Research on anti-explosion performance of a new composite structure

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Abstract. A rigid-flex composite composite structure is proposed and its impact resistance under blast load impact is studied. Using the finite element software Abaqus/Explicit, the three-dimensional Hashin failure criterion was established by writing the VUMAT subroutine, and the three-dimensional solid finite element model of the composite laminate was established by using the Cohesive interface unit as the bonding layer. The reliability is verified by comparing the simulation results of the finite element model with the results of the existing literature. Through simulation analysis, it is found that after adding the flexible layer, the energy absorption capacity of the structure is improved, the resistance to deformation is slightly reduced, the design requirements are met, and the expected effect is achieved.

1. Introduction

In recent years, composite materials have been widely used in aerospace, protective engineering and other fields due to their high specific modulus, specific strength, their design and shock absorption. In recent decades, terrorist attacks have brought enormous economic losses to many countries around the world. Among them, the bombing of buildings is the biggest loss. Therefore, the study of the protective structure of buildings is particularly important.

Composite materials are made up of multi-phase materials, and the components are complemented by each other, complementing each other and making up for the shortcomings of a single material. Therefore, the composite materials can combine the characteristics of various constituent materials to make a material have various properties. The composite laminate has a combination of multiple layers of single-layer sheets to expand the performance of the sheet.

For the impact of composite laminates, scholars at home and abroad [1, 2] have begun their research. Gargano A et al. [3] studied the dynamic response of laminates combined with glass fiber reinforced composites and polyethylene matrix with higher toughness under the impact of explosion, and found that it exhibits higher toughness and flexural capacity. Kenneth B Morrill et al. [4] proposed the use of composite winding columns to enhance their antiknock ability. Pingkarawat K et al. [5] carried out an explosion impact test on carbon fiber composite laminates with different matrix bond strengths, and found that fiber reinforced composite laminates have higher flexural strength and interlaminar fracture, compared with weak fiber matrix interface bonding. The toughness is higher, the ability to withstand explosion shocks is stronger, and the residual strength after the impact load is also higher. Yang Jie et al. [6] found that the glass fiber reinforced silica aerogel as the composite elastic layer of the elastic properties, greatly improved the integrity after impact. Mourtize AP et al. [7] calculated the propagation law of shock wave in the three-layer medium of "steel plate-porous
aluminum-steel plate" and the impact load in each layer of medium, and carried out the attenuation process of stress wave in porous composite structure. Li Xiudi et al. [8] studied the failure mode of the protective door under the action of the explosion shock wave. It was found that the damage mode of the protective door gradually changed from bending failure to bending failure due to the increase of the distance from the explosion source.

It can be found that most of the composite laminates currently used for explosion research have only one single-layered board, which fails to maximize the structural function of the composite laminate. In this paper, a rigid-flex composite laminate is proposed. By adding a flexible single-layer board, under the premise of meeting the requirements of resistance to deformation, the energy absorption effect of the structure is improved. And the quality of the composite laminate can be further reduced, so that the structure is safe and economical.

2. Numerical simulation and verification

Today's finite element programs allow simulations to be performed under these dynamic conditions without the need for destructive air impact experiments [9]. You can use Aabqus / Explicit to simulate.

2.1. Finite element modeling

The composite laminate has a total of 21 single-layer boards and 20 layers of cohesive elements. The dimensions of the laminate are: 200 x 200 x 4.4 mm, the thickness of the single layer is 0.2 mm, and the geometric thickness of the cohesive unit is 0.01 mm. CONWEP blast loading was performed using Abaqus / Explicit, and the CONWEP blast load was applied to the top surface of the plate. The source of the explosion was 300 mm perpendicular to the center of the top surface and the explosive equivalent was 150 g. The property of the blast load is specified using the incident wave interaction property and the CONWEP charge property at the model level and the incident wave interaction at the step level. The entire operation process uses a unit system of t-mm-s-k. A fixed boundary is used and the grid size is 2mm × 2mm. Because the material parameters of the laminate are anisotropic, it is not possible to use symmetry to simplify the model and reduce the amount of calculation. The whole model needs to be modeled. The final finite element model is shown in Figure 1.
The material parameters [10] of the rigid laminate and the material parameters [11] of the flexible board are shown in Table 1 and Table 2, respectively. The material parameters [12] of the cohesive elements are shown in Table 3.

