Finite element model and experimental verification of Glare laminate impact

X CUI\textsuperscript{1, a}, Z Y Zhang\textsuperscript{2, b}, S Wang\textsuperscript{2, c}

\textsuperscript{1}College of Civil Aviation, Shenyang Aerospace University, Shenyang, China
\textsuperscript{2}College of Aerospace Engineering; Shenyang Aerospace University, Shenyang, China

Email: \texttt{a772528788@qq.com, b285226827@qq.com, cwangshuo2552@sina.com}

Abstract. In this paper, a finite element simulation model is established for the impact of Glare laminates, and the reliability of the model is verified by experiments. Glare applies the continuum damage mechanics (CDM) model and inputs the user material subroutine VUMAT to determine the damage of the material based on the theory of CDM under plane stress state. By comparing the ultrasonic scanning experiment after impact damage with the CDM finite element simulation cloud pattern used in this paper, the constitutive relation of the fibre continuous damage model used in this paper can better simulate the damage initiation, evolution and damage of internal materials.

Keywords: Glare; CDM; VUMAT in Abaqus; Low speed impact

1. Introduction
In order to improve the damage tolerance of aviation structures and reduce the quality of structures, the aviation industry has been devoting itself to the development of new materials. Glare is a new generation of fibre reinforced metal laminates developed to solve the problem of fibre breakage in ARALL under fatigue loading \cite{1}. It is made of 0.3-0.5mm thick aluminum alloy sheet and 0.25-0.5mm thick unidirectional or bi-directional glass fibre reinforced composite material laying and pressing in a specific order. The prepreg layer is bonded with epoxy resin and glass fibre. The number of layers can be selected according to the design requirements \cite{2}.

As a new practical composite material with super-hybrid structure, the failure mode of Glare laminates under impact is relatively complex \cite{3}, which not only includes metal layer cracking and fibre layer cracking\cite{4}, but also has an important failure mode, namely interlaminar debonding. Therefore, the simulation of the impact of Glare is complicated. In the theoretical study and numerical simulation of interfacial debonding, many new theoretical models and methods have been proposed by scholars at home and abroad. For example, Jiang et al \cite{5} proposed a concise constitutive model for interface debonding, which describes the interface cracking process in mixed mode. The simulation results in finite element software LS-DYNA are in good agreement with the experimental results. Turon et al \cite{6} proposed a thermodynamic damage constitutive model of layered interface under thermo-mechanical coupling. The model is based on damage mechanics theory, fully considering the thermodynamic effect of interface, and avoids the interpenetration of adjacent layers after debonding. Compared with the experimental results, the numerical prediction has better results. Li Biao et al \cite{7} proposed a new interface element for simulating interface debonding, which combines rigid element and zero-thickness cohesion element \cite{8}. On the premise of ensuring the accuracy of calculation, it can reduce the number of elements in the interface crack tip area, reduce the calculation scale and improve the calculation
efficiency. Using this element, the interface cracking of FMLs can be well simulated in the simulation of mixed bending test and double cantilever beam tension test [9].

Based on previous studies, this paper conducts finite element modeling and simulation of low-speed impact of GALARE laminates by abaqus under the theory of continuous damage medium.

Finally, the finite element model is verified by experiments.

2. Finite element simulate method

In this study, for the finite element modeling of Glare laminates subjected to impact, we divide the Glare laminates micro-structure into three parts: fibre reinforced composite layer, metal layer and bonding layer[10].

For fibre composite layers in Glare. By comparing various failure , such as the classical HASHIN failure criterion. The theoretical model of Continuous damage MODLE is selected[11].

CDM mechanics includes three parts: damage characterization, damage determination and damage evolution [12]. Corresponding to different damage modes of composite materials, damage characterization establishes the constitutive relationship between damaged materials and intact materials by introducing damage state variables [13]. The finite element type is C3D8R Three-dimensional solid element. For metal layers in Glare, The conventional Jonson cook constitutive model is chosen for the isotropic metal layer. Find and use the properties of 5052 aluminium alloy panel. Cohesive zone theory is adopted in the bonding layer, and cohesive element built in ABAQUS is used to realize the bonding between layers [14].

The simulation process of the failure problem is realized by adding damage subroutine into ABAQUS finite element software. The model (three-dimensional solid model) uses Shokrieh's improved Hashin failure criterion to judge the failure mode of the model, and degrades the material properties [15]. Four failure modes are considered in the model: matrix tensile or compressive failure, fibre tensile or compressive failure, fibre matrix shear failure, normal tensile or compressive failure [16].

