New method for the assessment of adhesive joint failure under cyclic loads

Kazumasa Kato[1)] Masatoshi Yamakawa[1)] Noriyuki Muramatsu[1)] Manuel Frank [1)] Klaus Hofwimmer[1)]

1) Magna International Japan Inc., Nihonbashi Plaza Building 6F, 2-3-4 Nihonbashi, Chuo-ku, Tokyo, 103-0027, Japan
2) MAGNA Powertrain, Engineering Center Steyr GmbH & Co KG, Steyrer Strasse 32, St.Valentin, Austria

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Adhesive bonding has become established in Body in White (BIW) structures in recent years. One reason for this is the increasingly complex material combinations, but also the advantages of hybrid and elementary bonding. The fatigue analysis in bonded joints was now made possible in FEMFAT software. A guideline for coarse modeling serves as a basis. Tests have shown that failure to crack initiation is a conservative criterion when high local stresses occur in ductile modified adhesives. Therefore, a method for assessing the damage distribution in adhesive layers was developed and integrated into the simulation process. It is presented the modeling of adhesive, the simulation process, and validation results in this paper.

Coarse modeling is typically used in global models, where the sheets are meshed by shell elements. The modeling guideline for coarse modeling uses 2 layers and 3 stripes of HEXA8 elements coupled by RBE3 (Fig.1). To increase accuracy, only the nodes in the mid-plane are considered.

The characteristic values for compression, bending and shear were estimated based on the values for tension with ratios that depend on the material class. To consider the material properties known from tests, the shear strengths were equated with the tensile strengths. In addition, the compressive strength was reduced, the characteristic values (ν, E, $A5$ from quasi-static tensile tests) and the S-N curve data (slope k, cycle limit N_{CL}, survival probability P_S from Master S-N curve) were adjusted.

Tests were carried out on MP1 specimens designed by Magna ECS together with the joint research company. The specimen has highly stressed and visible areas in a total of two adhesive joints. The formation and growth of cracks were recorded by cameras. Fig.2 shows the F-N curves determined with EP1 (= ductile modified epoxy) under load perpendicular to the bonding plane. EP1 shows pronounced crack propagation phases, whereby the cohesive macroscopic crack did grow from a multitude of cracks. This fact led to the idea of introducing the failure criterion 'Zone', which is defined by the critical extent of a cracked zone.

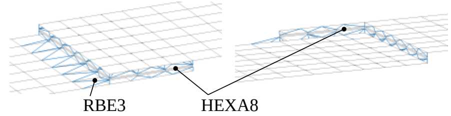

Fig.1 Coarse modeling

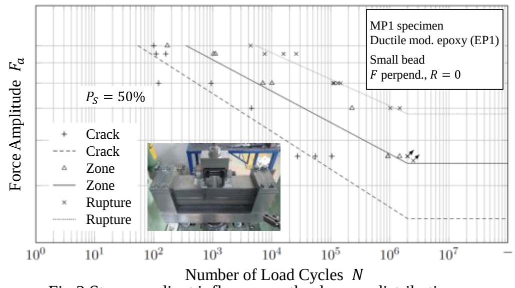

Fig.2 Stress gradient influence on the damage distribution

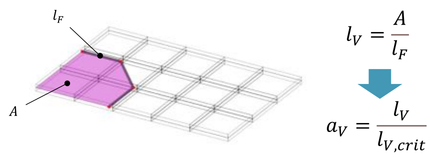

Fig.3 The definition of Virtual Crack Zone and utilization degree

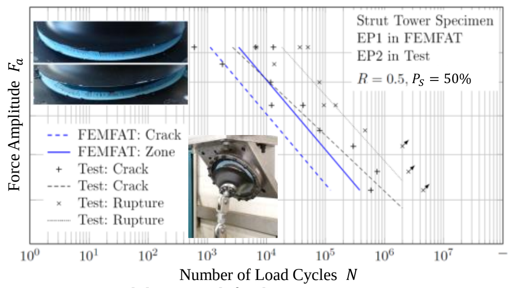

Fig.4 Validation result for the strut tower specimen

The new method determines the intersection points between the linearly interpolated damage results D of the adhesive mid-plane and the plane D_{lim}=1, which describes the damage when technical crack occurs. These points are used to analyze a zone with section A and front length l_F (Fig.3). The zone is called 'Virtual Crack Zone' because its smaller extent due to the neglect of fracture mechanics effects.

The validation was carried out on base and component-like specimens from IGF/FOSTA. The simulated S-N curves for 'Crack' and 'Zone' were compared with the available failure S-N curves from test (Fig.4). The simulation gives slightly conservative results here, where the simulated 'Zone' failure roughly correlates with the crack failure in the test. The diagram also shows one of the major problems: The lack of test data for adhesive system EP1. Therefore, the validation of the EP1 (= ductile modified epoxy) system had to be carried out based on test results of component-like specimens bonded by EP2 (= brittle epoxy).

The advantage of this method, applied downstream the fatigue analysis, is that linear stress superposition is possible in channel-based simulations. The preliminary validation on basic and component-like specimens has shown that the method provides sufficient correlation for practical use under uniaxial loading. Further work is required for comprehensive validation, with focus on generating experimental data for the ductile modified epoxy (EP1) under investigation. S/N curves for various failure criteria must be determined and crack propagation documented in detail. Subsequently, the validation for complex multi-axial loads can be considered.