

A STUDY ON FAILURE STRENGTH EVALUATION OF HYBRID COMPOSITE JOINT

Jin-Ha Park¹, Kang-Woo Jeong², Jin-Ho Choi^{1*} and Jin-Hwe Kweon²

¹Department of Mechanical Engineering, Research Center for Aircraft Parts Technology, Gyeongsang National University, South Korea (correspondingauthor,email : choi@gnu.ac.kr)

²Department of Aerospace Engineering, Research Center for Aircraft Parts Technology, Gyeongsang National University, South Korea.

Keywords: *Hybrid composite joint, Damage Zone Theory, Failure Area Index (FAI), Failure strength*

Abstract

As composites have become popular in recent years, the design of the composite joint has become a very important research area because the structural efficiency of the composite structure is determined by its joints, not by its basic structures. Generally, the joining methods of the composite structures are classified into mechanical and adhesive types. We evaluated the failure strength of the hybrid joints composed of an adhesive bond in conjunction with mechanical fastening. The double lap joint jig was used for the tensile test of the hybrid joint. The 10 hybrid joint specimens which have different width-to-diameter (w/d) ratio, edge-to diameter (e/d) and thickness were manufactured and tested. Carbon-epoxy unidirectional prepreg (USN125) and plain weave prepreg (HPW193) were used for the hybrid composite joint. The stacking sequence of the hybrid composite joint was $[\pm 45_3/90/\pm 45_2/0_4/90/0_4/\pm 45_2/90/\pm 45_3]$. To predict the failure Strength of the hybrid joints, finite element analyses were performed using the ANSYS 10.0 commercial soft-ware and 3-D structural solid element. From this study of the failure strength prediction of hybrid joints, the experimental failure loads of the hybrid joints were nearly identical to those of the adhesive joints and were at least twice as large as those of the mechanical joints for all 10 cases investigated. In addition, the adhesive failure in the hybrid joint occurred before the mechanical failure, for all 10 cases investigated. Finally, using the damage zone theory and the failure area index method, the failure load of the hybrid joints could be predicted to within 25.5% for all of the investigated cases. Further study of the dynamic characteristics of hybrid joints, such as fatigue life and crack propagation, is recommended.

1 General Introduction

Hybrid joints are a combination of adhesive bonding and mechanical fastening and have previously been considered in relation to repair and improvement in damage tolerance. Hart-Smith [1] conducted a theoretical investigation of hybrid (boned/bolted) stepped lap joints and found that there was no significant strength benefit over perfectly bonded joints. Fu [2] studied the fatigue of hybrid joints with different washer designs in SRIM (structural reaction injection molded) composites. Kelly [3] predicted the load transfer in a hybrid, composite, single-lap joint using a three-dimensional finite element model that included the effects of both the bolt-hole contact and the non-linear material behavior. However, there exists minimal published research on the hybrid joint, and most studies are restricted to hybrid joint analysis and performance testing. In addition, we know of little research regarding failure load prediction for hybrid joints.

In this paper, we evaluate and compare the strengths of hybrid composite joints. Ten hybrid joint specimens with different width-to-diameter (w/d) ratios, edge-to-diameter (e/d) ratios and adherend thicknesses were manufactured and tested. In addition, the strengths of the hybrid joints were predicted using the FAI method and the damage zone method.

2 Manufacturing of hybrid Joint specimens

Ten hybrid joints with different w/d ratios, e/d ratios and adherend thicknesses were manufactured. The shapes of the hybrid joints are shown in Figure 1, and their dimensions are listed in Table 1. We fabricated ten specimens with different w/d ratios,

e/d ratios and adherend thicknesses. Figure 2 shows the manufactured hybrid specimens.

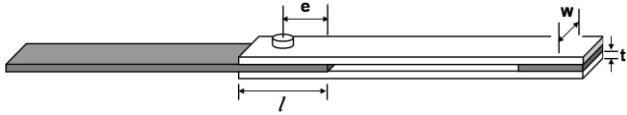


Figure 1: Shape of hybrid joint specimen

Table 1: Failure indices when the hybrid joints failed

Model	Adhesive bonding		Mechanical fastening	
	Max. Strain	D_R	Max. Failure index	FAI
H01	23%	0.2133	0.20	0
H02	28%	0.2136	0.43	0
H03	29%	0.2139	0.17	0
H04	28%	0.2136	0.05	0
H05	25%	0.2134	0.10	0
H06	23%	0.2136	0.23	0
H07	23%	0.2143	0.84	0
H08	15%	0.2135	0.85	0
H09	16%	0.2147	0.89	0
H10	13%	0.2143	0.77	0



Figure 2: Manufactured hybrid specimens

3 Tensile test of the hybrid joint

We evaluated the failure loads of the hybrid joints composed of an adhesive bond in conjunction with mechanical fastening. Figure 3 shows the double lap joint jig for the tensile test of a hybrid joint. We used the Universal Testing Machine 5582 manufactured by Instron Co., with a crosshead speed fixed at 1 mm/min. Figure 4 shows the force-displacement curves of several hybrid joints. Two peaks were observed, and the magnitude of the force of the first peak was smaller than that of the second peak.

