

National Transportation Safety Board

Office of Research and Engineering

Washington, DC 20594



DCA23FA339

MATERIALS LABORATORY

Factual Report 23-069

February 21, 2024

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A. ACCIDENT INFORMATION

Location: Charlotte, North Carolina
Date: June 28, 2023
Vehicle: Boeing 717-200, N955AT
Investigator: Brice Banning, AS-10

B. COMPONENTS EXAMINED

Fractured nose landing gear upper lock link

C. EXAMINATION PARTICIPANTS

Specialist Michael Meadows
National Transportation Safety Board
Washington, D.C.

D. DETAILS OF THE EXAMINATION

On June 28, 2023, about 0858 eastern daylight time (EDT), Delta Air Lines flight 1092, a Boeing 717-200, sustained substantial damage when the nose landing gear did not extend before landing at Charlotte Douglas International Airport (CLT), Charlotte, North Carolina. The 104 passengers and crew evacuated with no injuries. The flight was operating as a 14 Code of Federal Regulations Part 121 scheduled domestic passenger flight from Atlanta, Georgia, to CLT.

A post-accident examination of the nose landing gear system revealed a fractured upper lock link, the component highlighted in red in the schematic in figure 1, which was sent to the NTSB materials laboratory for examination.

Figure 2 shows the as received fractured upper lock link component. Greasy soil deposits were observed covering some areas of the part and some areas of chipped, bubbled, and wrinkled paint were observed. The following part identification information was observed stamped or vibro-etched on the web of the aft piece:

3914464-509 V
3911464-505
S/N 0007

The component was fractured at approximately mid-span, between 7.2 and 7.9 inches from the forward lug. The section height of the component was 1.122 inches as measured on the forward piece, just below the point of fracture. Figure 3 shows both sides of the fracture surface, as received. A relatively shiny and flat thumbnail shaped region approximately 1.07 inches wide by 0.42 inch deep was observed emanating from the lower surface with visible curved crack arrest (beach) marks,

consistent with a progressive cracking mechanism. Outside of the thumbnail shaped region, the fracture surface was rougher and exhibited a generally matte appearance. Figure 4 shows a view of the lower surface of the part adjacent to the fracture origin area which exhibited evidence of horizontal and vertical scratch features near the fracture surface and under the paint layer.

An acetate tape replica technique was performed prior to disassembling and cleaning the part and fracture surfaces for closer examination. The subsequent cleaning procedure used a combination of soapy water with soft bristle brush followed by an ethanol rinse. Paint was stripped chemically from the part surface using a methylene chloride-based paint remover. A non-destructive fluorescent penetrant inspection was performed on the lower surface of the part and no relevant linear cracklike indications were observed. Linear indications observed were attributable to visible scratch features on the part surface.

A section cut was performed on the forward piece of the upper lock link approximately 0.6 inch below the fracture surface to facilitate closer examination. Figure 5 shows a digital microscope image of the cleaned fracture surface. The fracture origin area, as marked by a yellow bracket, was observed on the lower surface of the part near a parting line feature.¹ A prominent ratchet mark was observed at the origin area as indicated by the blue arrow.² A darker thumbnail shaped region approximately 0.26 inch wide by 0.10 inch deep was observed emanating from the fracture origin area. Several crack arrest (beach) marks were observed within this region. A larger thumbnail shaped region that was lighter and shinier in appearance extended outward and terminated at the yellow boundary. Several crack arrest (beach) marks were observed in this region with prominent ones indicated by black arrows. This relatively flat thumbnail shaped region of fracture with curved arrest marks was consistent with a region of progressive fracture with growth direction indicated by white arrows. The portion of the fracture surface outside of this region was relatively rough and matte in appearance with some curved progression marks indicated by red arrows and shear lip features observed at the free edges of the part. The overall appearance of the fracture surface was consistent with cyclic tensile or bending loads and progressive fracture from the lower surface with an overstress dominated fracture mode at final separation.

The surface adjacent to the fracture surface near the origin area showed evidence of vertical and horizontal scratch features near the parting line as shown more closely in figure 6. The fracture plane at the origin was oriented parallel to a horizontal scratch feature just below the fracture surface, indicated by a black arrow.

¹ A raised line or projection on the surface of a forging that corresponds to the intersection of the parting plane between forging dies with the mold or die cavity.

² Ratchet marks are slight vertical steps in the fracture that link slightly offset planes of fatigue cracking at a fatigue origin area. Ratchet marks generally are aligned in the direction of cracking and taper off as distance from the origin is increased and a unified crack front is produced.

Surface roughness profile (Rq) measurements were performed longitudinally and transversely along the parting line and the lower surface away from the parting line using a Mitutoyo Surftest 402 Series 178 Surface Roughness Tester fitted with standard detector 178-350 with a 5 μm tip radius.³ Roughness measured over a 0.03-inch sampling length on the lower surface was 59-66 microinches compared to 185 – 508 microinches on the parting line. Roughness measured over a 0.1-inch sampling length was performed in the longitudinal direction and resulted in values of 86 microinches and 347 microinches for the lower surface and parting line, respectively.

The fracture surface was examined more closely using a Thermo Fisher Scientific Apreo S field emission scanning electron microscope (SEM). Figure 7 shows a secondary electron image of the fracture origin area and the adjacent surface. Several ratchet marks were observed as indicated by blue arrows, consistent with multiple fracture initiation sites. The fracture had a feathery appearance with radial features emanating in the direction of crack growth indicated by black arrows. A horizontally oriented trough shaped feature, consistent with a scratch, was observed along the edge of the fracture origin area along with several other horizontal and vertical scratches on the adjacent surface as indicated by red arrows. Figure 8 shows secondary electron images at different magnification levels near the fracture origin area within the darker colored thumbnail shaped region. Prominent fatigue striations were apparent with smaller fatigue striations observed in between, consistent with a fatigue fracture mechanism under block or spectrum type loading conditions. Fracture direction is upward these images, perpendicular to striation features. Figure 9 shows secondary electron images at different magnification levels closer to the end of the fatigue crack. Similar striation features were observed with generally wider spacing, consistent with a higher crack growth rate. Figure 10 shows SEM images at the fatigue crack terminus, indicated by the yellow dashed line with the general crack growth direction indicated by the white arrow. Just below this region, curved arrest marks were observed intermixed with dimpled features. Above the terminus, dimpled fracture features were observed consistent with microvoid coalescence and overstress separation.

