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Numerical investigation on novel geometrical configuration for adhesively bonded T-joint between aluminum and sandwich panel

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ABSTRACT

One of the applications of adhesive joints in marine structures can be the attaching of superstructure to main hull, which classifies as T-joint. Although previous researches have covered T-joint between similar materials (composite to composite and aluminum to aluminum), joining aluminum and sandwich panels has not been considered yet. In this paper, the common lightweight T-joint with triangle fillets were investigated and based on the FEM results, the geometry was modified in order to increase the load bearing capacity subject to tension load. Results show that change in joint geometry can dramatically enhance the strength, and it was observed that the modifications made by authors caused vertical failure load of the joint to rise by 725%. However, in order to utilize full capacity of the joint strength, materials with high strength features should be used, unless the joint components will fail before debonding. Load carrying capacity of joint was increased while the applied adhesive decreased by 10% compared to the common lightweight T-joint. The results of numerical analyses were in a good agreement with experimental tests and confirm the accuracy of numerical analyses. Adhesion interfaces were modeled with contact elements along with Cohesive Zone Model in ANSYS. Contact stress and contact gap at the instance of collapse are also presented to provide the reader with the better understanding of the joint performance and the behavior of various components of the joint in load bearing and force transition.

1. Introduction

The notion of designing structures with dissimilar materials in order to optimize the design with respect to the strength to weight ratio has been enticed designers in all industries. However, attaching materials with different characteristics has been a formidable task for engineers.

Although bolts and rivets are the most common fastening system across the industry, designers always have to struggle with stress concentration and corrosion in the place of bolts and rivets. In contrast, adhesively bonded joints provide a smooth transition of stress, which is beneficial to reduce the stress concentration. In addition, adhesives do not generally induce corrosion problems unlike bolts and rivets. In general, adhesive joints could be divided into two groups: (1) in plane (various types of butt joints) and (2) out of plane (T and X joints). It should be noted that in-plane joints are investigated more than out-of-plane joints. In the following, a review of conducted researches about the out-of-plane joints is presented.

Li et al. [1] conducted finite element analysis to evaluate the fracture behavior of glass fiber reinforced polymer T-joint between sandwich panels in marine vessels. They assumed initial disbond in various locations with various sizes under a straight pull-off loads and used strain energy release rate (SERR) for assessing fracture behavior. They concluded that the loading direction is a dominant factor in fracture of the joint.

Dharmawan et al. [2] assessed the effect of geometry and disbonds on the strain distribution in a typical marine composite T-Joint under pure tension. They found out that in tension, disbond causes outward bending in overlaminate. In addition, the outward bending became worsen when the filler removed completely. They concluded that the presence of the filler is critical for load transition among joint components.

Tension and compressive strength of X-joint connecting superstructure bulkhead to the deck panel in way of internal bulkhead was studied by Hayman et al. [3] with both FEM analysis and experimental tests.

Conducted FEM analysis and experimental tests to evaluate the strength of X-joints in core, core-laminate interface and the debonding of adhesive filler. Their research covered tension and compression loading. They concluded that face-core debond defects can reduce the load-carrying capacity of the joint, however it is possible to limit this effect adjacent to the interface. In compression loading, the load carrying capacity of core was also investigated. Zhou et al. [4],

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implemented 3D model along with static and dynamic tensile loading to evaluate the performance of sandwich panel T-joints. They detected two failure modes in dynamic loading condition, (1) failure between overlaminate and base panel and (2) shear failure in core foam. It was shown that the shear force in core is a dominant parameter in failure modes of the joint. In addition, they concluded that the presence of fillet and large radius of fillet would increase the strength of the joint. Shenoi and Hawkins [5] and Dodkins et al. [6], found out that the radius of fillet and the thickness of overlaminate layers could affect the performance of the joint. Phillips and Shenoi [7] investigated the disbanding of overlaminate by using FEM analysis. Blake et al. [8], evaluated the effects of viscoelastic insert in new type of composite T-joint. They observed that using viscoelastic material insert. They used progressive damage model to assess structural response and observed improvement in noise and vibration attenuation. Besides, they found out that for using the advantages of this method, joint dimensions are to be increased.

The size of fillet radius and the thickness of overlaminate are the dominant factors in the performance of the T-joints under tension load with 45° out of plane direction. Rispler et al. [9] and Kumari and Sinha [10], proposed the same conclusion as mentioned earlier. Khalili and Ghaznavi [11], studied the sandwich panel T-Joints with triangle fillet angle and various fillet angles and core materials. They conducted FEM analysis and concluded that failure modes of the joint under tension is sensitive to core material.

In a research conducted by Akpinar et al. [12], it was shown that geometry of the bonded zone will affect stress distribution, stress concentration, load bearing capacity and prolonged performance of aluminum to aluminum bonded T-joints under bending moment. Akpinar et al. [13] also studied the normal and shear stress distribution at bi-adhesively (using two different types of adhesive in various parts of the joint) T-joint (aluminum to aluminum) by conducting nonlinear 3D FEM analysis and experimental test. They found out that by applied bi-adhesive bond line the strength is increased by 20% and the peel stress values is decreased. In addition, the shear stress values decreased meanwhile the higher degree of shear stress detected into inner area of bi-bond line.

