Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 31
ISSUE 2
December
2008

The effect of design on adhesive joints of thick composite sandwich structures

O.E. Canyurt*, C. Meran, M. Uslu
Mechanical Engineering Department, Engineering Faculty,
Pamukkale University, 20070 Kinikli, Denizli, Turkey
* Corresponding author: E-mail address: ocanyurt@pau.edu.tr

Received 13.09.2008; published in revised form 01.12.2008

Properties

ABSTRACT

Purpose: of this paper is to provide the joint the behavior caused by the material, pre-stress, bonding thickness and the tongue length.

Design/methodology/approach: A simple but effective design can considerably improve the joint strength of thick adhesive composite joints. The joint under investigation consists of thick woven E-glass/vinyl ester laminates joined together with tongue and groove geometry. Longitudinal tensile loads were applied to the joints, resulting in large concentrated shear and peel stresses near the free edges of bondlines.

Findings: The new design intends to reduce the adhesive peel stress by application compressive pre-stress on the free edges of bondlines and thus leads to an increase of joint strength. The bonding clearances, tongue length, pre-stress and using different tongue made of steel/aluminum have an effect on the joint strength. The tests further confirm that joint strength increases significantly by applying the transverse pre-stress. There is a 2 times increment on the joint strength by applying pre-stress on the edge of tongue and groove geometry.

Practical implications: Selection of Steel SAE-235 insert materials and selection of Aluminum 5083 insert materials 1.7 times and 1.2 times increased the joint strength compared with the selection of composite insert materials, respectively.

Originality/value: The results indicate that the better quality joint can be obtained by selecting the steel as an insert.

Keywords: Thick composites; Sandwich structures; Adhesive bonding; Design

1. Introduction

Composites are gaining popularity in many areas including aerospace, ship, automobile structures and micro-electronic devices. Composite sandwich structures have benefits such as low weight, high strength, good fatigue resistance, excellent thermal and sound insulation, flatness for signature requirements, corrosion resistance, etc.

Joining technologies and therefore adhesives become an important role in composites. Adhesive joints have many advantages over the traditional mechanical fastened or riveted, bolted joints [1, 2], such as high strength-to weight ratio, electrical and/or thermal insulation, conductivity, corrosion and fatigue resistance [3].

Adhesive joining of thin section of composite laminates with similar adherents or metals is well understood and widely used in aerospace and other structures. Many researches have been described in the literature. The focus of most of the work has been on the joints in flat plates loaded by simple tension, where the strength of the joints is typically limited by stress concentrations in the adhesive and adherents at the leading edges of the doublers, and by often low shear and peel strengths of the adhesive. Ikegami et al. investigated different adhesive joint designs including the single lap, double lap, and scarf joints [4]. Thick composites material adhering by single lap joints causes many problems. Hart-Smith and Adams investigated the strength of adhesive bonding [5, 6].

The present paper extends our recent results Dvorak et. al. and Bahei-El-Din on analysis and design of tongue and groove (T&G) joint for joining thick laminated plates to metal or composite laminate adherends [7, 8]. This study examines an approach to design of adhesive joints for composite laminates, where the adhesive is applied to contour though the thickness interfaces in tongue and groove geometry. In this work, adhesive (Loctite-Hysol 9464 adhesive) was applied along though-thickness contoured interfaces, employing tongue-and-groove geometry. The high in plane shear strength and geometry of the laminate prevent any possibility of delamination. The bond area increases in proportion to laminate thickness and so does the total force that the joint can support; hence joint strength is independent of plate thickness. The local stresses can be reduced by suitable contouring of the leading edges, or under sustained loading, relieved by local creep and other inelastic deformation of the adhesive. Since the latter can lead to damage accumulation and failure of the adhesive, long overlaps are required such that a central section of the adhesive layer stays elastic and help in reversing the strains after unloading. The bonding clearances (thickness), tongue length, pre-stress and using different tongue made of steel/aluminum have been investigated in this study. With the presented configuration, failure modes associated with delamination and tensile and/or shear failure of the surface plies that were often observed in joints were reduced or eliminated, and a better stress distribution in adhesive and a better joint strength were obtained by selecting proper design parameters.

