the Energy/AD as Compared to 11/BCb/11/BCb/11

ACKNOWLEDGEMENTS

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