EXPERIMENTAL INVESTIGATION ON FATIGUE AND TENSILE BEHAVIORS OF ADHESIVE AND HYBRID COMPOSITE-STEEL JOINTS

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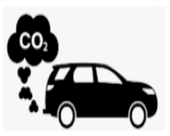
INTRODUCTION

➢ **Addressing environmental issues: Enhanced fuel efficiency via lightweight structures.**

- As environmental conservation becomes more crucial, research on weight reduction is being actively conducted.
- Utilizing composite materials with benefits like lightweight, specific strength, and high specific stiffness can decrease vehicle weight and CO_2 emissions.
- Mechanical fixing and bonding are suggested methods for joining different materials.
- As parts originally made of metal need to be replaced with composite materials, research on joining composites and metals is necessary.
- However, more research is necessary as the current scope and scale of studies evaluating fatigue life in hybrid and adhesive joints are limited.
- In this research, the tensile and fatigue properties of carbon fiber reinforced composite-steel hybrid and adhesive bonded joints were examined based on the overlap length.



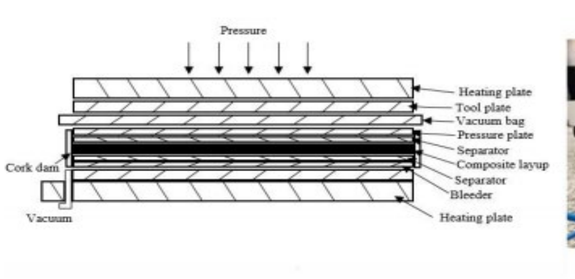
Co_2

Composite material

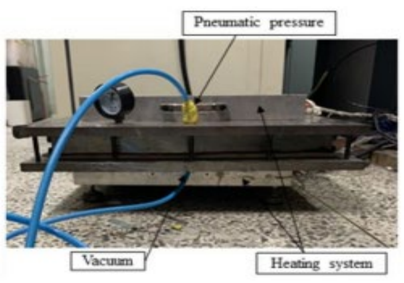
MATERIALS AND METHODS

➢ **Specimen preparation**

- Carbon/epoxy composite USN-125B (from SK Chemicals Co.) as the adherend, with a $[0/90]_{5s}$ stacking sequence and 0.123 mm ply thickness
- ASTM D5868-01 standard for bond and hybrid joint fabrication
- Bond and hybrid joint fabrication according to ASTM D5868-01 standard
- M10 8.8T PFZn8-D bolt with a clamping torque of 50Nm
- Epoxy-based adhesive with a thickness of 0.1mm
- Joint overlap lengths of 30mm, 40mm, and 50mm



<Schematic drawing of miniclave curing>



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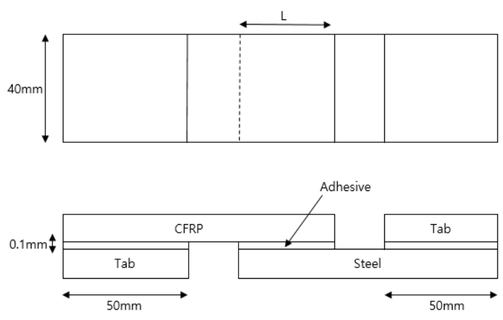
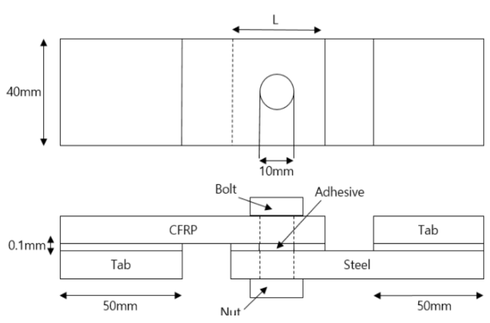


Bonded Joints



Hybrid Joints

➢ **Experiment**

- Tensile tests were conducted to determine load levels before fatigue testing for both joint types.
- Tensile test performed at a speed of 2 mm/min
- Fatigue tests carried out at a stress ratio ($R = \sigma_{min} / \sigma_{max}$) of 0.1 and a frequency of 3 Hz, with six repetitions for each overlap length (30, 40, and 50 mm)
- For adhesively bonded joints, fatigue life was determined by the final breaking point after initial bond failure.
- For hybrid joints, fatigue life was considered as the time until adhesive failure.

<Experimental Setup>

➢ **Material Properties**

- The specimens for the bulk tensile tests were manufactured and tested in accordance with ASTM D638-14.

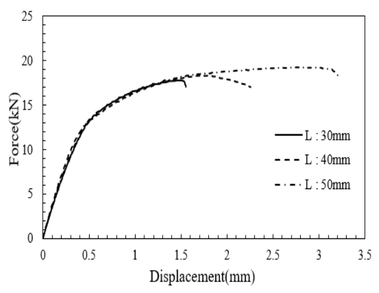
Material	Ultimate tensile strength [MPa]	Elastic modulus [GPa]	Poisson's ratio [ν]
Steel (SS400)	313	206	0.29
CFRP [0/90]5s	1866	75	0.312
Adhesive (Type D)	31	1.8	0.37

