THE CRASHWORTHINESS SIMULATION AND FAILURE MODE ANALYSIS OF COMPOSITE THIN-WALLED C-CHANNEL SPECIMEN SUBJECT TO AXIAL COMPRESSION LOAD

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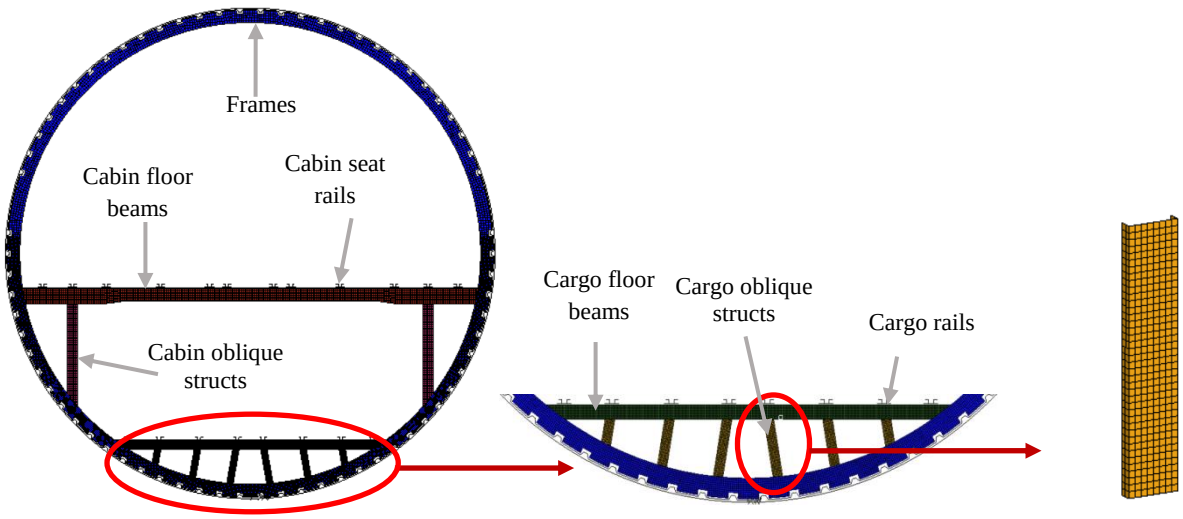
ABSTRACT

To study the crushing energy-absorbing characteristics and failure mode, the multi-layer finite element model of composite thin-walled C-channel specimen was established based on the quasi-static axial compression experiments results. The simulation results show that the delamination failure, local buckling and beam bending failure of C-channel specimen can be simulated with the multi-shells finite element model.

1 INTRODUCTION

Crashworthiness has been identified as a key area of focus to improve occupant survivability in aircraft impact events [1, 2]. For middle or large transport aircrafts, the subfloor structures have sufficient space to arrange some useful energy-absorbing components, which can dissipate the kinetic energy, maintain the acceptable acceleration and maintain the survivable volume during the impact events [3]. Because of the high specific energy absorption (SEA) and high strength-to-weight ratio, composite materials have been considered as the feasible candidates for constructing energy absorbing devices that can be integrated into the subfloor structure to increase its energy absorption capability and improve the crashworthiness of the structure. For example, to develop a prevalent energy absorbing components, The Boeing Company had designed a series of short composites energy-absorbing C-channel stanchions under the cargo floors of B787, based on the simulation results in 2005, as shown in Figure 1, and had conducted a lot of experiment and simulation to guarantee the crashworthiness level equivalent to that of the metal aircrafts. Hence, integrating the failure mechanisms of this typical component into the existing subfloor structures could mitigate the impact energy greatly and improve the safety of the occupants.



(a) Fuselage section (b) Crash zones under cargo floor (c) C-channel specimen

Figure 1 Fuselage section structure and crash zone

In this study, based on the size and quasi-static axial compression experiments of composite thin-walled C-channel specimen in reference [4], the multi-layer finite element model were developed by using LS-DYNA to simulate the crushing process.

2 FINITE ELEMENT MODEL

The specimen was fabricated from Hexcel IM7/8552. The appearance and detailed dimensions of composite C-channel specimen were shown in Figure 2. The composite C-channel specimen was consisted of 10 layers of unidirectional laminates with orientations $[0/0/+45/-45/0]_s$, and each layer thickness was 0.15 mm. The 45-degree chamfer sided weakness was set up at the top of the composite C-channel specimen in order to initiate steady crush, as shown in Fig.3. The uniform crushing rate was 7.6 mm/min. The typical morphology of composite C-channel specimen after crush testing was shown in Figure 2.

