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Numerical Analysis and Experimental Failure Mode Determination of Composite T -Joint

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Abstract:- The use of fibre composite materials in more demanding roles is increasing due to increased performance requirements in various applications. One type of joint in a sandwich panels in superstructure is a T-joint. An existing design consists of panels joined by filler material and overlaminates of the same thickness as the skin laminates. The aim of the research was to determine the methodology to predict the failure mode of the T-Joint under a pull-off tensile loading using Finite Element model. The outcome of the research was that the Finite Element (FE) simulations were used in conjunction to determine the failure mechanism of the T-Joint in the presence of disbonds in the critical location. Stress distributions are investigated by both laboratory tests and numerical modeling, and design criteria for core pieces are presented.

Keywords: Sandwich panels, Overlaminates, T-joint, Core pieces, FRP.

I. INTRODUCTION

Adhesively bonded T-joints have been extensively used in assembling sandwich structures made from glass fibre reinforced plastic skins and a PVC foam core in naval vessels. The advantage of adhesive bonded joints over bolted or riveted joints is that the use of fastener holes in mechanical joints inherently results in micro and local damages to the composite laminate during their fabrication. The objective of the project is to strengthen the technological basis for the large scale application of fibre reinforced composite material for naval vessels and structures, so that such vessels (or major parts, e.g. superstructures) can be designed with confidence on the basis of modelling and failure predictions [3]. The Base Design T-joint consists of balsa core sandwich panels joined by filler forming a smooth transition (radius 35 mm) from the T-panel to the base panel, and over-laminated with laminates of the same thickness as the skin laminates, as shown in Fig.1. In the next phase of the project Candidate New Designs (CND) of T-joint were proposed, and some of them were selected for further investigation by testing, see Fig. 2 [3].In a superstructure a T-joint may be loaded in tension if an internal blast occurs in two adjacent compartments, or by an underwater explosion, where the whole ship is moving upward (out of the water), and acceleration forces acts on heavy equipment placed in two adjacent rooms with no support underneath the separating wall. In this paper, the T-joint is designed newly by considering defects in existing design by inserting core pieces, in order to increasing surface area for adhesion. Also couple of overlaminates are applied in vertical column, as shown in Figure. 3.

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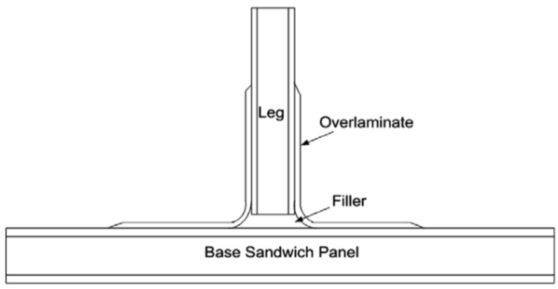

Fig. 1 Illustration of composite sandwich panel T-joint.

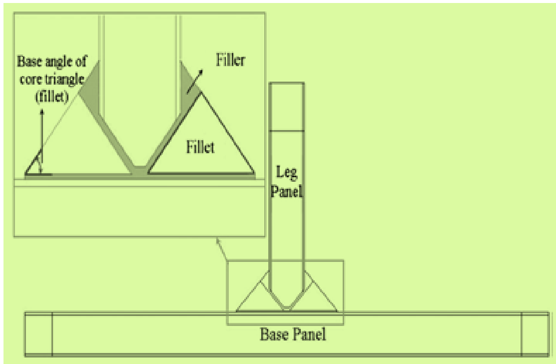

Fig. 2 DK-CND T-JOINT [3]

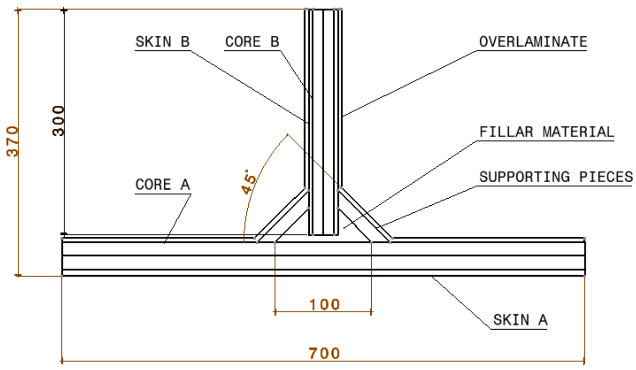

Fig. 3 Conceptual composite T- joint outline

II. TYPES OF FAILURE MODE

The main consideration in designing of the T- joint is to prevent the main bonding zone from different failure modes. Hence the supporting pieces were inserted to cover up the main bonding zone and to increase the surface area for adhesive bonding. Adhesives played a major role in this experiment so it was important to ensure that the adhesive is not the weakest link or element in this design of T- joint.

