CHARACTERISTIC OF THE INSERT JOINT STRENGTH OF COMPOSITE SANDWICH PANEL OF FORMOSAT-5 REMOTE SENSING INSTRUMENT

Mei-Yi YANG*, Heng-Chuan HUNG, and Jen-Chueh Kuo

National Space Organization, 8F, 9 Prosperity 1st Road, Hsinchu Science Park, HsinChu, Taiwan,
** myyang@nspo.narl.org.tw*

Keywords: Insert failure loads, Sandwich, Composite, Honeycomb

Abstract
FORMOSAT-5 is the first space program that National Space Organization (NSPO) takes full responsibility for the satellite system engineering design including the optical payload of Remote Sensing Instrument (RSI), which can provide 2-m resolution panchromatic and 4-m resolution multi-spectral images. The main purpose of this paper is to experimentally study the pull-out and shear failure loads of composite sandwich insert joints of RSI. The main supporting structure, "Main Plate" of RSI was made by sandwich panel of two 2mm carbon fiber/cyanate ester composite skins with 50mm aluminum honeycomb core. The Redux 312 adhesive film was used for core and composite skin bonding while EA9394 adhesive was used as potting material. From the experiments, the mechanical characteristics of composite sandwich insert joints can provide proof test data for further RSI structure strength design.

1. Introduction

The program mission of FORMOSAT-5 would like to build up Taiwan's self-reliant space technology on the remote sensing payload and spacecraft bus as well as integrate the domestic resources to develop the key components of the RSI and spacecraft bus. FORMOSAT-5 is currently scheduled to be launched by Falcon 9 of SpaceX [1]. The RSI structure is consists of two composite sandwich panels: the "Main Plate", supporting the optical elements of primary mirror, corrector lens assembly and focal plane assembly, and the "M2 Support Ring", linking the secondary mirror. These two composite sandwich panels are connected by six composite struts called "M2 Supports Frame". The whole RSI structure will be installed on the spacecraft bus top panel through the "Main Plate Support Frame" and "M2 Support Ring Supporter". The configuration of RSI structure model is shown in Figure 1.

In order to comply with the dismountability requirements of the optical element to the sandwich panels, mechanical fastened joint design is adopted rather than the adhesive joints. Thus, the investigation of the insert capability of sandwich structure is important. The effects of the honeycomb core height and density, the face thickness, and the insert clearance on the failure loads of a sandwich insert joint has been studied by Song et al. [2]. The static and dynamic pull-out tests of the composite sandwich panel with various shapes of inserts were performed to investigate the insert type effect on the mechanical characteristics in [3]. Besides to experimental studies on the failure behavior of honeycomb sandwich inserts, Heimbs and

Pein [4] developed a simple finite element model to simulate the joining between inserts and sandwich panels, which are able to represent the failure behavior. The most comprehensive study on the design, manufacturing and verification of insert systems can be found in the Insert Design Handbook [5] of the European Space Agency.

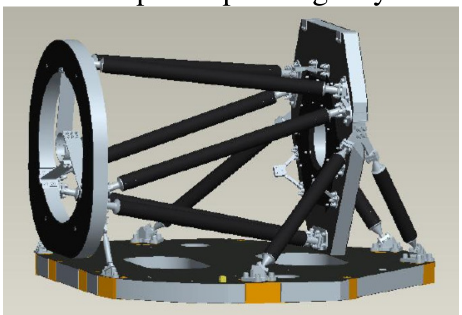

Figure 1. RSI structure model

This paper intends to gain an insight into the characteristic of the insert joint strength of composite sandwich panel of FORMOSAT-5 RSI. In order to improve the stiffness and long term stability of the optical payload, a high modulus of carbon fiber of M55J and a low moisture absorption feature of cyanate resin has been chosen as the composite skins of sandwich panels. The composite sandwich panels have been manufactured by Aerospace Industrial Development Corporation (AIDC), a domestic partner for developing the RSI structure model. Insert pull-out and shear tests were experimentally studied and compared with the analytical calculation values based on the formulas in [5]. Furthermore, the flat-wise tensile tests were performed to obtain the flat-wise tensile strength and failure modes of the composite sandwich panel. From these experiments, the mechanical characteristics of composite sandwich insert joints can provide proof test data for further RSI structure strength design.

