Study on the Preparation Process of X-cor Sandwich

*Xudan Dang[1, a], Shaojie Shi[2,b], Jun Xiao[3,c], Weimin Long[4,d], and Rui Zhang[5,e]

[1]School of Mechanical Engineering, Henan Institute of Engineering, Zhengzhou, China, 451191

[2]Department of Human Resources, Henan Institute of Engineering, Zhengzhou, China, 451191

[3]College of Material Science & Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, China, 210016

[4]Zhengzhou Research Institute of Mechanical Engineering, Zhengzhou, Henan, 450001

[5]Zhengzhou Institute of Aeronautical Industry Management, Zhengzhou, China, 450015

[a]email: dangxudan2011@163.com, [b]email: shishaojie81@126.com, [c]email: 149853982@qq.com, [d]email: 592556824@qq.com, [e]email: 14793842@qq.com

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Abstract. As a new type of structural material, X-cor sandwich with high specific strength and high specific stiffness effectively improves the through thickness mechanical properties of the foam sandwich and is promised to be used in the field of Aerospace. Through three steps of pultrusion process, insertion process and vacuum curing process, the X-cor sandwich was prepared and the suitable process parameters were determined. The research results show that according to the selected process parameters, the X-cor sandwich with good quality can be prepared.

Introduction

The composite sandwich with light weight, high specific stiffness and high specific strength is composed of three parts of the face-sheets, core and adhesive[1-2] and is widely used in the field of Aerospace. The X-cor sandwich is a new type of integral structure in which the foam sandwith's face-sheets are connected with carbon fiber composite needles-Z-pins and the foam core is reinforced by the three-dimentional network structure. The X-cor sandwich can be regarded as the application of Z-pin reinforcement technology in the foam sandwich[3] and further improve the foam sandwich's properties and structural efficiency[4-5]. In X-cor sandwich, composite face-sheets are direct co-curing with Z-pins that insert face-sheets without the adhesive, and the process is simple[6]. The X-cor sandwich's diagram is shown in figure 1.

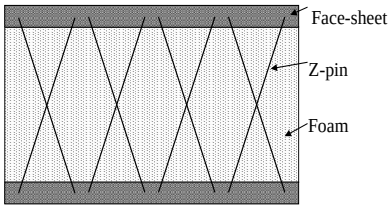

Fig.1 The cross-section of X-cor sandwich

The concept of X-cor (reinforced foam without face-sheets) was proposed and commercialized abroad in 2001 and the X-cor was produced by American Aztex company. As the structural composites, the application research of X-cor sandwich in the rotary wing aircraft has been carried out, for example the RAH-66 Camanche armed helicopter[7-8]. Overseas, Marasco[9] and Partridge[10] studied X-cor sandwich's tensile, shear and compressive properties, the result showed X-cor sandwich's specific stiffness is higher than that of the foam sandwich but with strength slightly lower. O'Brien[11] studied the mechanical properties of transtion region between the foam sandwich and laminate under different loads. Cartie[12] explored X-cor sandwich's quasi static and dynamic compressive properties, and the contributions of Z-pin and foam for compressive properties were elaborated. At home, Xu Tian and Jun Xiao[13] tried to prepare the X-cor sandwich. Long Du and Guiqiong Jiao[14-17] studied X-cor sandwich's shear and compressive properties and

tried to reveal the Z-pin's reinforcement mechanism from the aspects of theory. Jijun Hao and Zuoguang Zhang[18-19] explored the influence of Z-pin's insertion parameters on compressive properties. Now at home more research of X-cor sandwich's process and properties is still needed[20-22]. In order to lay the foundation for its design, application and estalishment of database of mechanical properties, the X-cor sandwich's preparation process is studied.

Preparation process of X-cor sandwich

The preparation process of X-cor sandwich has three steps: the first is Z-pin's pultrusion, the second is Z-pin's insertion and the third is X-cor sandwich's curing.

