Chapter 10 – SIMULATING CORROSION DAMAGE: EXFOLIATION

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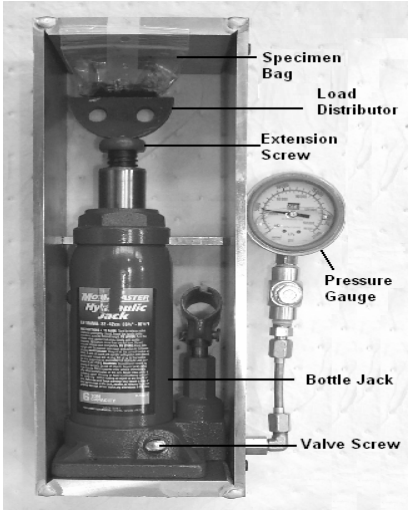
10.1 INTRODUCTION

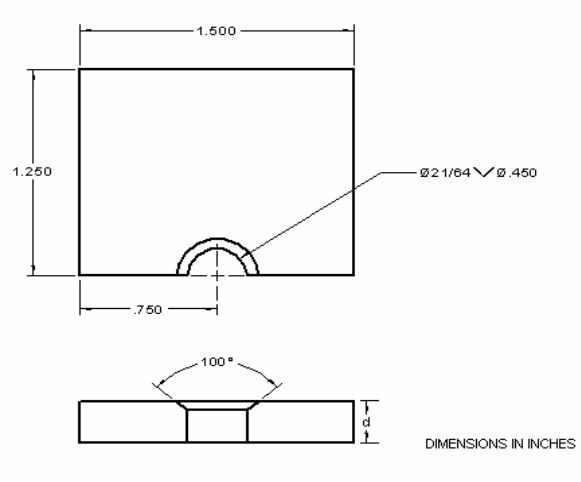
To determine the effect that exfoliation has on the fatigue strength of upper wing skins, fatigue tests need to be carried out on coupons that contain this type of damage. Since it is difficult to obtain naturally exfoliated wing skins because maintenance procedures require that exfoliated areas be ground out to remove the damage, an accelerated artificial exfoliation protocol is required to create the damage in specimens needed to carry out material testing. The methods developed by the National Research Council of Canada to simulate exfoliation damage in a controlled laboratory environment are briefly reviewed in this short note.

10.2 METHODOLOGY

The ASTM G34 EXCO Standard Test Method [1] was developed to determine the susceptibility of 7XXX and 2XXX series material to exfoliation. The EXCO solution has been successful in generating near surface exfoliation at holes that were originally machined in the wing skin material. However, the results were inconsistent when the process was applied to newly manufactured material as well as new holes machined in old material. In an effort to produce exfoliation more consistently, it was suggested that a compressive load, emulating the predominant upper wing skin flight loading, be applied to the specimens. It was proposed that due to the Poisson effect the induced compressive stress, which would occur along the LT direction, would cause a tensile stress in the ST direction making the exposed grain boundaries along a machined edge more susceptible to intergranular corrosion (i.e., exfoliation). A proof-of-concept rig [2] was designed to introduce a static compressive load into simple specimens, Figure 10-1, which would be sectioned and progressively polished to characterize the exfoliation damage generated.

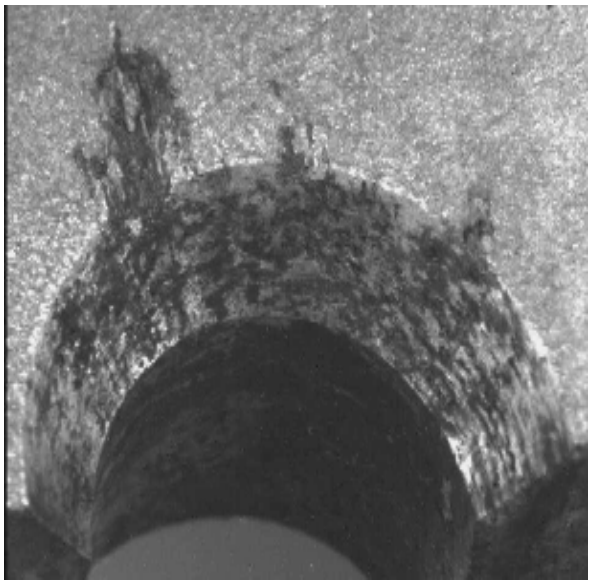


(a) Compression rig.