Compositional analysis of the upper lock link component was performed using x-ray fluorescence (XRF) spectroscopy and was consistent with aluminum alloy 7075. Electrical conductivity and hardness measurements were performed per ASTM E1004 and ASTM E18, respectively.^{4,5} The conductivity averaged 40.2 % IACS, and the hardness averaged 83.1 HRB. These data were consistent with the alloy having an

³ Root Mean Square (RMS) roughness parameter (Rq) corresponds to the standard deviation of the height distribution, in microinches, defined on the sampling length.

⁴ ASTM E1004 – Standard Test Method for Determining Electrical Conductivity Using the Electromagnetic (Eddy-Current) Method. ASTM International, West Conshohocken, PA

⁵ ASTM E18 – Standard Test Method for Rockwell Hardness of Metallic Materials. ASTM International, West Conshohocken, PA

overaged T73 or T76 temper, per AMS 2658.⁶ A transverse section of the component was mounted, polished, and etched with Keller's reagent to reveal the microstructure, as shown in figure 11, which was consistent with a forged aluminum alloy component.⁷

A quantitative crack growth rate analysis was performed over the fatigue crack fracture surface to estimate the number of cycles to failure. The fracture surface was cleaned progressively using a combination of solvents with ultrasonic agitation followed by a heated Chromic/Phosphoric acid solution soak. A series of 35 locations, progressing along the crack depth direction, were imaged using the SEM and stage positions were recorded to correlate crack growth rate and crack depth. Prominent fatigue striations were counted and averaged along these increments with minor striations excluded from this analysis. Fatigue striations were not resolvable within 0.043 inch of the fracture origin and the maximum fatigue crack depth was measured to be 0.417 inch. The estimated number of major fatigue striations was calculated to be 39,059. According to maintenance records, the upper lock link component had accumulated 41,257 flight cycles. Boeing engineers indicated that the lock link component experiences 2 major loads and several minor loads per flight cycle (extension and retraction of the nose landing gear), with the extension load being greater due to the gravitational force. Table I summarizes the result of the striation count exercise and representative SEM fractographs are contained in Appendix A.

Submitted by:

Michael Meadows
Materials Engineer

⁶ AMS 2658 - Hardness and Conductivity Inspection of Wrought Aluminum Alloy Parts. SAE International, Warrendale, PA.

⁷ Keller's Reagent: 1% Nitric acid, 1.5% Hydrochloric acid, 3.5%Hydrofluoric acid in Distilled water

Table I. Crack Growth Rate Analysis Data

SEM Image	Mag (X)	Stage Position		Depth (in)	Increment (in)	# of Striations	Segment Length		Growth Rate da/dN (in/cyc)	Cycles/Inc.	Cycles from Origin
		X (mm)	Y (mm)				(um)	(in)			
1	1000x	0.7064	-15.1463	0.000	0.000	--	--	--	--	--	0
2	5000x	1.6756	-14.6304	0.043	0.043	6	0.284	1.12E-05	1.86E-06	23196	23196
3	35000x	1.6501	-14.0848	0.056	0.013	10	0.75	2.95E-05	2.95E-06	4298	27495
4	35000x	1.6359	-13.9403	0.060	0.004	5	0.617	2.43E-05	4.86E-06	829	28323
5	10000x	2.0165	-14.1639	0.064	0.005	6	0.75	2.95E-05	4.92E-06	919	29242
6	15000x	2.1926	-13.8892	0.077	0.012	7	1.81	7.13E-05	1.02E-05	1195	30437
7	15000x	1.6323	-13.3796	0.079	0.002	7	1.825	7.19E-05	1.03E-05	184	30621
8	20000x	1.6669	-13.2818	0.083	0.004	6	1.586	6.24E-05	1.04E-05	389	31010
9	15000x	2.2203	-13.5825	0.086	0.003	10	2.417	9.52E-05	9.52E-06	328	31338
10	8000x	2.2558	-13.5194	0.088	0.003	6	1.618	6.37E-05	1.06E-05	260	31598
11	12000x	2.2593	-13.5129	0.089	0.000	7	1.782	7.02E-05	1.00E-05	28	31626
12	20000x	1.7331	-13.0814	0.091	0.002	7	2.004	7.89E-05	1.13E-05	183	31808
13	25000x	1.8529	-12.9331	0.098	0.007	5	1.159	4.56E-05	9.13E-06	804	32613
14	25000x	0.814	-12.5634	0.102	0.004	8	1.387	5.46E-05	6.83E-06	534	33147
15	25000x	0.8029	-12.55	0.102	0.001	8	1.387	5.46E-05	6.83E-06	75	33222
16	20000x	0.7989	-12.4419	0.107	0.004	5	3.562	1.40E-04	2.81E-05	151	33373
17	20000x	1.8055	-12.6479	0.107	0.001	9	3.529	1.39E-04	1.54E-05	60	33433
18	10000x	0.8178	-12.3392	0.111	0.003	11	6.247	2.46E-04	2.24E-05	141	33573
19	8000x	0.8346	-12.2184	0.115	0.005	12	7.925	3.12E-04	2.60E-05	184	33757
20	10000x	0.7958	-12.081	0.121	0.005	10	6.31	2.48E-04	2.48E-05	215	33973
21	6500x	0.7721	-11.9396	0.126	0.006	14	9.861	3.88E-04	2.77E-05	200	34173
22	6500x	0.7477	-11.5635	0.141	0.015	9	7.37	2.90E-04	3.22E-05	459	34631
23	6500x	0.7487	-11.3845	0.148	0.007	11	8.909	3.51E-04	3.19E-05	221	34852
24	6500x	0.7858	-11.1876	0.156	0.008	8	4.95	1.95E-04	2.44E-05	319	35171
25	8000x	0.7956	-11.0612	0.161	0.005	5	4.47	1.76E-04	3.52E-05	142	35313
26	5000x	0.8154	-10.8446	0.169	0.009	8	8.371	3.30E-04	4.12E-05	207	35520
27	5000x	0.8738	-10.6478	0.177	0.008	9	8.564	3.37E-04	3.75E-05	209	35729
28	5000x	0.7539	-10.3374	0.189	0.012	5	4.842	1.91E-04	3.81E-05	318	36047
29	5000x	0.782	-10.1705	0.196	0.007	11	9.954	3.92E-04	3.56E-05	185	36231
30	5000x	0.7317	-9.4473	0.224	0.028	7	9.372	3.69E-04	5.27E-05	540	36771
31	3500x	0.8475	-8.3555	0.267	0.043	7	11.01	4.34E-04	6.19E-05	695	37466
32	2500x	0.9999	-7.6311	0.296	0.029	6	8.879	3.50E-04	5.83E-05	492	37959
33	2000x	1.0013	-7.3909	0.306	0.009	10	19.48	7.67E-04	7.67E-05	123	38082
34	2500x	1.0613	-7.145	0.315	0.010	10	17.59	6.93E-04	6.93E-05	141	38223
35	2000x	2.2762	-6.3319	0.352	0.037	7	21.61	8.51E-04	1.22E-04	306	38529
--	--	Assumed Max. Depth		0.417	0.048	Assume previous GR			1.22E-04	531	39059