2. Material ve method

Figure 1 shows a typical design of tongue and groove (T&G) geometry of a laminated composite sandwich structure plate (groove) connected through steel (St 37), aluminum (5083) and composite plate insert (tongue) that was adhesively bonded to the exterior surface of the adherents.

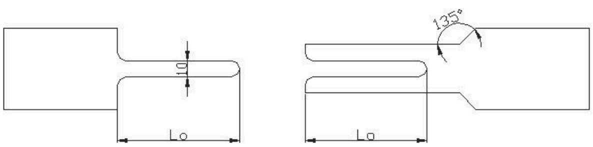


Fig. 1. Tongue and groove (T-G) geometry configuration

Experiments in this study were performed in the composite laboratory of Mechanical Engineering Department at Pamukkale University. Instron 8801 universal uni-axial test machine that has the capacity of the 50 kN has been used in all quasi-static experiments. The adhesive used in this study is Loctite-Hysol 9464, which was used with proper curing temperature and time specified by the manufacturer (minimum 4 days at room temperature).

Four main parameters, tongue length, bonding clearance, pre-stress and tongue materials were analyzed. Lengths of tongues were selected as 75 mm, 150 mm and 275 mm and shown in Figure 2.

The second design parameter, adherent thickness can affect the bonding strength. Low adherent thickness can led to the insufficient epoxy in the bonding surface. Proposed adherent thicknesses in this design allow a much shorter joint by extending the bonded surface through the adherent thickness. Moreover, the new joint designs do not rely on the double plates as the primary component for load transfer between the adherents. Loctite Hysol 9464 A&B adhesive was used in the experiments and adherent thickness (d) was determined as t= 0.1 mm, t= 0.2 mm and t= 0.4 mm. Adhesive properties of Loctite Hysol 9464 are listed in Table 1.

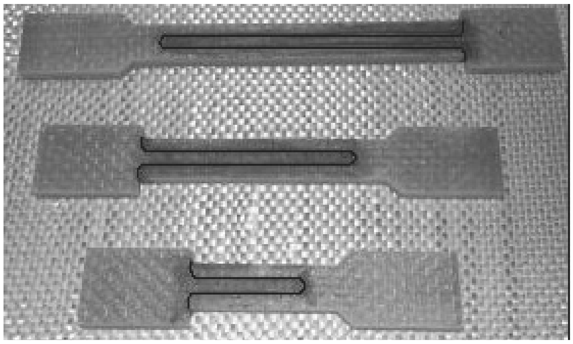


Fig. 2. Tongue and groove bonded joint configuration of 225 mm 150 mm and 75 mm

Table 1.
The properties of adhesive Loctite Hysol

Shear strength	22 MPa
Peeling strength	10.5 MPa
Viscosity	270 Pa.s
Youngs Modulus (E)	1.75 GPa
Shear Modulus (G)	0.65 GPa

The third parameter was selected as transverse stress. Pre-stressed was applied 0 Nm, 7 Nm, 15 Nm by using torque meter. The pre-stress can effectively reduce the magnitude even reverse the sing of the peel stress in the adhesive layer and the adherends, but would increase the shear stress. For those composite joints with low transverse inter laminar strength and susceptible to delamination, this simple design/technique can considerably improve their joint strength. [3].

Transverse compressive pre-stress was generated by clamping mechanism shown in Figure 3. The mechanism provides uniform stress distribution at the end of groove material shown in Figure 4.

