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Cover Structure Design of Titanium Alloy Based on the SPF/DB Process

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ABSTRACT

Five titanium alloy SPF/DB cover structures such as aircraft engine nacelle hatch, booster hatch, air conditioning hatch, pneumatic pump door are designed based on SPF/DB process. Use of SPF/DB and combination process such as welding, split, the covers design have good structural integrity, less stress concentration, high strength, high stiffness, long life and good sealing.

INTRODUCTION

Super Plastic Forming (SPF) is a forging forming method using super plasticity of some metal under certain conditions [1, 2]. Diffusion Bonding (DB) refers to the material surfaces touch each other and to be near under the action of temperature and pressure, the local plastic deformation occurs, mutual diffusion between atoms, the diffusion layer is formed at the interfaces, so as to realize reliable connection [3]. SPF/DB technology is formed by combination of SPF technology and DB technology, it uses of metal materials with the characteristics of super plastic and diffusion bonding in a temperature range, forming an integral components with sandwich structure by once. Compared with the mechanical connection, the titanium alloy SPF/DB structure has the such characteristics as good entirety, fastening hole quantity greatly reduced; geometry transition uniformity, small stress concentration; high net strength, high stiffness and high durability; good formability, no rebound,

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no residual stress; good sealing. Hollow sandwich structure made of SPF/DB process can achieve the best ratio of stiffness to weight, it can reduce the structure weight than normal weight 10%~50%, and the manufacturing cost can be reduced 25%~40%, and the economic benefit is very high, so it is applied in aerospace field widely.

This paper is based on the SPF/DB process, five kinds of common titanium alloy SPF/DB structure on the plane are designed, from choosing the appropriate material, according to the different types of cover to set up the reasonable design plan, to ensure that the cover structure has good integrity, light weight, high stiffness, long life and good sealing.

TABLE I. THE COVER OF TITANIUM ALLOY SPF/DB ON PLANE.

Name of cover	Installation location	Structure form	Mechanical characteristics
Upper cover of the nacelle	Real fuselage	TC4 double layers welding	Main bearing
Lower cover of the nacelle	Real fuselage	TC4 double layers welding	Main bearing
Booster hatch cover	Real fuselage	TBSSPF/sport welding double layers	Secondary bearing
Air conditional cabin cover	Fore body	TC4 double layers	Secondary bearing
Pneumatic pump door	Center fuselage	TC4 double layers	Non bearing

STRUCTURE CHARACTERISTICS OF TITANIUM ALLOY SPF/DB

Because installation and maintenance requirements of equipment in modern aircraft, many kinds of hatch are opened on the aircraft body, these hatch and cover are one of the main tasks of aircraft structural design. There are many kind of body cover, according to the force situation, it can be divided into non stress cover and stress cover; the former structure is simple, only bear local pneumatic load; the latter structure is relative complex, it has requirements in strength, stiffness and life, its design method is different from non-stress cover. According to the configuration and material technology, cover can be divided into integrative milling cover, integral stamping cover, riveting combination cover, composite cover and integrative cover of titanium alloy processing of SPF/DB. Integrity of titanium alloy SPF/DB structure is good, high strength and rigidity, suitable for large mechanical cover, especially suitable for large maintenance cover with hot strength requirement in nacelle. Like SPF/DB technology, titanium alloy SPF/ DB cover has the advantage in weight, performance, cost etc. Examples of titanium alloy SPF/DB cover of plane is shown in table I. Booster hatch cover adopts double-layer structure of TB5 SPF/spot welding because of SPF and DB is not in the same temperature range, synchronization is unable to complete between SPF and DB. The reason of large cover on engine using TC4 SPF/DB double welding split structure, is that the cover size is bigger than TC4 board size, electron beam welding or laser welding

technology must be taken to split. Compared with traditional structure composite cover, the structural integrity of the titanium alloy SPF/DB cover is good and structure light (reduce weight 30%), less number of molds and fixtures required, short manufacturing cycle, production cost is reduced significantly.