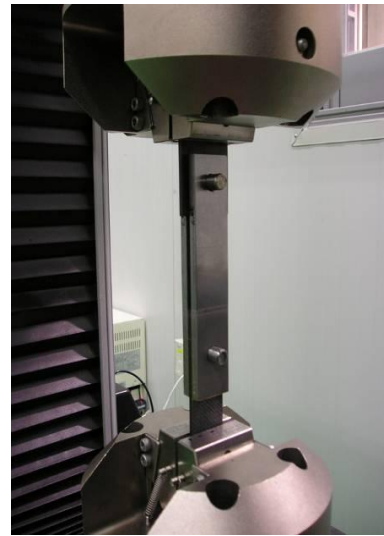


Figure 3: Tensile test of a hybrid joint

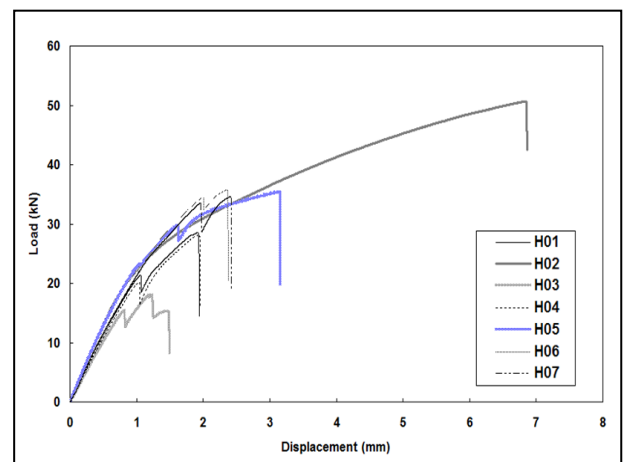


Figure 4: Force-displacement curves of hybrid joints

4 Predicting the failure loads of the hybrid joints

To predict the failure loads of the hybrid joints, finite element analyses were performed using the ANSYS 10.0 commercial software and 3-D structural solid elements. Figure 5 shows half of the finite element model of the hybrid joint. As shown in Figure 5, contact pair elements were used for the nonlinear contact between the pin and the hole. Because the adhesive was highly nonlinear, the multi-linear curve, which had a different elastic modulus in different strain zones, was used as an input to the finite element model. Figure 6 shows the multi-linear curve calculated from the shear stress-strain curve [4].

Since the hybrid joints comprised a combination of adhesive bonding and mechanical fastening, we had to establish the failure criteria of both the adhesive joint and the mechanical joint. In this paper, the damage zone theory [4, 5] and the FAI method [6, 7] were used for the adhesive bonding and the mechanical fastening, respectively. The hybrid joints were assumed to fail if either of the two failure criteria was satisfied. Figure 7 shows the predicted failure load of the hybrid joints with different w/d ratios. As shown in Figure 7, the failure loads of the composite joints could be predicted to within 25.5%.