There are number of potential failure modes for adhesively bonded composite joints, the major are, shown in fig.4

a) Adhesive failure
b) Cohesive failure of the adhesive
c) Thin layer Cohesive failure
d) Fiber-tear failure
e) Light-fiber-tear failure
f) Stock-break failure

Fig. 4 Possible failure modes in bonded joints between composite adherends [11]

III. DESCRIPTION OF EXPERIMENT

The design of T-joint is based on existing model except the core pieces and double coat of overlaminate. Epoxy resin was used for filler material at main bond as well as it was used as a matrix for fibreglass. PVC foam was used as a core material. Though PVC foam is porous in nature, its surface is glossy which is unsuitable to expose in main bonding zone. Hence it was also coated by same overlaminates.

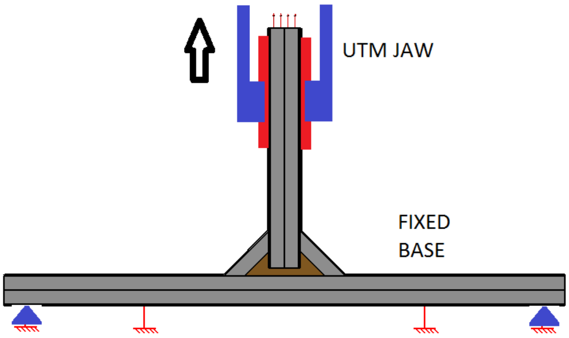

Fig. 5 Schematic of T-joint tensile test setup

The filler angle is kept as it is (45 degrees) to obtain equal surfaces in vertical as well as horizontal directions. Fig. 3 and Table 1 show all the dimensions and description of T-joint. The overlaminates of T-joint are manufactured by Hand lay-up method and filler is made by pouring the resin with hardener in to the cavity created by both plates and core pieces.

Table 1
Parts Used In T-Joint Concept

SR. NO.	PART NAME	MATERIAL	QUANTITY
1	CORE A	PVC FOAM	1
2	CORE B	PVC FOAM	1
3	SKIN A	FIBERGLASS	1
4	SKIN B	FIBERGLASS	2
5	CORE PIECE	PVC FOAM	2
6	FILLER TRIANGLE	RESIN	1
7	OVERLAMINATE	FIBERGLASS	2

As a part of validation, a prototype was manufactured and testing on UTM in tensile test. Fig 5. shows the conceptual drawing and loading condition.

In order to carry out the numerical analysis on T-joint the FE model was created using ABAQUS 6.12.

IV. DEVELOPMENT OF FE MODEL

ABAQUS 6.12 was utilized to simulate the damage behaviour of the T-joints under static loading conditions. The main aim of FEA is to determine stress concentration areas by Von Mises stress distribution and compare different T-joints. The boundary conditions are applied by fixing the bottom plate and Distributed force in vertical plate.

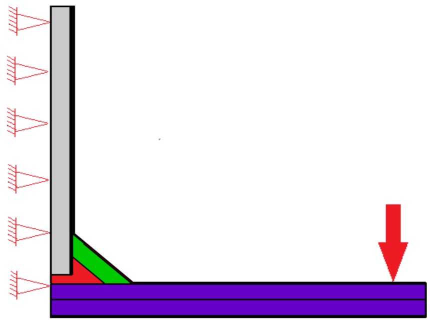

Fig.6 Boundary conditions and loading point

The geometric size of the T-joint is the same as described in the experiment and given in Fig. 3 and Table 1. Because of the symmetry of T-joint geometry, material and loading conditions, only half part of T-joint is modelled [2]. Figure 5 shows the boundary conditions and applied load. Material compositions for individual parts are also given in Table 1. Fig. 4 gives a schematic description of the numerical model for simulation of the dynamic tensile test. A total of six material properties were involved within the FE model, specifically

A. Properties of material for FEA model

Core = PVC Foam; Density= 200 kg/m3

Crushable Foam properties

Skin= Fibreglass Cloth; Density= 2500 kg/m3

1) PVC foam and fibreglass:

Table 2
Material Properties Of Pvc Foam And Fibreglass-

Properties	CORE	SKIN
Exx(GPa)	0.35	20.3
Eyy(GPa)	0.35	4.48
Ezz(GPa)	0.35	20.3
Gxy(GPa)	0.035	2.5