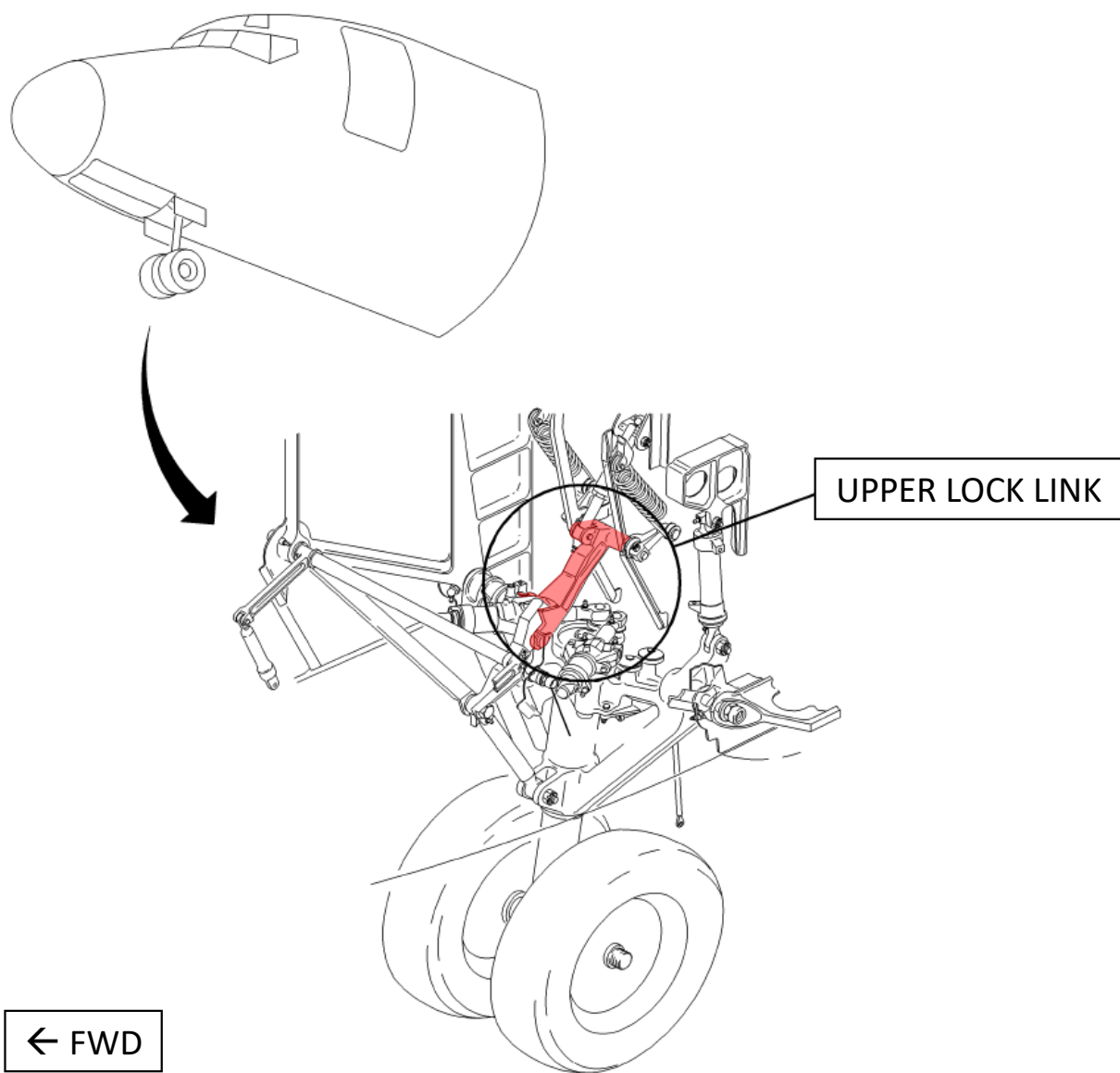


Figure 1. A schematic showing the position of the upper lock link component, highlighted in red, with the nose landing gear in the extended position. (Source: Boeing Service Bulletin 717-32-002)