Demir Aydin and Akpinar [14], assessed the mechanical properties of different aluminum T-Joints under tensile load and validated the results with experimental results. It was concluded that different bonding zone with different geometries where the support was embedded, leads to different stress distributions and accordingly, various stress concentration and load carrying capacities.

Nimje and Panigrahi [15], studied the performance of double supported T-joint of laminated FRP composites having embedded interfacial failures. They observed that the interfacial failures in the joint occurred at the interface of base plate and adhesive layer from both ends of base plate. Additionally, they found out that the strain energy release rate (SERR) is the dominant factor for damage propagation. Furthermore, they used functionality graded adhesive (FGA) with various SERR. It was shown that the FGA affect the SERR and decreases it at the embryonic stage of failure in which necessitate the application of FGA for joint and increase the service life of the structure.

Freitas and Sinke [16], evaluated the strength of stiffener (aluminum and CFR) to skin (aluminum) connection by pull-off test and compared the failure mechanism and load bearing capacity of both joints. They concluded that for using the full capacity of adhesively bonded hybrid joints, the strength of connection between carbon fibers (intralaminar strength) are to be improved. If not, other methods such as aluminum stringers is better option.

As for composite stiffener, they concluded that for using the full capacity of adhesively bonded hybrid joints, the strength of connection between carbon fibers are to be improved.

Riccio et al. [17] employed experimental (three point bending test) and numerical simulation to assess the effect of the stitches on the out-of-plane strength of composite skin in way of stringer (Stringer is a stiffening member which is a part of airplane structures to prevent buckling under compression or shear loads) foot interface. Two types of stitches, blind stitching and tufted, and they concluded that the stitched skin has better mechanical characteristics which is related to the stitches' density and the thickness of the stitching yarn. In addition, they found out that blind stitches are more ductile compared to the tufted specimens. The mechanical behavior of repaired bonded composite structures and scarf joint have been studied by Riccio et al. [18]. A novel material model for ductile adhesive, which was proposed by Riccio et al. [19], was utilized to simulate both crack propagation in adhesive and to assess stress distribution in the joint and repaired structure. They concluded that the proposed material model is in good agreement with experimental results.

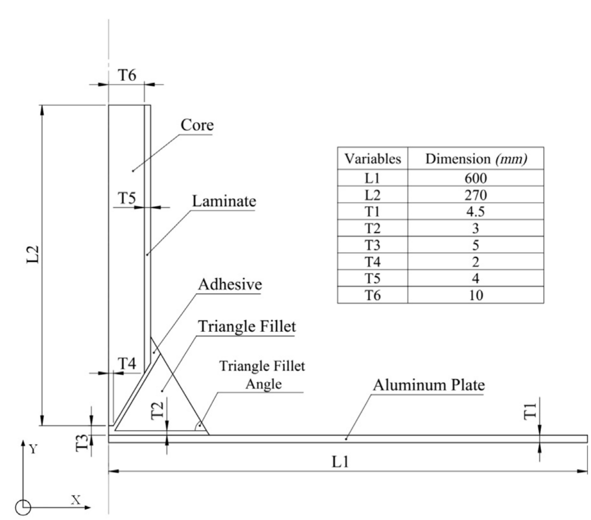
According to what was noted, it could be said that the T-joint between sandwich panels and aluminum has not been investigated by the researchers. Joint between these dissimilar materials is needed to be assessed due to its application in the industry such as attaching the FRP superstructure to main hull (constructed of steel or aluminum). Geometry of the joint was selected from a small high-speed craft [20] and applying Det Norske Veritas (DNV) Rules' formulas in [21]. Contact elements in conjunction with Cohesive Zone Model (CZM) were implemented in ANSYS so that we could be able to detect adhesive debonding [22].

There is an ongoing researches to use FRP or other similar materials as construction materials in building superstructures of passenger ships. Superstructure of ships, especially in large ships with long superstructure, are subjected to high value of tension loads in hogging condition. Thus, the load capacity of the joints needs to be increased as much as possible. The joint was modeled with triangle fillet at initial design, but the design was modified (new design) to increase the strength of the joint. The results of the new design showed that the changes in the geometry of the design will lead to a noticeable improvement of the load bearing capacity of the joint.

2. Description of the FEM model

In this paper, two joints with different geometrical configurations have been studied. Joint configuration and structural scantlings for initial design are presented in Fig. 1. The joint has been designed according to the Det Norske Veritas rules for classification of high-speed, light craft and naval surface craft [21] based on a high speed craft particulars shown in Table 1 [20]. The initial design has been modified by authors and a modified geometry with higher load capacity proposed. Details of this new design is discussed in Section 6.

In all geometries, the triangle fillets have been assumed to be



Variables	Dimension *(mm)*
L1	600
L2	270
T1	4.5
T2	3
T3	5
T4	2
T5	4
T6	10

Fig. 1. Joint geometry-initial design (half of model depicted).