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Research on Moulding Technology of Composite Payload Bay Frame

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Abstract. This paper describes a large-size grid closed cavity composite payload bay frame moulding technology, focusing on the process research of the moulding process scheme, mould design scheme and layering curing mode. The research shows that: the moulding of large-size grid closed cavity composite frame can be realized by layering the layer of each unit separately and integral co-curing. Through the process research, the key technology of integral autoclave curing and individual silicon rubber pressurization has been broken through to meet the requirements of even and stable pressure at all positions in the of moulding process of composite products. The residual internal stress can be effectively removed after several cycles' temperature variation, and then the dimensional accuracy of the frame tends to be stable in a specific temperature range. The vertical bar position deviates from 0.3mm-0.8mm, and the deviation of the frame's thickness is ±2%. The overall flatness of the plane where the installation interfaces of all key equipment are located is better than 0.2mm. The testing shows that the mechanical properties of the specimen are better than the design index, meeting the user's requirements.

Keywords: Frame, Composite, Moulding technology

1. Preface

As important parts of spacecraft, the structure and mechanism subsystems provide support and transmits loads for each subsystem. The stability of spacecraft structure plays an important role in its normal orbit operation of spacecraft [1]. The main load of earth observation series of spacecraft is usually from high precision optical camera, star sensor and other key equipment. As an important part of the main load-bearing structure of this series of spacecraft, the payload bay frame is responsible for connecting the payload bay and the service module, and provides the connection interface for the high precision optical camera, solar wing, star sensor and other important loads [2-3]. The frame of the payload bay not only bears the longitudinal, transverse and torsional loads brought by the equipment, but also needs to transfer the longitudinal loads, so it has high requirements on the structural strength. Spacecraft in orbit need to deal with the temperature field of repeated alternation, so the thermal stability of payload bay frame structure is highly required [4-5].

Carbon fibers reinforced matrix composites (CFRP) are widely used in various spacecraft due to their features like excellent specific strength, specific modulus, low density and zero thermal expansion. Integral co-curing moulding technology of composite materials is the main research direction in recent years, and research on integral moulding technology of structural products is an important way to realize high efficiency and heavy load [6-7]. Compared with the single application scenarios of autoclave moulding, compression moulding, RTM moulding and other traditional moulding methods, there are international studies on the mixed use of various pressure methods to meet the complex configuration of product moulding, among which the most widely used pressurizing material is silicone rubber. According to the study of thermal expansion of silicone rubber, by adjusting the theoretical gap between silicone rubber and the frame to control the keep pressurizing time and the pressure on the frame, the moulding quality of the frame can be guaranteed [8-12].

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2. Features of Payload Bay Frame Structure

The payload bay frame introduced in this paper is a large-size grid closed cavity frame made of high modulus carbon fiber reinforced matrix composite, which is composed of transverse and longitudinal beams, ring beams and outer frame. See Figure 1 for schematic structure diagram of the wing plates of the payload bay frame, and the 34 closed cavities composed middle grid web.

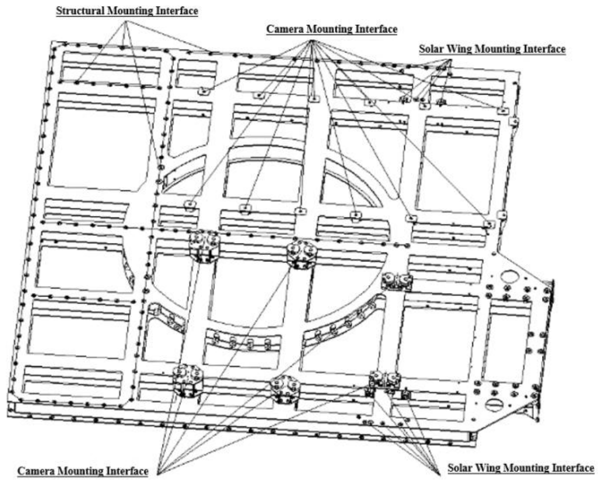

Figure 1. Payload Bay Framework Structure Diagram

3. Analysis and Validation of Moulding Technology

3.1 Scheme of Moulding Process

The frame can be divided into three parts: upper wing plate, middle part and lower wing plate according to the frame's position of vertical bar, layering design, structural characteristics and layering way. The middle part can be divided into 34 independent units. The wing plates are 3mm thick with symmetrical layering. After each unit of the middle part completes the layering prepressing independently, it is co-cured with the wing plates together. From this, how to split the lamination moulding unit, design a reliable pressure transfer mode, and maximize the accurate fibers orientation and continuous lamination are the key to realize the frame configuration and meet the requirements of design strength and dimensional accuracy.

Through the analysis of the frame structure of the payload bay, it is found that the middle part and the corner of the frame is difficult to be pressurized, and unreasonable pressurization method is easy to produce moulding defects such as delamination, porose and residual resin. Therefore, reasonable pressurization method must be designed to ensure the uniform and effective pressurization of each surface. Therefore, the frame is pressurized by autoclave, and each cavity is supported by metal mould enfolded by silicone rubber, so as to ensure that each part of the frame can be simultaneously pressurized and solidified during the solidification process.

