Chapter 6 – CORROSION MORPHOLOGY: INTERGRANULAR CORROSION AND EXFOLIATION

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6.1 INTRODUCTION

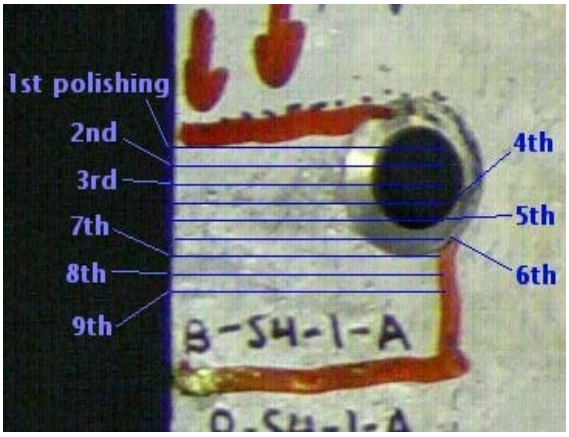
Intergranular corrosion in highly textured aluminum alloys, such as those used in aircraft structures, can cause severe flaking of the surface grains in a process commonly referred to as exfoliation. This chapter shows typical examples of this type of corrosion and describes investigations carried out at the National Research Council Canada to characterize the damage.

6.2 CHARACTERISTICS AND DOCUMENTATION

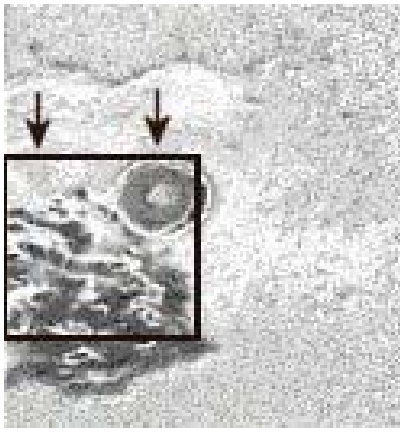
Exfoliation corrosion, or exfoliation, is defined as corrosion that proceeds laterally from the sites of "initiation" along planes parallel to the surface, generally at grain boundaries, forming corrosion products that force metal away from the body of the material, giving rise to a layered appearance [1]. In other words, exfoliation is a form of severe intergranular corrosion, which occurs at the boundaries of grains elongated in the rolling or extrusion direction. Generally, exfoliation corrosion occurs when there is a combination of three factors: a highly directional microstructure, a preferential anodic path and a specific type of corrosive environment. In aircraft materials exfoliation corrosion is most common in the heat-treatable Al-Zn-Mg-Cu (7000 series), Al-Cu-Mg (2000 series), and Al-Mg alloys, but it has also been observed in Al-Mg-Si alloys [2]. The generation of exfoliation corrosion products forces layers apart and causes the metal component to swell. Flakes of metal may be pushed up and may even peel from the surface. The results from this particular study also indicated that the depth of penetration for the exfoliation present was small and there was very little intergranular corrosion present below the main area of exfoliation.

To document the damage caused by exfoliation corrosion, sections were taken from service exposed 7178-T6 upper wing skins from retired Boeing 707 aircraft [3]. As outlined in Chapter 4, these sections were cold mounted and progressively polished to determine the damage state. An image of this section along with the NDI and polishing results are shown in Figure 6-1. It is interesting to note how the damage morphology substantially changed over a small distance, 1.067 mm (0.042 inches), from very little intergranular corrosion to considerable amounts of exfoliation. Although very little intergranular corrosion was present below the observed exfoliation, as can be seen from the arrows in Figure 6-1, the intergranular corrosion that was present was located very close to the maximum exfoliation depth. This suggests that if this area of the wing skin was repaired the intergranular corrosion would probably also be removed.

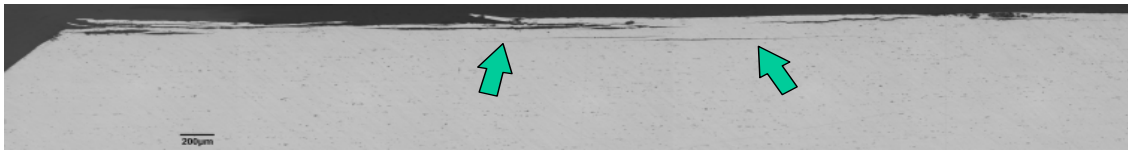
Another section that was taken from an upper wing skin contained both visible exfoliation and a repaired (ground-out) area. An image of this section along with the NDI and polishing results are shown in Figure 6-2. Although visible exfoliation was clearly present outside of the repaired area, no damage was detected within the area. It is interesting to note that as the polishing progressed the severity of the exfoliation decreased to intergranular corrosion, which extended into the repaired area. Whether the intergranular corrosion at this depth was present before the repair process was carried out could not be determined.



