中国民航大学 Civil Aviation University of China

Research Progress of Crashworthiness for Composite Structures

Reporter: Dr. Xie Jiang
Civil Aviation University of China
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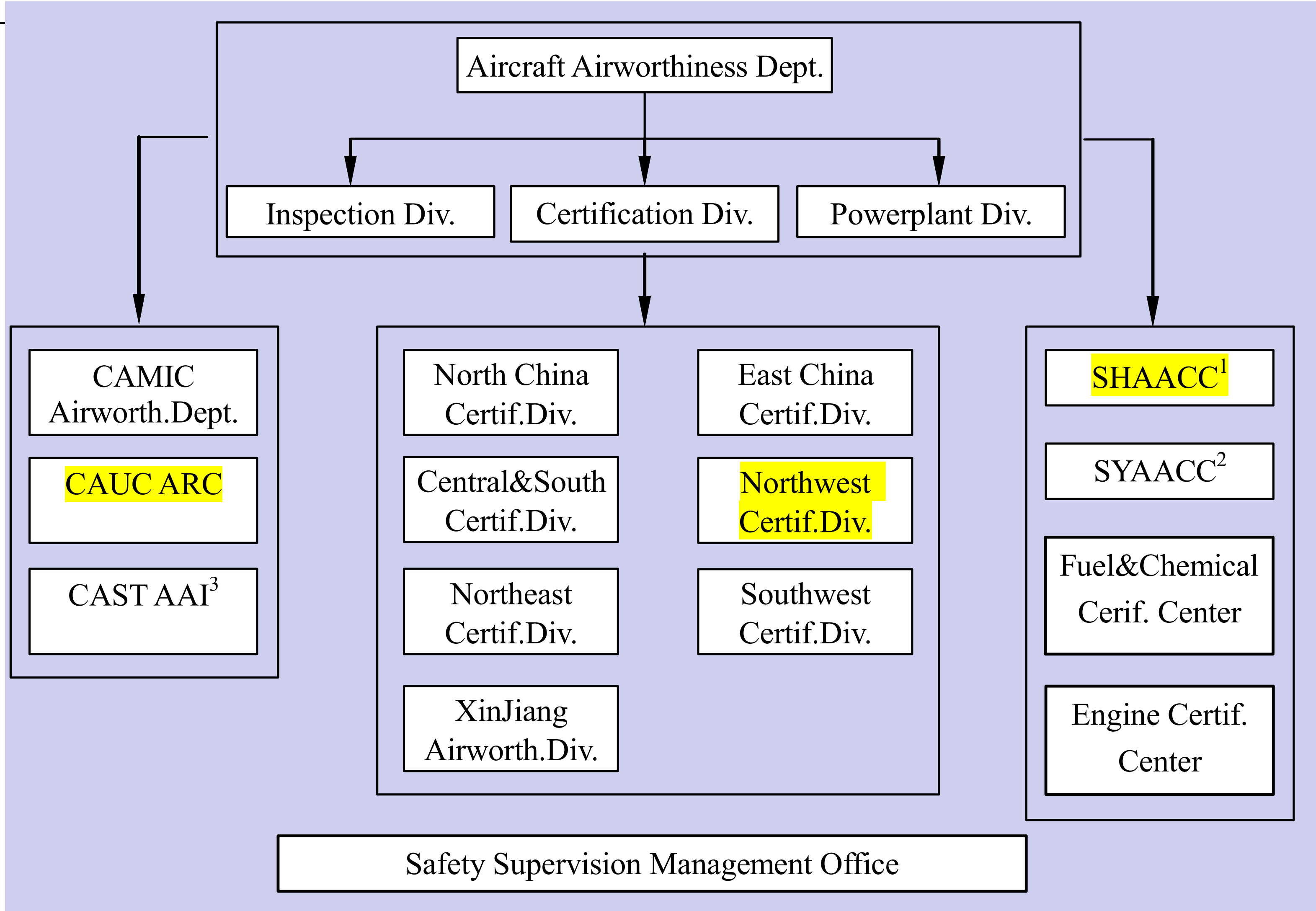
Organization of Aircraft Airworthiness Department of CAAC



1 Shang Hai Aircraft Airworthiness Certification Center of CAAC
2 Shen Yang Aircraft Airworthiness Certification Center of CAAC
3 China Academy of Civil Aviation Science and Technology(CAST) Aircraft Airworthiness Institute(AAI)

1. About Civil Aviation University of China(CAUC)

Location

1. About Civil Aviation University of China(CAUC)

Campus

- Covered an area of *1.1 million* m^2
- North / South Campus
- Total build-up area: *540,000* m^2
- Third campus covers *467,000* m^2, the Airworthiness Research Center covers *34,000* m^2.

