Application of Foldcore Sandwich Structures in Helicopter Subfloor Energy Absorption Structure

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Abstract. The intersection element is an important part of the helicopter subfloor structure. The numerical simulation model of the intersection element is established and the crush simulation is conducted. The simulation results agree well with the experiment results. In order to improve the buffering capacity and energy-absorbing capacity, the intersection element is redesigned. The skin and the floor in the intersection element are replaced with foldcore sandwich structures. The new intersection element is studied using the same simulation method as the typical intersection element. The analysis result shows that foldcore can improve the buffering capacity and the energy-absorbing capacity, and reduce the structure mass.

1. Introduction

When considering the ability to absorb kinetic energy, the subfloor structure is one of the most important structural components in helicopter. Consequently, it has to be designed to limit the deceleration forces by structural deformation and provide post-crash structural integrity of the cabin floor [1]. Figure 1 shows a typical subfloor structure. In such a structure, the structural intersections of beams and bulkheads play an important part in the overall crash response of the subfloor structure. The intersections have higher stiffness and strength, so they create high deceleration peak loads and cause dangerous inputs to the occupant system. In order to design a subfloor structure which is able to fulfil the crashworthiness requirements, it’s first of all to design a good structural intersections.

Figure 1. Typical subfloor structure.  

Experimental and numerical studies of structural intersections are conducted by Bisagni C [1-5]. A fast reanalysis methodology based on neural network is proposed with the intent to reproduce the
crash behaviour of structural intersections. Based on the method, size and topological optimization are conducted.

The foldcore structures, as shown in Figure 2, are geometric structures formed by folding plates or foils according to regular repeated lines. According to different lines, M-type (Figure 2 (a),(b)), V-type and other types of foldcore structures can be formed, even shells with large curvature (Figure 2(c)), stepped plates (Figure 2 (d)) and plates with variable thickness (Figure 2 (e)) can be manufactured using foldcore. Foldcore sandwich structures have a lot of cavities, which provides the possibility of large plastic deformation. So the foldcore has the common feature of energy absorbing structures and may have good energy absorbing capacity.

The geometric design method and the mechanics model of foldcore have been studied by Wang Z J and her team [6, 7]. Methods of designing different kinds of foldcore structures are introduced. The relations of elastic constants and geometric parameters of a foldcore are derived.

The energy absorption capacity of foldcore sandwich structures is studied by Zhang Y C. Due to his study, foldcore is proved to be a good anti-crash element [8, 9]. The basic mechanical properties of foldcore is studied by Ren Y F [10]. Experimental and numerical studies are conducted on the bending capacity of foldcore composite sandwich beams by Sun Y G [11].

Many experiments and simulations have also been conducted on the foldcore by S. Heimbs and his team [12-20]. Compression and shear experiments have been conducted on foldcore from CFRP and aramid paper. Besides, a numerical simulation method has been carried out to study the mechanical properties in all period from starting loading to the densification stage of the core. The residual strength and the impact property of honeycomb core and foldcore sandwich structures have been studied with the help of experiments and numerical simulations. In order to model foldcore with higher accuracy, a new way to model the material imperfections and geometrical defects of foldcore has been set up by E. Baranger, P. A. Guidault and C. Cluzel [21, 22]. The issue of the relation between the strength of wedge-shape foldcore sandwich structures and the geometrical parameters has been considered by Falk Hähnel and Klaus Wolf [23].

Foldcore sandwich structures have been proved to have good energy absorption capacity. In order to reduce the deceleration peak loads and improve the energy-absorption capacity of structural intersection elements of subfloor structures, foldcore sandwich structures are considered to be applied in the intersection elements. In this paper, an intersection element containing foldcore sandwich structures is designed and studied.

2. Numerical simulation model of a typical intersection element

A typical intersection element is shown in Figure 3. The engineering drawing of the intersection element experiment sample is shown in Figure 4. Comparison of the experiment sample before and after crush test is shown in Figure 5.

The finite-element analysis software ABAQUS is used to simulate the crush procedure of the intersection element. The numerical simulation model is established according to the crush test in paper [1]. The impact velocity is 7.4m/s. The geometric parameters of the intersection element sample are shown in Figure 4. The thickness of the cabin floor and the skin are 1.27mm, and the thickness of the rest panels are 0.81mm. The material used is aluminium alloy 2024 T3.

In the numerical simulation model, the element type is chosen as 4-node shell reduced integration element S4R. The impact mass is applied on a reference point. The reference point locates on the middle of the floor top surface, and is coupled with the floor top surface. Contact in the structure are modelled using ABAQUS general contact controls. The contact property is defined as “Hard” contact in the normal direction and “penalty” in the tangential direction. The friction coefficient is 0.17. The rivets are simulated by connecting nodes around the rivets of two panels using tie constraint.
Comparison of the simulation results and the experiment results in paper [1] is shown in table 1. The force-shortening diagrams obtained from simulation and experiments are shown in Figure 6. The deformed structure after experiment and the corresponding simulation results are shown in Figure 7.

|                          | Experiment result | Simulation result | Error/% |
|--------------------------|-------------------|-------------------|---------|
| Peak load/kN             | 52.0              | 50.1              | 3.65    |
| Average load/kN          | 25.5-28.0         | 22.8              |         |
| Mass/kg                  | 0.481             | 0.481             | 0.00    |
| Specific energy absorption/KJ/kg | 6.5       | 6.29              | 3.23    |

Figure 3. A typical subfloor intersection element.  
Figure 4. Engineering graphic of a typical subfloor intersection element sample.  
Figure 5. Comparison of the experimental sample before and after crush test.  
Figure 6. Comparison of the force-shortening diagrams of the simulation and experiment results.  
Figure 7. Comparison of the experimental sample before and after crush test.
It can be concluded from the comparison above that the simulation method can correctly reflect the crush procedure of the intersection element.

