NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

September 13, 2006

MATERIALS LABORATORY FACTUAL REPORT

Report No. 06-076

A. ACCIDENT

Place	:	Memphis, Tennessee
Date	:	July 28, 2006
Vehicle	:	McDonnell Douglas MD-10-10F, N391FE
Operator	:	FedEx Corporation
NTSB No.	:	DCA06MA058
Investigator	:	Bill English IIC, Clint Crookshanks, Structures

B. COMPONENTS EXAMINED

Portions of the Left Main Landing Gear Outer Cylinder, p/n ARG 7002, from Main Landing Gear Strut Assembly p/n NRG 6020, s/n CPT 0125HT.

C. DETAILS OF THE EXAMINATION

The received pieces of the landing gear outer cylinder are displayed in figure 1. The outer cylinder was circumferentially fractured at the air valve boss just below the intersection of the aft drag brace arm as indicated by red lines in figures 1(b) and (c). The landing gear had reportedly accumulated 33,148 landing cycles since new with 27,042 cycles since its last overhaul.

The outer cylinder was initially examined in the Materials Laboratory on August 16 and 17, 2006 with representatives of Boeing, FedEx Corporation and the Air Line Pilots Association present.

The outer cylinder was fractured into two large pieces comprising the upper and lower portions of the cylinder and two smaller pieces. The majority of the cylinder had been cut away prior to shipment and one to two foot long sections above and below the fracture were received. The yellow boxes in figures 1(b) and (c) denote the approximate received portions of the outer cylinder. One of the small pieces was from the lower half of the air valve boss; the other was a portion of the cylinder wall from the forward side of the cylinder. The separated air valve was also received.

Measurements of the cylinder at the plane of the fracture found the inner diameter to be between 12.549 and 12.554 inches in the fore and aft directions and 12.620 to 12.630 in the inboard - outboard orientation. The engineering drawing shows an inner diameter of 12.540 inches at the air valve hole location. The inner diameter at the chromium plated region below the fracture measured 12.497 to 12.498 inches fore and aft and 12.503 to 12.504 inches at 90 degrees. The inner diameter specified at this location is 12.500 to 12.505 inches. The wall thickness adjacent to the air valve boss measured 0.776 to 0.781 inch after removal of the outer surface paint. The drawing specified thickness is 0.763 to 0.798 inch.

Optical examinations of the fracture faces found chevrons and other markings indicating that the overall separation initiated at individual locations on the inboard and outboard sides of the air valve hole and propagated separately around the cylinder. The two fractures, referred to as the inboard and outboard fractures, joined at the forward side and separated the outer cylinder into two main pieces. Away from the air valve hole, the fracture features were typical of overstress separations in high strength steel. Figure 2(a) displays the entire lower fracture face with arrows denoting the directions of propagation.

Close examinations established that the chevron markings led back to initiation sites on the smooth portion of the air valve hole near the inner diameter as shown in figures 2(b) and (c). The threaded portion of the hole was at the outer diameter of the cylinder and contained in the small portion of the boss fractured from the lower cylinder piece. Silver colored plating, later determined to be nickel, was noted on portions of the air valve hole bore, see figure 2(c). The plating was discontinuous and spotty with a nodular surface appearance. Both chromium and cadmium plating are noted for specific areas of the cylinder, but no nickel plating was specified for any location on the original component. Maintenance[1] and service documents do allow repair nickel and chromium plating in the bore of the outer cylinder but not in the air valve hole.

The air valve hole and portions of the surrounding fracture were saw cut from the lower fracture half and used for the majority of following examinations.

At the initiation site for the outboard fracture, a slightly darkened thumbnail-shaped fracture region was observed at the outboard side of the air valve hole as shown in figure 3. The thumbnail was centered about 0.20 inch from the projected inner diameter of the cylinder. The inner corners of the hole were heavily blended and located a distance from the projected inner diameter of the outer cylinder. The thumbnail region measured about 0.13 inch along the hole bore and about 0.025 inch deep. The bore surface adjacent to the thumbnail was covered with a 0.008 inch thick layer of nickel plating. The plating appeared tightly adherent to the bore and was fractured in-plane with the cylinder separation.

Scanning electron microscope (SEM) examinations in conjunction with energy dispersive x-ray spectrography (EDS) revealed an oxide layer on the thumbnail region at

[1] Douglas Aircraft Company, Component Maintenance Manual, Main Landing Gear Shock Strut Assembly.

the outboard side of the hole, as shown in figure 4(a). Multiple pores were also discovered in the nickel plate layer. The fracture features within the thumbnail were a mixture of intergranular and transgranular separations, as shown in figure 4(b). The intergranular features were consistent with stress corrosion cracking and the transgranular features were consistent with fatigue propagation. The fracture immediately outside of the thumbnail region was composed entirely of ductile dimples consistent with overstress separation.

A metallographic section cut through the air valve hole and the thumbnail region perpendicular to the air valve hole axis is displayed in the views of figure 5. When etched with 4% Nital[2], a fine tempered martensite microstructure was revealed in the cylinder material. The fracture path was generally transgranular with some intergranular areas. No crack branching was noted.

The nickel layer was clearly visible on the section and displayed extensive porosity and through – the - thickness cracking, as shown in figures 5(b) and (c). Corrosion and corrosion products were found where the plating cracks intersected the cylinder surface as illustrated in figure 5(c).

Examinations on the inboard fracture initiation area revealed a single point initiation on the bore surface approximately 0.14 inch from the projected inner diameter of the cylinder as displayed in figure 6(a). SEM viewing uncovered a small spherical corrosion pit at the initiation but no plating. The pit measured 0.004 inch wide and 0.002 inch deep as illustrated in figure 6 (b) and (c). Closer view also revealed a small semicircular region of transgranular fatigue features surrounding the pit, outlined in yellow in figure 6(b). The fatigue region measured about 0.009 inch along the bore and 0.004 inch deep, including the pit. Ductile dimples were evident outside of the fatigue region.

The smooth portion of the air valve hole displayed a fine surface finish with no machining tears or marks. However some corrosion pits up to 0.002 inch in diameter, were noted as shown in figure 7(a) and (b). The inner diameter of the cylinder also displayed corrosion pitting in the unplated band at the location of the hole; see figure 7(c).

A metallographic section perpendicular to the air valve hole axis was cut through the inboard fracture initiation site, intersecting the initiating corrosion pit as shown in figure 8(a). At this point the pit measured 0.0017 inch deep and 0.0032 inch along the bore. The metallographic section also intersected other pits in the bore as displayed in figure 8(b). The pit shown in figure 8(b) measured less than 0.001 inch wide and deep.

EDS maps and spectra along the bore of the air valve hole revealed the previously mentioned nickel plating in localized areas of the smooth bore portion but no other plating materials. EDS maps in the threaded region of the bore on the small separated piece uncovered cadmium plating on the majority of the threads but no indications of nickel or other materials.

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[2] 4% concentrated nitric acid in ethanol.