2. Overview of Airworthiness Research Center (ARC)

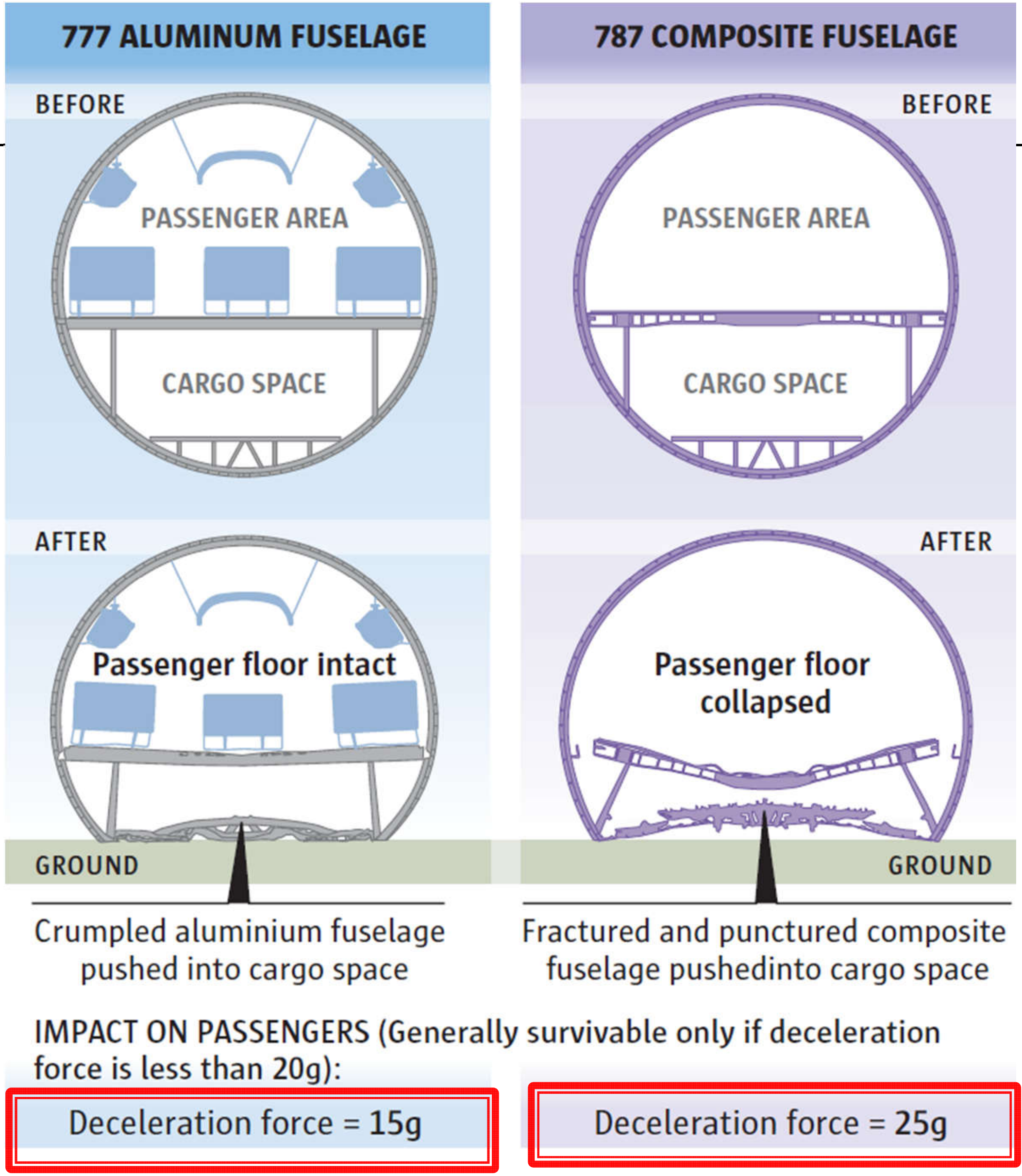
- **Full name: Civil Aviation Aircraft Airworthiness Certification Technology and Management Research Center.**
- **Established as a Technical Center supporting CAAC-AAD in 2007.**
- **Objective:**
  - Provide technical support for the decision-making of CAAC
  - Conduct research on airworthiness development strategies, planning and policy
  - Organize and conduct airworthiness certification technology research
  - Organize and provide airworthiness training, carry out certification under entrusted and provide public services and consultancy
  - Track the development trend of the international airworthiness and organize international exchange activities
  - Accomplish other tasks entrusted by the CAAC

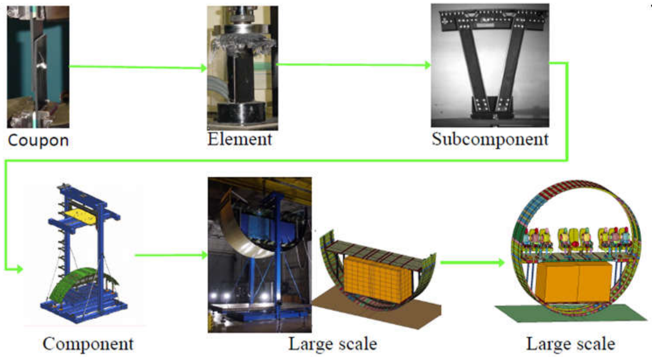
2. Overview of Airworthiness Research Center (ARC)

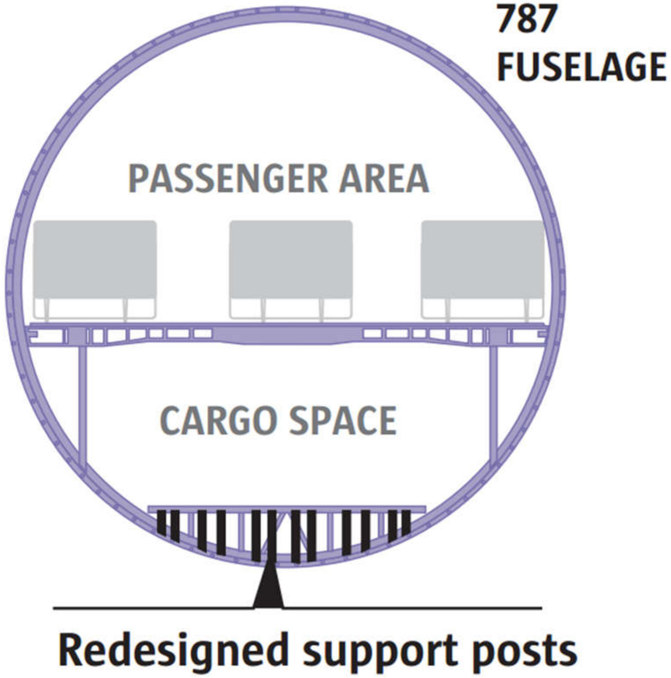
Labs:

- System Safety Lab
- Software and Hardware Lab
- Electromagnetic Environment Lab
- Crash Safety Simulation Lab
  - High performance Cluster
  - HyperWorks、LS-DYNA、PAM-CRASH...