Pultrusion process of Z-pin

The basic process of pultrusion is that the continuous fiber impregnating resin is pulled out through the mould after heating, then the oven tunnel is used to make the resin cure further, in the end the unidirectional and continuous fiber reinforced composite with high strength is prepared[23].

Test equipment and materials. Z-pin's pultrusion machine is composed of 7 parts:unwinding device;fiber orientation device;impregnation device;pultrusion mould;pulling device;winding device;control system. The structure principle of pultrusion machine is shown in figure 2.

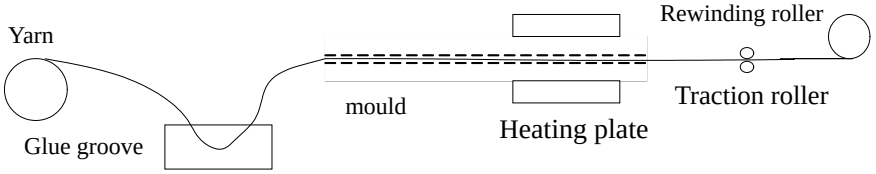

Fig.2 Diagram of Z-pin's pultrusion machine

In figure 2, the mould is the key part of pultrusion process and will direct affect the Z-pin's quality. For mould the requirements are smooth surface so as to reduce the pulling force, prolong its service life, improve the productivity and ensure Z-pin's quality; the larger length, but if the length is too long during the preparation process the resistence imposing on Z-pin will increase and the result is dying mould or Z-pin's damige; suitable cavity structure, the mould's cavity design is calculated according to the yarn model. All things considered, finally the mould's cross section is 65mm×85mm(after the mould closing), its length is 600mm. The X-cor sandwich's curing process needs the Z-pin to have higher glass transition temperature T_g, so generally the resin that is used in the Z-pin's pultrusion process is medium or high temperatuer resin system to meet the requirement of the Z-pin's curing degree. The photo of Z-pin's pultrusion process is shown in figure 3.

The carbon fiber and glass fiber are used in Z-pin's pultrusion. The carbon fiber is produced by Japanese Toray company, and its model are T300-3K and T300-6K. The carbon fiber's main properties are that tensile strength is 2971Mpa and tensile modulus is 230Gpa. The glass fiber's model is HS4 and offered by Nanjing Glass Fiber Research Institute. The resin system is FW-63 epoxy resin and produced by Kunshan Yubo company.

The requirements of pultrusion process for resin system are low viscosity, quick impregnating speed for the fiber, good adhesion, long storage period, fast curing and certain flexibility. After the sample proportion test, the proportion of the resin system's two components is FW-63 A：FW-63 B=100：145 and can meet the requirement of pultrusion process. Through the formula below the fiber volume content of Z-pin can be calculated.

$$V_{\mathrm{fb}}=\frac{\dfrac{l_{\mathrm{p}}\cdot\rho_{\mathrm{l}}}{\rho_{\mathrm{fb}}}}{\dfrac{l_{\mathrm{p}}\cdot\rho_{\mathrm{l}}}{\rho_{\mathrm{fb}}}+\dfrac{m_{\mathrm{fb}}-l_{\mathrm{p}}\cdot\rho_{\mathrm{l}}}{\rho_{\mathrm{m}}}} \tag{1}$$

In formula (1), ρ_{l}, ρ_{fb} are fiber's linear density and density respectively, l_{p}, m_{fb} are Z-pin's

length and quality, ρ_m is resin's density. The Z-pin's fiber volume content is listed in table 1.

Table 1 Z-pin's fiber volume content

Model	Z-pin's diameter/mm	Density/ g/cm^3	Linear density/tex	Fiber volume content/%	Discrete coefficient/%
Carbon fiber T300	0.7(C)	1.76	396	61.30	1.30
	0.5(C)	1.76	198	63.20	1.40
Glass fiber HS4	0.7(G)	2.53	575	61.20	1.30
	0.5(G)	2.53	240	58.40	1.80

Pultrusion process. Z-pin's pultrusion is composted two periods of resin impregnating fiber and resin curing. Pultrusion resin system is very sensitive to temperature so the control of mould's temperature is very strict. The distribution principle of temperature is that the two ends' are low and the middle is high. During the Z-pin's pultrusion, according to the resin's state in the mould, the mould is divided into preheating region, Gel region and curing region(Figure 4). It is very important to reasonably determine the temperature and distribution of different region of mould.