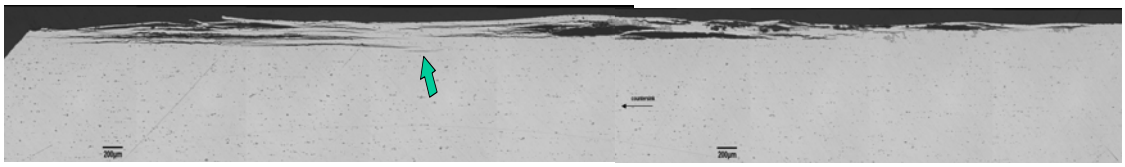
(a) Photograph of section showing locations of polishing.



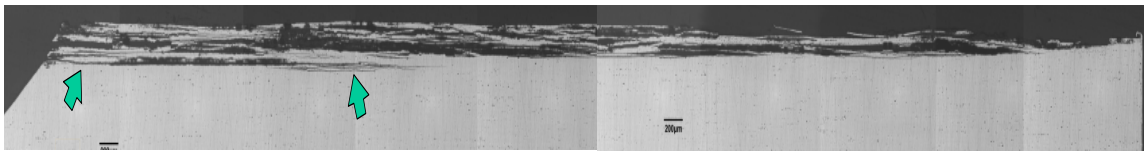
(b) Ultrasonic inspection results.



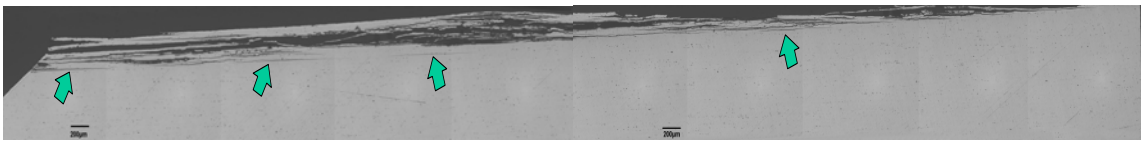
(c) Second polishing that removed 1.118 mm (0.044 inch) from the first polishing.



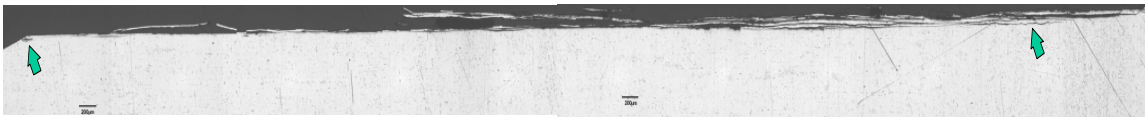
(d) Third polishing that removed 1.067 mm (0.042 inch) from the second polishing.



(e) Fourth polishing that removed 1.041 mm (0.041 inch) from the third polishing.

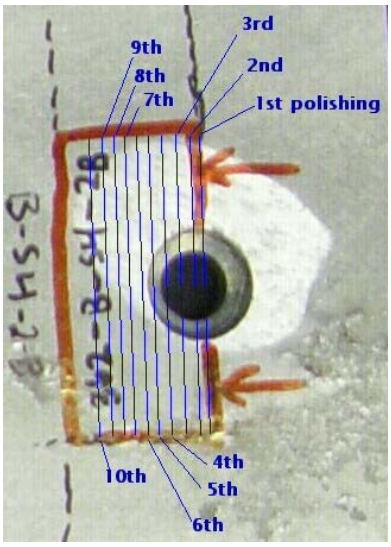


(f) Fifth polishing that removed 1.118 mm (0.044 inch) from the fourth polishing.

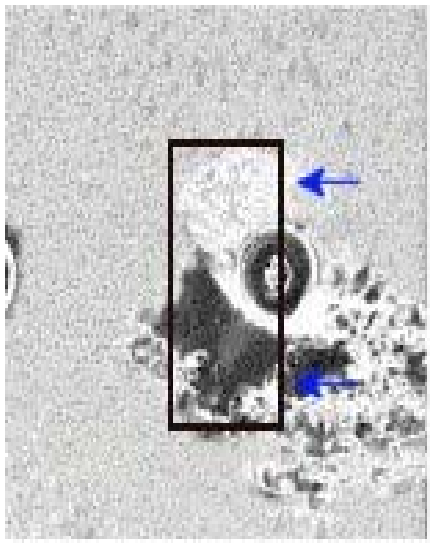


(h) Sixth polishing that removed 1.092 mm (0.043 inch) from the fifth polishing. It should be noted that additional polishing revealed similar damage to that found in the sixth polishing.