3. Crashworthiness of B787







- 25-362-SC（Boeing Model 787-8 Airplane; Crashworthiness）

4.Study on energy absorption of Composite Structures

Develop modeling and simulation techniques based on Finite Element Analysis

Develop methods to evaluate the energy absorbing characteristics of composite structures

4.1 modeling techniques: Laminates material property test

Laminates material properties required by software

PLY	/	1	1	1.52E-6	1	---
		TITLE				
NAME		Material_Test				
E0t1		E0t2				
145.		9.				
G012		G023	G013	NU12	KAPPA23	KAPPA1
3.		3.		0.317	0.	0.
Yc		Y0	Ycp	Y0p	b	Ysp
0.04		0.01				
EPSIfti		EPSIftu	Dftu	Dsat1	Dsat2	
0.		0.	1.	0.8	1.	
IFUNd1		IFUNd2				
E0c1		GAMMA	EPSIfci	EPSIfcu	Dfcu	IBUCK
117.		0.15	0.	0.	1.	---
R0		BETA	m	A		
0.025		2.1	0.75	0.3		
SIGtu11		SIGtu22	SIGtu33	TAUpu12	TAUpu23	TAUpu13
0.		0.	0.	0.	0.	0.
SIGcu11		SIGcu22	SIGcu33	TAUnu12	TAUnu23	TAUnu13
0.		0.	0.	0.	0.	0.

Param.	Distr.	Mean	S.D.	Unit
E_x	N.D.	126	4.32	Gpa
E_y	N.D.	8.71	0.14	Gpa
G_{xy}	N.D.	3.6	0.06	Gpa
V_{ba}	N.D.	0.165	0.013	
X_t	N.D.	2571	143.98	Mpa
X_c	N.D.	1060	215.18	Mpa
Y_t	N.D.	41.8	3.62	Mpa
Y_c	N.D.	184	10.95	Mpa
S_c	N.D.	98.8	1.85	Mpa
h	U.D	1.5	0.07	mm
ID	U.D	50	0.09	mm

Tension test

Compression test

4.1 modeling techniques: composite element test

Test condition: Quasi-static load applied axially

Corrugated plate：

index	layups	initiator
1	$[0/90]_{4s}$	45° chamfer
2	$[45/-45]_{4s}$	45° chamfer
3	$[0/45/-45/90]_{2s}$	45° chamfer

Cylinder：

index	layups	initiator
1	$[0/90]_{3s}$	Null
2	$[0/90]_{3s}$	45° chamfer
3	$[45/-45/0/90/0]_{s}$	45° chamfer

Rectangular tube：

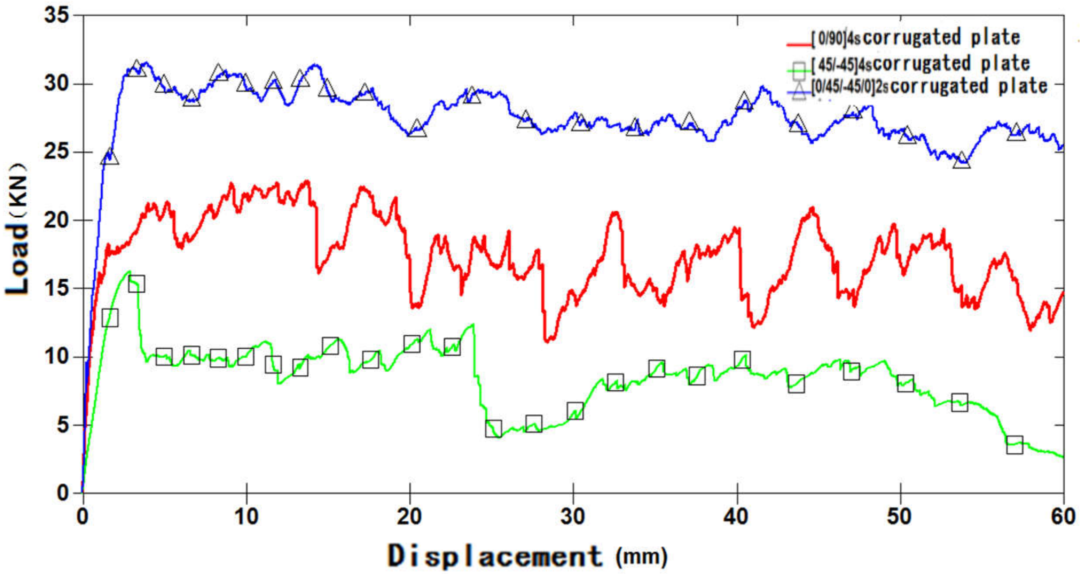
index	layups	initiator
1	$[0/90]_{3s}$	45° chamfer
2	$[45/-45]_{3s}$	45° chamfer
3	$[45/-45/0/0/90/0]_{s}$	45° chamfer

4.1 modeling techniques: composite element test

Test results for corrugated plate

index	Layups(Deg)	Peak Force (KN)	SEA (J/g)
1	[0/90]4s	21.47	59.65
2	[45/-45]4s	16.38	29.03
3	[0/45/-45/0]2s	31.66	94.19