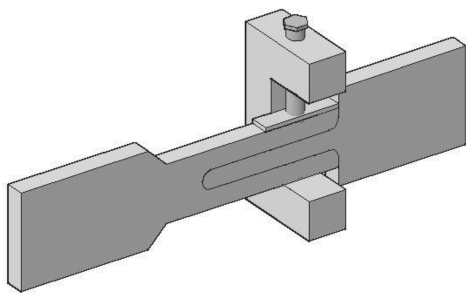


Fig. 3. The transverse pre-stress clamping mechanism

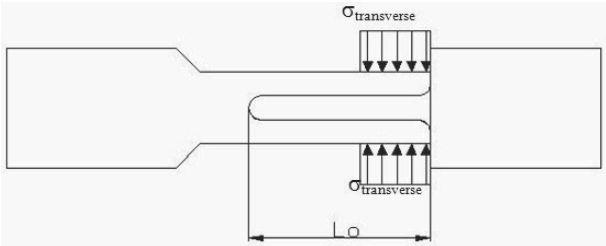


Fig. 4. The application of transverse pre-stress

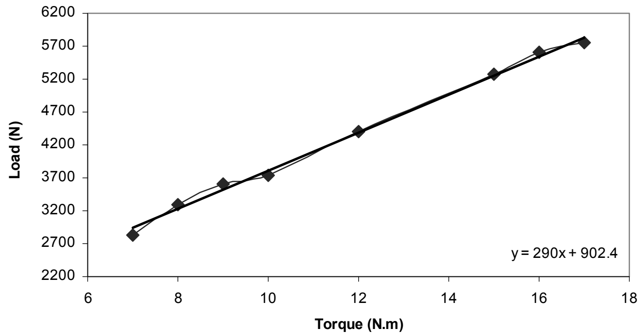


Fig. 5. The mechanism of transverse pre-stress

It can be seen that the clamping mechanism aligned with the free edges of the laminates was utilized to accommodate prestressing on the both grove ends. The bolt tightened by a prescribed torque, which may also provide additional load-bearing capacity. Bolts with the nominal diameter d=8 mm, acting on the transverse surface using 20x12 mm rigid plate. The amount of pre-stress applied on the bonded region was calculated and well controlled. The load and corresponding torque were determined by using load cells. The linear relation can be seen in Figure 5. In order to apply 12 MPa and 22 MPa pre-stress in one side of clamping mechanism surface, 2.93 and 5.25 kN preload needs to be generated in the bolt by the wrench torque. Desired preloads were obtained at the 7 N.m and 15 N.m torques using torque meter.

The effects of material on bonding were also examined by changing composite, steel and aluminum insert. Steel (St 37), composite and aluminum (5083) insert were used in this study shown in Figure 6. Material properties are listed in Tables 2-4. Joints with four design parameters were tested by using quasi static loading (1500 N/min) under load control.

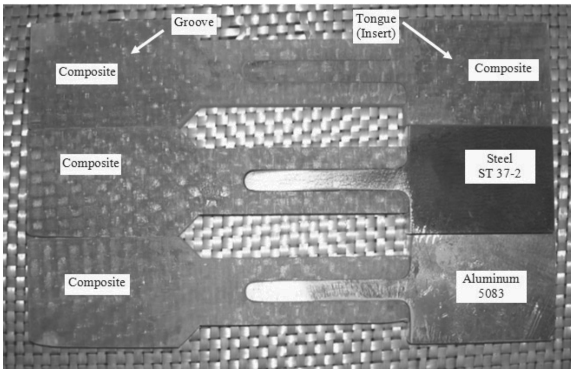


Fig. 6. The application of composites-steel-aluminum inserts

Table 2.
The properties of steel (St37-2)

Material	Ultimate Strength R_m (MPa)	Tension (σ) (MPa)		Bending(σ) (MPa)		Torsion (τ) (MPa)	
		Static	Full Dynamic $\sigma_{çbD}$	Static σ_{ea}	Full Dynamic σ_{eD}	Static τ_{ba}	Full Dynamic τ_{bD}
SAE 235 (St37)	360	235	150	330	170	140	100