2. Experiment

2.1 Materials and specimen preparation

The sandwich panel consists of two 2mm carbon fiber/cyanate ester composite skins with 50mm aluminum honeycomb core. The Redux 312 adhesive film was used for core and composite skin bonding while EA9394 adhesive was used as potting material. Two types of insert were used in the study. The detailed description of the sandwich panel is listed in Table 1. The composite skins were first cured in an autoclave according to the cure procedure of HSP-C2 provided by Hexcel. Then the honeycomb core was co-cured with the composite skins with additional Redux 312 film adhesive in an autoclave by using a flat mold and a vacuum bag. After the fabrication of the panel, the flatness and delamination of the sandwich panel has been measured and checked. Then, the inserts were installed into the panel by injecting the potting adhesive in the drilled hole as shown in Figure 2.

Item	Specification	Type
Skin	CFRP	$[0_2/\pm45_2/90_2]$s M55J/954-3
Core	MIL-C-7438 Grade G	8.1-1/8-002-P-5056
Insert	NSPO-SPEC-0008-X-2-2SL 603	SL10068M6-4-S; SL10068M8-5-S
Film adhesive	NSPO-SPEC-0007-3	Hexcel Redux 312L
Potting adhesive	MMM-A-132, Type I, Class 3	Hysol EA 9394 part A/B

Table 1. Sandwich panel component description

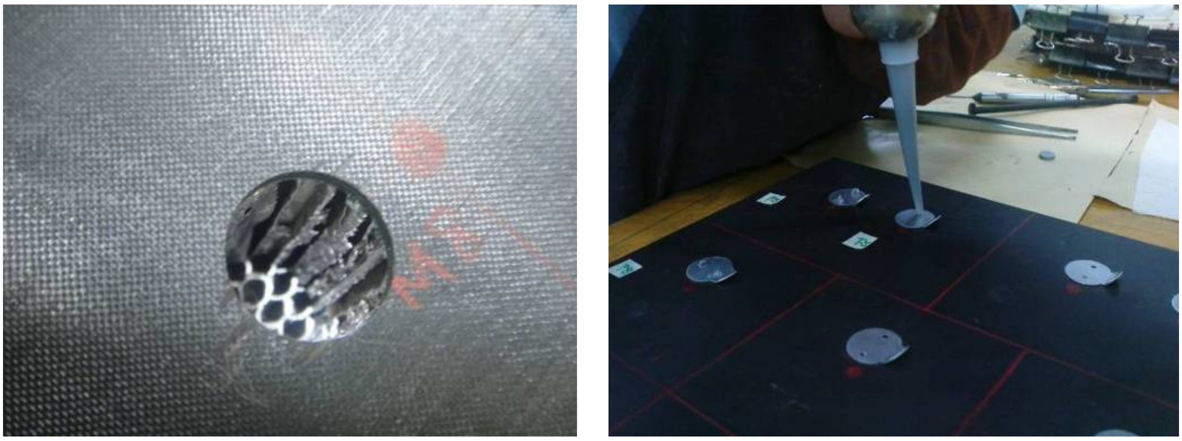

Figure 2. Insert installation by injecting potting adhesive into drilled hole.

2.2 Pull-out and Shear Test

The dimensions of the pull-out and shear specimens were 100mm × 100 mm and 120 mm × 150 mm, respectively. Three specimens each of SL10068M6-4-S and SL10068M8-5-S were tested for pull-out until past their ultimate load capacity while two specimens of SL10068M6-4-S were tested for shear until failure. The pull-out test method of the insert is followed the suggestion in the ESA Insert Design Handbook [5]. The insert is pull-out vertically. The set-up of the insert shear test is shown in Figure 3. These two tests were performed with an MTS QTest 100 universal material testing machine. The cross-head speed of the machine is 1.27 mm/min (0.05inch/min) and the tests were performed at room temperature.

Figure 3. Insert shear test.

2.3 Flat-wise tensile Test

The purpose of this test was to check core flatwise tensile strength or the bond between core and facing of an assembled sandwich panel. Five specimens were tested with an MTS QTest 100 universal material testing machine. A constant rate of 0.5 mm/min (0.02inch/min) of movement of the testing machine cross-head was applied in tensile. The test were done according to ASTM standard C297 [6], with exception of the spcimen size was 20mm × 20mm relative to the test fixture.