[0/90]4s [45/-45]4s [0/45/-45/0]2s

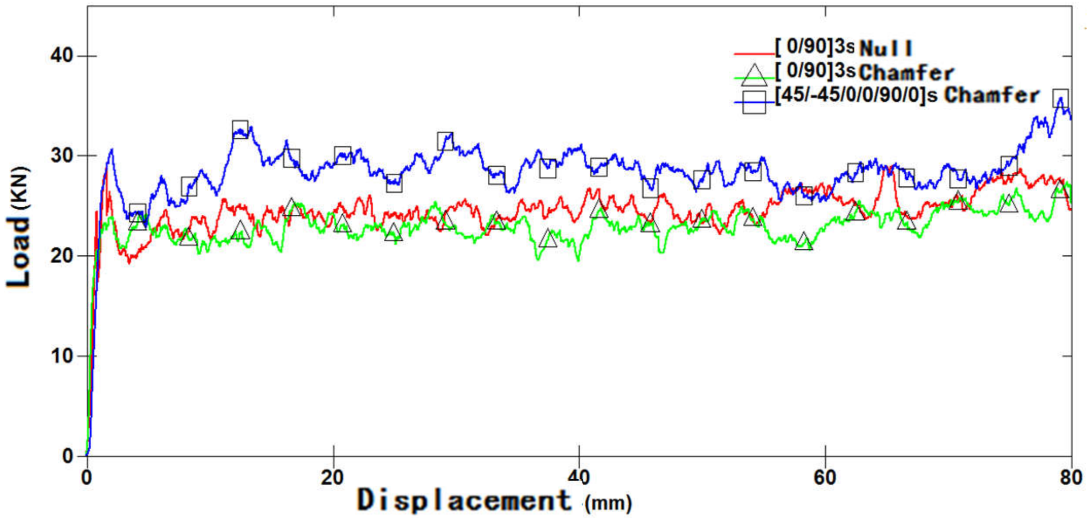


4.1 modeling techniques: composite element test

Test results for cylinder

index	Layups(Deg)	Peak Force (KN)	SEA (J/g)
1	[0/90]3s	28.81	61.78
2	[0/90]3s	24.47	58.49
3	[45/-45/0/0/90/0]s	30.73	69.68

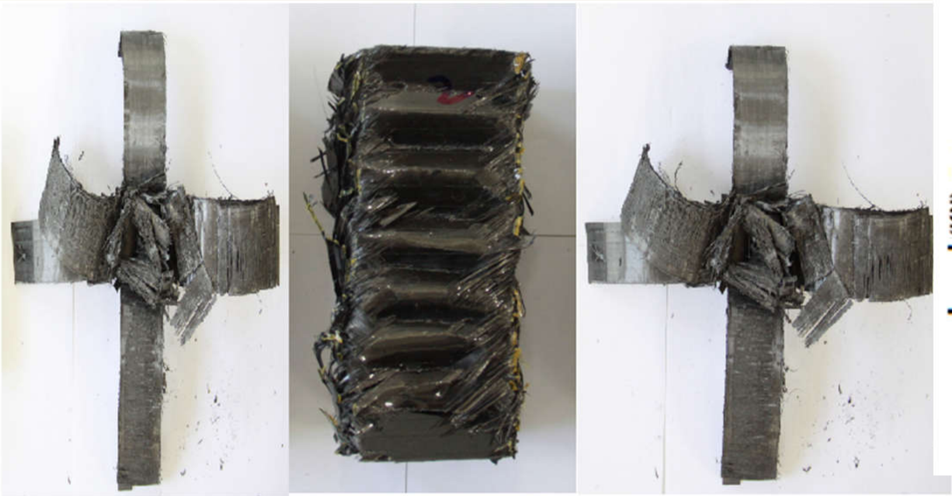
[0/90]3s Null [0/90]3s Chamfer [45/-45/0/0/90/0]s Chamfer



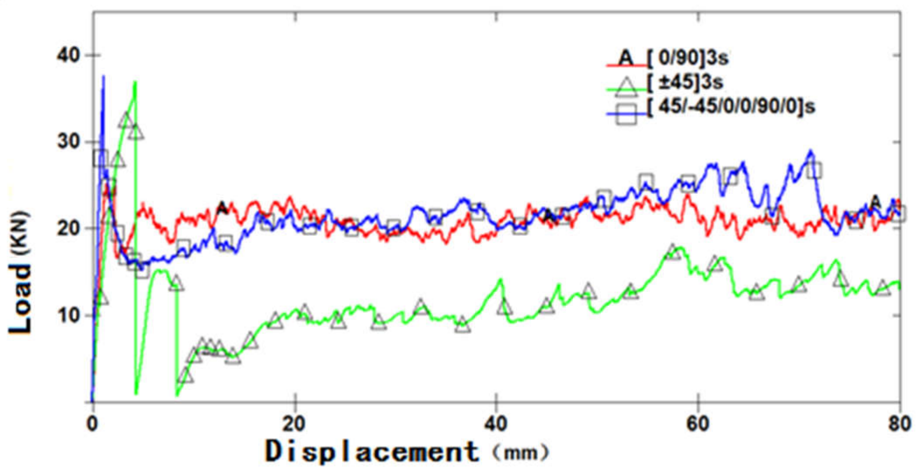
4.1 modeling techniques: composite element test

Test results for rectangular tube

index	Layups(Deg)	Peak Force (KN)	SEA (J/g)
1	[0/90]3s	25.25	44.75
2	[±45]3s	37.08	27.78
3	[45/-45/0/0/90/0]s	37.70	46.85