(b) Detailed specimen drawing.

(c) Specimen placement in compression rig.



(d) Exfoliation produced at countersink side of wing skin after 28 days of exposure to EXCO / compressive load combination for new hole / old material.

Figure 10-1: Configuration of Compression Rig Set-Up and an Example of the Exfoliation Damage Produced.

10.3 RESULTS

The polishing results showed the presence of large pits, which appeared prior to the formation of intergranular corrosion, Figure 10-2. These large pits, which are not normally found in natural exfoliation, have been attributed to the initial pH level of the EXCO solution [3]. During the first 24 hours of the EXCO test, the solution (234 g of NaCl, 50 g of KNO_3 in water, 6.3 mL of concentrated HNO_3, 70% and dilute to 1 L) is highly acidic, starting at a pH of 0.4 and gradually stabilizing at a pH of 3.2. To eliminate this initial acidity, the EXCO solution was modified to produce an initial pH level of 3.2, which would

remain constant over an extended period of time [3]. The new protocol, known as the Aluminum-Nitrate-Chloride Immersion Test (ANCIT) [3], was developed that consists of 235 g of NaCl, 60.6 g of KNO_3, 5.31 g of $AlCl_3 \cdot 6H_2O$ in water and diluted to 1 L.

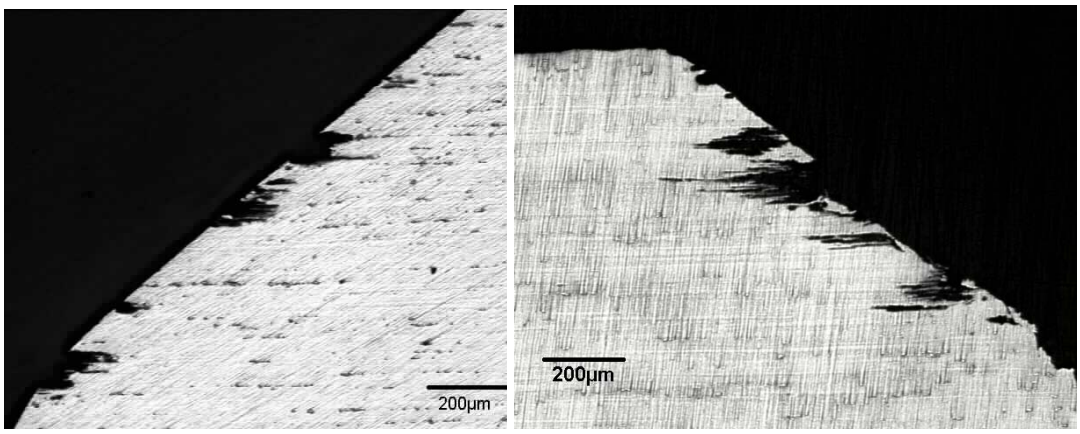
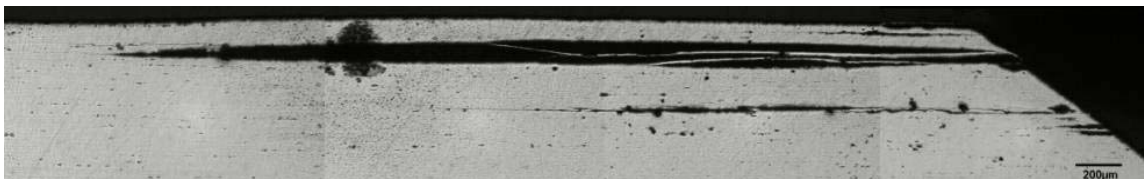
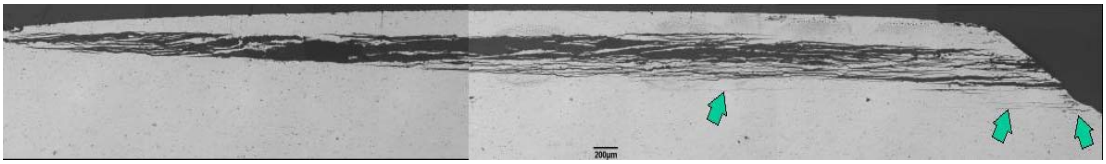


