Composite Sandwich T-joints for Satellite Structures Types, Manufacturing and Key parameters– A Review

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Abstract – As the complexity on the engineering structures increases, so is the need to reduce the weight has also became a important factor while designing. Hence using the Fiber Reinforced Plastics (FRP) has become the primary option. FRP Sandwich panels provides good specific strength and specific stiffness hence the weight reduction. However joining of sandwich is still a challenge. This review paper aims to address the beginners, the need for CFRP sandwich structures and the advantages of Sandwich structures by comparing with 'I' beam. Subsequently the need for the T-joint is also discussed. Various types of T-joints are listed which are mostly available in the literature. Manufacturing methods and key parameters affecting the usage of the T-joints are also discussed.

***Keywords*—FRP, Sandwich structures, T-joints, key parameters**

I. INTRODUCTION

Current technology needs light weight structures which can give the same or better performance than the existing structures, especially in the fields of space, military, naval, sports, transportation, medical, structural etc. Applications of satellites are countless; it includes not only government and military applications but also commercial organizations. The missions of satellites include science ventures such as earth observation, interplanetary exploration, astronomy, and solar physics. They also include commercial endeavors such as television signal transmission and satellite telephone communication [1]. Specific stiffness and specific strength are usually used two criteria for selecting a material for this need. Composite materials are especially suitable for aerospace structures due to their light weight, high strength and durability, structural stability upon temperature variations when used in conjunction with metals.

Sandwich construction, which is made of two thin face sheets sandwiched in a light weight core, are extensively used in satellite structures because of their low weight combined with high bending stiffness, high buckling resistance and adequate strength [3]. Materials with high specific strength and stiffness reduce the mass of satellites and components which leads to significant overall mass savings and reducing launching costs. Additionally, the high specific stiffness is needed to increase the natural frequencies of a satellite to avoid the resonance vibrations due to low frequency excitations of the launch vehicle [1].

Making of sandwich construction instead simple laminate structure has the following reasons. Firstly the bending stresses are high at top and bottom so it makes sense to keep the higher strength materials (Face skins) there and use the light weight low strength material (Core) at the middle where those stresses are low. Secondly increasing the thickness increases the resistance against bending by increasing the moment of inertia. For space applications in a high vacuum environment the perforated type honeycomb panel (honeycomb panel had small vent holes of diameter 0.2 mm on the wall) is preferred.

Several researchers have estimated the failure of composite honeycomb sandwich panels. Li and Crocker [4] investigated the effects of the thickness of the core and face sheets, and delamination on damping through experiments and analysis.

Although sandwich constructions possess high bending rigidities, they are locally quite flexible and weak, because of their very high strength or stiffness to weight ratios. They are especially susceptible to damage inflicted by concentrated loads such as impact of hard objects. For the same reason, joining sandwich panels presents a great challenge [5].

Since sandwich panels are widely used in the aerospace region, many researchers have investigated joining methods of sandwich panel. Toftegaad and Lystrup [6] described the design and testing of a sandwich T-joint with reduced weight (by 60%), but with the higher strength (by 20%) than the existing design. Sandwich panels were joined using filler and two triangular poly vinyl chloride (PVC) foam fillets (core triangles) rather than the traditional circular fillet. A method for a finite element parameter study was developed and used to select a T-joint promising configuration [6].

Ramakrishna et al. [7] described the tensile behavior of bolted joints of pultruded sandwich composite laminates. The joint strength of longitudinal specimens was independent of the specimen width, whereas it increased with width in the case of transverse specimens. The joining efficiency of pultruded sandwich laminates was greater in the longitudinal direction than in the transverse direction. Finite element numerical analysis was carried out to predict the failure mode and joint strength.

Shenoi et al. have investigated the influence of material and geometry variations on the behavior of single composite skin T-joint under static loading [8–10]. They found that the radius of the fillet and thickness of the overlaminate are critical to the performance of the joint. In general, a larger radius of the fillet or smaller thickness of the overlaminate results in improved performance of the T-joint under 450 pull-off loading. Similar results have also been reported by Rispler et al. [11] and Kumari and Sinha [12]. Dharmawan et al. investigated the effect of geometry and disbond between the fillet and the overlaminate on the Tjoint with a triangular fillet [13]. It was found that the presence of an initial disbond altered the distribution of axial strain through the thickness of the overlaminate; this caused outward bending of the overlaminate when the Tjoint is subjected to tension load. This effect indicated that the fillet functioned as an important medium of load transfer in the T-joint.