The diameter of the smooth portion of the hole was estimated based on measurements of the radius of the segments of the hole contained in the metallographic sections. From these measurements, the hole diameter was estimated to be between 0.453 and 0.462 inch. The engineering drawing calls out a 0.4460 to 0.4537 inch diameter hole.

Hardness measurements were also made on the metallographic samples. They ranged from HRC 53.8 and 55.3 and averaged 54.5 HRC. The drawing specifies the material to be heat treated to 275,000 to 305,000 psi ultimate tensile strength with a hardness of 53 to 56 HRC. EDS spectra acquired during SEM viewing of the fracture face was consistent with the specified material, 300M alloy steel per DMS[3] 1935.

The bore of the outer cylinder was plated over a wide area below the air valve hole and a narrow band above the hole, as noted in figure 2(a). The plating appeared relatively thick with a stepped runout as shown in figure 9(a) and (b). A metallographic cross section through the plating along with EDS mapping revealed a two layer structure, as shown in figure 9(c) and (d). As illustrated with color mapping in figure 9(d), a thick underlying nickel layer (light blue) was overplated with chromium (purple). The nickel layer measured about 0.007 to 0.008 inch thick with a 0.002 to 0.003 inch thick chromium overplate. The chromium plating appear well bonded to the base metal and to the nickel but was cracked at the edge of the nickel as shown in figure 9(c). The adjacent area of the nickel was debonded from the base metal.

Joe Epperson
Senior Metallurgist

[3] Douglas Materials Specification.

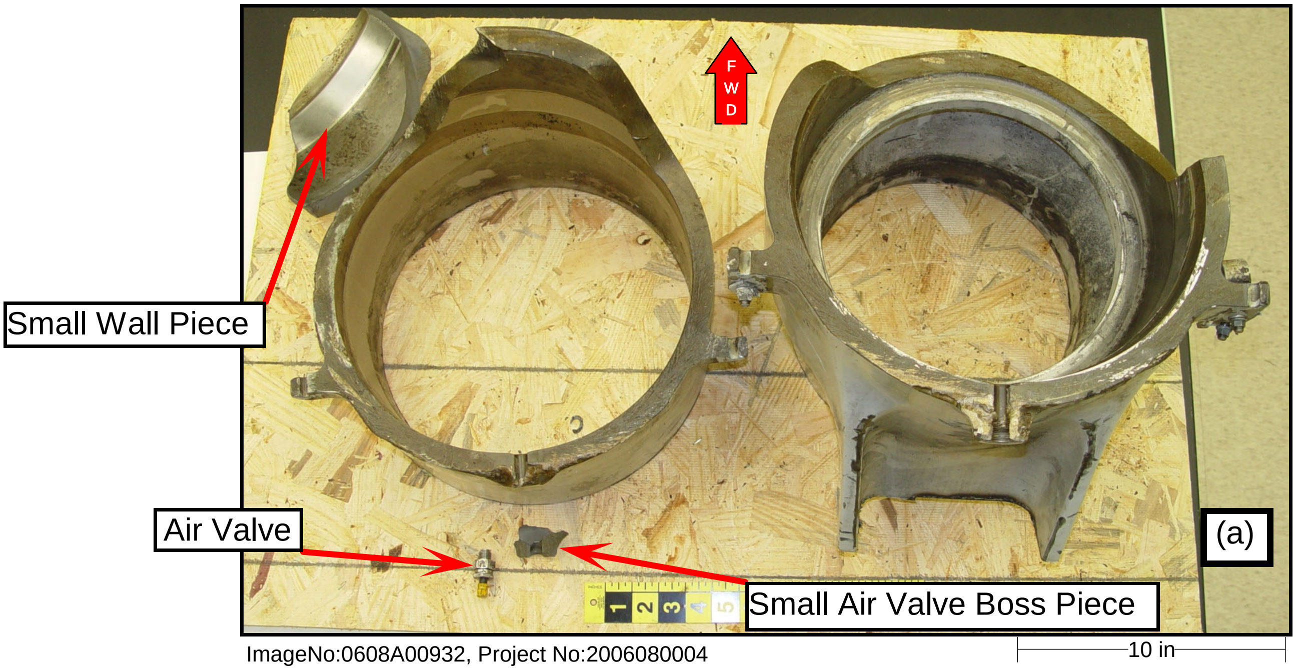

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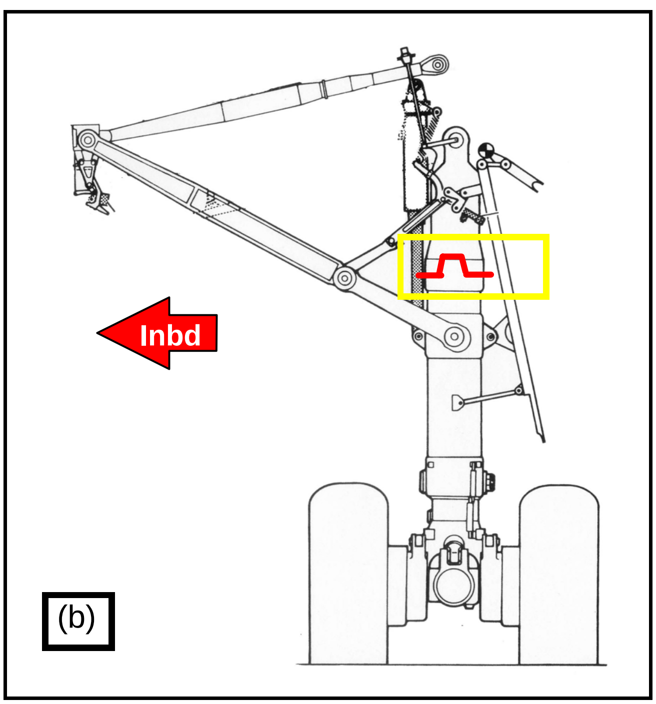
Figure 1--The received fractured pieces with the lower fracture on left and the upper piece on the right. The small pieces and air valve are noted. The received region of the landing gear is denoted on the illustration below (yellow box) along with the approximate fracture location (red line).