3.2 Design Scheme of Moulding Mould

The mould should meet the requirement of product configuration, ensuring the uniform pressure of all parts, and completing mould installation, curing and demoulding operations. The mould is composed of top board, infrabasal plate and mandrel. Among them, the top board and infrabasal plate are not only the laying mould, but also the curing mould of the frame.

See Figure 2 for schematic diagram of mandrel sectional view. The wedge surface in mandrel and infrabasal plate are designed as guide and limit, to ensure that the position of each vertical bar meets the design requirements. The assembly wedge surface designed on the mandrel and infrabasal plate is used as the guide and limit of each unit's moulding to ensure that the position of each vertical bar meets the design requirements. The mandrel is made of R-10301 silicone rubber

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wrapped 45# steel metal mandrel structure. In order to ensure the uniformity of pressure, silicon rubber of the same thickness is used in each cavity. Whether the frame can succeed depends on the reserved clearance between the core mould and the theoretical size of the frame.

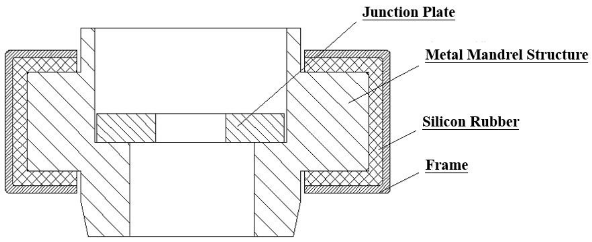

Figure 2. Diagram of diagram of mandrel sectional view

The coefficient of thermal expansion of 45# steel is 12.32×10^{-6} mm/mm • ℃. Using ANSYS software for thermal analysis of the infrabasal plate, we will have its thermal deformation diagram at the highest curing temperature, as is shown in Figure 3. To modify the dimensions of the top plate and infrabasal plate according to the results of thermal analysis, to make sure that the frame can reach its theoretical size at the highest curing temperature.

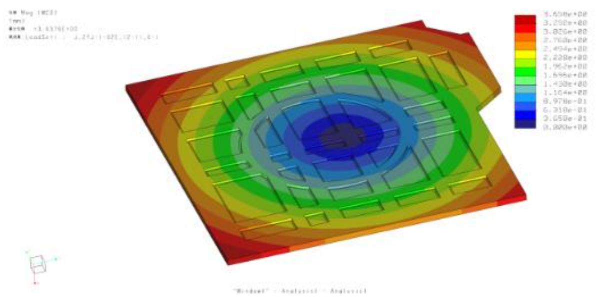

Figure 3. Diagram of thermal deformation analysis of infrabasal plate

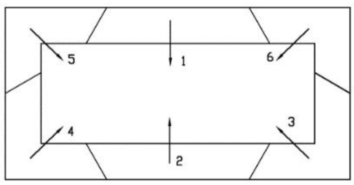

Figure 4. Diagram of demoulding sequence

In order to avoid damage to the frame caused by cold shrinkage of the metal mould during the cooling process, demoulding operation should be started after the mould temperature drops to 100℃. The demoulding sequence is in accordance with the platens - metal core mould. Among them, the mandrel demoulding is completed by taking out the blocks in the order of Figure 4.

3.3 Specimens Preparation

The forming quality of the frame is greatly affected by the thickness and thermal expansion of silicone rubber, and the reserved gap between silicone rubber and the frame plays a key role in the forming process. Considering this, trial-produce are designed according to product configuration to confirm the relationship between appropriate reserved clearance and product forming quality.

The theoretical wall thickness of the trial-produce is 4mm, and its ply stacking sequence is same as the frame. In order to facilitate the convergence of variables, the thickness of silicone rubber is set at 10mm. The curing temperature is set at (185±5) ℃, the curing pressure is set at 0.7MPa, and the curing time is 120min. With the simulation condition designed according to the above experimental conditions, the theoretical clearance value of 0.8mm can be obtained through thermal analysis simulation calculation by ANSYS software. Three kinds of trial-produce with reserved gap

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of 0.5mm, 0.8mm and 1.2mm are made respectively, and the wall thickness values measured at each position of each trial-produce after curing are shown in Table 1. It can be seen that when the gap value is set at 0.8mm, the wall thickness of the frame is uniform and closest to the theoretical value. Therefore, the size of the reserved gap is of great significance to the design of the mandrel and the final moulding quality of the frame.

Table 1. Wall Thickness of Spcimens` Each Position

Wall Thickness	Position 1	Position 2	Position 3	Position 4	Position 5
1	3.67	3.78	3.82	3.81	3.86
2	3.97	4.01	3.96	3.93	4.05
3	4.31	4.28	4.37	4.12	4.22

3.4 Layering and Curing

Payload bay as a frame structure with large bearing capacity, high precision and large size, its accuracy of layering angle and the continuity of each layer of fibers are the key to ensure the mechanical properties and structural stability of the frame. When the frame is layered, the long side is 0° direction. Based on this laying angle, the continuity of the fibers in each direction is preferentially guaranteed. The layering principle is as follows:

(1) The 0° layering direction of each independent unit shall be consistent with that of the frame. Laser blanking machine is used to ensure the accuracy of blanking angle. And preload every four layers to ensure a firm layering;

(2) Maximize the continuity of fibers and the accuracy of each layer's angle. For the area that cannot be continuously layered, could lap or butt layering different layers.