In contrast to the use of a single composite skin, composite sandwich panel T-joints were respectively investigated by Theotokoglou et al. [14–16] and Turaga and Sun [17]. Two fracture models were identified in the papers [15,17]: (1) the delamination between the leg and base panel, and (2) core shear failure in the base panel. Theotokoglou and Moan [15] stated that there were no significant differences in the ultimate strength of the two failure modes; the ultimate failure mode for a specific T-joint depends on the fabrication defects, e.g. voids in the fillet area. It is also found that the strength of T-joints is slightly influenced by the geometry of the overlaminate. Turaga and Sun [17] developed a few designs to improve the strength of T-joints. It was shown that using bolts in a circular fillet joint could cause early failure in the core and would not increase the ultimate join strength.

II. SANDWICH CONSTRUCTION

One group of laminated composites used extensively in the aerospace field is sandwich composites. Sandwich panels consist of thin facings (also called skin) sandwiching a core. The facings are made of high-strength material, such as graphite/epoxy; the core is made of thick and lightweight materials such as foam, cardboard, plywood, etc.

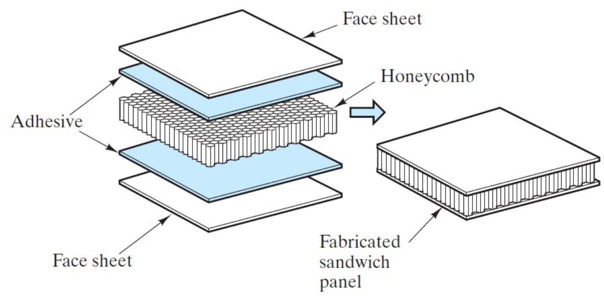

Fig 1 Sandwich construction

The motivation in doing this is twofold. First, if a plate or beam is bent, the maximum stresses [σ] occur at the top and bottom surfaces [$\sigma = M.y/\mathbf{I}$]. Therefore, it makes sense to use high-strength materials only at the top and bottom and low -lightweight strength materials in the middle. The strong and stiff facings also support axial forces. Second, the resistance to bending of a rectangular cross-sectional beam/plate is proportional to the cube of the thickness [because $\mathbf{I} = bd^3/12$]. Thus, increasing the thickness by adding a core in the middle increases this resistance. This advantage in weight and bending stiffness makes sandwich panels more attractive than other materials.

III. SANDWICH AND I BEAM

The facing skins of a sandwich panel can be compared to the flanges of an I-beam, as they carry the bending stresses to which the beam is subjected. With one facing skin in compression, the other is in tension. Similarly the honeycomb core corresponds to the web of the I-beam. The core resists the shear loads, increases the stiffness of the structure by holding the facing skins apart, and improving on the I-beam, it gives continuous support to the flanges or facing skins to produce a uniformly stiffened panel. The core-to-skin adhesive rigidly joins the sandwich components and allows them to act as one unit with a high torsional and bending rigidity.

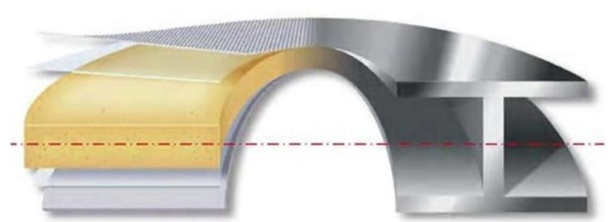

Fig 2 Sandwich and I beam

Sandwich panels are evaluated based on strength, safety, weight, durability, corrosion resistance, dent and puncture resistance, weatherability and cost.

The most commonly used facing materials are aluminum alloys and fiber-reinforced plastics. Aluminum has high specific modulus, but it corrodes without treatment and is prone to denting. Fiber-reinforced plastics such as graphite/epoxy and glass/epoxy are becoming popular as facing materials because of their high specific modulus and strength and corrosion resistance. Fiber-reinforced plastics may be unidirectional or woven laminae.