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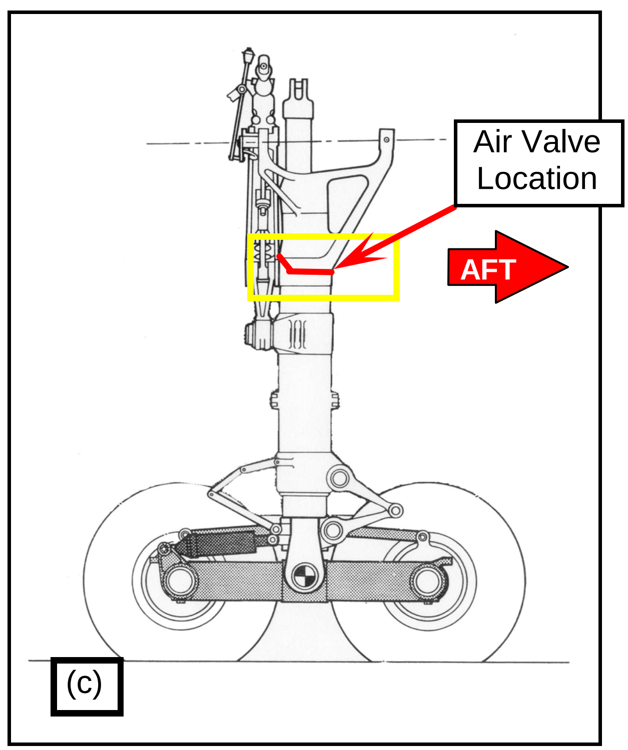

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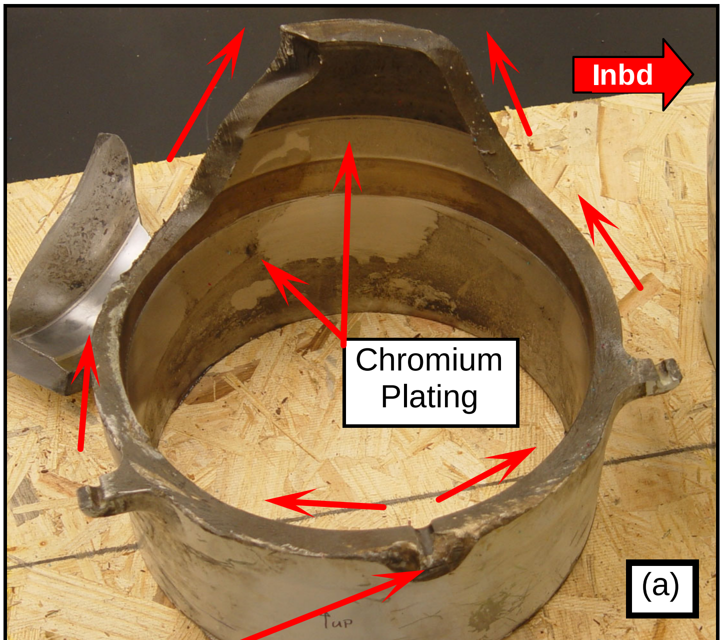

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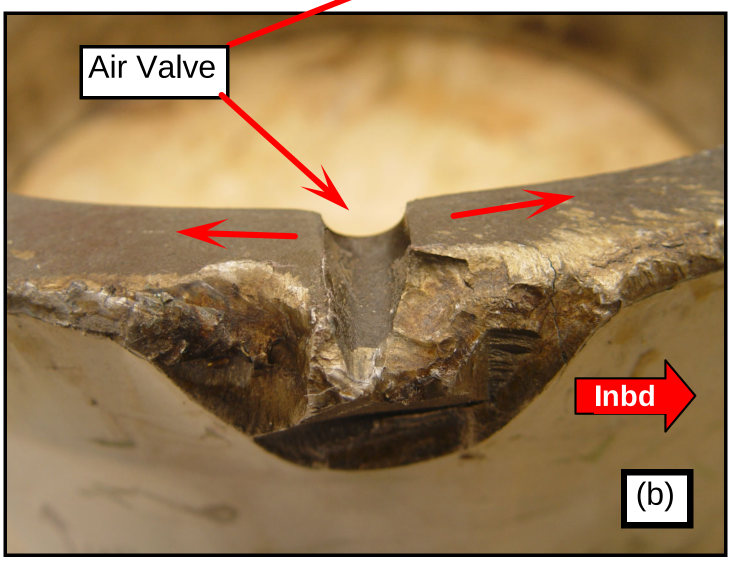

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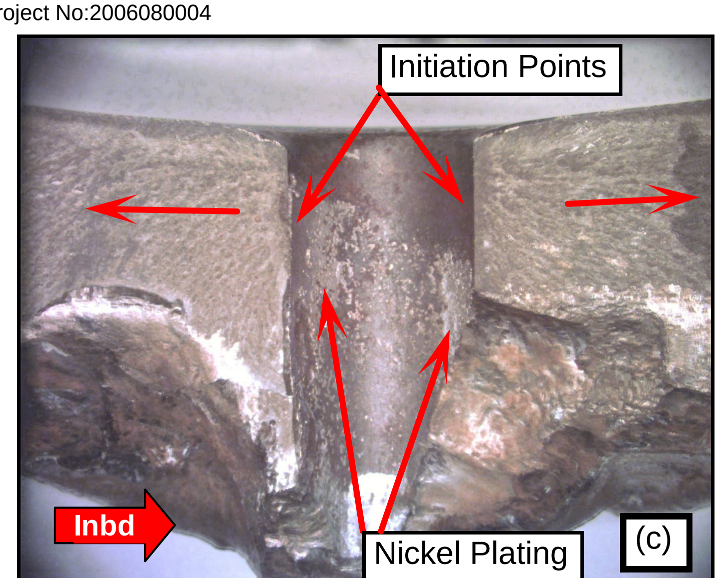

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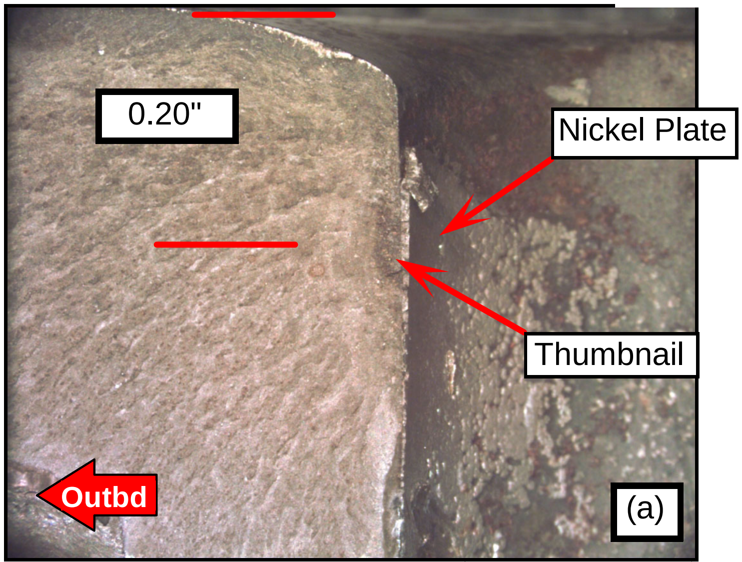
Figure 2--The lower fracture face (a) with arrows denoting the fracture directions away from the air valve hole. Closer views of the fracture initiation area (b) and (c) and air valve boss and hole. Areas of nickel plating (c) are indicated in the smooth portion of the hole.