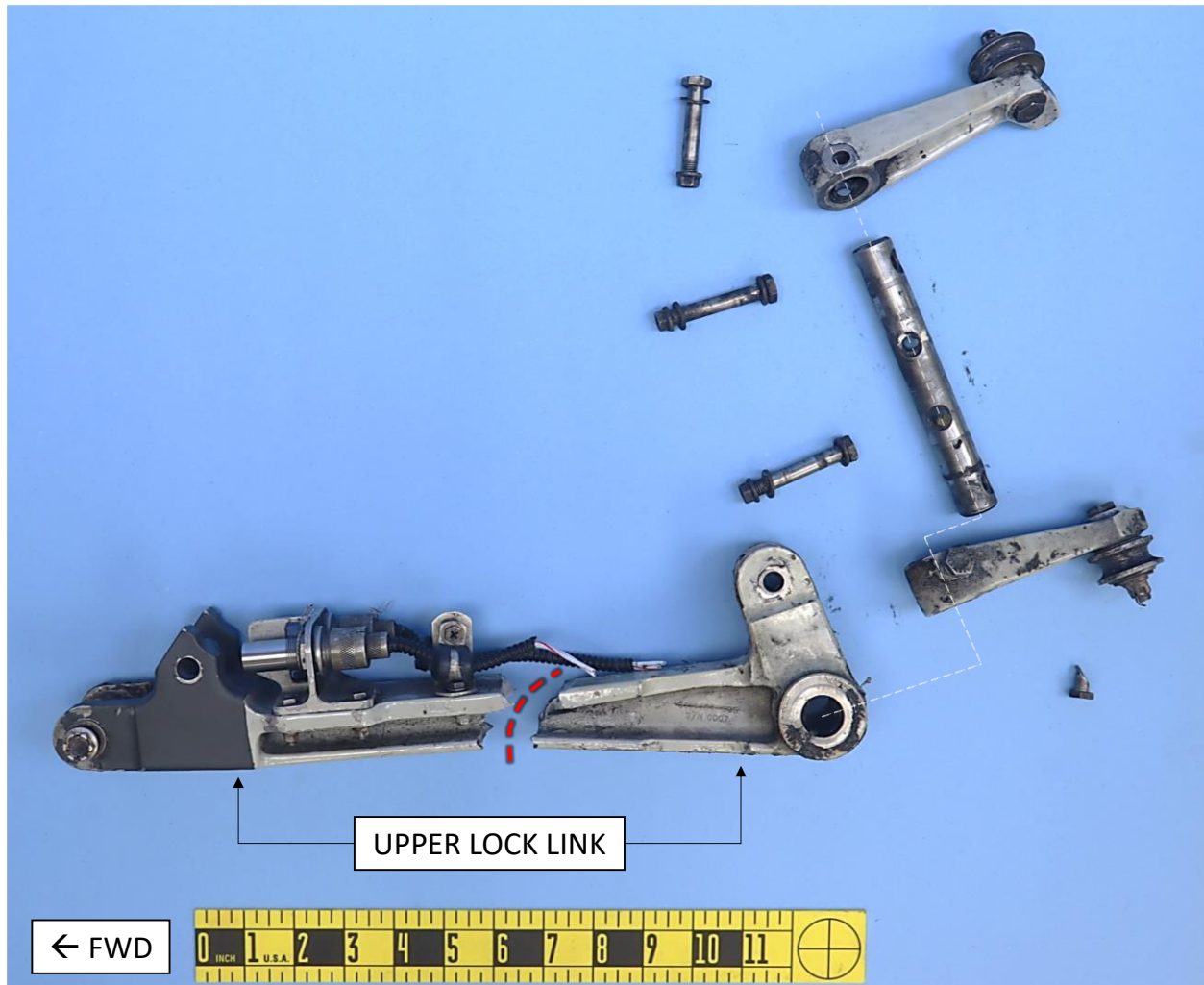


Figure 2. A photograph showing an exploded view of the as received components with the fracture location highlighted by the red dashed line.