3. Results

3.1 Pull-out load test and shear test results

The force-displacement curves of the SL10068M6-4S and SL10068-M8-5S insert pull-out test are shown in Figure 4.These curves show similar behavior especially in the smaller size of SL10068M6-4-S. The pull-out failure load results of these six specimens are listed in Table 2. Both of the coefficients of variation (CV) of the two type inserts are quite small, about 2.0% for SL10068M6-4S and 2.8% for SL10068M8-5S. It shows that the quality of potting the inserts into the composites sandwich panel is quite stable. Moreover, the samples of SL10068M8-5S have been cut out to observe the post-failure cross-section as shown in Figure 5. The failure mode is tensile rupture of potting among these samples due to the heavy core used in the sandwich panel. Also, the top-view of the failed specimen of P6 insert is show in Figure 6. The insert shear test results are shown in Figure 7. Again, it shows similar behavior of the two curves. The peak shear failure loads are 8017 N and 8377 N for PS and FS respectively.

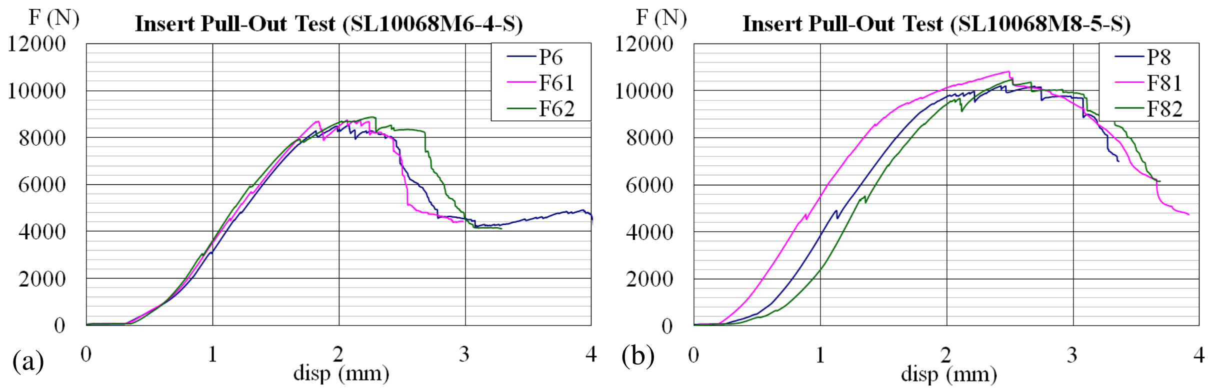

Figure 4. Force-displacement curve of insert pull-out test (a) SL10068M6-4-S (b) SL10068M8-5-S.

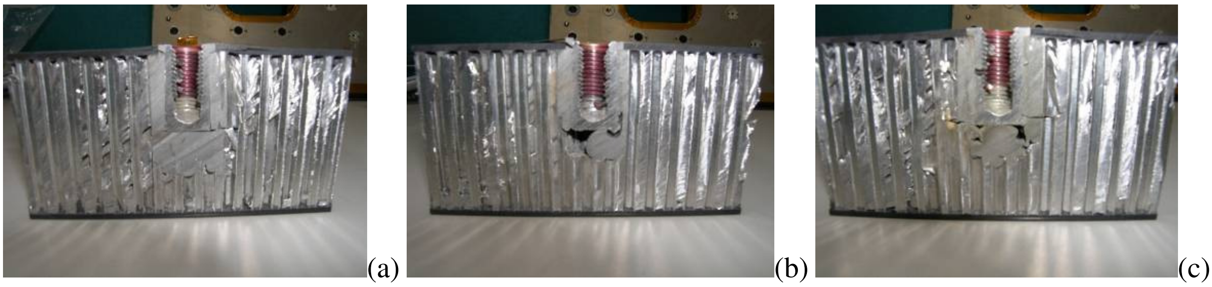

Figure 5. Post-failure cross-sections of SL10068M8-5-S insert (a) P8; (b) F81; (c) F82.

SL10068M6-4-S Specimen	Failure Load (N)	SL10068M8-5-S Specimen	Failure Load (N)
P6	8547	P8	10230
F61	8769	F81	10827
F62	8890	F82	10497
Average	8735	Average	10518
SD	174	SD	299
CV=SD/Average	2.0%	CV=SD/Average	2.8%

Table 2. Pull-out load test results

Figure 6. Top-view of failed specimen of P6 insert.