<Measurement of Adhesive Properties>

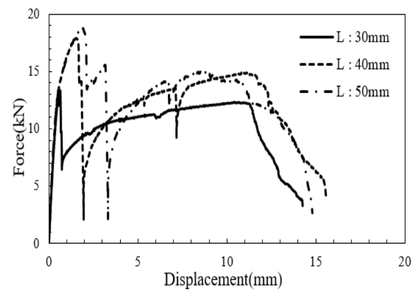
RESULTS AND DISCUSSION

➢ **Tensile behaviors of joints**

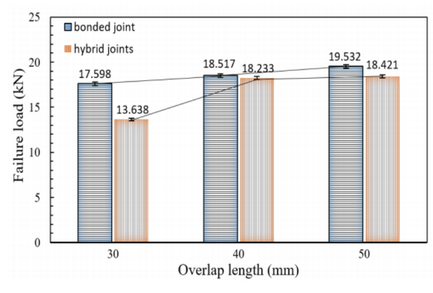
- Hybrid and adhesive joints with overlap lengths of 30, 40, and 50 mm were tested in the study
- Adhesive joint failure loads were 17.60, 18.52, and 19.53 kN, with a 5% increase for every 10 mm overlap length increase.
- Hybrid joint failure loads were 13.64, 18.23, and 18.42 kN for 30, 40, and 50 mm overlap lengths, respectively.
- Hybrid joints exhibited lower tensile strength than adhesive joints.



Adhesively bonded joints force–displacement curves



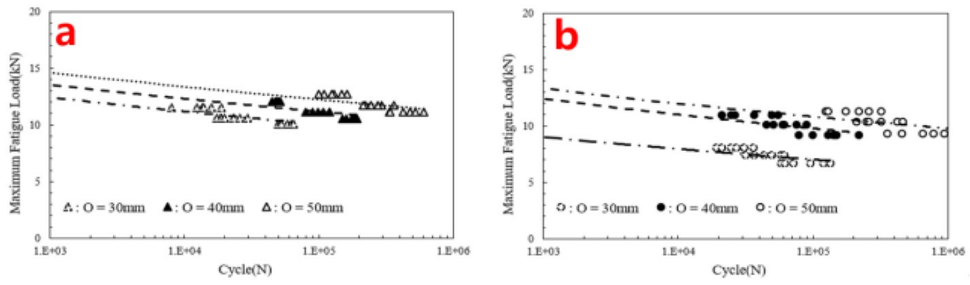
Hybrid joints force–displacement curves



Failure loads of adhesively bonded joints and hybrid joints

➢ **Fatigue behaviors of joints**

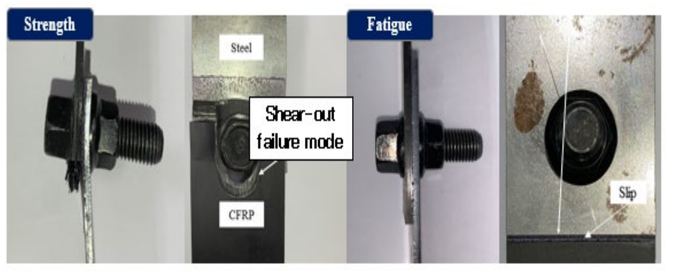
- The evaluation was conducted on specimens of adhesively bonded joints and hybrid joints, which combined dissimilar materials, such as CFRP composite and steel.
- Bonded Joint
  Compared with the overlap length from 30mm to 40mm, the fatigue load increased by 10% from 10.08 kN to 11.1 kN (for 10^5 cycle)
- Hybrid Joints
- Compared to the overlap length from 30mm to 40mm, the fatigue load increased by 40.4% from 7kN to 9.83kN (for 10^5 cycles)



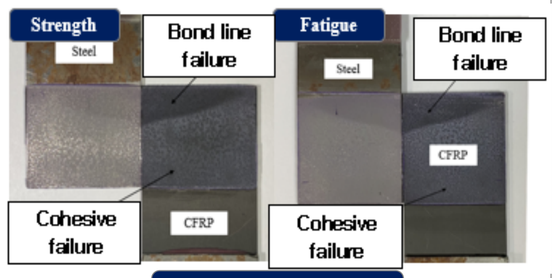
Fatigue diagrams for overlap lengths of 30, 40, and 50 mm (a) adhesively bonded and (b) hybrid joints

➢ **Fatigue failure modes**

- Stress concentration at the overlap length's end led to bond line failure, followed by sudden adhesive layer failure during a fatigue cycle.
- Cohesive failure area increased with overlap length, while bond line failure area remained relatively constant.
- In hybrid joints, failure criteria were based on adhesive failure for comparison. While adhesively bonded joints completely failed under fatigue load, hybrid joints experienced slip due to adhesive failure at different overlap lengths.
- Upon continuous repetitive loads after adhesive failure, bolts supported hybrid joints until complete failure occurred.
- Adhesively bonded joints showed enhanced fatigue life with increased overlap length due to reduced stresses from load dispersion over a larger adhesive area.



Hybrid Joints



Bonded Joints

Conclusions

- Adhesively bonded joints showed enhanced fatigue life with increased overlap length due to reduced stresses from load dispersion over a larger adhesive area.
- The adhesive's relatively high stiffness in this study led to inadequate load sharing for hybrid joints, causing a decrease in fatigue life as overlap length increased.
- Comparing the fatigue lives of adhesive and hybrid joints in relation to overlap lengths, the hybrid joint's fatigue life improvement rate decreased with increasing overlap length.
- This is due to the study measuring hybrid joint fatigue life based on adhesive bond failure rather than complete joint failure.

REFERENCES

(1) Hart-Smith L.J. (1985). Bonded-bolted composite joints. Journal of Aircraft, Vol 22, pp 993–1000.

(2) Kim T.H., Kweon J.H., Choi J.H. (2008). An experimental study on the effect of overlap length on the failure of composite-to-aluminum single-lap bonded joints. Journal of Reinforced Plastics and Composites, Vol 27, pp 1071–1081.

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