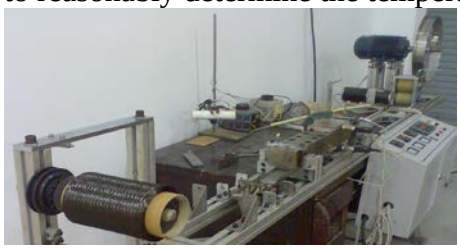

Fig.3 Test device of Z-pin's pultrusion

Fig.4 Diagram of the pultrusion mould

During the pultrusion process, there is pultrusion resistence in the mould. The preheating region's resistence comes from the resin's viscosity shearging force; the gel region's resistence comes from the tensile resistence induced by the friction; the curing region's resistence comes from the combination the thermal expansion, volume compression and low shrinkage. For the epoxy resin the friction of curing region is very high. So in order to decrease the Z-pin's resistence the preheating region's temperature should be decreased and the length of preheating region and gel region should be increased. In additiong the curing region's temperature should be increased to make the Z-pin to achieve certain curing degree. So the mould's heating plate is fixed at the Z-pin's pulling out position. Figure 5 is the pultrusion Z-pin using carbon fiber/FW-63 epoxy resin.

Insertion process of Z-pin

Test equipment and materials. The numerical control insertion machine is used to uniformly insert the pultrusion Z-pin into the foam to finish the preparation of Z-pin reinforced foam. Utilizing the insertion machine the preparation efficiency can be increased and the accuracy of Z-pin's insertion angle and the uniformity of Z-pin's spatial distribution can be ensured. Z-pin's insertion machine is composed of two parts of three axix numberical control machine and insertion head and can realize the automatical insertion of Z-pin with the angle range of 0°~45°. The main functions of insertion machine are: ①Z-pin's fixed length feeding; ②Z-pin's regulation of insertion angle; ③ Z-pin's cutting.

The materials used in Z-pin's insertion process are Z-pin and PMI foam. The PMI foam's model is Rohacell 31IG and produced by Germany Degussa Company. The PMI foam's main properties are that density is 32kg/m3, compressive strength is 0.4Mpa, shear strength is 0.4Mpa, tensile strength is 1Mpa, elastic modulus is 36Mpa and shear modulus is 13Mpa.

Insertion process. According to the references the X-cor sandwich's mechanical properties are very sensitive to the Z-pin's insertion angle and the uniformity of Z-pin's distribution and depth of

Z-pin's end inserting into the face-sheets have great effect on the X-cor sandwich's strength. So the Z-pin's insertion process needs to meet the listed requirements:①the Z-pin's insertion angle is accurate; ②if there is no local reinforcement, the Z-pin's spatical distribution should be uniform; ③the depth of Z-pin's inserting into the face-sheet should be enough, that is the length of Z-pin's end extending the foam should be accurate. After the Z-pin's insertion the photo of X-cor is shown in figure 6.