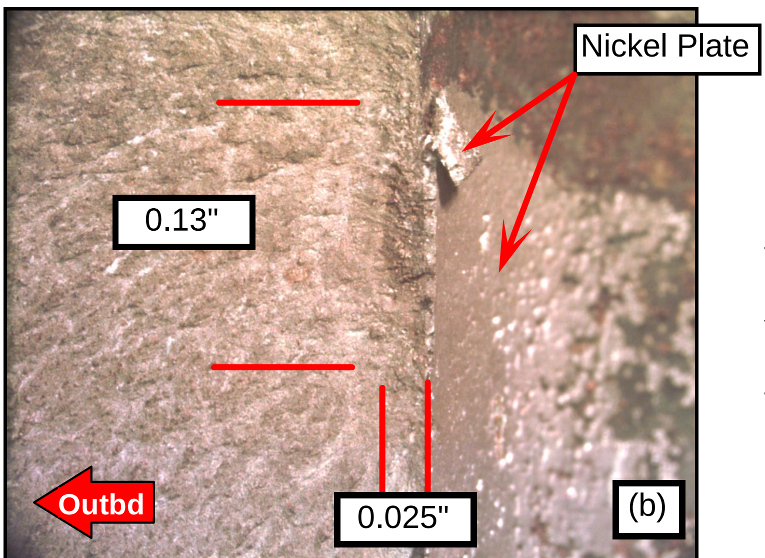
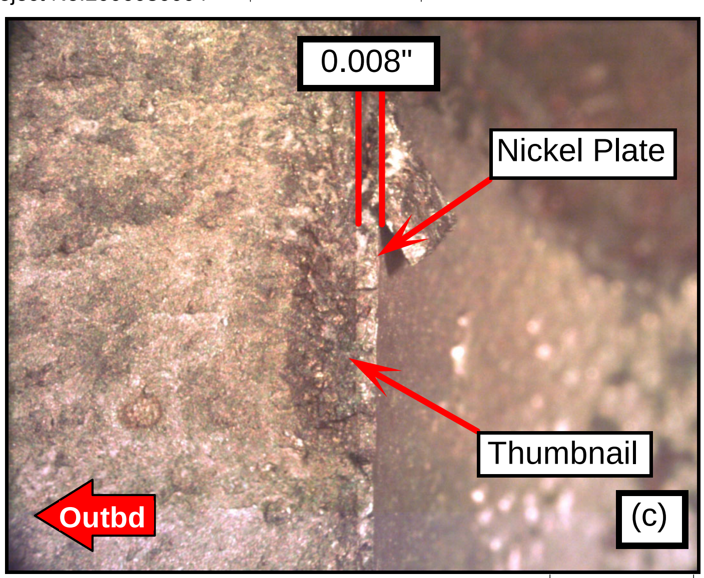


Figure 3--Sucessively closer views of the outboard side of the hole at initiation area. (a) the darker preexistant thumbnail is centered ~0.2" from projected ID. (b) thumbnail region ~0.13" wide and 0.025" deep with the overlaying nickel plate visible on the bore. (c) 0.008" thick nickel layer on hole surface covering the thumbnail region and adjacent areas.