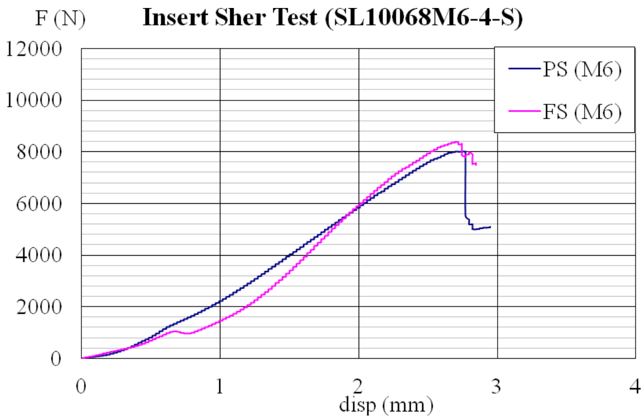

Figure 7. Force-displacement curve of insert shear test.

3.2 Flat-wise tensile strength test results

The flat-wise tensile strength test results are listed in Table 3. The failure modes of each sample are also provided according to the photographs of failed flat-wise tensile samples shown in Figure 8. The failure modes of the composite sandwich panel are mostly the composite skin delamination and accompany with some portions of cohesive failure of adhesive. Due to the high density honeycomb core used in the sandwich panel, the core flatwise tensile strength are stronger than the bond between core and facing of the composite panel or the delamination strength of the composite skin. Thus, no core shear failure occurred.

Specimen	Flat-wise tensile strength (MPa)	Failure mode Adhesion-Cohesion-Core-Facing
1	4.98	0-20-0-80
2	4.59	0-5-0-95
3	4.99	0-40-0-60
4	4.55	0-0-0-100
5	5.45	0-20-0-80
Average	4.91	
SD	0.4	
CV=SD/Average	7.5%	

Table 3. Flat-wise tensile strength test results.

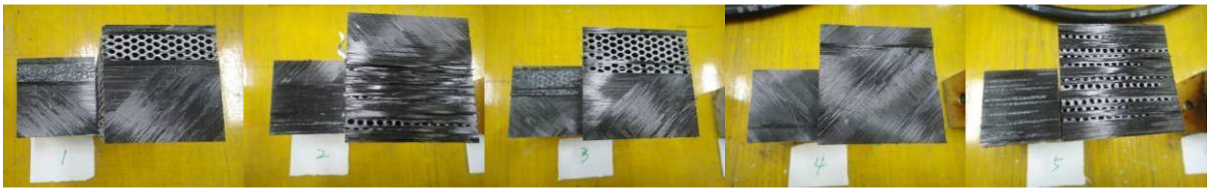

Figure 8. Photographs of failed flat-wise tensile samples

3.3 Comparison with the analytical calculation

The insert pull-out load calculation was conducted from the equations provided in the appendix A in Insert Design Handbook [5]. For fully potted insert, the core shear stress of a sandwich panel provided with a central insert is related to the potting radius of the potting material (b_p), the thicknesses of the facing (t_f) and core (t_c) as well as the elastic modulus of the facing material (E_f) and the shear modulus of the core (G_c). When the maximum core shear stress reaches the core shear strength ($\tau_{c,crit}$) the insert capability is given by:

$$P_{F,crit} = \frac{2\pi b_p t_c \tau_{c,crit}}{C^* K_{\max}} \tag{1}$$

In the above equation, $C^* = \beta/(\beta+1)$; $\beta = t_c/t_f$; $K_{\max} = b_p/r_{\tau_{\max}}[1-\sqrt{r/b_p}\,e^{\alpha(b_p - r_{\tau\max})}]$; $r_{\tau\max} = b_p/[1-e^{c_2(\alpha b_p)^n}]$; $\alpha = 1/t_f\sqrt{(G_c/E_f)12(1-\nu_f^{\,2})(\beta/2+1+2/(3\beta))}$, $c_2 = -0.931714$ and $n = 0.262866$.