Table 3.
The properties of aluminum (5083)

Tempered	Ultimate Strength, R_m (MPa)	Yield Strength, (MPa)	Youngs Modulus (GPa)
Aluminum 5083	290	145	70

Table 4.
The properties of 0/90 woven vinyl ester composite laminates

	Youngs Modulus (GPa)			Shear Modulus (GPa)			Ultimate Strength, (MPa)		
	E_{11}	E_{22}	E_{33}	G_{12}	G_{23}	G_{13}	F_{1t}	F_{2t}	F_6
Composites (Woven Fabric 0/90 Laminates)	22	22	9	5.3	3.1	3.1	350	350	95

3. Results and discussion

From the experiments results, the strength of the joints were measured for many design composition and analyzed.

The plot in Figure 7 clearly shows the benefit provided by the change of the insert material and compressive pre-stress. Three joints, which have similar geometry fail at 18.33 kN using composite, 37.38 kN using steel, 26.90 kN using aluminum insert on the joint configuration without pre-stress. The results indicate that adhesively bonded tongue-and-groove joints between steel-composite plates loaded in monotonically increasing longitudinal tension are stronger than composite-composite joints without pre-stress condition. Strengths of joints with steel St37 material were approximately 103%, 39% higher than the strengths of joints with composite material and aluminum material with equivalent tongue lengths. Composite-composite joints were determined the worst design configuration among other joints without pre-stress.

Composite materials were primarily affected due to the pre-stress. The composite-composite joint with pre-stress gained strength, passed aluminum-composite and even get close to steel-composite joint. The strength of composite-composite joint is 18.29 kN without pre-stress, when the pre-stress was applied, the strength of joint almost doubled to 33.17 kN with 12 MPa and 36.78 kN with 22 MPa pre-stress for the same tongue length of 75 mm. With adding pre-stress, composite-composite joints were more benefited from compressive stresses compared with metals. Three joints under pre-stress fails 33.17 kN using composite, 37.90 kN using steel and 27.10 kN with 12 MPa pre-stress, and 36.08 kN using composite, 38.07 kN using steel and 28.91 kN with 22 MPa pre-stress. This results indicates that the strength of composite-composite joint is 18.30% higher than aluminum joint and 14.26% lower than steel joint with 12 MPa pre-stress and 19.87% higher than Aluminum and 5.52% lower than steel joint with 22 MPa pre-stress. Composite-aluminum joints were concluded the worst design configuration among other joints with pre-stress.

The strength of joint was also affected from the length of tongue. This effect is the highest in composites and the lowest in the steel material. Three times increase on the insert tongue (75 mm to 225 mm) led to an increase of 30.56% (18.29 kN to 23.88 kN) for composite-composite joint without pre-stress and 11.38% (36.83 kN to 41.02 kN) for composite-composite joint with pre-stress. The comparison of pre-stress effect and the length of tongue on the composite-composite joint strength are depicted in Figure 8. This comparison have pointed out that joint strength of the composite-composite specimens which were not applied pre-stress were much lower than of the pre-stressed ones. This joint strength difference became almost 2 times, 1.8 times and 1.7 times for the tongue length of 75 mm, 150 mm and 255 mm, respectively.

Similar but small trends were observed for steel and aluminum material. The joint strength raised 8.18% and 9.59% for aluminum insert and 4.04% and 4.55% for steel insert of 150 mm and 255 mm tongue lengths without pre-stress, respectively. Same trends were observed both with and without compressive pre-stress conditions. The joint strength increased 7.99% and 8.45% for aluminum insert and 8.01% and 11.38% for steel insert of 150 mm and 255 mm tongue lengths with pre-stress, respectively. The comparison of steel, aluminum material and pre-stress effect based on the length of tongue is depicted in Figures 9-10.