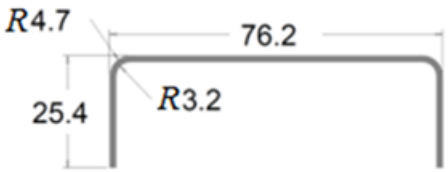


Figure 2 Size of C-channel specimen

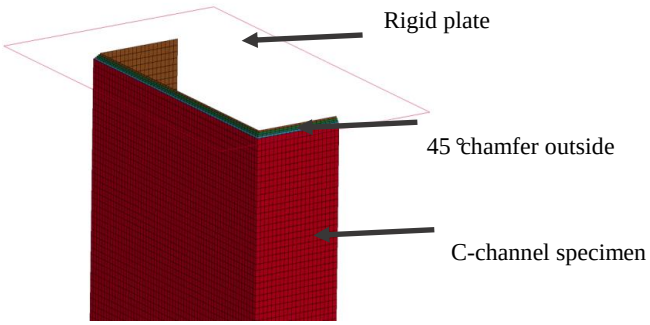


Figure 3 Multi-layered FE model of C-channel specimen

The finite element analysis was performed in Hypermesh environment with non-linear explicit transient solver.The Belytschko-Tsay shell element was chosen to establish finite element model of composite C-channel specimen. The element size was 1.3 mm×1.3 mm. The finite element model consisted of 45341 shell elements. The card * PART_COMPOSITE was used to define the 10 layers of composite C-channel specimen, and the finite element model was adopted the material model of Mat 54_Enhanced_Composite_Damage [5], which used the Chang-Chang failure criterion in the LS-DYNA theoretical manual. The material parameters of Mat_ Enhanced_ Composite_ Damage were shown in Table 1. The bottom nodes were fixed and the top were free.

Parameter	Value
Density, ρ/ （g cm^{-3}）	1.52
Longitudinal young's modulus, Ea /GPa	171.42
Transverse young's modulus, Eb /GPa	9.08
Shearing modulus in AB plate, Gab /GPa	5.29
Shearing modulus in BC plate, Gbc /GPa	3.92
Shearing modulus in CA plate, Gca /GPa	5.29
Minor Poisson's ratio, νba	0.32
Longitudinal tensile strength, Xt /MPa	2326.2
Longitudinal compression strength, Xc /MPa	1200.1

Transverse tensile strength, Yt /MPa	62.3
Longitudinal compression strength, Yc /MPa	199.8
In-plane shear strength, Sc /MPa	92.3

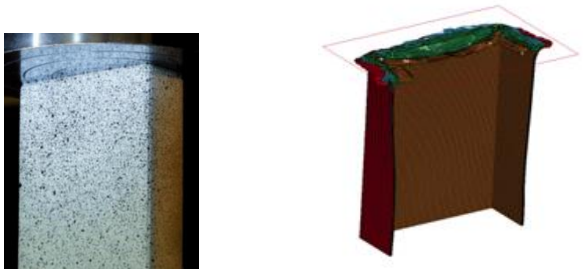
Table 1 MAT-54 material properties of composite C-channel

The loading rigid plate was modeled by using the MAT 20 material model. The automatic surface to surface contact algorithm was selected between the rigid plate and composite C-channel specimen, and the friction coefficient is 0.3. The contact tiebreak algorithm (contact one way surface to surface tiebreak, option 8) was used to define the connections among the shell elements of composite C-channel specimen.

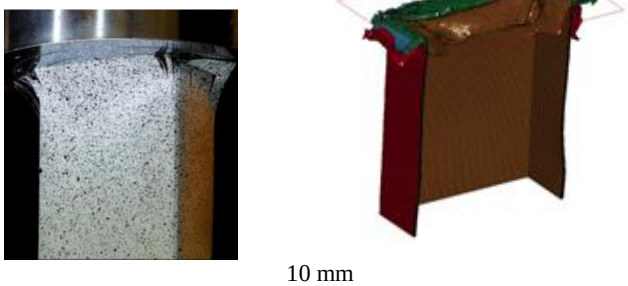
3 RESULTS AND ANALYSIS

The results were compared with experiments in terms of the load-displacement curve, specific energy absorption (SEA), and failure process to verify the consistency of the model. And result analysis was performed to investigate the energy absorption capacity and failure characteristics of the composite C-channel specimen.

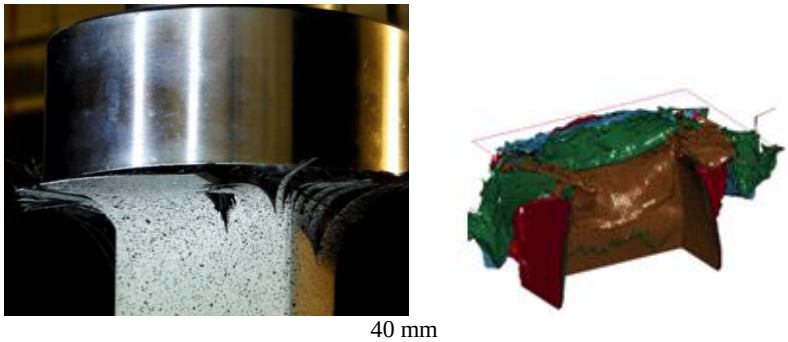
At the beginning of crushing, the simulation accurately predicted the damage initiation as the chamfer crushes and the buckling in the flanges and web with increasing crosshead displacement. As the crushing progresses, the simulation predicted the formation and growth of matrix cracks at the corners and in the web of the C-channel, as well as outward splaying of the outer plies, Figure 4.