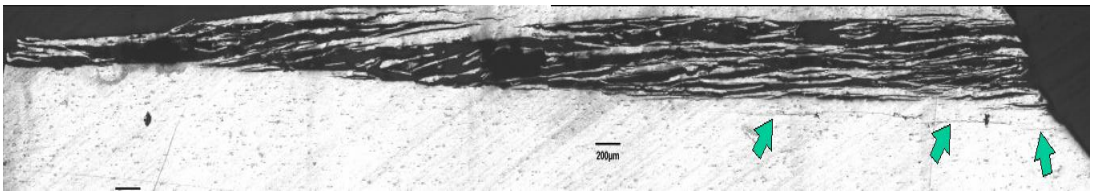
Figure 6-1: Results from the Progressive Polishing Carried Out on Specimen 362-B-S4-1 that Contained Visible Exfoliation (arrows indicate the location of the deepest intergranular attack).



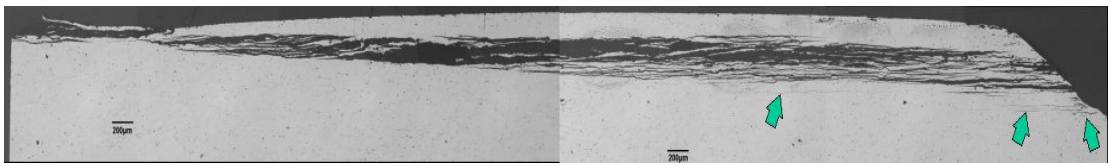
(a) Photograph of section showing locations of polishing.



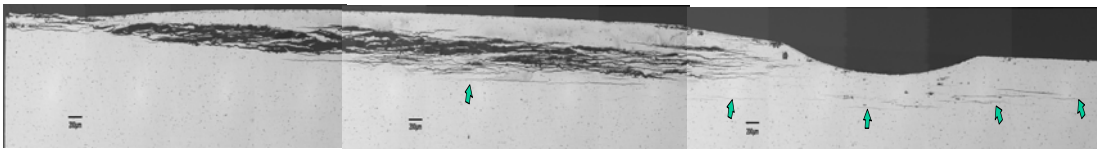
(b) Ultrasonic inspection results.



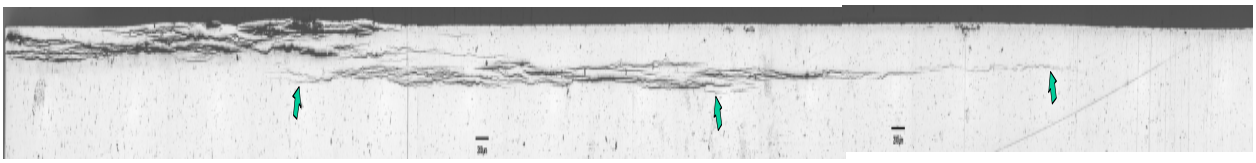
(c) First polishing.



(d) Fourth polishing that removed a total of 3.15 mm (0.124 inch) from the first polishing.



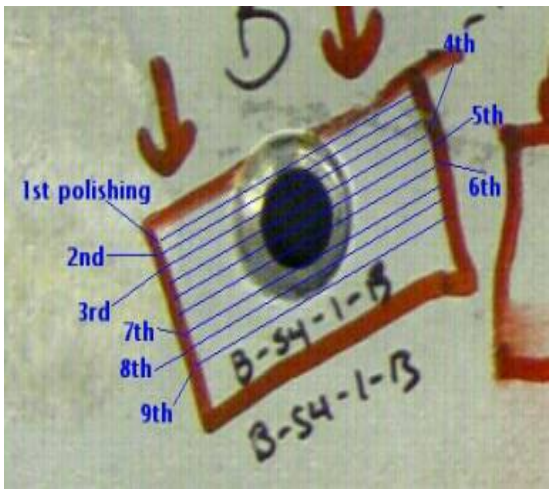
(e) Fifth polishing that removed a total of 1.189 mm (0.0468 inch) from the fourth polishing. The "indent" is the result of a repair procedure that was carried out to remove previous exfoliation damage. Note the intergranular corrosion that is present below the indent.