For partially potted insert in the sandwich panel, the load is carried by upper facing, shear stresses in the core around the potting and normal stresses in the core underneath the potting and is given by:

$$P_{p,crit} = \frac{P_{F,crit}}{2} + \pi r_{\tau\max}(2h_p - t_c)\tau_{c,crit} + \pi r_{\tau\max}{}^2 \sigma_{c,crit} \tag{2}$$

where h_p is the potting height and $\sigma_{c,crit}$ is the tensile strength of the honeycomb core. The permissible tensile load for partially potted insert is then multiplying by a model correlation coefficient (RC) and is given by:

$$P_{ss} = RC \cdot P_{p,crit} \tag{3}$$

with $RC = 1.172 - 0.0063t_c - 0.2641t_f$ for minimum values of perforated core or $RC = 1.207 - 0.0054t_c - 0.2088t_f$ for average/typical values of perforated core.

Based on the mechanical properties of sandwich panel in this study as listed in Table 4, the calculated minimum insert pull-out loads are 6529 N and 7733 N for SL10068M6-4S and SL10068-M8-5S respectively, which are 25 and 27 % lower than the test results. The calculated average insert pull-out loads are 10077 N and 11934 N for SL10068M6-4S and SL10068-M8-5S respectively, which are 15 and 14 % higher than the test results. Thus, the calculated minimum insert pull-out loads are suitable for use in the preliminary design stage before the insert pull out test has been made.

Skin	$[0_2/\pm45_2/90_2]_s$ M55J/954-3	Core	8.1-1/8-002-P-5056	Potting	EA9394
E_f	130 GPa	G_c	117.2 MPa	h_p(SL10068M6-4-S)	27 mm
ν_f	0.315	$\tau_{c,crit}=1.36\tau_{w,crit}$	3.3 MPa	b_p(SL10068M6-4-S)	8.7 mm
σ_{fy}	190 MPa	$\sigma_{c,crit}$	13.78 MPa		
t_f	2 mm	t_c	50 mm		

Table 4. Mechanical properties of the sandwich panel

The calculated insert shear force is related to the potting radius of the potting material (b_p), the shear strength of core in W-direction ($\tau_{w,crit}$), the thickness of facing (t_f) and the yield strength of facing material (σ_{fy}) and is given by the semi empirical formula [5]:

$$Q = 8b_p^{\,2}\tau_{w,crit} + 2t_f b_p \sigma_{fy} \tag{4}$$

The analytical calculation of insert shear failure load leads to 7866 N, which correlate very well with the experimental values of 8017 N and 8377 N for PS and FS respectively. The maximum deviation is about 6.5% for FS sample. Thus, the insert shear force can be estimate by using equation (4).

4. Conclusion

The characteristic of the insert joint strength and flat-wise tensile strength of composite sandwich panel of Formosat-5 RSI has been investigated experimentally in this study. The insert pull-out failure loads of SL10068-M6-4S and SL10068-M8-5S are 8735 N and 10518 N respectively. Comparisons with the experimental results to the analytical calculations show that the insert pull-out failure loads are exceeding the given minimum permissible insert tensile loads. Thus, the calculated minimum insert pull-out loads are suitable for use in the preliminary design stage before the insert pull-out test has been made. Furthermore, the analytical calculation of insert shear failure load correlates very well with the experimental values. The flat-wise tensile strength test results show that the failure modes of the composite sandwich panel are mostly the composite skin delamination and accompany with some portions of cohesive failure of adhesive. From the experimental study of the composite sandwich panel, the mechanical characteristics of composite sandwich insert joints can provide proof test data for further RSI structure strength design. Furthermore, the manufacturing process of the composite sandwich panel and insert installations are also verified.

References

[1] *www.nspo.narl.org.tw*

[2] K. I. Song, J. Y. Choi, J. H. Kweon, J. H. Choi and K. S. Kim. An experimental study of the insert joint strength of composite sandwich structures. *Composite Structures*, 86(1-3): 107-113, 2008.

[3] B. J. Kim and D. G. Lee. Characteristics of joining inserts for composite sandwich panels. *Composite Structures*, 86(1-3): 55-60, 2008.

[4] S. Heimbs and M. Pein. Failure behavior of honeycomb sandwich corner joints and inserts. *Composite Structures*, 89(4): 575-588, 2009.

[5] ESA PSS-03-1202 issue 1. *Insert design handbook*, European space agency, Paris, 1987.

[6] ASTM C297/C297M-04. Standard test method for flatwise tensile strength of sandwich constructions. *ASTM International*, 2004.