Gyz(GPa)	0.035	2.5
Gzx(GPa)	0.035	8.5
υ-xy	0.3	0.05
υ-yz	0.3	0.15
υ-xz	0.3	0.15

2) Epoxy resin:
Curing with Hardener Epoxy – PAM
Mixing ratio = 100:10 or 100:12
Properties -Mix viscosity MPa.s at 30°C 2000+/- 1000

Table 3: Properties Of Epoxy Resin

Pot life of 500 gm mix	Min	10-15
HDT	°C	100
Flexural Strength	Psi	17000
Compressive strength	Psi	16000
Tensile strength	Psi	10300
Impact strength	lb/in	0.45
Volumetric Shrinkage	%	0.01 Max

Modulus of elasticity, E = 72000 Mpa
Poissions ratio = 0.22
Tensile strength = 3.45 X 10^3 MPa

B. Properties of Bonding

It is important to be able to control the degree of bonding between the matrix and the reinforcement. To do so, it is necessary to understand all the different possible bonding types i.e. mechanical, physical or chemical, one or more of which may be acting at any given instant. A simple mechanical interlocking effect between two surfaces can lead to a considerable degree of bonding. Any contraction of the matrix onto a central fibre would result in a gripping of the fibre by the matrix. This would lead to a gripping of the fibre by the matrix even in the absence of any chemical bonding. In figure 4, we have a radial gripping stress, σr. This is related to the interfacial shear stress, τi, as

$$\tau i = \mu \sigma r$$

where μ is the coefficient of friction.

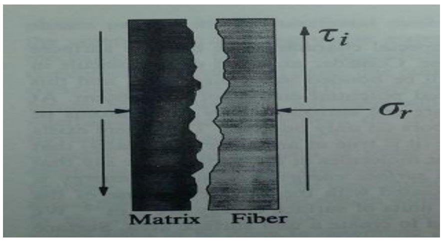

Fig. 7 Mechanical Gripping due to Radial Shrinkage of a matrix in a composite. [9]

C. FEA Model and Analysis

It was created in ABAQUS and properties were assigned to different section. A fine mesh was applied to main filler triangle to examine accurate result in that region by tri elements with suitable element size. Figure 8 shows the mesh of the T-joint.

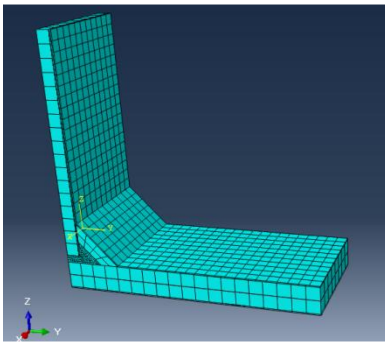

Fig. 8 Meshed assembly of T-joint

It is seen from above analysis that, maximum stress is developed on overlaminate shown by colour difference of Von Mises stress. It is measured 15.98 Mpa. A very little stress about 0.5 Mpa is developed on main adhesive zone i.e. on fillet triangle for load of 4.2 kN. The bottom skin is stressed about 2 Mpa. Excluding overlaminates and skins all parts having comparatively less stress concentration showing in fig. 10.

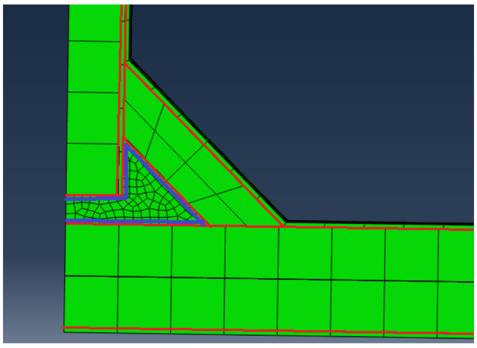

Fig. 9 Detailed meshing at the intersection of T-joint

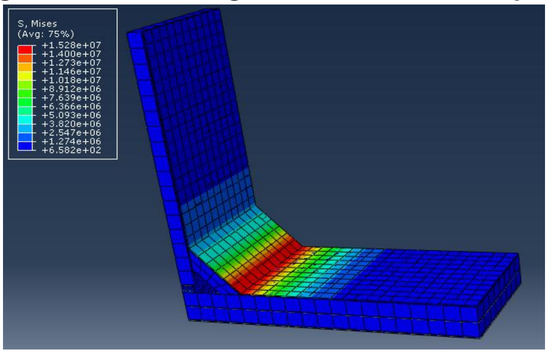

Fig. 10 Contour plot- Von Mises stress distribution

In fig. 9, the detailed meshing at the intersection of T-joint is shown. The primary bonding surfaces are indicated by blue lines which is the main bonding zone and it should not affected whereas the secondary bonding zone created by composite laminates. The failure of this experiment is the deformation of damage of the main bonding zone i.e. filler triangle.