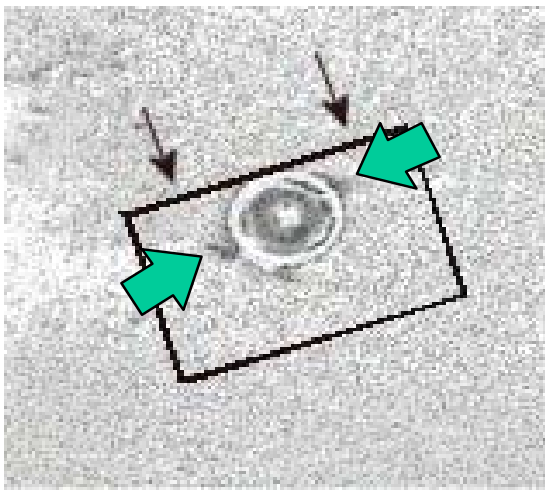
(f) Tenth polishing that removed a total of 4.902 mm (0.193 inch) from the fifth polishing.

Figure 6-2: Results from the Progressive Polishing Carried Out on Specimen 362-B-S4-2 that Contained both Visible Exfoliation and a Repaired (Ground-Out) Area (arrows indicate the location of the deepest intergranular attack).

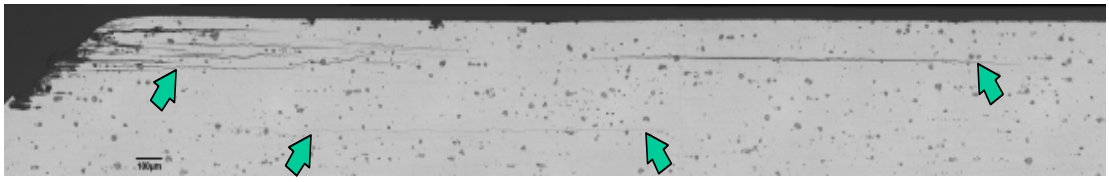
A section was taken from a 7178-T6 upper wing skin that did not contain any visible exfoliation, cold mounted and progressively polished, the results of which are shown in Figure 6-3. As can be seen from this figure, intergranular corrosion was present in the fastener area, which was detected by the ultrasonic inspection technique. This result demonstrated the sensitivity of the ultrasonic techniques to detect small levels of intergranular corrosion. It should also be mentioned that if a repair procedure were to be carried out in this area it is highly unlikely that all the intergranular corrosion would be removed, which is a requirement.



(a) Photograph of section showing locations of polishing.



(b) Ultrasonic inspection results.

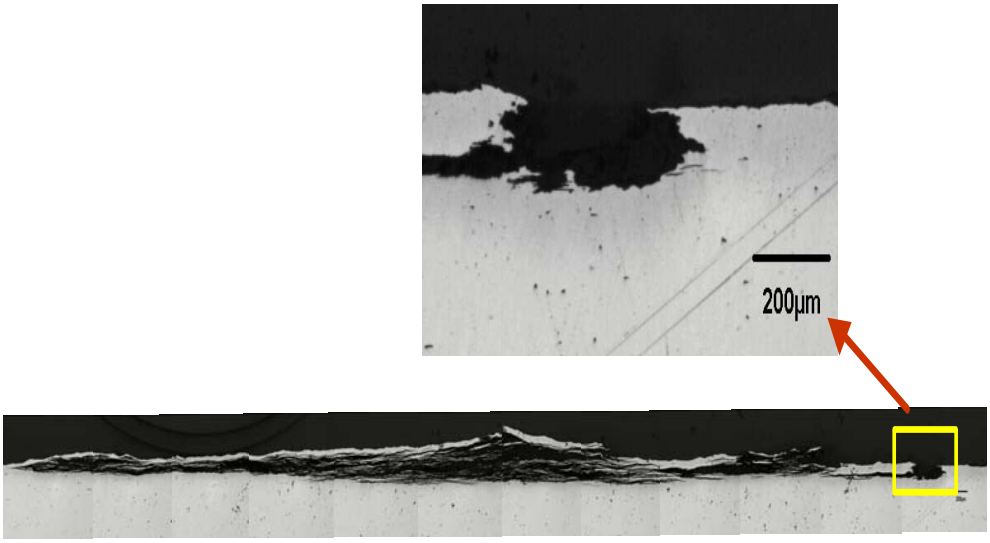


(c) Fourth polishing that removed a total of 2.59 mm (0.102 inch) from the first polishing.