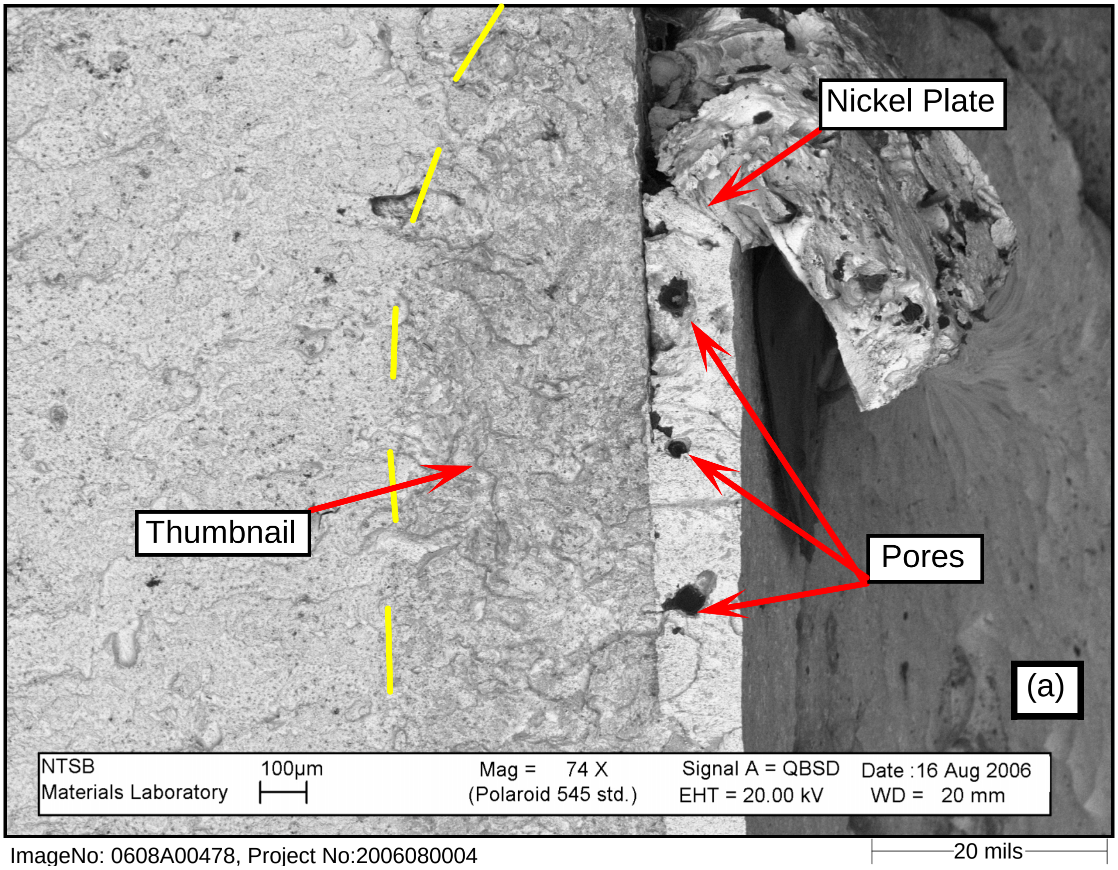
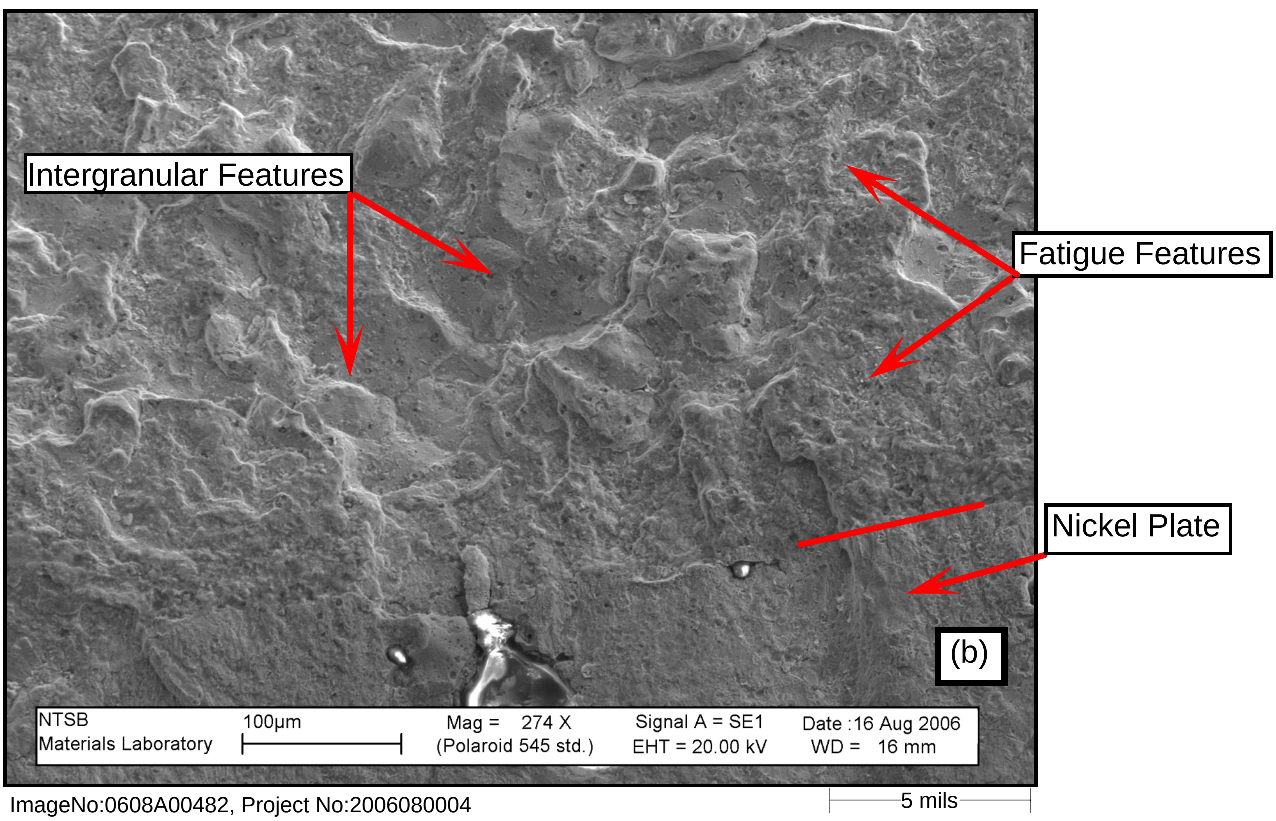
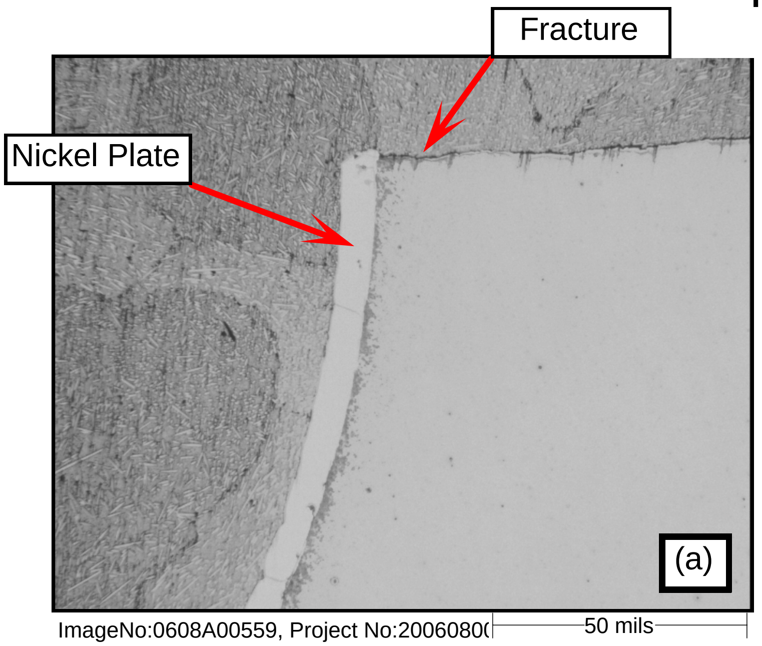


Figure 4--Backscattered electron image (a) of the thumbnail, outlined in yellow, at the outboard initiation and the adjacent porous nickel plate. Secondary electron image (b) shows mixed fatigue and intergranular (SCC) features in thumbnail region at higher magnification.





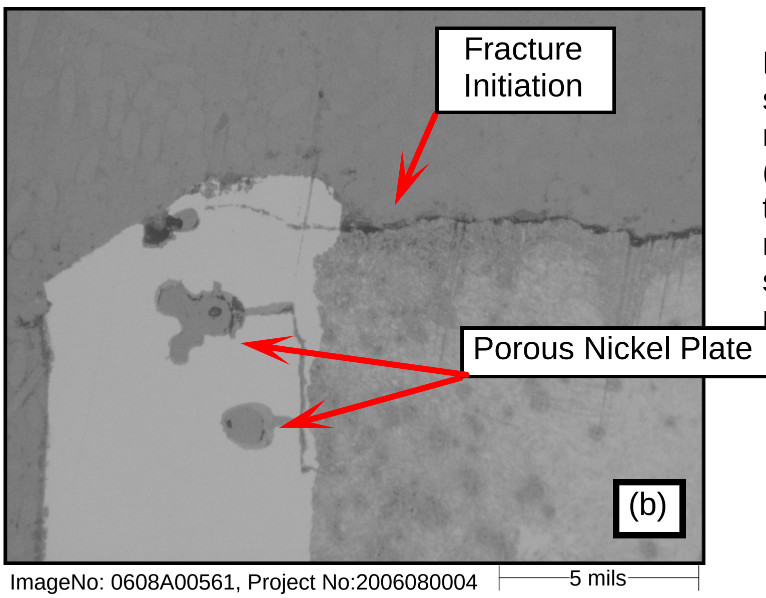
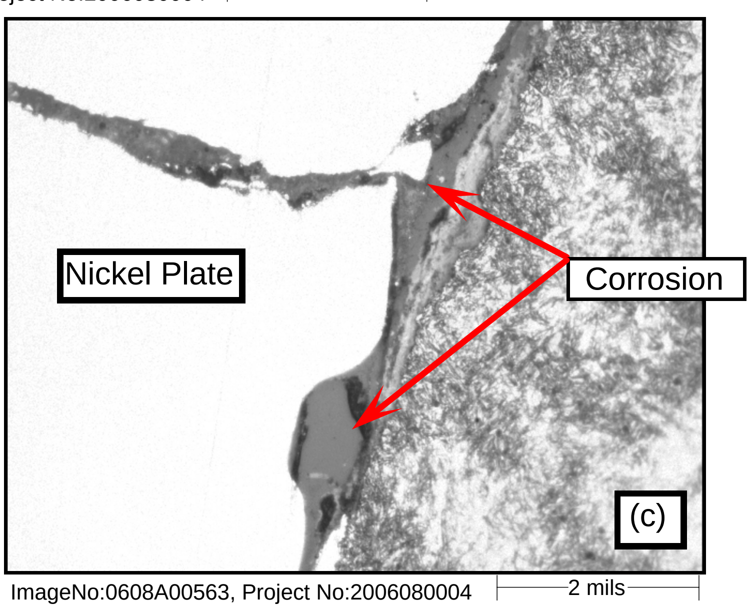
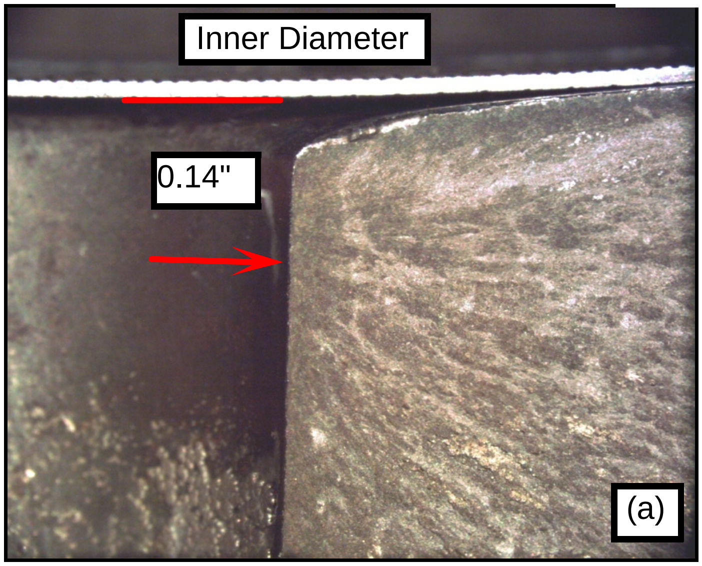