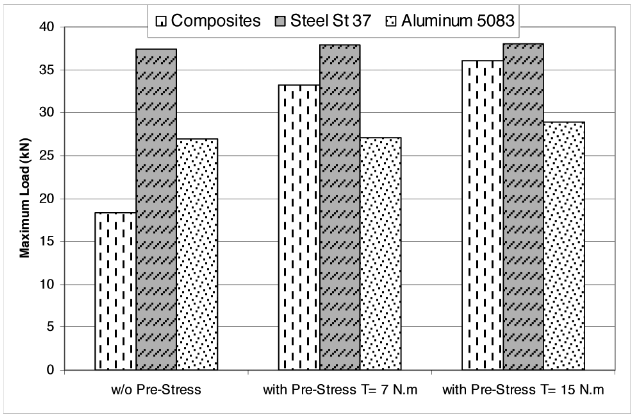


Fig. 7. The comparison of materials under with or without pre-stress on the joint strength

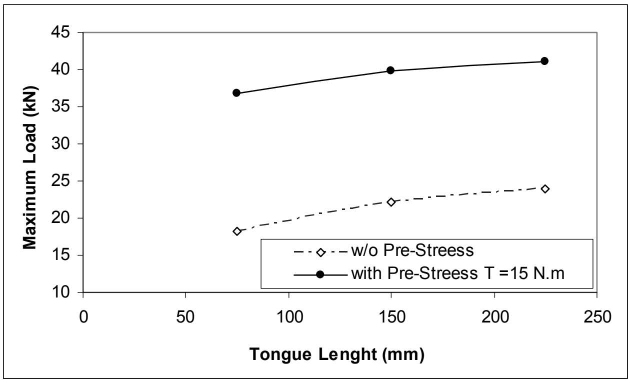


Fig. 8. The comparison of composite-composite bonding and pre-stress effect based on the length of tongue

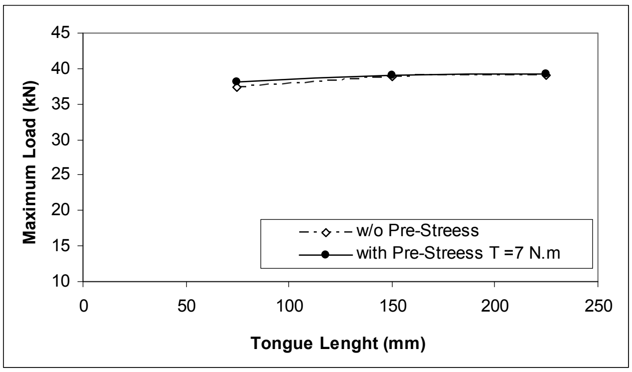


Fig. 9. The comparison of composite-steel bonding and pre-stress effect based on the length of tongue

Although bonding thickness from 0.1 mm to 0.4 mm increases the joint strength from 24 kN to 35 kN for L_o=225 mm and 18 kN to 25 kN for L_o=75 mm composite-composite joint without pre-stress condition.

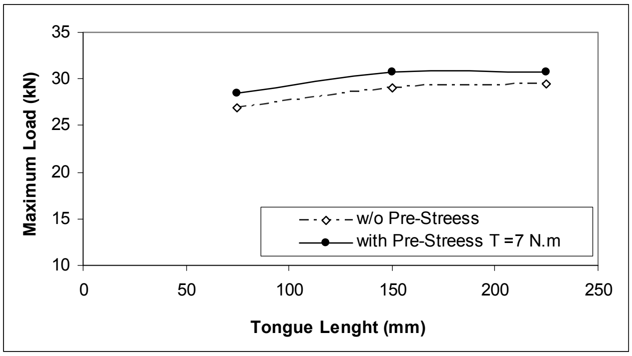
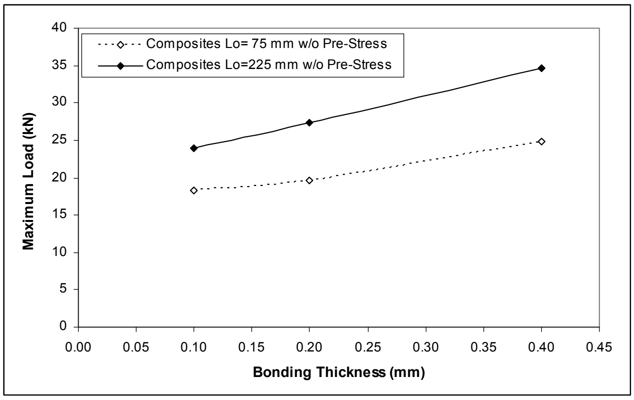