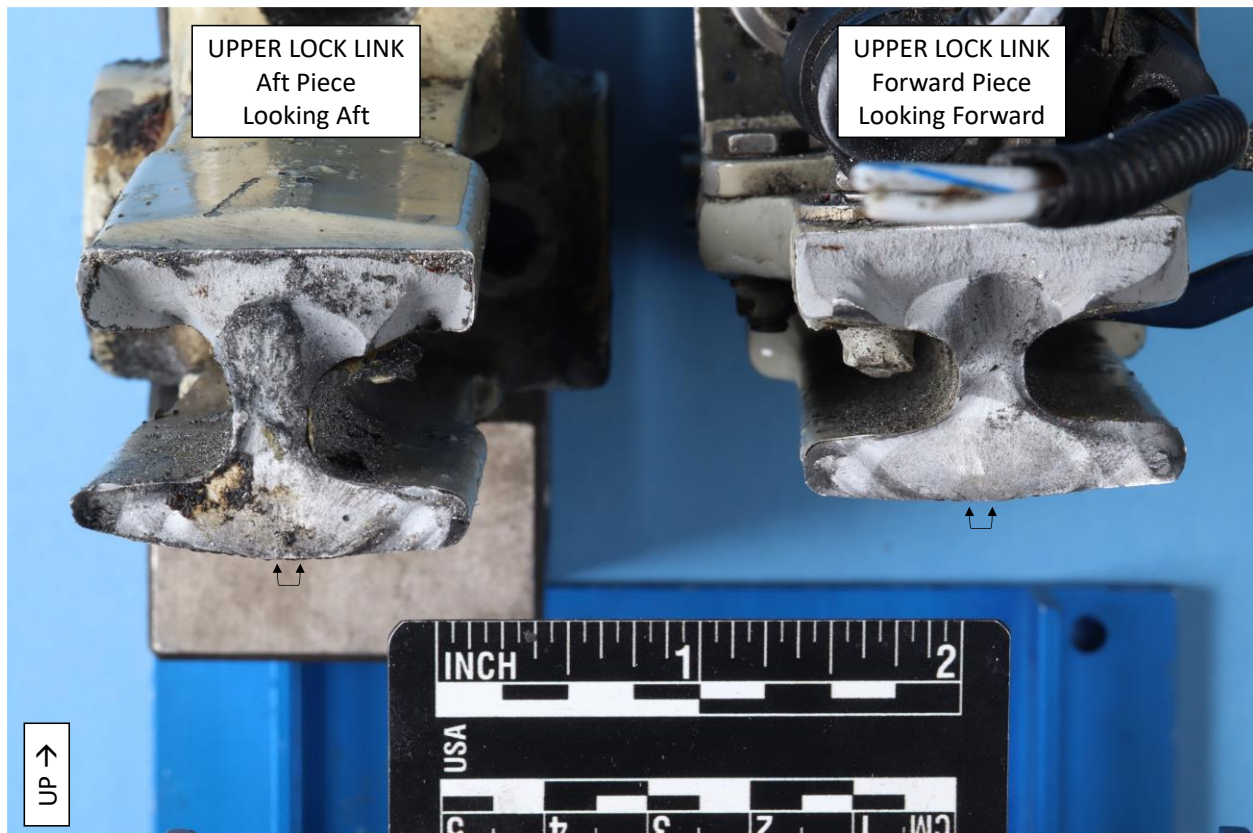


Figure 3. A photograph showing both sides of the fracture surface of the upper lock link, as received, with the fracture origin area indicated with a black bracket.



Figure 4. Digital microscope images of the fracture origin area and adjacent lower surface on the forward piece, as received. Horizontal and vertical scratch features were observed near the origin on the adjacent surface beneath the paint layer.

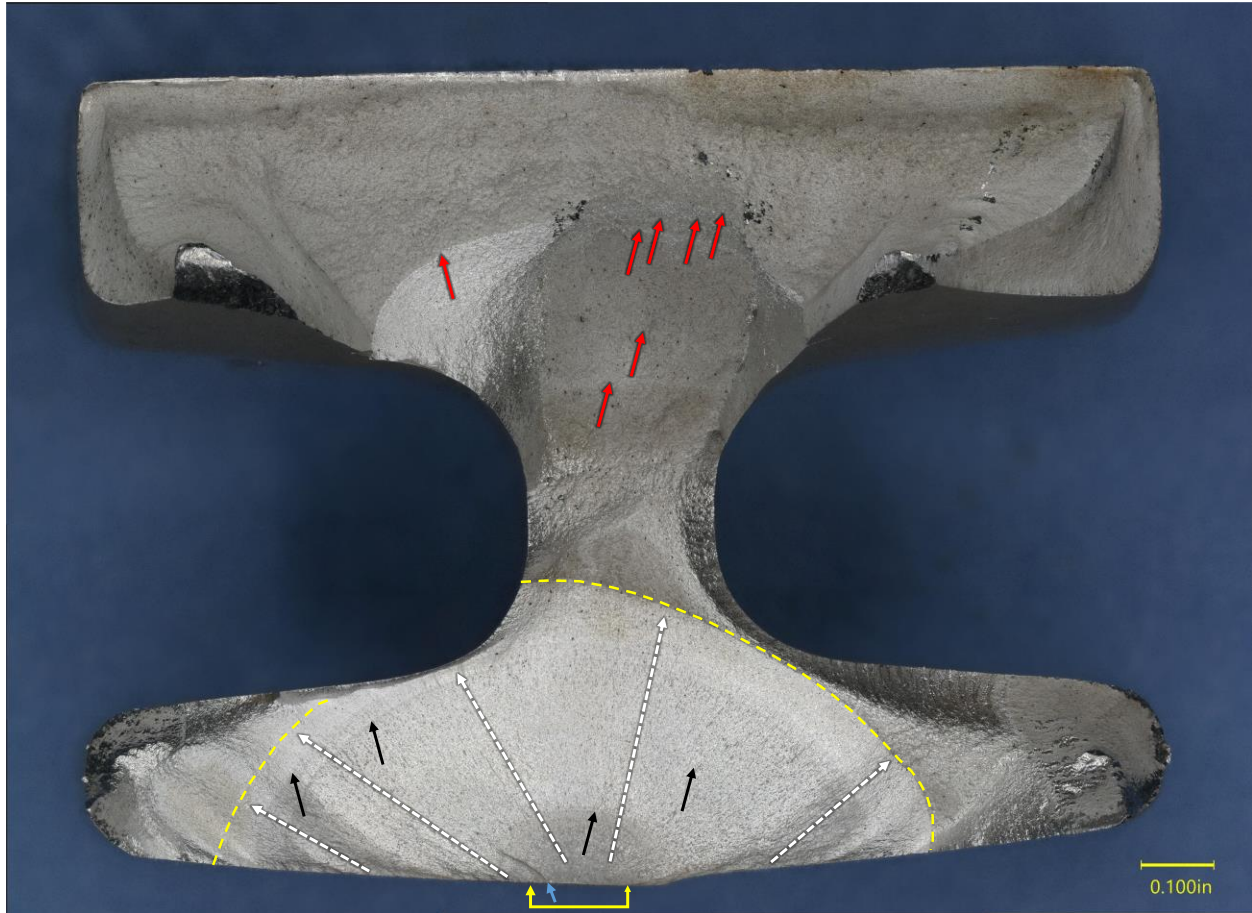


Figure 5. A digital microscope image of the cleaned fracture surface on the forward piece of the upper lock link. The fracture origin area is indicated by a yellow bracket with progressive crack growth direction indicated by white arrows. A ratchet mark was observed as indicated by the blue arrow. The curved yellow line highlights the boundary of progressive crack growth with several curved arrest (beach) marks indicated by black arrows. Curved arrest marks observed outside of the progressive region are indicated by red arrows.