Figure 5--Metallographic images of a cross section of outboard initiation area. (a) Low magnification image of the nickel plating (light gray) on the bore. (b) Closer view of the initiation region with adjacent porous nickel plate. (c) An area away from fracture showing corrosion under the cracked plating.





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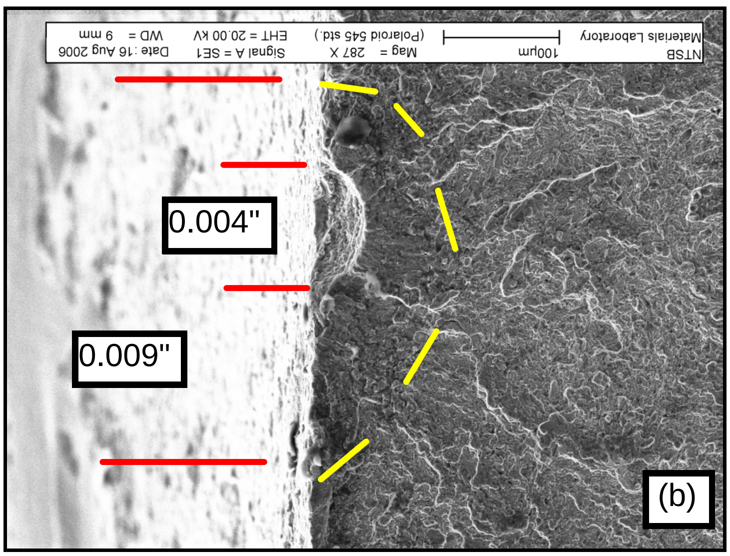

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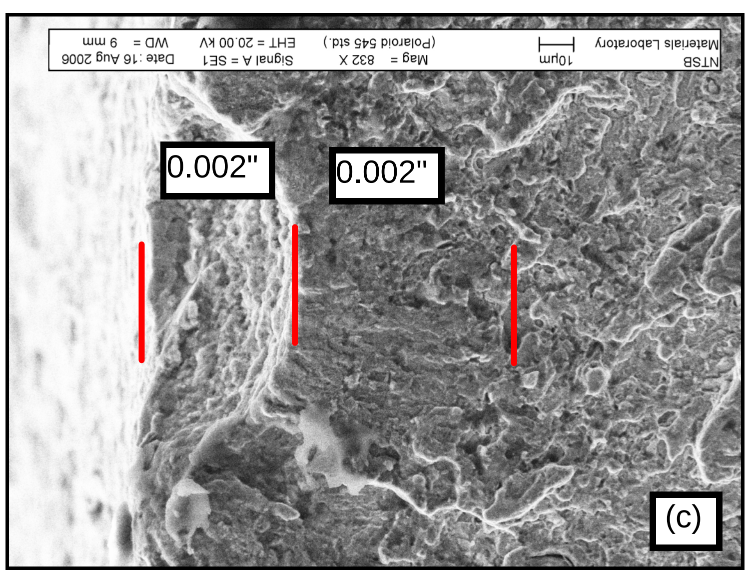
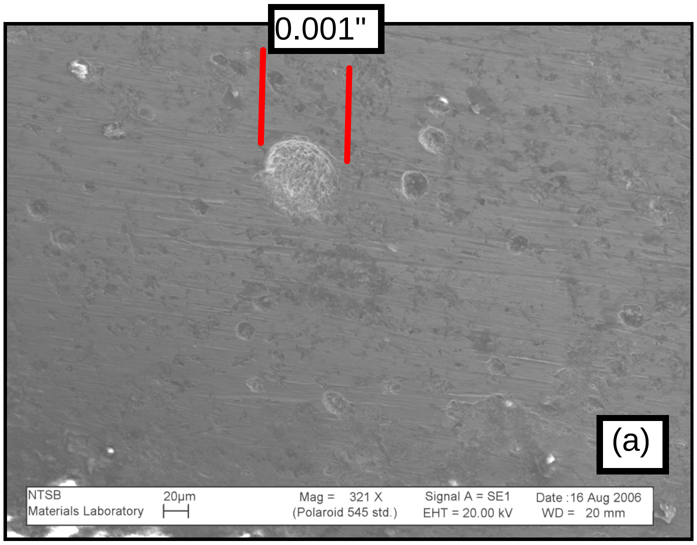
Figure 6--Optical image (a) of the inboard fracture showing fracture initiation at a corrosion pit located ~0.14 inch from projected inner diameter of the cylinder. SEM image (b) shows fatigue region 0.009 wide (yellow dashed lines) surrounding the 0.004" wide pit. Image (c) shows depth of corrosion and fatigue region.