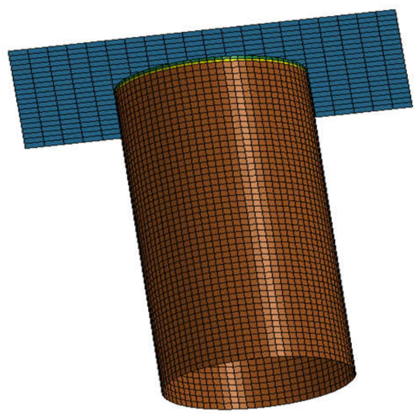
[0/90]3s [±45]3s [45/-45/0/0/90/0]s

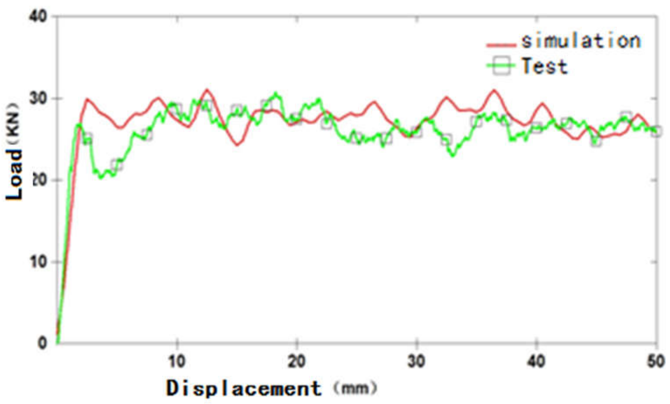


4.1 modeling techniques: benchmark

LS-DYNA MAT 54(ENHANCED_COMPOSITE_DAMAGE)

Parameter	Value	Parameter	Value
ρ	1.53 g/cm^3	Y_c	184MPa
E_x	126 GPa	S_c	98.8MPa
E_y	8.71GPa	BETA	0.0
G_{xy}	3.60GPa	FBRT	1.0
ν_{ba}	0.011	YCFAC	1.5
X_t	2571 MPa	TFAIL	0.4
X_c	1060 MPa	SOFT	0.6
Y_t	41.8 MPa	EFS	0.7





Load vs displacement

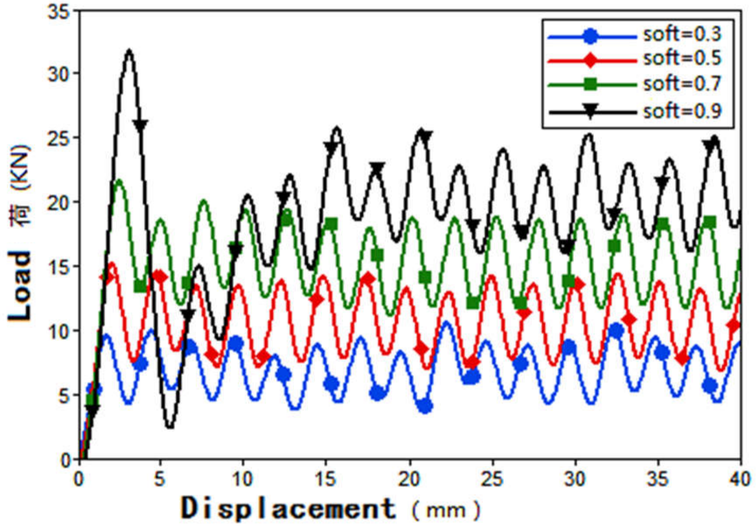
	Peak force (KN)	Error %	SEA(J/g)	Error %
test	26.67	—	74.86	—
simulation	29.58	10.91	77.41	3.82

Simulation is able to repeat test

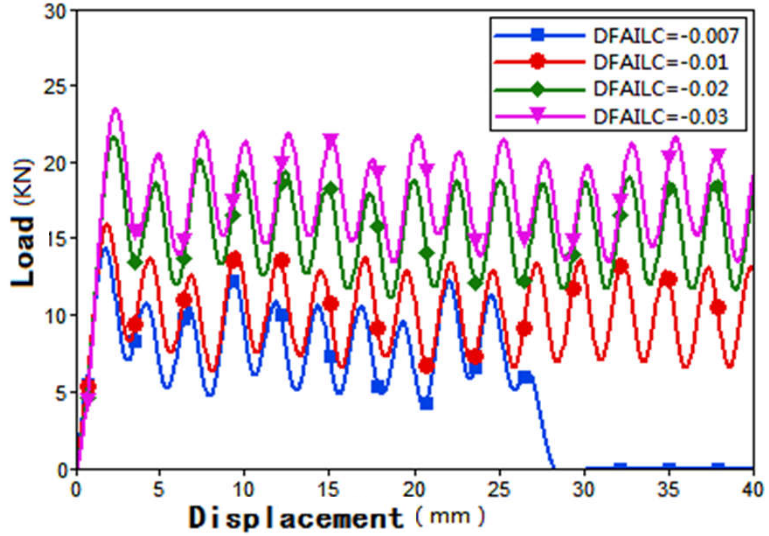
4.1 modeling techniques: Parametric study

Parameters	Beseline	Simulation matrix
XT	2571	0, 50, 500, 1000, 1500, 2000, 2500, 2550, 2700, 3500, 4500
XC	1060	0, 650, 1000, 1400, 1500, 1700, 1800, 1900, 2100
SC	84.1	0.006897, 69, 103, 120, 124, 131, 138, 207, 241, 345
YT	41.8	0, 20, 47, 52, 68, 345, 3450
YC	184	0, 35, 103, 172, 207, 242, 482, 1379, 1986, 2206, 2758, 3448
DFAILT	0	0.005, 0.00625, 0.00688, 0.0075, 0.01, 0.015, 0.04, 0.08, 0.1
DFAILC	0	-0.005, -0.0075, -0.00813, -0.00875, -0.01, -0.012, -0.015, -0.02, -0.0225, -0.025, -0.03, -0.1
DFAILM	0	0.01, 0.015, 0.0163, 0.0165, 0.018, 0.02, 0.03, 0.06
DFAILS	0	0.006, 0.01, 0.037, 0.05, 0.1
EFS	0.95	0.01, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0
FBRT	1.0	0, 0.1, 0.5, 0.95
YCFAC	3.0	0, 0.5, 2, 4, 5
SOFT	0.48	0, 0.05, 0.4, 0.55, 0.565, 0.575, 0.6, 0.8, 1.0