V. VALIDATION OF THE NUMERICAL SIMULATION

In order to validate the accuracy of the model of FE analysis, the numerical results were compared with the results of experiment tests performed on manufactured prototype of T-joint [8]. The test was carried on UTM for tensile loading in 100kN load cell (Fig. 11).

Fig. 11 T-joint loaded to UTM

As per the concept, the bottom plate was fixed and vertical plate was attached to the upper jaw of the UTM with the help of fixtures and load applied gradually.

VI. EXPERIMENTAL RESULT AND DISCUSION

The crack initiated from the interface between the overlaminate and bottom skin through core A at about 19.82 kN after 8.6 mm displacement. The damaged T-joint is shown in fig.12.

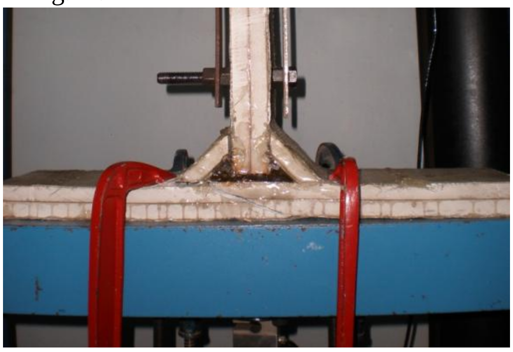

Fig.12: A failed T-joint with crack to the bottom plate [8]

The failure mechanism of this undamaged T-Joint verifies the experiment done by St. John *et al.* (2000) [7] that the failure will be always along the overlaminate bond line. However, the initial location where the crack begins to grow may be either at the core A- overlaminate interface or the core B- overlaminate interface. No matter where the crack initiates, the crack will grow along the filler region to cause fracture along the overlaminate bond line. It is suggested that the initial crack growth is due to the manufacturing imperfections, such as poor bonding.

According to Finite Element Analysis result, maximum stress was developed on overlaminate and bottom skin as shown in Figure 13.

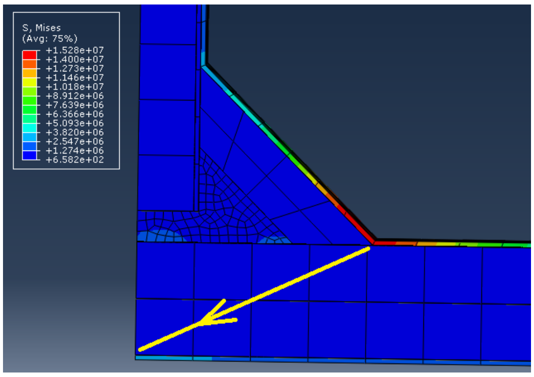

Fig. 13: FEA model of T-joint symmetric about Y-axis

A starting point of a crack may not be predicted but it should be on the line of joining weak regions i.e. the overlaminate corner to the weakest region on base plate skin. In this kind of failure the material may fail and the main bonding zone was away from failure. In actual testing, fig. 14, the prototype was failed in same fashion as predicted by FEA results. The material was failed and no changes in main bonding zone and filler triangle.

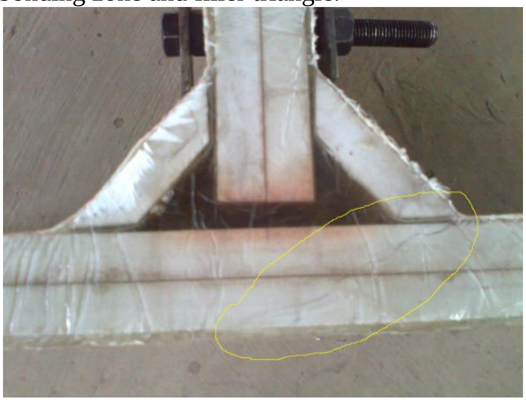

Fig. 14: Actual failure mode (crack propagation)

VII. CONCLUSIONS

This design of T-joint was made after studying the existing design. The problems in the existing design were eliminated and strength was increased by changing geometry and filler material. Supporting pieces and extra vertical skin were used to protect the main bonding zone as well as to increase the adhesive area of the resin.

Different types of modes of failures in composites were studied and FEA analyses were carried for predicting the failure mode and the weak regions. Two types of failure modes were seen in this result i.e. Fiber-tear failure and Stock break failure. High stresses were developed in overlaminate and the bottom skin initiates crack and above failures had arrived. In actual testing, the crack follows the same pattern and location as in FEA result. This is the degree of accuracy of FEA result.

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