Figure 6-3: Results from the Progressive Polishing Carried Out on Section B Taken from Specimen 362-B-S4-1 that did Not Contain any Visible Exfoliation (arrows in (c) indicate the location of the deepest intergranular attack).

Another study was carried out on exfoliated integrally stiffener extruded 7075-T6511 upper wing skins (that is fasteners were not present) [3]. Wing skins that were accidentally subjected to an age degradation process while in storage were used in this study. However it was determined that the damage sustained from this process was representative of the damage that occurred in service. Sections were taken from exfoliated areas; cold mounted and progressively polished using standard metallurgical techniques to determine the origin of the exfoliation as well as to characterize the damage present. Some of the results are shown in Figure 6-4 and Figure 6-5. From this characterization study it was found that the intergranular corrosion, which developed into exfoliation, originated at a modified discontinuity state (corrosion pit) that evolved from the age degradation process.

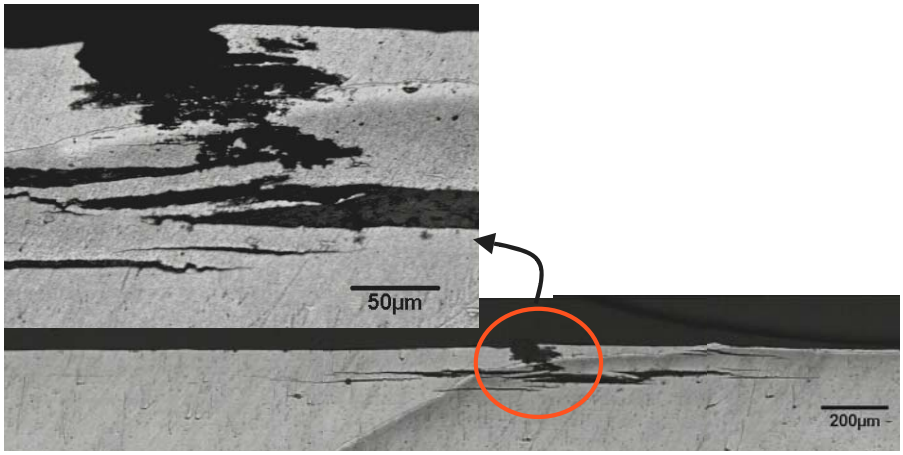
(a) Photograph of section SC3-1A.



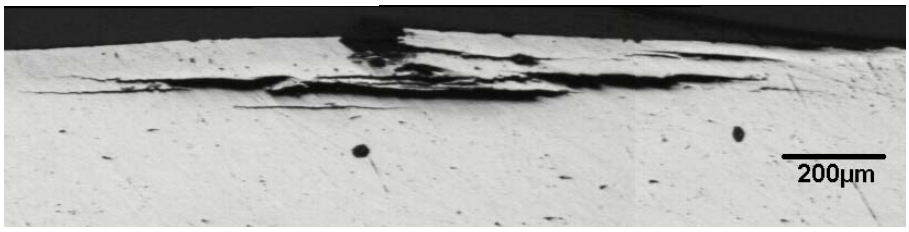
(b) Photomicrograph showing exfoliation present in section. Note corrosion pit (square) that was present, which may have started the intergranular corrosion.

Figure 6-4: Exfoliation Present Along S-T Direction 7075-T6 Upper Wing Skin.

(a) Photograph of section SC5-3E.



(b) Photomicrograph of exfoliation present in section after first polish. Note presence of corrosion pit (circle).



(c) Photomicrograph of exfoliation present after second polish in same area as (b).

Figure 6-5: Exfoliation Present Along S-T Direction of Section Taken from 7075-T6 Upper Wing Skin.

6.3 REFERENCES

[1] ASTM G15-97a, “Standard Terminology Relating to Corrosion and Corrosion Testing”, 1997.

[2] Speidel, M.O. and Hyatt, M.V., “Stress Corrosion Cracking of High-Strength Aluminum Alloys”, Chapter 3 in “Advances in Corrosion Science and Technology”, Vol. 2, Edited by M.G. Fontana and R.W. Staehle, Plenum Press, 1972.

[3] Bellinger, N.C., Marincak, A., Harrison, M. and Reeb, T., "Effect of Exfoliation Corrosion on the Structural Integrity of 7075-T6 Upper Wing Skins", Proceedings of the 2003 USAF Aircraft Structural Integrity Program Conference, Savannah, GA, USA, 2-4 December 2003.