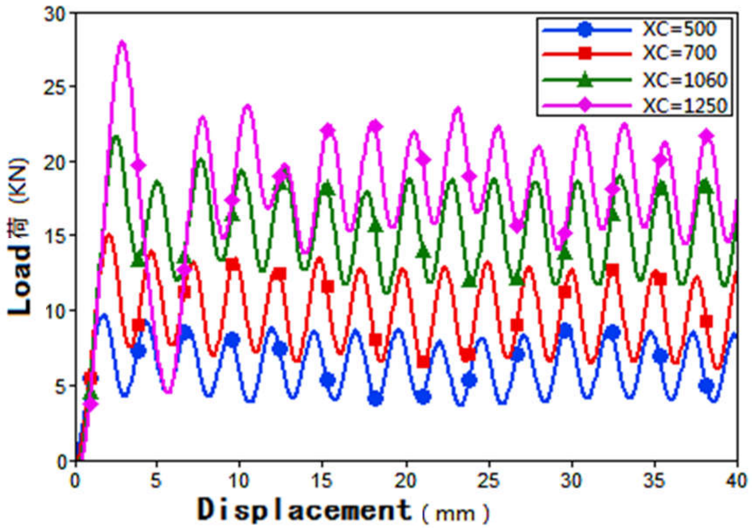
4.1 modeling techniques: Parametric study



load-displacement curves with different SOFT values



Load-displacement curves with different DFAILC values



Load-displacement curves with different XC values

4.1 modeling techniques: Parametric study

Parameters	effects
XT	major
XC	major
YT,YC	minor
SC	minor
DFAILC	major
DFAILT	major
DFAILM	major
DFAILS	minor
SOFT	major

- Simulation is not able to predict test

4.Study on energy absorption of Composite Structures

Develop modeling and simulation techniques based on Finite Element Analysis

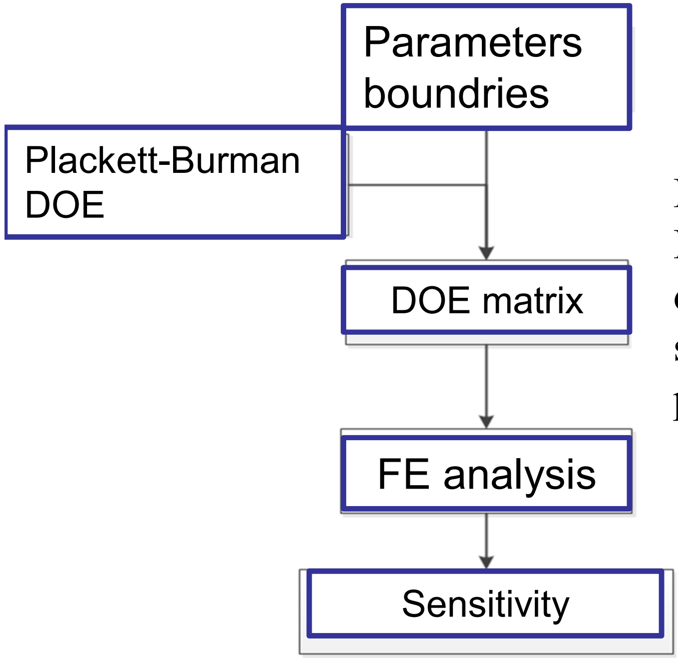
Develop methods to evaluate the energy absorbing characteristics of composite structures

4.2 Evaluation method development: uncertainty

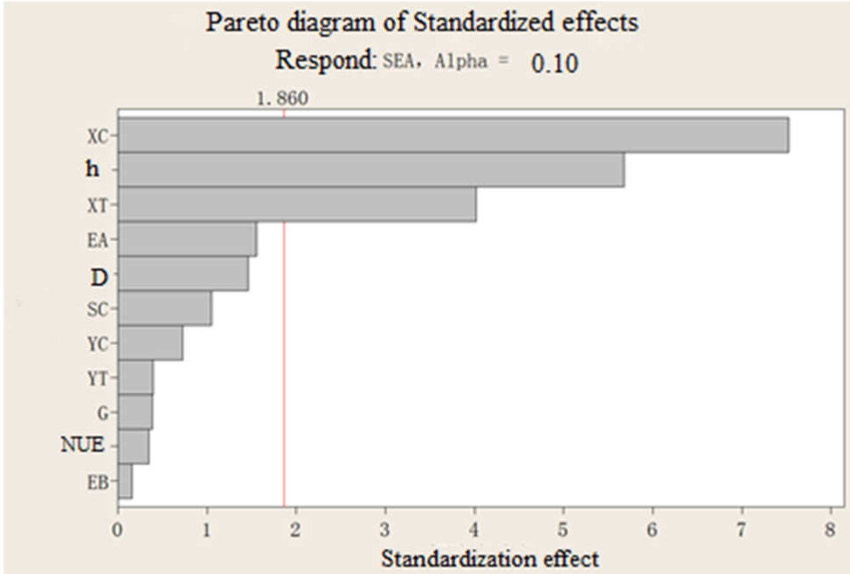
- **Due to the scattering of material properties and mechanical tolerance, uncertain factors should be considered for designing and analyzing composite structures.**
- **An evaluation method for energy-absorbing characteristics of thin-walled composite structures with uncertain parameters was proposed**

Paramter	Distribution	mean	s.d.	unit
E_x	N.D.	126	4.32	Gpa
E_y	N.D.	8.71	0.14	Gpa
G_{xy}	N.D.	3.6	0.06	Gpa
V_{ba}	N.D.	0.165	0.013	
X_t	N.D.	2571	143.98	Mpa
X_c	N.D.	1060	215.18	Mpa
Y_t	N.D.	41.8	3.62	Mpa
Y_c	N.D.	184	10.95	Mpa
S_c	N.D.	98.8	1.85	Mpa
h	U.D	1.5	0.07	mm
ID	U.D	50	0.09	mm