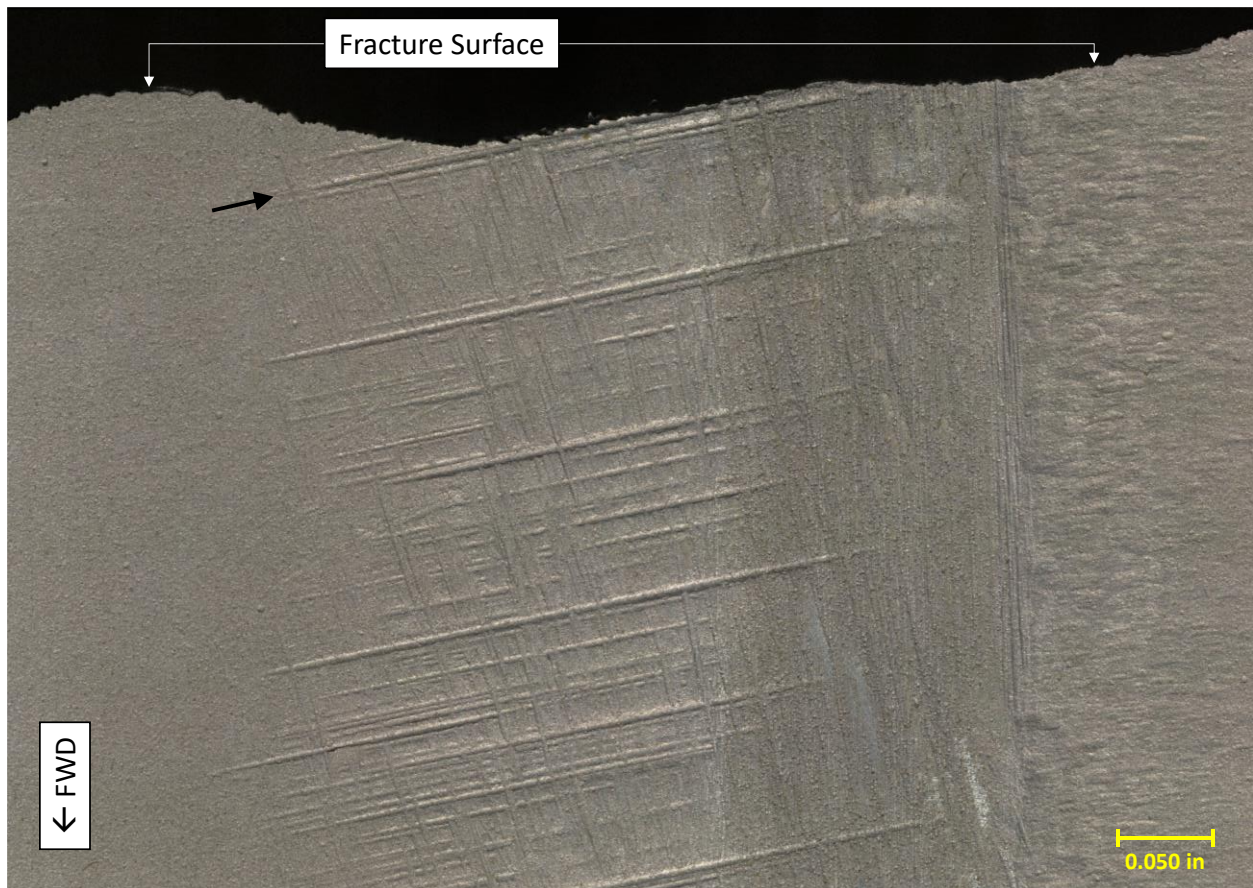


Figure 6. A digital microscope image of the lower surface of the forward lower lock link piece adjacent to the fracture origin area. Visible horizontal and vertical scratches were observed. The fracture plane was oriented parallel to a horizontal scratch as indicated by the black arrow.

