Examination of the KAWAI CLD Method for Fatigue Life Prediction of Composites

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1. Introduction

The use of advanced composite materials in aircraft primary structures has been significantly increased over the past 25 years. Modern large commercial aircraft are designed with more than 50 percent composite materials, due to the demand for fuel-efficient, light-weight, and high-stiffness structures that have fatigue durability and corrosion resistance [1-3].

It is well known that aircraft structures are subjected to complex fatigue loading that accompanies changes in the amplitude, mean, frequency and waveform of stress cycling during service. Apparently, a large number of fatigue tests under different kinds of cyclic loading conditions is required to elucidate the effect of loading ratio on the composites sensitivity to fatigue; thus, this consumes considerable time and cost. Therefore, a time and cost-saving procedure for identifying the loading mode dependence of composites fatigue strengths is required. This procedure should assure reasonable accuracy on the basis of a minimal amount of test data.

The KAWAI CLD [4,5] is a Constant Life Diagram (CLD) method that has been examined in IAI for fatigue life predictions of composites. In this method, fatigue tests are carried out at one critical R-ratio, defined as the ratio of the Ultimate Compression Strength (UCS) over Ultimate Tensile Strength (UTS) of the material. This critical ratio is designated by χ. This method is a time and cost-saving procedure that provides reliable data, as compared to the linear Goodman curve, that its use for composites does not reflect the actual behavior of the material [4-6]. It may be further noted that there are several models for constant life diagrams presented in the literature (for example see [6-8]). However, each of these methods requires fatigue tests in at least three R ratios, as opposed to the KAWAI method in which fatigue tests are conducted only for the critical R ratio.

Static and fatigue tests were carried out for open-hole coupon specimens made of unidirectional carbon/epoxy tapes for examination of the applicability of the KAWAI constant life model. The Goodman CLD is examined as well.

2. Kawai CLD model for fatigue life prediction

Kawai and his coworkers developed an asymmetric constant life diagram, named the anisomorphic Constant Fatigue Life (CFL) diagram in [4,5] for CFRP materials. The main feature of this formulation is that it can be constructed by using only one experimentally derived S-N curve, which is called the critical S-N curve. The R-ratio of this S-N curve is defined as the ratio of the UCS over UTS of the material. The formulation is based on three main assumptions:

a. The stress amplitude for a given constant value of fatigue life is greatest at the critical stress ratio.
b. The shape of the CFL curves changes progressively from a straight line to a parabola with increasing fatigue life.
c. The diagram is bounded by the static failure envelope that consists of two straight lines connecting the peak point on the critical straight line with the UTS and UCS, respectively.

After determining the critical S–N curve by fitting to the available fatigue data, the CFL diagram can be constructed based on the static strengths, UTS and UCS, and the reference S–N relationship.

3. Experimental Procedure and Results

Static and fatigue tests were carried out for open-hole coupon specimens for examination of the applicability of the KAWAI modified constant life model. A quasi-isotopic lay-up of intermediate modulus unidirectional (UD) Carbon/epoxy tapes was examined. The lamination sequence, $[(+45^0, 90^0, -45^0, 0^0)s]s$, is balanced and symmetrically stacked. The geometry of the specimens was in accordance to ASTM standard for open-hole tests (ASTM D5766, ASTM D6484). The specimen is illustrated in *Figure 1*. A total of 56 composite specimens are tested. The tests included static compression and tension

strength tests to obtain the critical R ratio. Fatigue testing included five R ratios; i.e., 0.5, 0.1, χ, -1 and -10. Most R-levels consisted of five levels of stresses (with two tests at each stress level).
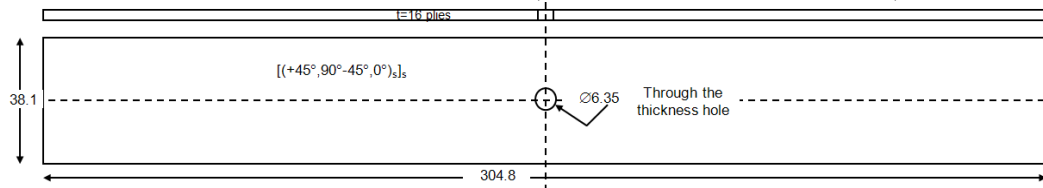

Figure 1: IM Carbon UD/ER450 Open-Hole Tension and Compression Specimen for Quasi-isotropic lamination

The critical R-ratio obtained from the static tests is χ=-0.5. Hence, CLD was built based on the fatigue tests results for R= χ. The predicted CFL and test results of fatigue tests are shown in **Figure 2**. Note that the values of the mean and amplitude stress in **Figure 2** are normalized with respect to the reference stress σ_b. A relatively good agreement was obtained between the predicted and experimental results, with the exception of R=-10. More tests are currently conducted to improve the accuracy of the CLD model. It may be further noted that according to test results, the Goodman curve highly overestimates fatigue life for purely tension and tension-compression areas and underestimates fatigue life for R-ratios lower than R=-1.
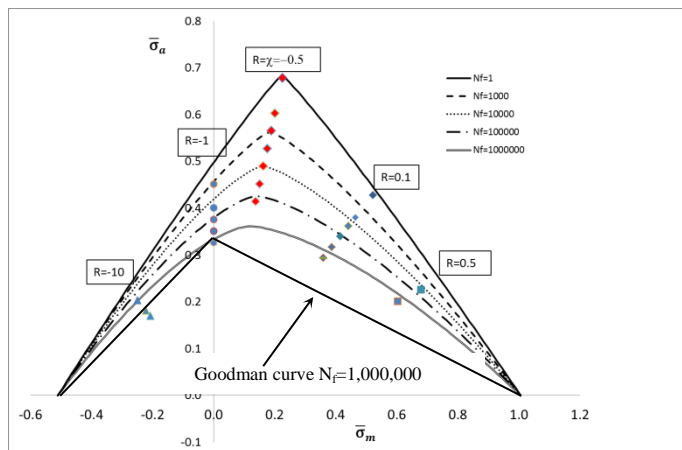

Figure 2: Normalized Constant Fatigue Life Diagram for unidirectional Carbon/epoxy laminates

4. References

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