4.2 Evaluation method development: uncertain sources identification

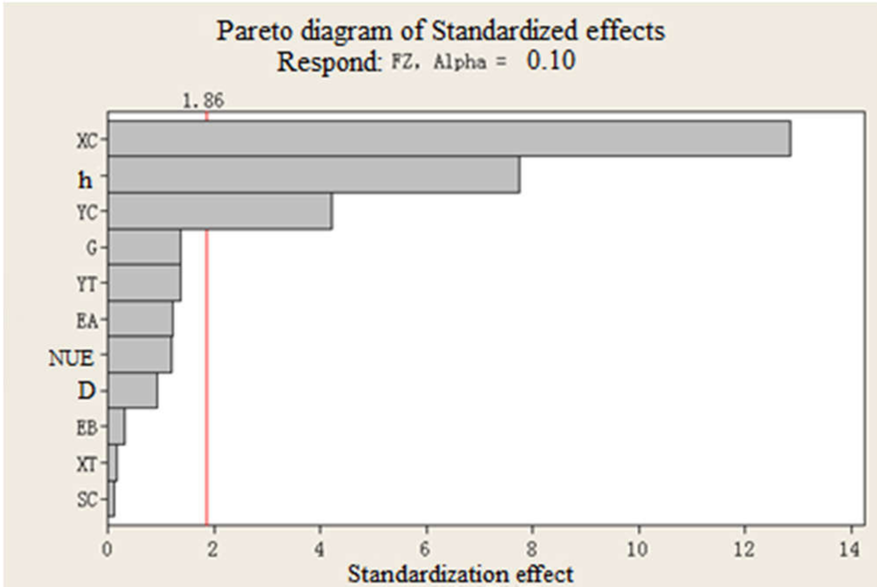


Plackett-Burman DOE is used to determine sensitivities of the parameters.

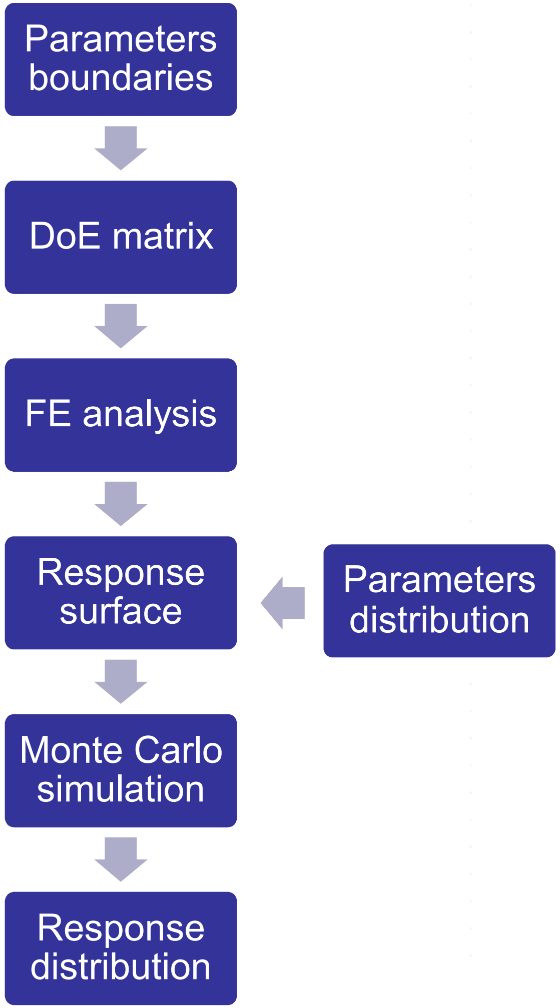


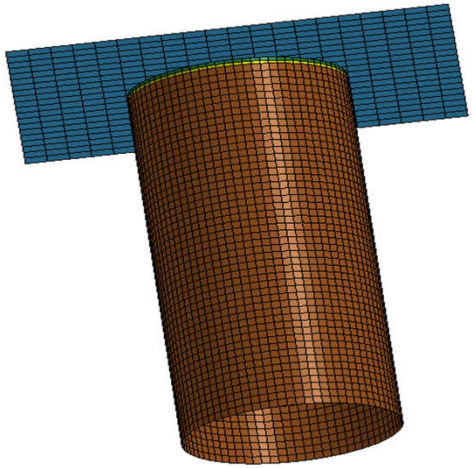
Paramter	Distribution	mean	s.d.	unit
E_x	N.D.	126	4.32	Gpa
E_y	N.D.	8.71	0.14	Gpa
G_{xy}	N.D.	3.6	0.06	Gpa
V_{ba}	N.D.	0.165	0.013	
X_t	N.D.	2571	143.98	Mpa
X_c	N.D.	1060	215.18	Mpa
Y_t	N.D.	41.8	3.62	Mpa
Y_c	N.D.	184	10.95	Mpa
S_c	N.D.	98.8	1.85	Mpa
h	U.D	1.5	0.07	mm
ID	U.D	50	0.09	mm

Four parameters are selected.