1.5 mm



10 mm

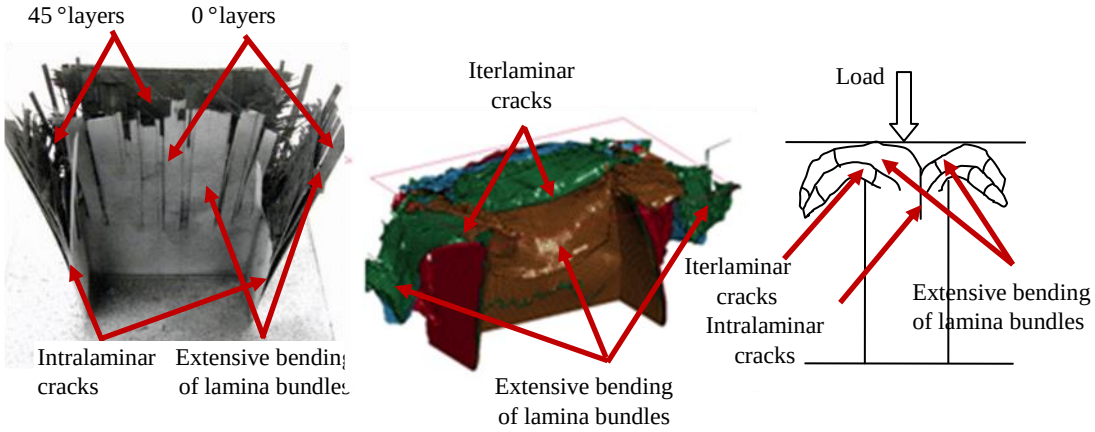


40 mm

(a) Experiment (b) Simulation

Figure 4 Comparison of experimental and numerical crashing progress

The experimental failure model, numerical failure model and the bending failure mode were shown in Figure 5. Stable progressive crushing processes with local buckling failure mode [6] were observed during experiments. The compressive failure is shown in Figure 5(a) and illustrated in Figure 5(c). The simulation results show that the delamination failure, local buckling and beam bending failure of C-channel specimen can be simulated with the multi-shells finite element model. The energy-absorbing mechanism could be discussed in combination with explanation of local buckling failure mode.



(a) Experimental failure mode; (b) Numerical failure mode; (c) Bending failure mode

Figure 5 Comparison of experimental and numerical failure model

The load-displacement curve, as shown in Figure 6, fit well with the test results, and the deviation of initial peak load, specific energy absorption and crushing mean load was small compared with the test results. The initial peak load of C-channel specimen was larger and the load efficiency was lower. It is necessary to further reduce the initial peak load by optimizing design.

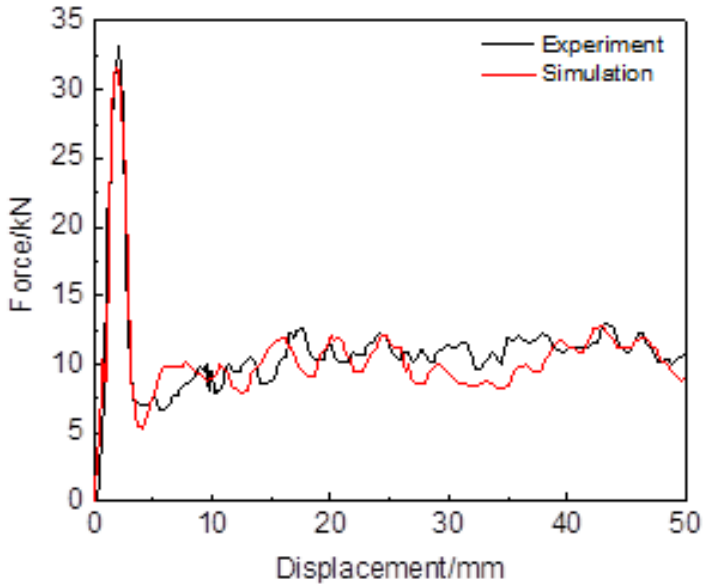


Figure 6 Load-displacement curves of experimental and numerical results

The SEA is the energy absorbed per unit of mass of crushed materials. The CE is defined as the ratio between the average crushing load and the initial peak load. In Table 2, the values of those parameters aforementioned were calculated from load-displacement curve as shown in figure 6.

	Initial peak load (kN)	Difference (%)	Mean crushing load (kN)	Difference (%)	SEA (kJ/kg)	Difference (%)
Experiment	33	—	10.93	—	38	—
Simulation	31.67	4.03	10.50	2.71	36.97	1.06

Table 2 The comparison of experimental and numerical results

4 CONCLUSIONS

The main conclusions are listed as follows: (a) The multi-layer modelling approach is capable of approximately capturing the progressive failure process for the composite C-channel specimen undergoing progressive crushing. (b) The multi-layer modelling approach is able to yield good correlation with experimental load- displacement curves generally. (c)The more analysis will be further studied to explain the influence law of layer sequence and failure mechanisms.

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