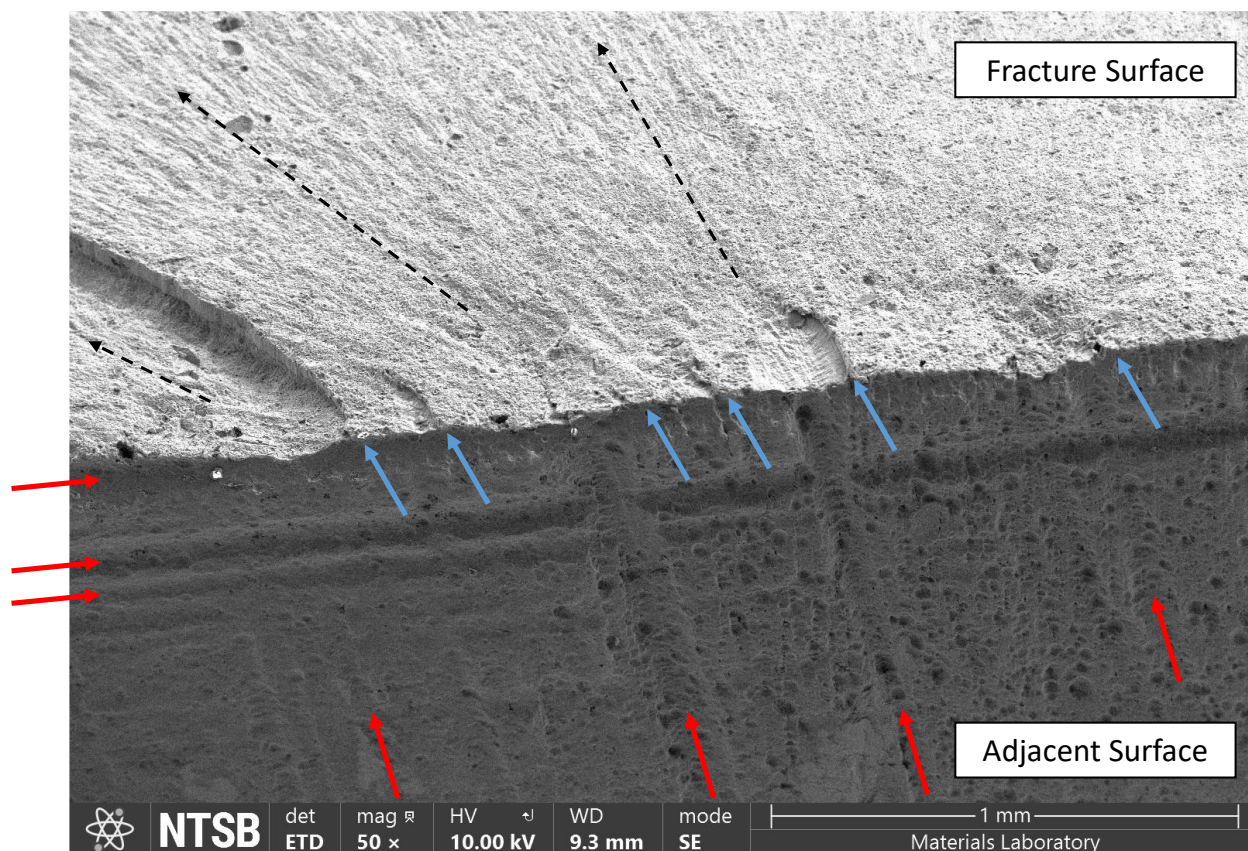


Figure 7. A secondary electron image of the fracture origin area and adjacent lower surface. Several ratchet marks were observed at the edge of the fracture surface as indicated by blue arrows. Crack growth direction is indicated by black arrows. Red arrows highlight several scratches observed near the fracture origin area.

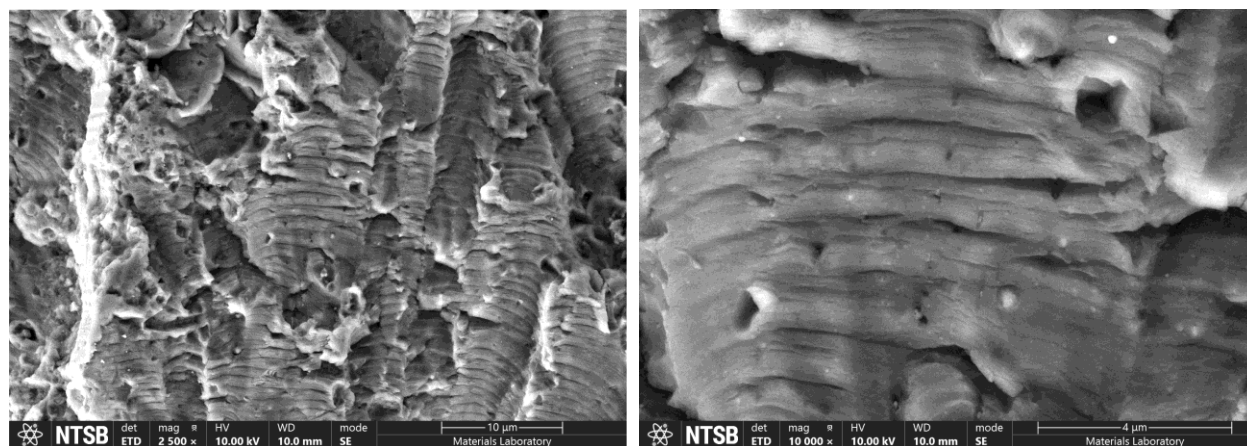


Figure 8. Secondary electron fractographs showing fatigue striations observed in the dark thumbnail shaped region near the fracture origin area.

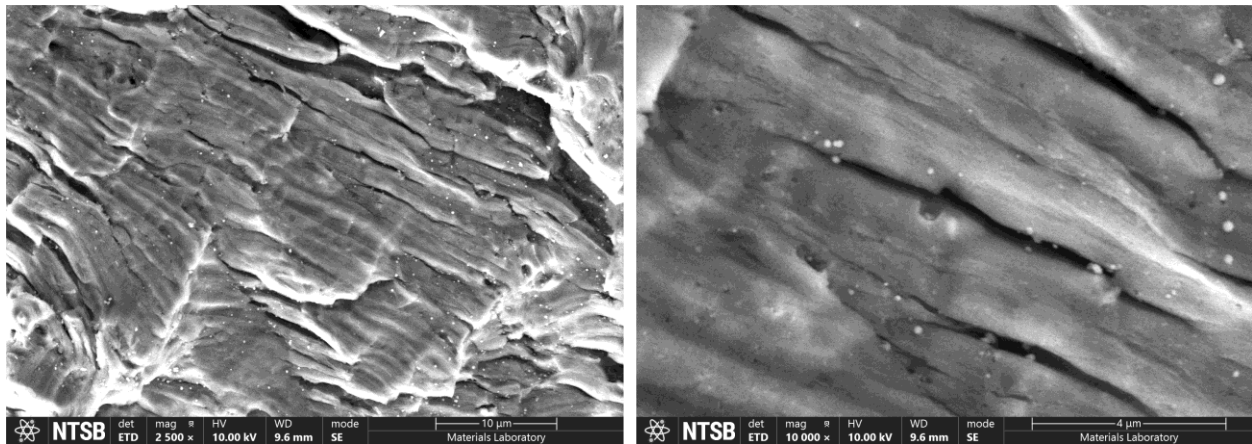


Figure 9. Secondary electron fractographs showing fatigue striations near the end of the progressive crack growth region.