Table 1. Material parameters of rigid plates.

|   |   |   |   |   |   |
|---|---|---|---|---|---|
| E1  | E22=E33 | G12=G13 | G23 | μ12=μ13 | μ23 |
| 149000 | 10300 | 7500 | 3450 | 0.29 | 0.45 |

Table 2. Material parameters of flexible plates.

|   |   |   |   |   |   |
|---|---|---|---|---|---|
| E11 | E22=E33 | G12=G13=G23 | μ12=μ13=μ23 |
| 12630 | 4590 | 2330 | 0.235 |

Table 3. Material parameters of cohesive elements.

|   |   |   |   |   |
|---|---|---|---|---|
| E_{nn} | E_{ss}=E_{tt} | N | S=T | η |
| 13733 | 4933 | 62.3 | 92.3 | 1.45 |

2.2. Verification of numerical simulation

Make an numerical simulation of the experimental process of Dharmasena et al. [13] with continuum elements. During numerical simulation, the size and material of the composite laminate, as well as the distance and equivalent of the explosive, were the same as the experiment. The numerical simulation results and experimental results are shown in Figure 2, and the two have good consistency, indicating that the Abaqus numerical simulation method is reliable and the calculation results are accurate.

![Figure 2. Comparison of center deflection between Abaqus and experiment.](image-url)
3. Numerical simulation results analysis

3.1. Resistance to deformation of laminate

After the impact, the laminate will reciprocate and the deformation is difficult to analyze. Therefore, the deformation of the laminate is represented by obtaining the maximum displacement of the finite element model, that is, the displacement of the center of the finite element model. Figure 3 shows the displacement of the center point under M1 and M2 conditions.

![Figure 3. Comparison of center deflection between M1 and M2.](image)

Through the Figure 3, it can be found that in the calculation process, the displacement values of the center points under the M1 and M2 operating conditions are gradually increased from 0, and the value of the M1 working condition is always lower than the M2 working condition, and as time increases, two The gap between the people has increased slightly. The calculation results show that the ability of the laminate after the addition of the flexible layer to resist impact deformation is slightly reduced.

3.2. Energy absorption capacity of laminate

When an explosion occurs, a large amount of gas is released, which generates high temperatures and releases a large amount of capacity. Therefore, the energy absorbing ability of the laminate is a particularly important indicator of the anti-explosion impact performance of the laminate. The energy absorption capacity of the laminate can be obtained by analyzing the total strain energy under two conditions [14]. Therefore, this section compares the energy absorption abilities of the two models by capturing the maximum strain energy of the finite element model under two operating conditions.
Figure 4. Comparison of ALLIE between M1 and M2.

From Figure 4, it can be found that the total strain energy of the M2 condition is higher than the total strain energy under the M1 condition, which indicates that the energy absorption effect of the laminate under the M2 condition is better than that of the laminate under the M1 condition. That is, the energy absorption effect of the laminate added to the flexible layer is better than that of the laminate without the flexible layer. Therefore, it can be concluded that the anti-explosive energy absorption effect of the composite laminate is enhanced after the addition of the flexible layer, which is consistent with the expected result and has practical value.

4. Conclusions

At present, in the field of composite mechanics, there are not many numerical simulation analysis of blast using finite element software Abaqus. This paper can provide some basic modeling methods and analysis techniques for other scholars. Composite laminates can be designed on the basis of their composition to achieve the desired results. After the composite laminate is added to the flexible layer, the deformation resistance is slightly lower than that of the laminate with all the rigid layers, but its energy absorption capacity is strengthened. In the case of explosion shock, the practical type is strengthened.

This is a very meaningful finding because researchers can use this conclusion to conduct further research. Within the appropriate range, the total number of layers of the composite laminate is kept constant, the number of layers of the flexible board is increased to increase the energy absorption ability of the laminate, or the number of layers of the flexible board is reduced to improve the resistance to deformation.

What's more, researchers can further study the model to maximize the value of this model. That is finding a balance between the resistance to deformation and the ability to absorb energy under CONWEP blast loading. After finding this balance point, researchers can develop composite laminates with the best overall performance and minimize damage and loss when an explosion occurs. At last, achieve results that is practical and economical for the whole society.
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