The most commonly used core materials are balsa wood, foam, and honeycombs. Balsa wood has high compressive strength (10.34 MPa), good fatigue life, and high shear strength (1.37 MPa). Foams are low-density polymers such as polyuretherane, phenolic, and polystyrene. Honeycombs are made of plastic, paper, cardboard, etc. The strength and stiffness of honeycomb depend on the material and its cell size and thickness.

Adhesives join the facing and core materials and thus are critical in the overall integrity of the sandwich panel. Adhesives come in forms of film, paste, and liquid.

IV. JOINING OF SANDWICHES

The following joining methods are generally disused in literatures.

A. T-joint with I-shape side inserts
B. T-joint with filler and core triangles
C. T-joint with L-cleats

In this review paper, manufacturing methods andkey parameters of those types are discussed.

A. T-JOINT WITH I-SHAPE SIDE INSERTS

I-shaped inserts are used to join the two sandwich structures. Typical insert is as shown in figure 3.

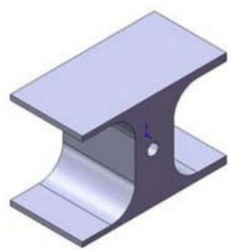

Fig. 3 Side insert for sandwich joints

These side inserts are placed in sandwiches which are going to be joined as shown in figure 4.

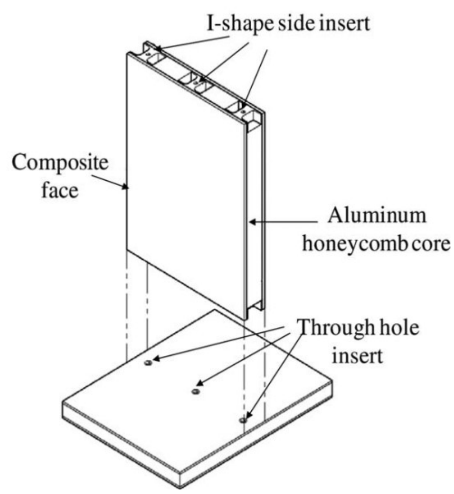

Fig.4 T-joint with I-shape side inserts

MANUFACTURING METHOD

The manufacturing of the T-joint involves the following steps.

- Laminate preparation for skin
- The composite faces, aluminum honey comb core and I-shape side inserts were bonded using an epoxy film adhesive for rib.
- The composite faces, aluminum honey comb core and I-shape inserts with central hole were bonded using an epoxy film adhesive for base panel.
- Base panel and rib were joined by fasteners.

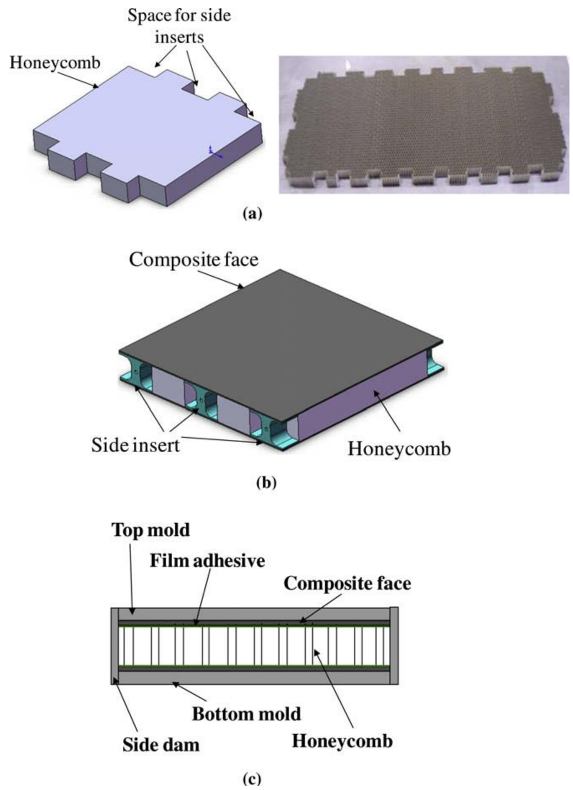

Fig. 5 Manufacturing method for T-joints with side inserts

PARAMETERS

The deciding parameters to consider this method are,

- Size and shape of the side inserts
- Number of side inserts

B. T-JOINT WITH FILLER AND CORE TRIANGLES

Adhesively bonded joints have been extensively used in assembling sandwich structures made from glass fiber reinforced polymer skins and a PVC foam core. Advantage of this kind of the joints in comparison to mechanical joints like screw and rivet, is lack of local damages and high stress concentration factor in components of the joints [7]. One of the most common adhesive bonded joint is the T-joint. Figure 6 gives an illustration of a T-joint. It consists of a horizontal base panel, a vertical leg panel, fillers and triangular fillets. The purpose of the use of the filler and the triangular fillets is to transfer the load and creation of connection between the base panel and the leg [7].