According to the above failure criteria, the progressive damage judgment process as shown below can be summarized:

![Progressive damage assessment procedure](image-url)

*Figure 1. Progressive damage assessment procedure.*
3. Manufacturing and impact testing

3.1. Part of manufacturing

Glare5 types laminates were used in this study, laminates consist of four 0.3 mm thick 2024-T3 aluminium layers, bonded together with glass fibre prepregs S2-glass/X1101. In Glare5, each glass prepreg laminate between the aluminium plates is made of uni-directional (UD) plies with a layup of [0/90/90/0]. The size of prepreg (Fig 2a) and aluminium alloy sheet cut to 110 cm × 110 cm.

Figure 2. Basic materials and pretreatment.

Prior to bonding, the aluminium surfaces were pre-treated with chromic acid anodizing and primed with X1101 (Engineered Materials, Key Laboratory of Advanced Polymer Matrix Composites in Liaoning Province, China). The surfaces pre-treated aluminium plates are shown in the figure 2b.

Glare plates are manufactured using Hot-pressed Autoclave in the Composite Materials Laboratory of Shenyang Aerospace University, China, Showing in fig 3. Hot-pressed Autoclave links to the digital operating table, which can be heated according to the set temperature curve, and can also be pressurized according to the set pressure curve.

Figure 3. Hot-pressed Autoclave Manufacturing.

3.2. Part of impact testing

The standard drop hammer impact test bench is used in the experiment, including fuselage, frame, upper platform and lower platform. The chassis is installed on the upper platform. The chassis consists of a box-shaped frame, a driving stepper motor, two lead screws and two polished rods. The fuselage consists of two parallel guide pipes fixedly connected to the bottom of the mounting pedestal, a driving
device for adjusting the impact height, a hammer body and an anti-secondary impact device. Fig 4 is standard drop hammer impact test bench.

Figure 4. Standard drop hammer impact test bench.

After the finite element simulation, corresponding experiments are set up to verify the simulation results. In order to study the damage of glitches caused by low-speed impact, we set different impact energies and respectively tested the impact damage of blazes at different energies. Different impact energy can be achieved by changing the height of the test bench punch. The height of the punch is 0.1 to 2.3 m, the mass of the punch is 2.6 kg, and the tip radius of the punch is 8 mm. The impact energy of the punch is 10.22j, 12.38j and 14.46j. The impact velocity is calculated from the kinetic energy of the punch [17].

4. Results and discussion
Metal layered observation results, such as Fig 5 shows that upper Aluminum layer (a) and lower Aluminum ply layer (b). It can be observed that the plastic deformation of the uppermost metal laminate is evenly distributed throughout the laminate, while the plastic deformation of the lowermost metal laminate is concentrated at the impact point. Similarly, we can observe that in the composite layer, the degree of matrix crack and interface damage also increases gradually from top to bottom.

(a) upper Al layer (b) lower Al ply layer

Figure 5. Damage model: plastic dissipation in Aluminum.
As shown in the following Figure 6, the bottom illustration shows four layers of composite laminates from top to bottom. It shows areas of plastic deformation in Aluminum layers, debonding in cohesive interface elements and matrix failure in composite plies. These areas are mainly concentrated around the impact. Some plastic dissipation owing to clamping can be observed in the upper Aluminum layer. More damage is observed in the lower plies owing to bending. The damage area in the lower Aluminum ply and the lower interface layer is significantly larger than in the corresponding upper layer.

5. Conclusion
In this paper, for the Glare laminate, we have done the finite element simulation and experimental verification of the low-speed drop hammer impact test, and finally reached the relevant conclusions. The continuous damage model (CDM) constitutive relation of the fibre used in this paper simulates the damage initiation, evolution and damage of the internal material better, and provides a dynamic response for the predicted Glare plate under impact load. A good theoretical basis. From the comparison of the ultrasonic scanning experiment and the finite element simulation cloud image after the impact damage, the tensile stress of the 90° layer of the Glare plate is greater than the tensile stress of the 0° layer, and the compressive stress of the 0° layer is greater than 90°. Compressive stress; and the tensile stress on the back side of the Glare board is particularly prominent.

6. References
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