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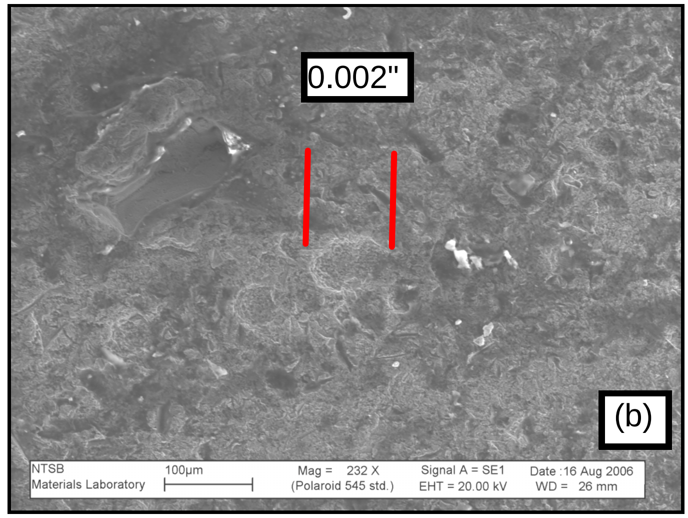

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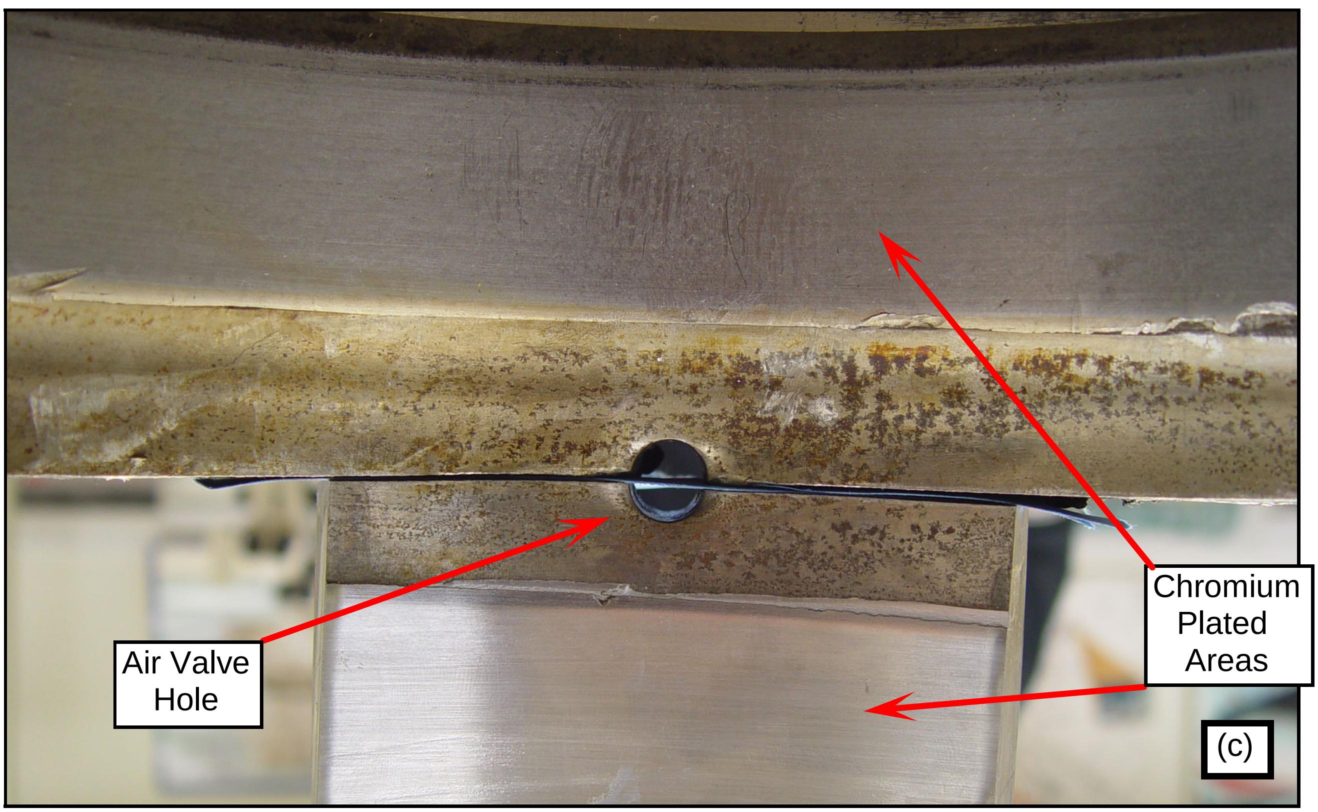

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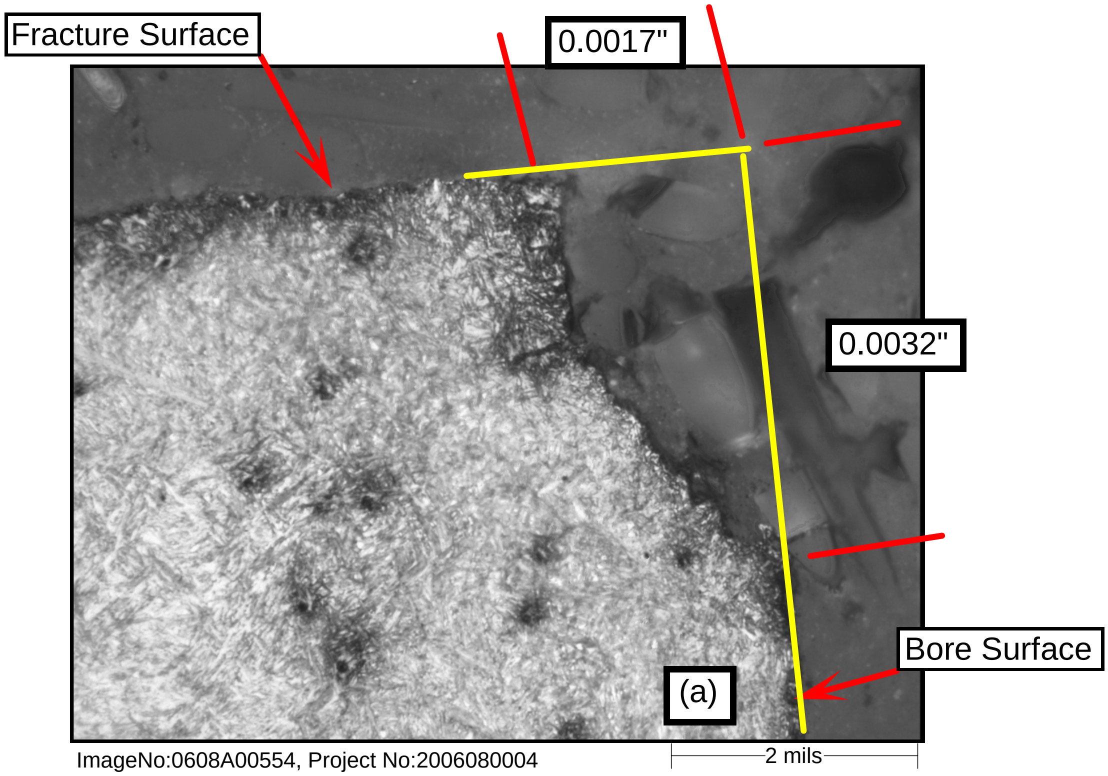
Figure 7--SEM views (a) and (b) of corrosion pits in the air valve bore. Optical view (c) showing widespread corrosion (brown spots) of the inside surface of the cylinder in the area of the air valve hole.