(3) Considering the overall strength and dimensional stability of the frame, filled with twisted yarn at each joint position when moulding to avoid defects at inflection point.

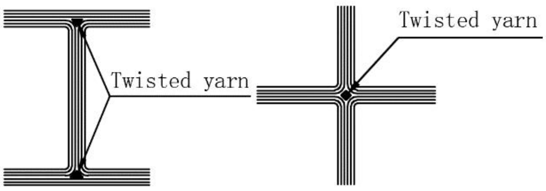

Figure 5. Diagram of Longitudinal and Cross - section Layering

3.5 Structural Stabilization

According to the specific environment requirements of the payload bay frame, multiple cooling and heating aging treatment at ±60℃ to further reduce the residual curing stress inside the frame. Through the measurement before and after the aging treatment, it is found that: the flatness of the flatness of the frame on a scale of 0.02mm-0.06mm and tended to be stable after 5 times aging treatment; the hole position of the cabin board and equipment on a scale of 0.1 mm to0.4 mm.

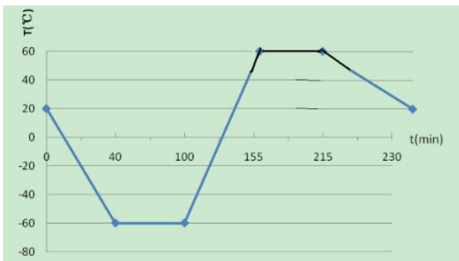

Figure 6. Graph of temperature cycling

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The results shows that: 1. The sensitivity of composite frame to temperature is not completely zero, but close to zero; 2. Multiple cooling and heating alternating tests have a certain effect on removing residual internal stress of the frame, which is of positive significance to ensure the structural stability of the frame in a specific environment.

4. Product Performance Evaluation

After curing and demoulding, the composite body of the frame is tested, and it is concluded that there are no defects such as layering and pores in the frame, no poor resin area is found, and the wall thickness of each position of the frame is even and smooth. After nondestructive testing in water medium, calculation of porosity and the carbon fibers volume fraction, along with the mechanical properties test of specimen and product dimensional accuracy test, the obtained results all meet the design index; at the same time, the rationality of the moulding process scheme is verified.

4.1 Ultrasonic Non-destructive Testing

The frame is tested by ultrasonic pulse reflection nondestructive testing method in water medium. The testing results shows that there are no obvious delamination, void and porosity defects in the inner parts of composite, and the moulding quality of the frame meets the requirements of GJB 2895-97 for Class A products.

4.2 Fiber Volume Fraction and Pore Content

According to GB3365-2008, the fibers volume content is 61.3%, which meets the design requirements of (60±3) %; the porosity test values of the frame are all lower than 1.0%, which can meet the GJB2895-1997 Class A standard.

4.3 Mechanical Index of Product

In order to verify the mechanical properties of the frame effectively during product development, 0° unidirectional tensile and compression trial-produce are prepared and tested according to GB/T3354-2014 and GB/T1448-2005, and the test results met the design index. At present, the frame has successfully passed various mechanical tests on the ground and mechanical verification at the launch stage.

4.4 Dimensional Accuracy Control Effect

After detection, the flatness of the camera installation surface reaches 0.06mm, the location degree of the camera installation interface hole is φ0.26mm, and the position of the vertical bar deviation degree is 0.3-0.8mm. The dimensional accuracy of the frame meets the requirements of the design index, and further verifies the rationality of the moulding process scheme.

5. Conclusion

During the frame development of composite payload bay frame structure, the co-curing moulding technology of large-size grid closed cavity composite structure is overcome, and the following technological innovations are achieved:

a. The moulding scheme of autoclave curing and silicone rubber assisted pressing is adopted to adjust the overall external pressing to press inside and outside of each unit at the same time, so as to ensure the equivalent pressure at each position of the frame in the curing process and improve the consistency of the moulding quality at each position of the frame;

b. The fibers layering optimization technology is adopted to realize the preforming of grid structure billet by symmetrically decomposing the layering unit and completing the layering and prepressing operation of each unit independently. The precise orientation and continuous layering

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of fibers are effectively controlled, and the dimensional accuracy and dimensional stability of the frame are improved;

c. Adopting multiple cooling and heating aging treatment to release the residual stress in the frame so as to ensure the dimensional accuracy of the frame in a specific environment and the stability of the spacecraft payload.

The payload bay frame with high stability, large size, grid type and closed cavity studied in this project, and the design scheme of the internal and external simultaneously pressurized mould combined with soft and hard mould, can be used for reference in the frame development of structural parts in the field of composite materials with extremely broad application prospect.

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