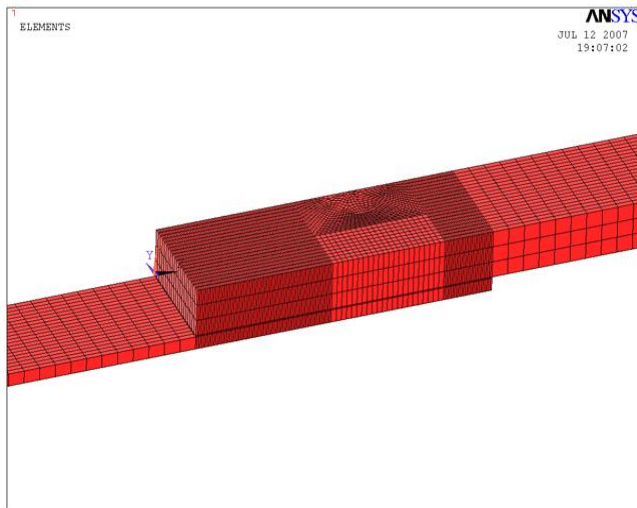


Figure 5: Finite element model for analysis of the hybrid joint

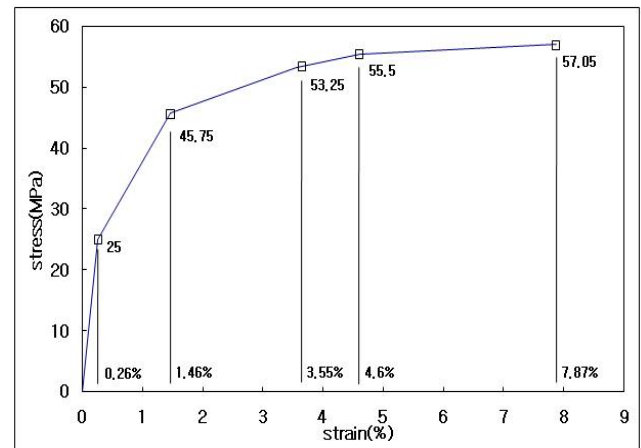


Figure 6: Multi-linear curve

5 Conclusions

In this paper, ten hybrid joints with different w/d ratios, e/d ratios and adherend thicknesses were manufactured and tested. From this study of the failure load prediction of hybrid joints using the damage zone theory and the FAI method, the failure loads of the composite joints could be predicted to within 25.5% for all 10 cases investigated. Further study of the dynamic characteristics of hybrid joints, such as fatigue life and crack propagation, is recommended.

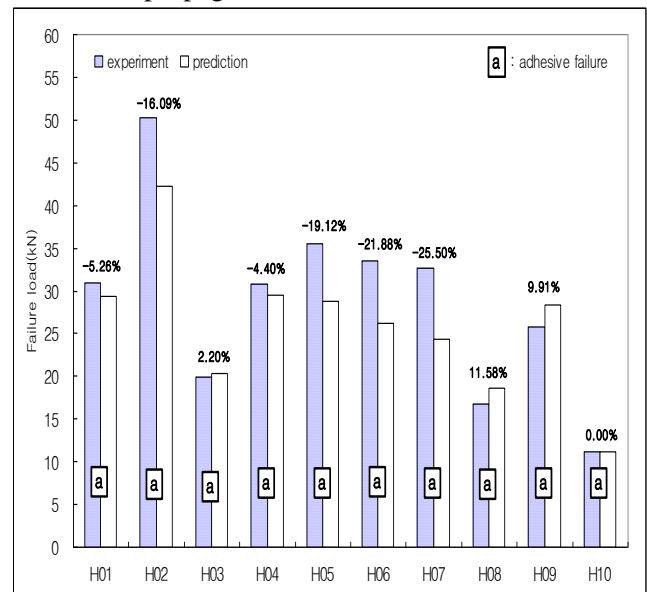


Figure: 7 Prediction loads of the hybrid joints

Acknowledgements

This work was supported by the Priority Research Centers Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education, Science and Technology(2010-0029689) and the second stage of BK21 project at Gyeongsang National University.

References

- [1] L. J Hart-Smith. *Design methodology for bonded-bolted composite joint*. Technical Report AFWAL-TR-81-3154, Douglas Aircraft Company, 1982.
- [2] M. Fu and P. K. Mallick, Fatigue of hybrid(adhesive/bolted) joints in SRIM. composites. *International Journal of Adhesion and Adhesives* Vol. 21, No. 2, pp 145-159, 2001.
- [3] Kelly G, Load transfer in hybrid(bonded/bolted) composite single-lap joints, *Journal of Composite Structures*, Vol. 69, No. 1, pp 35-43, 2005.
- [4] C. S Ban, Y. H. Lee, J. H. Choi and J. H. Kweon Strength prediction of adhesive joints using the modified damage zone theory. *Composite structures* Vol. 86, pp 96-100, 2008.
- [5] A. Sheppard, D. Kelly and L. Tong. A damage zone model for the failure analysis of adhesively bonded joints. *International Journal of Adhesion and Adhesives* Vol. 18, No. 6, pp 385-400, 1998.
- [6] J. H. Choi, Y. J. Chun. Failure Load Prediction of Mechanically Fastened Composite Joint. *Journal of Composite Materials*, Vol. 37, No. 24, pp 2163-2177, 2003.
- [7] C. O. Ryu, J. H. Choi and J. H. Kweon. Failure load prediction of composite joints using linear analysis. *Journal of Composite Materials* Vol. 41, No. 7, pp 865-878. 2007.