Figure 10-2: Optical Micrographs Showing Large Pits Generated by EXCO Solution.

When the ANCIT solution was used to generate exfoliation at the countersink of a hole in an upper wing skin, the damage produced was considered light, in that, the surface of the wing showed only a slight bulge. The results from the polishing showed the absence of the large pits that were present in the EXCO tests. The ANCIT tests resulted in similar damage to that present in naturally exfoliated wing skins, as shown in Figure 10-3.



(a) Artificial exfoliation (ANCIT).



(b) Natural exfoliation.

Figure 10-3: Examples of ANCIT Generated Artificial Exfoliation and Natural Exfoliation.

To artificially introduce exfoliation in undamaged wing skins, the surface of the test area within the hole was scratched with a probe to provide a nucleation site for the damage, after which the steel fastener was installed. In addition, the fastener can be modified according to Figure 10-4 in order to introduce exfoliation damage at specific locations along the countersink of a fastener hole. The top surface paint in the area of the fastener holes was removed and double sided-sealant tape was used to mask off the area that would be exposed. A syringe was then used to deliver the different solutions to the area of interest by moving the plunger periodically to force fresh solution into the test region. The double-sided tape was used to seal the syringe in order to prevent leakage of the solution. Figure 10-5 shows an image of the

syringes in which one contained the EXCO solution while the other held the ANCIT solution and the sealant tape that was located at two fastener holes, which prevented leakage.

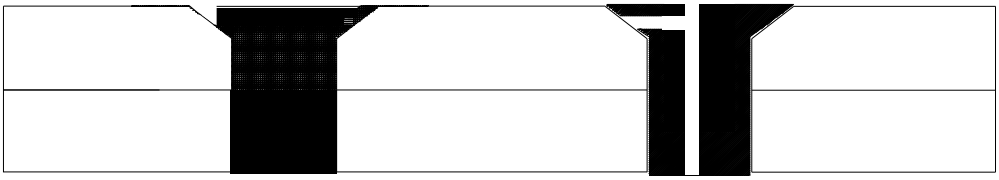


Figure 10-4: Modification Made to Steel Fastener to Introduce Exfoliation at Different Locations Along the Countersink.

Figure 10-5: Typical Set-Up for Accelerated Exfoliation Protocol.

During the development of the accelerated protocol, it was determined that the exfoliation damage that was generated could continue to grow after a solution is removed. To prevent this continuous growth, it is recommended that the specimens should be tested within a reasonable time frame. An alternative to this quick turn-around is to develop a protocol that would arrest the growth such as de-humidification and pH neutralization. It is also recommended that specimens be stored in a freezer to prevent further growth.

10.4 REFERENCES

[1] ASTM G34 EXCO Standard Test Method, American Society for Testing and Materials, West Conshohocken, PA, USA, Copyright 1996.

[2] Roe, P.W., Gould, R.W. and Bellinger, N.C., “Induced Exfoliation Compression Rig Experiment; Overview of Apparatus and Testing Procedure”, LM-SMPL-2002-0084, Institute for Aerospace Research, National Research Council Canada, 2002.

[3] Lee, S. and Lifka, B.W., “Modification of the EXCO Test Method for Exfoliation Corrosion Susceptibility in 7XXX, 2XXX and Aluminum-Lithium Alloys”, New Methods for Corrosion Testing of Aluminum Alloys, ASTM STP 1134, pp. 1-19, 1992.