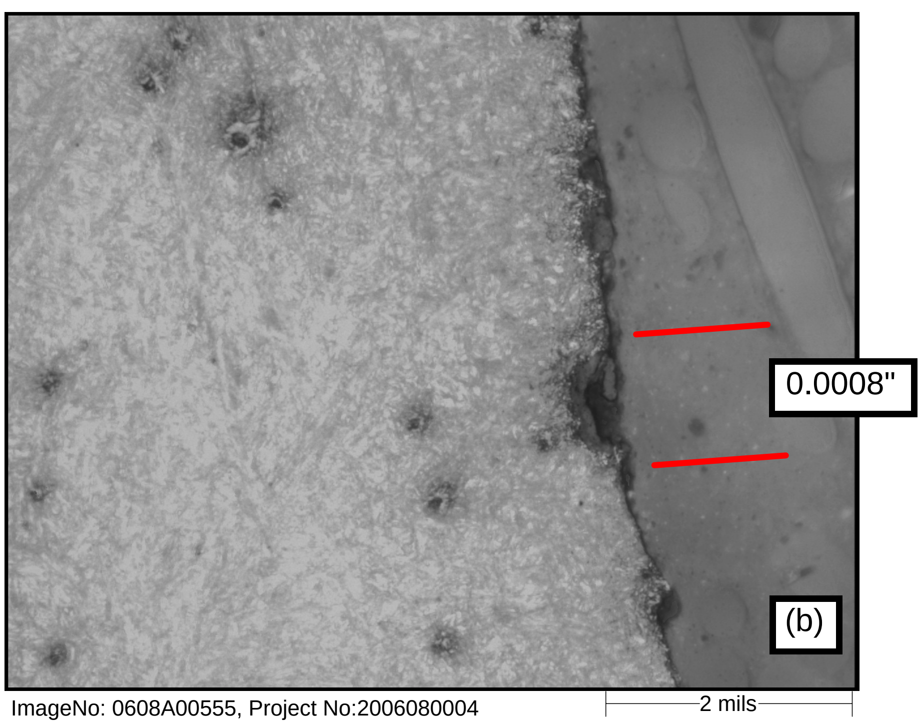


Figure 8--Metallographic sections through the pit at the origin of the inboard crack (a) and an additional pit in the air valve bore (b). Both Nital Etch.

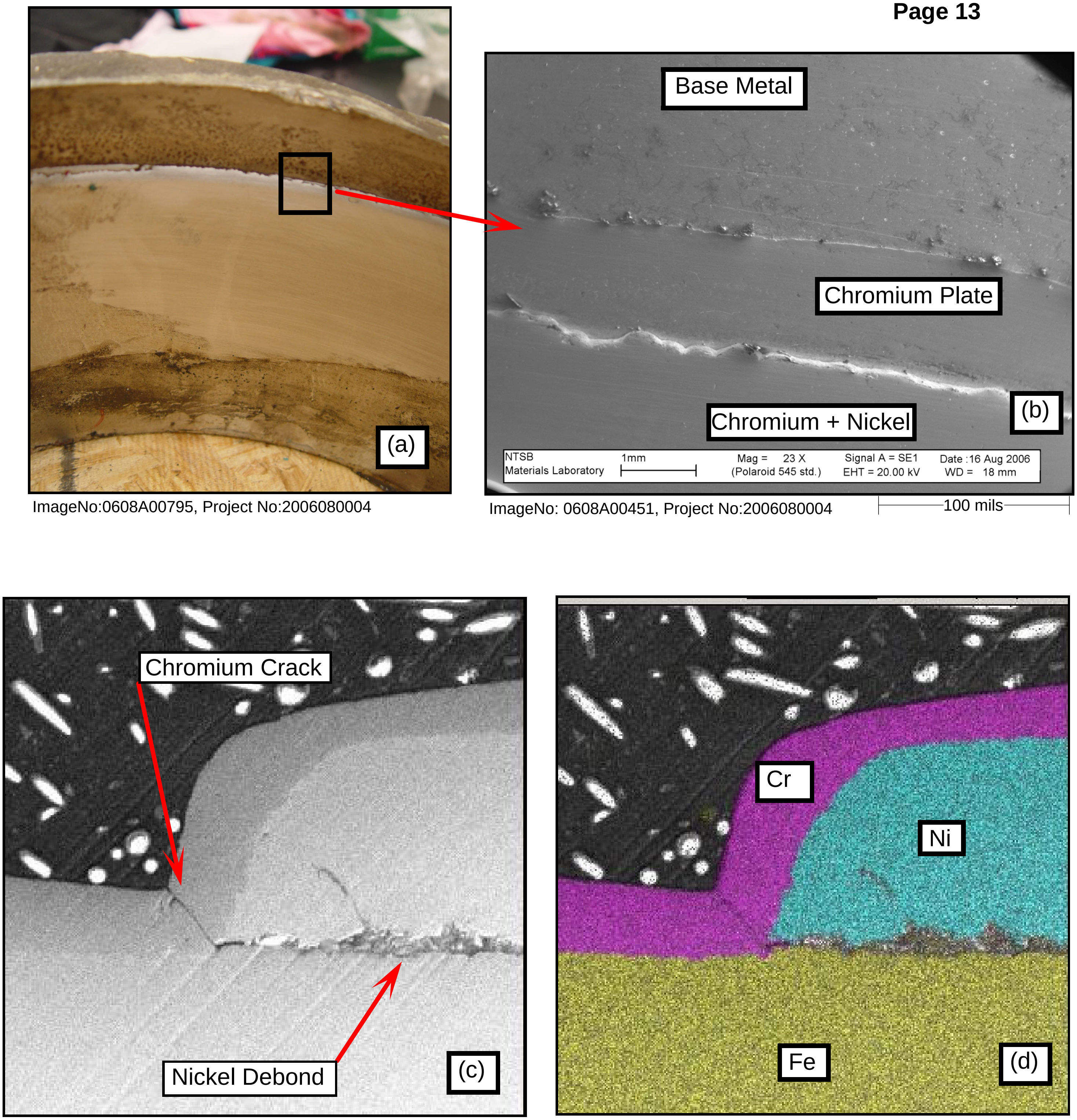


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Figure 9-- Wide plating region on ID below fracture (a) with an SEM closeup of plating edge (b) showing two plating thicknesses and the runout. SEM image (c) of a cross section through the plating showing the cracked chromium plating and adjacent debonded nickel. EDS maps (d) of the same section idetifying thick nickel (blue) underplating and thinner chromium (magenta) overlay on top of iron (yellow) base metal.