THE COVER STRUCTURE MATERIAL OF TITANIUM ALLOY SPF/DB

At present, cover design materials of the titanium alloy SPF/DB uses material for TC4 structure commonly, of the cover in high load area also can choose TB5 [4]. Mechanical properties of TC4 and TB5 super plastic titanium alloy plates are shown in table II. TC4 titanium alloy is two phase titanium alloy of α+β type, it has a good welding performance and machining performance. The fine crystal TC4 titanium alloy super plasticity and it can work long time in temperature 400C, now it has been applied in manufacturing various cover processing of SPF/DB widely.

TABLE II. MECHANICS PERFOMACES OF TITANIUM ALLOY BOARD OF TC4 AND TB5.

Plate Thickness (mm)	State	Room temperature performance				Performance in 400C	
		σ_b (MPa)	$\sigma_{0.2}$ (MPa)	δ %	E (GPa)	σ_b (MPa)	Endurance limit (MPa)
TC4(δ<3.0)	M	830	780	12	110	590	540
TB5(δ<3.0)	M	1000	965		102		540

TB5 titanium alloy is a kind of met as table β titanium alloy, the alloy has the similar to those of industrial pure titanium cold rolling and cold forming performance, it can be cold formed moderately complex sheet metal parts, and it has a good welding performance in high temperature. So it is an ideal material of aircraft structure. The property of TB5 is better than TC4 obviously in super plastic temperature and tensile properties [5]. The best forming temperature of TB5 is 740C, the temperature is lower than the TC4 about 200C, it need a low requirement of mold material. Because TB5 welded rate is low after DB, using of SPF/combination welding process is suggested.

COVER STRUCTURE DESIGN OF TITANIUM ALLOY SPF/DB

Structure Design of Pneumatic Pump Door

The pneumatic pump door processing of TC4 SPF/DB is a nonbearing cover located at the fuselage bottom, it does not transmit force to surrounding structure, therefore, as long as meet the stiffness requirement and local connection strength

requirement. Because of its stiffness requirement is the main design constraints, so, the door has a thicker section and a bigger bending stiffness. Structure parameters of the doors are determined according to the equivalent stiffness, a double cassette integral structure processing of TC4 SPF/DB is selected, its weight loss efficiency is 15.6%.

The Structure Design of Air Conditioning Hatch Cover

The air conditioning hatch cover is located between nose gear extension beam, its appearance size is 350 mm wide and 804 mm long. In complex working environment, the cover needs to bear local aerodynamic load, load from protection of the gun and to withstand local load and the instantaneous frequency impact load of muzzle smoke board. In the muzzle flame impingement zone, the gradient of temperature and pressure is large. The cover needs to meet the requirements of the stiffness and local strength in a complex environment, it is an important bearing cover on fore body. Based on the complexity work environment, the cover is designed as double layers TC4 SPF/DB overall structure. The cover with good integrity, low cost, short cycle and remarkable weight loss effect, greatly simplifies the manufacturing process, its weight reduction efficiency is as high as 45.9%.

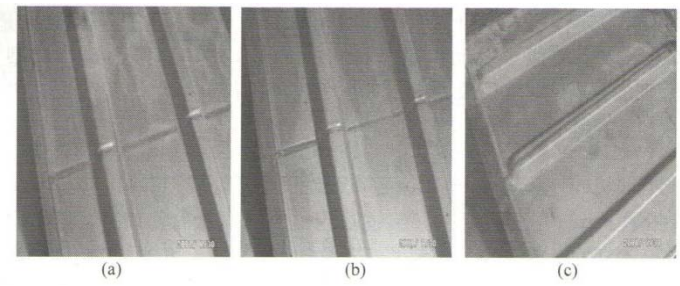

Figure 1. The process samples with different combination of welding and SPF/DB
(a) argon arc welding transverse welding (b)electron beam welding transverse welding
(c) electron beam welding longitudinal welding.

