Fatigue of Metallic Thermal Protection Systems for Reusable Launch Vehicles

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Introduction

Thermal protection systems (TPS) for reusable launch vehicles (RLV) are comprised of a brazed superalloy honeycomb panels with thin high-strength face sheets[1]. Traditional ceramic TPS have proven to be very brittle resulting in high maintenance costs and a low turnaround time between flights for their RLV. Conversely, newly developed metallic TPS have shown promise as damage tolerant systems that could provide a more cost efficient method for space travel[2]. Nonetheless, crack propagation of these metallic foils is still a relatively unexplored area. The goal of our research is determine crack propagation rates for an ideal metal foil that could help develop future metallic TPS. Fatigue of thin metals is also a concern in many other applications including electronic solder joints, electronics, and biomaterials.

Procedure

Al/Mg (97/3 wt%) specimens with thicknesses of 100 µm and 250 µm were machined with a center notch measuring 2.0 mm in overall length. The specimens were carefully pinned into an MTS servo-hydraulic test machine where they were subjected to an initial overload of 0.1 kN which would serve as the σ_{min}. Fatigue pre-cracking was performed under load control using a tension-tension sinusoidal waveform of frequency 20 Hz. The initial σ_{max} was 0.15 kN. This value was increased every 20K cycles by 0.05 kN increments until crack growth was observed, at which point the σ_{max} was held constant. Crack growth stemming from the notches in the specimens was measured using an optical microscope attached to a digital micrometer. Experimentation was preformed until crack growth measured 1 mm beyond the notch.

Results and Discussion

During constant amplitude crack propagation, the crack length, a, grows exponentially when plotted against the corresponding number of cycles, N. Experimental data shows that the 100 µm specimens had higher crack propagation rates than the 250 µm when a similar stress ratio is applied. Fatigue crack growth behavior is governed by the Paris-Law:

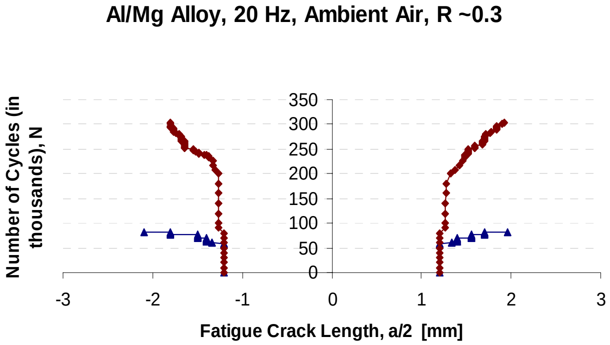

Figure 1 Crack growth data for two Al-Mg specimens with 100 µm (Blue) and 250 µm (Red) thicknesses

$$\frac{da}{dN} = C(\Delta K)^m \qquad (1)$$

Here, C and *m* are material constants and ΔK is the stress intensity range given by:

$$\Delta K = f(g)\Delta\sigma\sqrt{\pi a} \qquad (2)$$

The linear region of the crack growth rate curve is fit with the Paris Law, as shown below, to determine the m values for the specimens. Literature tends to report *m* values of 2.5-4 for standard materials. However, past research[1] has shown that thin metallic foils tend to have higher *m* values than thicker specimens, possibly due to low fracture toughness. Our findings support these high exponential values found in metallic foils by finding m values higher than 7.

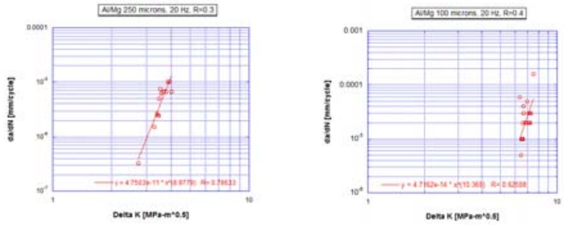

Figure 2 Paris Law Region II applied to Al-Mg-0.25 (left) and Al-Mg-0.1 (right)

Conclusions

Fatigue crack growth of thin Al/Mg alloy exhibits a much higher stress intensity range dependency than fatigue crack growth in thicker forms of the material. The values for the Paris-law exponent *m* for 100 µm and 250 µm thick Al-Mg (97/3) foils were experimentally determined to be higher than 7. Further testing will be extended to Ni and Ti based superalloys.

References

1. J. Holmes and E Vanswijgenhoven; "Fatigue Crack Growth in Inconel 718 Superalloy Foil at Elevated Temperatures," TMS, 2001
2. Max Blosser; "Advanced Metallic Thermal Protection Systems for RLV," UVA 2000
3. J. Bennantine et al., "Fundamentals of Metal Fatigue Analysis, Prentice Hall, 1990

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