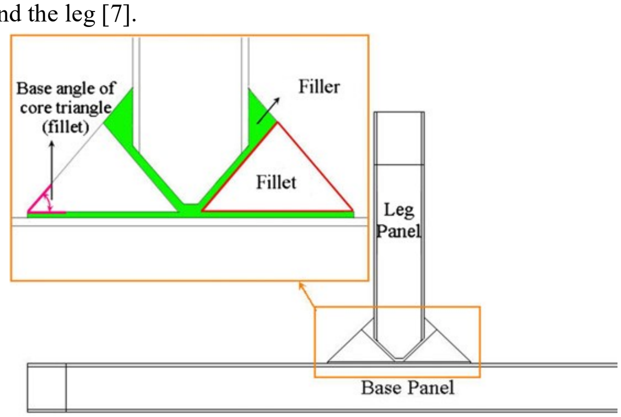

Fig. 6 T-joint with filler and core triangles

MANUFACTURING METHOD

The sandwich panels for the T-joints are manufactured by a resin infusion technique.

- All the glass fiber fabrics, the PVC foam core and the plywood blocks are laid up on a flat table
- Vacuum bagged, evacuated
- Small grooves are cut at both surfaces of the PVC foam core to facilitate resin flow and ensure a uniform and complete wetting of all fibers.
- Vacuum resin infused in one shot

PARAMETERS

- Base angle of core triangle

C. T-JOINT WITH L-CLEATS

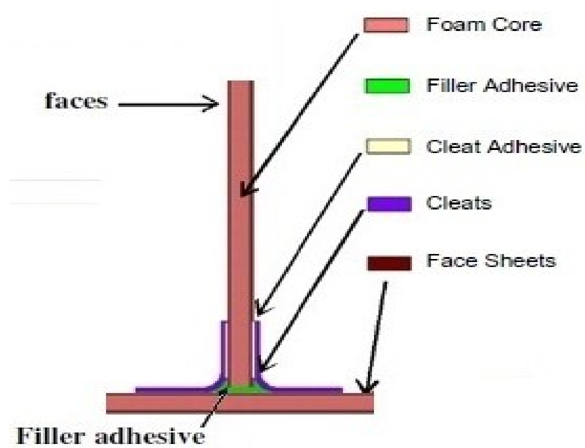

Fig. 7 T-joint with L-cleats – components

The two panels are joined at a right angle to each other by two L-shape cleats.

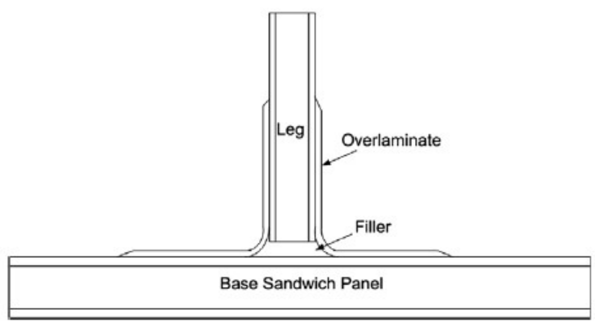

Fig. 8 T-joint with L-cleats

MANUFACTURING METHOD

- Both the panels are prepared
- Assembled as shown in figure 8 with L-cleats.
- Cured as per manufacturers data.

PARAMETERS

- Adhesive bond
- L – clip continuity
- L – clip configurations

V. CONCLUSION

Since the T-joint is for satellite application primary selection criteria for selecting the type of T-joint are weight and manufacturability.

Weight is the limiting factor for T-joint with I- shape inserts because of isotropic material addition. And the joining method requires machining and fasteners.

T- joint with filler and core triangles is a adhesive bonded joint and gives weight reduction (by 60%), but with the higher strength (by 20%) than the existing design [4]. Its manufacturing method is resin infiltration. It has limitation for complicated structures.

Absence of both machining process and isotropic material addition gives better advantages in T-joints with L-cleats.

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