3. Intersection element with foldcore sandwich structures

The intersection element with foldcore sandwich structures can be got by replacing the skin and the floor of the intersection element with foldcore sandwich structures. The floor is replaced with V-type foldcore structure and the skin is replaced with M-type foldcore structure. The two kinds of foldcore are shown in Figure 8. The simulation method of the foldcore sandwich structures are introduced in paper [24, 25].

The height of the folded core sandwich structures is set as 20mm. In order to maintain the bending stiffness of the skin and the floor, the thickness of the foldcore sandwich structure plates can be calculated as follows:

The bending stiffness of a panel can be calculated as follows:

\[ D = \frac{E t^3}{12(1-\mu)} \]  

In formula (1), \( D \) is the bending stiffness, \( t \) is the thickness of the panel, \( E \) and \( \mu \) are the elastic model and the Poisson ratio of the material of the panel.

\[ D_s = \frac{E_s t_s}{6(1-\mu_s)} \left(H_s^2 - 2H_s t_s + 4t_s^2 \right) \]  

In formula (2), \( D_s \) is the bending stiffness of the sandwich structure, \( t_s \) is the thickness of the plate, \( E_s \) and \( \mu_s \) are the elastic model and the Poisson ratio of the material of the plate, and \( H \) is the height of the folded core.

Let \( D \leq D_s \), \( H=20 \text{mm} \), \( t=1.37 \text{mm} \), it can be calculated that:

\[ t_s \geq 0.002 \text{mm} \]  

Considering the manufacturing technology and the ability to resistant impact, \( t_s \) is set as 0.3mm.

The height of the intersection element is 195mm, which is the distance of the middle surface of the skin and the floor. The height of the foldcore sandwich structures is 20mm, so the height of the beams and the angle elements are 175mm. The geometric parameters of other panels don’t change. The parameters of the foldcore are set as: \( H_M=H_V=20 \text{mm} \), \( A_M=A_V=15 \text{mm} \), \( a_M=a_V=30^\circ \), \( \lambda_M=\lambda_V=20^\circ \), \( B_M=5 \text{mm} \), the material of the foldcore is also aluminium alloy 2024 T3, and the thickness is 0.15mm. The intersection element structure with foldcore sandwich structures is shown in Figure 9.

Crush simulation of the structure is conducted. The impact velocity, impact mass and the boundary conditions are the same as the typical intersection element model. The deformation process of the
structure with foldcore sandwich structures is shown in Figure 10. The force-shortening diagrams are shown in Figure 11 and the acceleration of the impact mass-shortening diagrams is shown in Figure 12.

Figure 9. The intersection element structure with foldcore sandwich structures.

Figure 10. The deformation process of the intersection element structure with foldcore sandwich structures.

Figure 11. The force-shortening diagrams of the intersection element structure with foldcore sandwich structures.

Figure 12. The acceleration-shortening diagrams of the intersection element structure with foldcore sandwich structures.

It can be seen from Figure 10 that the damage first appears at the foldcore near the beam webs. The deformation of the rafters produce small disturbance to the webs, so the webs buckle easier, which decreases the peak load and improves the buffering capacity of the structure. The deformation of the foldcore form concave zones near the webs. In the deformation process of the webs and the angle elements, a series of plastic hinges are generated. The concave zones can affect the position of the plastic hinges near the foldcore. Besides, the height of the webs and the angle elements are also changed. Thus the distance between two plastic hinges are changed, which improves the crush load of the structure.

The force-shortening diagrams of the intersection element structure with foldcore sandwich structures and typical intersection element structure are shown in figure 13. The crush analysis results of the two structures are shown in table 2. It can be seen that the structure with foldcore sandwich structures has small peak force and bigger crush force. It means that the structure with foldcore sandwich structures has better buffering capacity and energy-absorption capacity. Besides, the mass of the structure with foldcore sandwich structures is smaller, so it’s better compared to the typical intersection element.
Figure 13. Comparison of the force-shortening diagrams of the structure with foldcore sandwich structures and typical intersection element.

Table 2. Comparison of the simulation results and the experiment results of the intersection element.

| Variable              | Typical structure | Structure with foldcore sandwich structures | Variable ratio /% |
|-----------------------|-------------------|---------------------------------------------|-------------------|
| Peak load/kN          | 52.0              | 41.9                                        | -19.4             |
| Average load/kN       | 25.5-28.0         | 26.8                                        |                   |
| Mass/kg               | 0.481             | 0.480                                        | -0.2              |

4. Conclusions

(1) The intersection element is an important part of the helicopter subfloor structures. A numerical simulation method is established to model the crush process of the intersection element. The analysis result is compared with the experiment result and they match well.

(2) The foldcore sandwich structures are used as buffering and energy-absorbing structures in helicopter subfloor structures and the intersection element is redesigned.

(3) Compared with typical intersection element structure, structure with foldcore sandwich structures have less mass, smaller peak force and bigger crush force. It means that foldcore can improve the buffering capacity and energy-absorbing capacity of the intersection element structure.

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