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Evaluation of Fatigue Crack Propagation Characteristics under Different Fracture Mode in CFRP Bonded Joints with Urethane Adhesive

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With the increasing demand for lightweight automotive structures to reduce CO_2 emissions, carbon fiber reinforced plastic (CFRP) has attracted attention due to its high specific strength and stiffness. For its application in automotive structures, reliable joining technologies are essential, and adhesive bonding is promising for weight reduction and stress distribution. While most studies have focused on epoxy adhesives, urethane-based adhesives have recently gained attention; however, their fatigue behavior under different fracture modes remains unclear.

In this study, the fatigue crack propagation behavior of CFRP joints bonded with urethane-based adhesives was investigated under various fracture modes. Double cantilever beam (DCB) and end-notched flexure (ENF) tests were conducted under Mode I and Mode II loading conditions, respectively. In addition, double cup (DC) tests were performed to evaluate fatigue properties under shear-dominant, tension-dominant, and mixed-mode loading using a single specimen geometry.

As results, he following findings were obtained:

1) DCB and ENF test
- The crack propagation resistance under Mode II loading is approximately three times higher than that under Mode I loading (Fig.1), demonstrating that fatigue design based on Mode I conditions provides a conservative and safe approach.
- Fracture surface observations revealed that Mode I loading leads to cohesive failure within the adhesive layer, whereas Mode II loading results in thin-layer cohesive failure near the interface(Fig.2).

2) DC test
- The fatigue strength under tensile loading is significantly lower than that under shear loading (Fig.3).
- Under mixed-mode loading with a tension-to-shear ratio of 1:2 (30°), the fatigue strength decreases to a level close to that under tensile loading, due to the influence of Mode I components(Fig.3).
- Regardless of loading conditions, fatigue fracture surfaces exhibit thin-layer cohesive failure; however, tensile loading shows a higher residual adhesive fraction, and mixed-mode loading results in fracture characteristics similar to those under tensile loading(Fig.4).

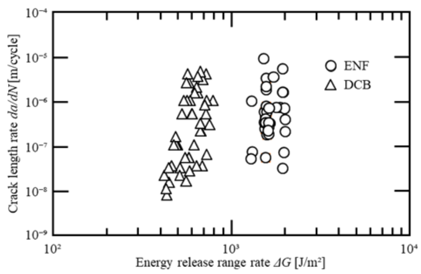


Fig.1 Fatigue crack growth behavior under each fracture mode of CFRP bonded joint with urethane adhesive.

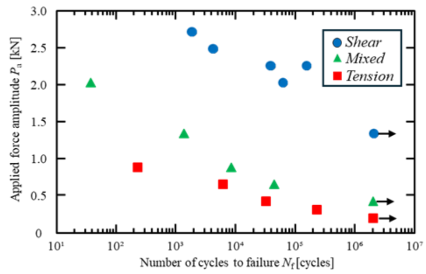


Fig.3 Fatigue test results of each fracture mode in DC specimen.

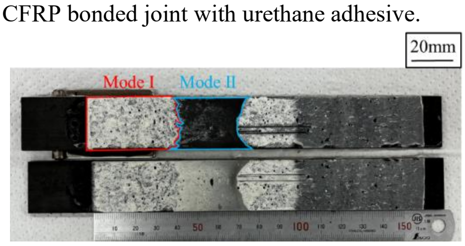
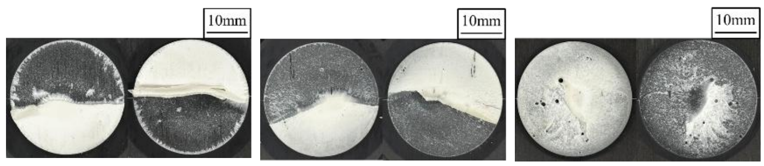


Fig.2 Fracture surface of DCB and ENF tests.



(a) *Shear* at P_a of 2.5 kN and N_f of 4.4×10^3 cycles. (b) *Mixed* at P_a of 0.9 kN and N_f of 8.8×10^3 cycles. (c) *Tension* at P_a of 0.7 kN and N_f of 6.4×10^3 cycles.

Fig.4 Fatigue fracture surface of each fracture mode in DC specimen.

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