Fig. 10. The comparison of composite-aluminum bonding and pre-stress effect based on the length of tongue

a)



b)

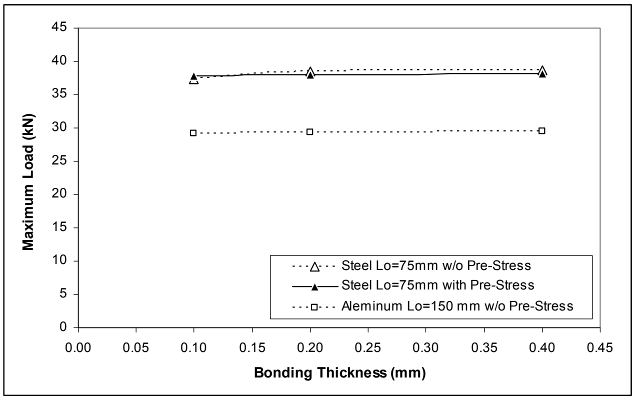


Fig. 11. The effect of bonding thickness a) composite-composite joint b) composite-metal (steel, Aluminum) joint on the joint strength

With comparing the results of steel and aluminum joints, there is no significant change for metal-composite joints. The joint strength raised 3.02% with 0.2 mm 3.58% with 0.4 mm thickness for steel and 0.62% with 0.2 mm 1.31% with 0.4 mm thickness for aluminum. The effect of bonding thickness on the joint strength can be seen in Figure 11a-b.

Aim of this paper is to provide the joint the behavior caused by the material, pre-stress, bonding thickness and the tongue length. Simple design rules indicate that the adhesive bond can be made stronger than that of the tongues, so that failure is transferred from the adhesive to the adherents. High joint efficiency can be achieved for selecting proper design parameters of the composite plates.

Acknowledgements

This work was financially supported by The Scientific and Technological Research Council of Turkey (TUBITAK). Authors are gratefully acknowledged the TUBITAK for their valuable support.

References

[1] T. Ireman, Three-dimensional stress of bolted single-lap composite, Composite Structures 43 (1998) 195-216.

[2] T. Ireman, T. Ranvik, I. Eriksson, On damage development in mechanically fastened composite laminates, Composite Structures 49 (2000) 151-171.

[3] O.E. Canyurt, J. Zhang, Pre-stressed adhesive strap joints for thick composite sandwich structures, International Journal of Mechanical Sciences 48 (2006) 389-399.

[4] K. Ikegami, T. Takeshita, K. Matsuo, T. Sugibayashi, Strength of adhesively bonded scarf joints between glass fibre-reinforced plastics and metal, International Journal of Adhesion 10 (1990) 199-206.

[5] L.J. Hart-Smith, Adhesive bonding of composite structures progress to date and some remaining challenges, Journal Composites Technology Resources 24 (2002) 133-153.

[6] R.D. Adams, Strength predictions for lap joints, especially with composite adherends. A review, Journal of Adhesion 30 (1989) 219-242.

[7] G.J. Dvorak, J. Zhang, O.E. Canyurt, Adhesive tongue-and-groove joints for thick composite laminates, Composites Science and Technology 61 (2001) 1123-1142.

[8] Y.A. Bahei-El-Din, G.J. Dvorak, New designs of adhesive joints for thick composite laminates, Composites Science Technology 61 (2001) 19-40.