Structure Design of TB5 Booster Hatch Cover

The booster hatch cover is located in the upper side of the fuselage, its projection size is 606 mm long and 485 mm wide [6]. The cover is connected with the body frame by bolts and plate nuts, in addition to withstand local aerodynamic load, but also to bearing the total load in the aft fuselage part. But because of its small structure size, the load is limited, so it belongs to the minor load-carrying cover. Because the cover is located in the aft fuselage nacelle section, so it must has thermal strength and stiffness in thermal environment of the engine compartment,

the titanium alloy structure scheme of the cover has two plans: the first plan is TC4 SPF/DB, it is relatively mature and widely used; the second plan is a TB5 SPF/spot welding in the test phase.TB5 SPF/spot welding plan still adopts the structure with four reinforcements in vertical and tow reinforcements in horizontal direction for keep the rigidity and stability of the cover. The weight loss efficiency of TB5 SPF/spot welding is 18.7%.

Structure Design of The Upper Cover on Nacelle

Upper cover of nacelle is refers to the large cover on the back of the engine compartment, it is mainly used for the engine accessory gearbox of installation and maintenance. The cover is a main bearing part of after fuselage. Its projected size is 1070 mm wide and 1188 mm long, string is 290 mm high, wingspan is 1250 mm. The scheme of the cover titanium alloy SPF/DB is TC4 skin + reinforcing board, and a reinforcement double-layer structure of in vertical and horizontal direction. nine stiffener layout in horizontal and four stiffener layout in vertical, the shapes are "cap" shape, Some reinforcement of "cap" form are also decorated around the cover. This design is mainly based on the strength, stiffness, use function and manufacture process. The method of combination welding is implementation of the SPF/DB process after TC4 board electronic welding. Weld is decorated in the second reinforcement with center axis, such segmentation can make up the lack of material width size and reduce the manufacturing difficulty.

Lower Cover Structure Design of Nacelle

The lower cover of nacelle is connected between fuselage frame with bolt, It is the main bearing part. Its projected size is1140 mm long and940 mm wide, string is 360 mm long, wingspan is 1355 mm long. The TC4 SPF/DB structure scheme of the cover adopts double layers structure made of skin and strengthen board, the reinforcing plate adopts the structure of vertical and horizontal reinforcement with surrounding reinforced, reinforcement rod adopt "cap" form, structure become high efficiency, good forming process. In order to make the large cover required specification of titanium alloy board and large curvature mold manufacturing difficulty, a similar to the upper cover on the engine of SPF/DB welding with a combination of configuration plan are used. The difference between them is that the lower cover processed with SPF/DB and then electron beam welding process, the weld arrangement is in the middle position of the cover on the body axis. The combination plan process sample as shown in figure 1, combination scheme of the performance test results shown in table III.

TABLE III. PERFOMANCE CONTRAST OF TC4 PLAN PROCESS STATE.

Serial number	State	σ_b (MPa)	$\sigma_{0.2}$ (MPa)	δ_s (%)	E (GPa)
1	After argon arc welding of SPF	879	838	6.5	110.5
2	After the electron beam welding SPF	962.8	942.6	10.8	107.3
3	Electron beam welding thermal cycle board	954.3	902.6	16.7	108.9
4	Original board	1119.4	1052.8	9.2	123.8

CONCLUSION

As SPF/DB technology of titanium alloy is used widely, it must be pay enough attention to design of the cover structure, both stress cover structure or non, the appropriate materials must be selected and reasonable structure design is made to ensure the integrity of the structure, light weight, high stiffness, long life and good sealing. SPF/DB technology will be expanded gradually from titanium alloy material to the lithium-aluminum alloy, metal matrix composites, intermetallic compounds, ceramic matrix composites, etc. The development trend of SPF technology in the future is researching on large complex whole structure forming, low cost and high efficient forming technology, plastic forming technology and various advanced connection combination technology process, the super fine crystal, nanocrystal line materials, difficult deformation of high temperature resistant material forming.

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REFERENCES

1. Junfei Ma, etc. 2015. Journal of Trainer, (4): 11-16. (In Chinese)
2. Chunhong Zheng. 2003, Aviation Manufacturing Technology, (5): 46-49. (In Chinese)
3. Qin Yang. 2015, North China Electric Power University. (In Chinese)
4. Liang Ding. 2015. Shanghai Jiaotong University. (In Chinese)
5. Xiang-ming Wang, Wen-ting Liu. National Defense Industry Press, 2010: 55-65. (In Chinese)
6. Bin Wang etc. 2015, Journal of Plastic Engineering. (2): 51-55. (In Chinese)