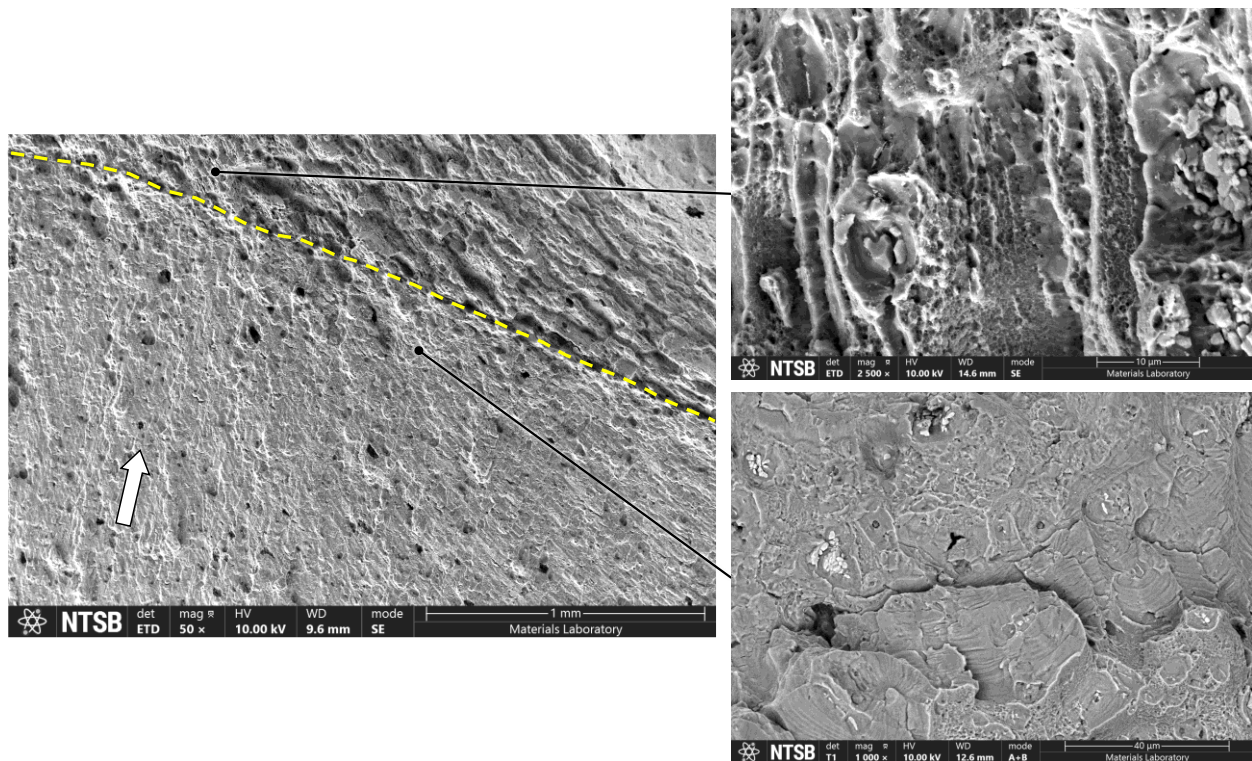


Figure 10. SEM fractographs showing the fatigue crack terminus highlighted by the yellow boundary and general crack growth direction indicated by the white arrow. Closer views of the indicated areas show fatigue striations intermixed with microvoid coalescence (lower right) and microvoid coalescence (upper right).

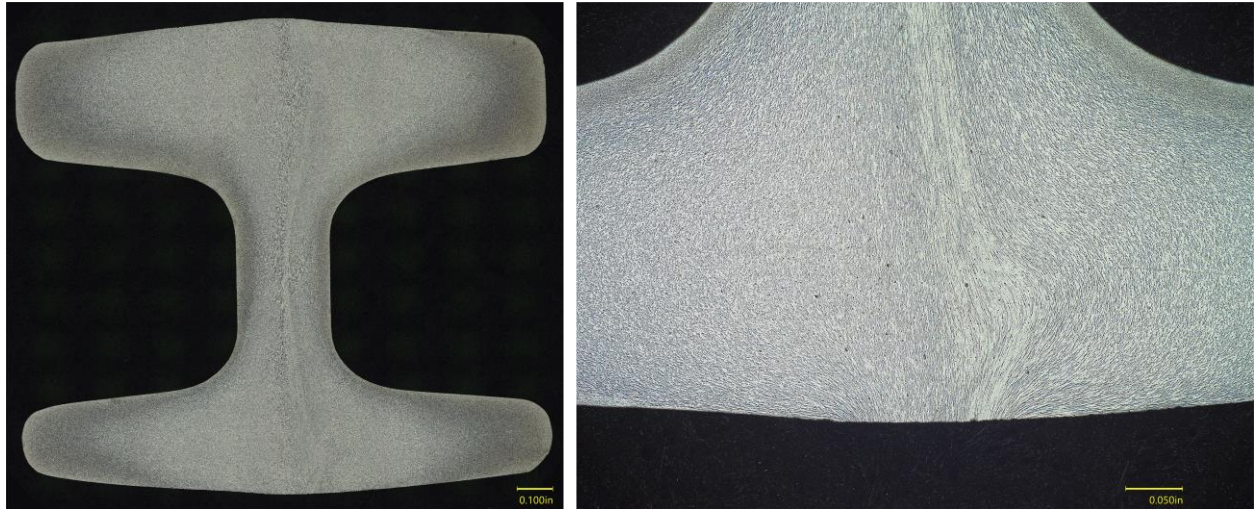


Figure 11. A bright field optical micrograph showing a cross section view of the component (left) and a closer view of the lower surface at the parting line (right). Grain flow lines were consistent with a forged component. (Etched with Keller's Reagent)

APPENDIX A

Supplemental SEM fractographs for crack growth rate analysis, reference Table I.