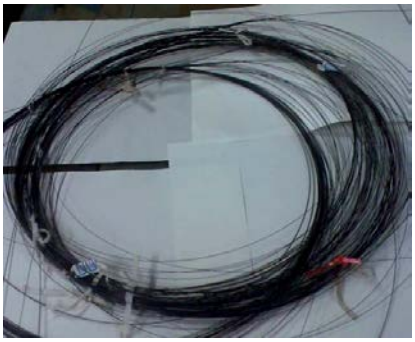

Fig.5 The pultrusion Z-pin

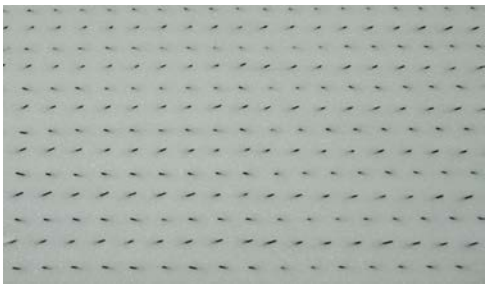

Fig.6 The X-cor core

Curing process of X-cor sandwich

Through the vacuum curing process the X-cor sandwich's curing is realized. After laying the prepregs onto the reinforced foam, utilizing the self-developed vacuum curing device, under the suitable curing system, the sample of X-cor sandwich is achieved. During this process the determination of curing system is the key factor.

Test equipment and materials. The so-called vacuum bag method is that the uncured product is put into the mould, then the mould is sealed and vacuumed, after the product's bubble and volatile are excluded, the product cures under pressure and temperature[24]. The photo of vacuum bag curing device is shown in figure 7.

The materials of X-cor sandwich's curing process are the X-cor and prepreg. The face-sheets are composed of 8 layers of prepregs and prepared by two kinds of materials. One of the prepreg is 12500 unidirectional carbon fiber prepreg cloth and produced by Shandong Guangwei Fishing Tackle Company, the stacking sequence is [0/90/0/90]s. The other prepreg is glass fiber prepreg textile offered by 637 Research Institute of Aviation Industry Group.

Curing process. The X-cor sandwich's curing process is not only the curing of composite face-sheets but also the formation of strong interface between the foam with Z-pin and the face-sheets. So the X-cor sandwich's curing must meet the double requirements of the curing of face-sheets resin and Z-pin's insertion into the face-sheets. According to the above requirements and the pressure and temperature that the foam can endure the curing process curve of vacuum bag is shown in figure 8.

Fig.7 Vaccum curing device

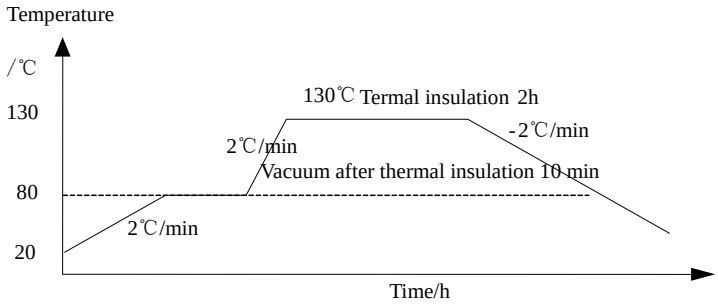

Fig.8 Vacuum curing process curve of X-cor sandwich

According to GB 7192-87《Test method of the prepreg's resin content》[25], by the method of Soxhlet extraction method, the resin content of 12500 prepreg is 39.5%. The resin content is high so during the curing process the glue treatment is needed. In the period of curing process, the function of temperature is to reduce the resin's viscosity and initiate the curing reaction and the function of

pressure is to compact the prepreg cloth and suppress the exstence of gaps. During the test the pressure point is chosen to be 80℃ after thermal insulation 10 minutes to ensure that the face-sheets soften when the pressure is loaded so the Z-pin's inserting into the face-sheets is effective. The X-cor sandwich is shown in figure 9.

Fig.9 X-cor sandwich

Conclusions

Through the exploration of X-cor sandwich's preparation process, the process parameters of Z-pin's pultrusion, Z-pin's insertion and X-cor sandwich's curing process are determined and the sample meeting the test requirements is achieved. The determination of the Z-pin's pultrusion temperature should be according to the epoxy resin's curing properties and the Z-pin should cure at the middle or back position of the mould; the Z-pin's insertion process should ensure the accuracy of insertion angle; The pressure point of X-cor sandwich's curing process is after 10 minutes thermal insulation at 80℃, and the pressure is 0.1MPa, the curing temperarure 130℃. Using the above process parameters the X-cor sandwich with good quality is achieved.

Acknowledgement

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