4.2 Evaluation method development: flow chart





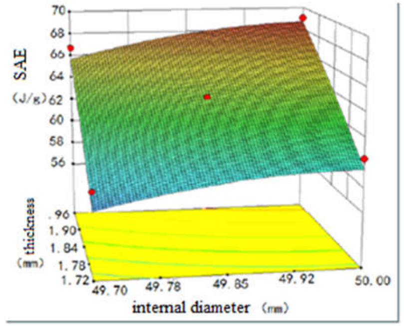
	Mean	S.D.	Distribution
XT(MPa)	2571	144	N.D
XC(MPa)	1060	212	N.D
YC(MPa)	184	10.9	N.D
h(mm)	1.5	0.069	U.D

Flow chart for evaluate EA characteristics of a composite cylinder with uncertain parameters

4.2 Evaluation method development: Response Surfaces

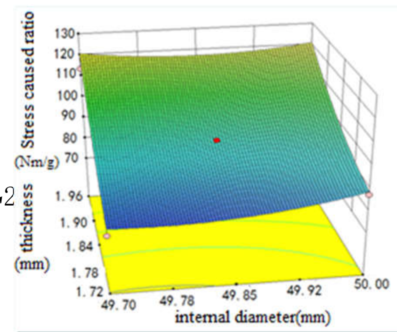
Response surfaces for SEA and Peak Force are obtained as follow:

$$SEA = -1090.12953 + 0.010317\,XC + 1572.8829\,h + 0.17386\,XT - 3.24048\,YC - 0.020277\,XCh + 1.22801e^{-5}\,XCXT + 1.22732\,e^{-4}\,XCYC - 0.11033\,hXT + 0.85432\,hYC + 3.31483\,e^{-4}\,XTYC - 9.82455\,e^{-6}\,XC^{2} - 463.44420\,h^{2} - 1.480\,e^{-5}\,XT^{2} + 2.96272\,e^{-3}\,YC^{2}$$



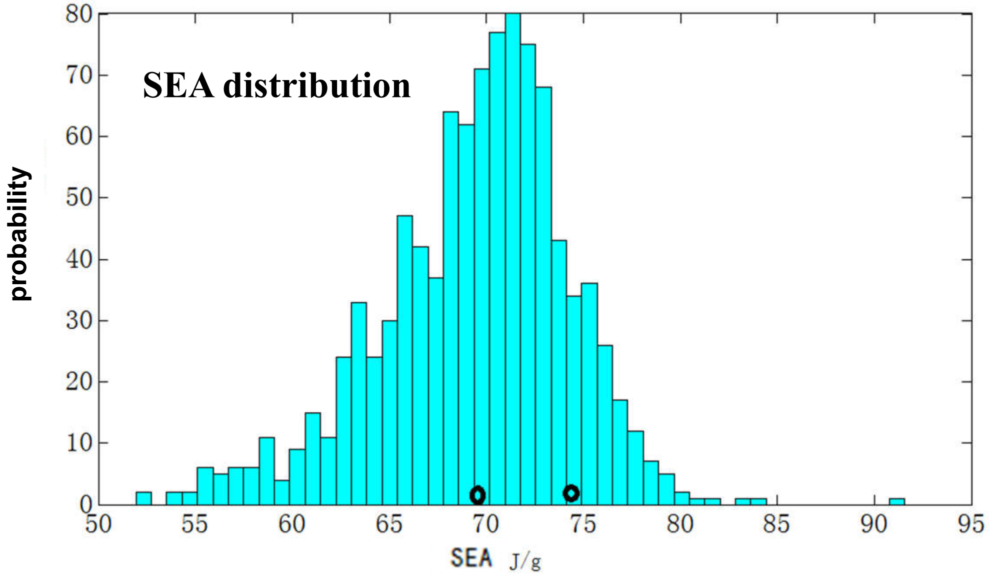
R^2=0.9556

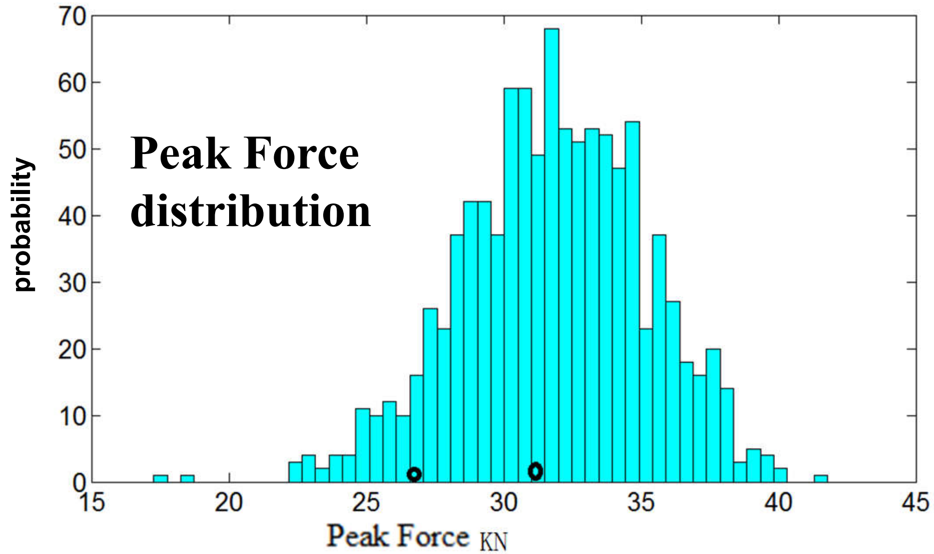
$$F_Z = -38.49872 + 0.04462XC + 122.02341h + 5.04609XT - 0.94235YC - 0.026175XCh - 4.02986e^{-6}XCXT + 1.068e^{-4}XCYC - 0.022111hXT + 0.23674hYC + 1.18459e^{-4}XTYC - 1.91683e^{-6}XC^{2} - 17.26974h^{2} + 1.66814e^{-6}XT^{2} + 7.72558e^{-4}YC^{2}$$



R^2=0.9556

4.2 Evaluation method development: Results





SEA:

- Mean: 69.39J/g
- Standard Deviation:4.92J/g
- A 95% confidence interval: [57.69,77.49]KN

Black circles in the figures represent the test results

Peak Force:

- Mean: 31.78KN
- Standard Deviation:3.35KN
- A 95% confidence interval: [25.89,38.03]KN

Thanks for your attention!

Great opportunity!