

Docket No. SA-522

Exhibit No. 15-C

NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D.C.

Materials Specialists' Submission
Selected Photographs of the Fractographic
Examination of the Vertical Stabilizer

(28 Pages)

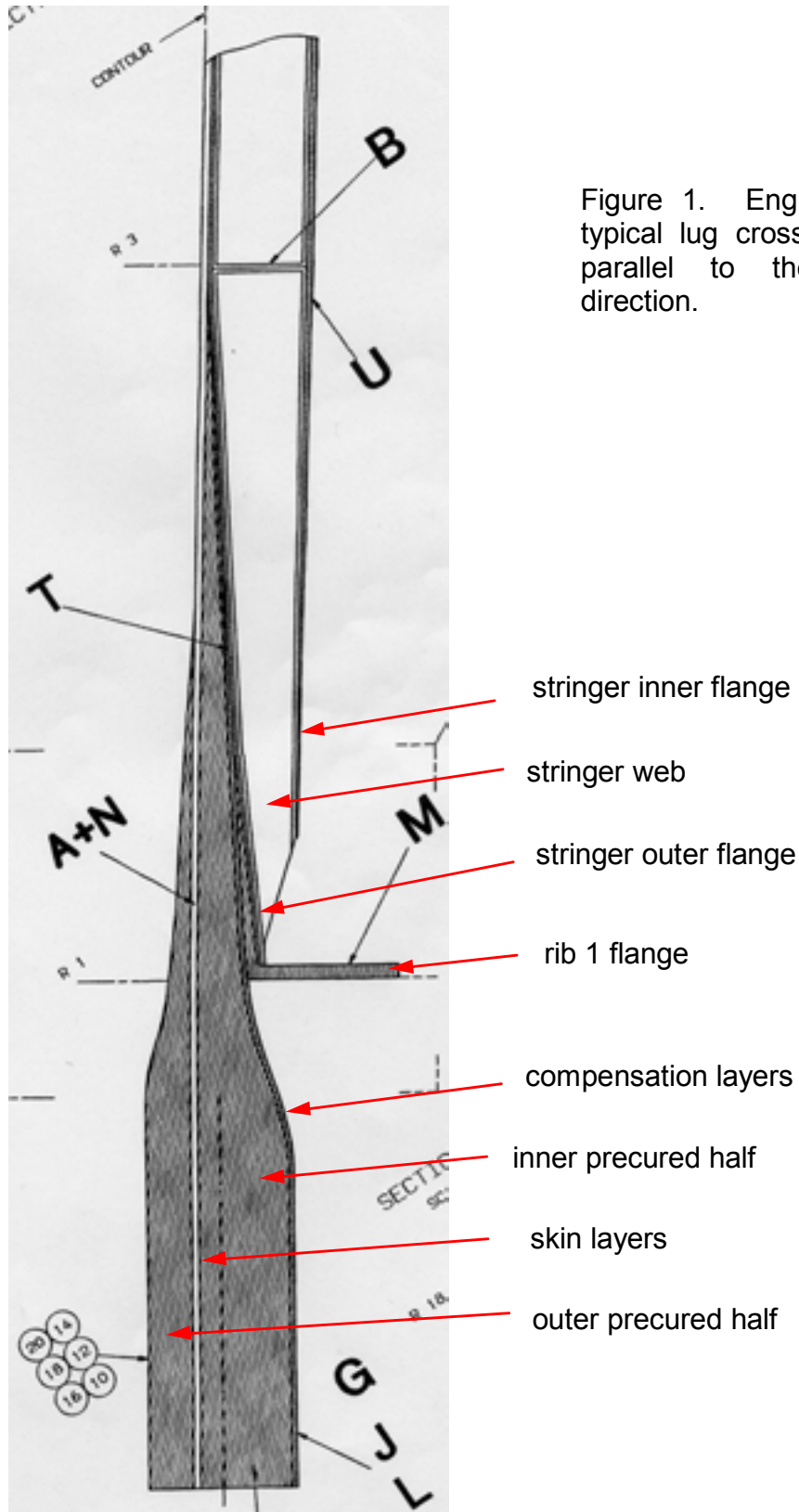
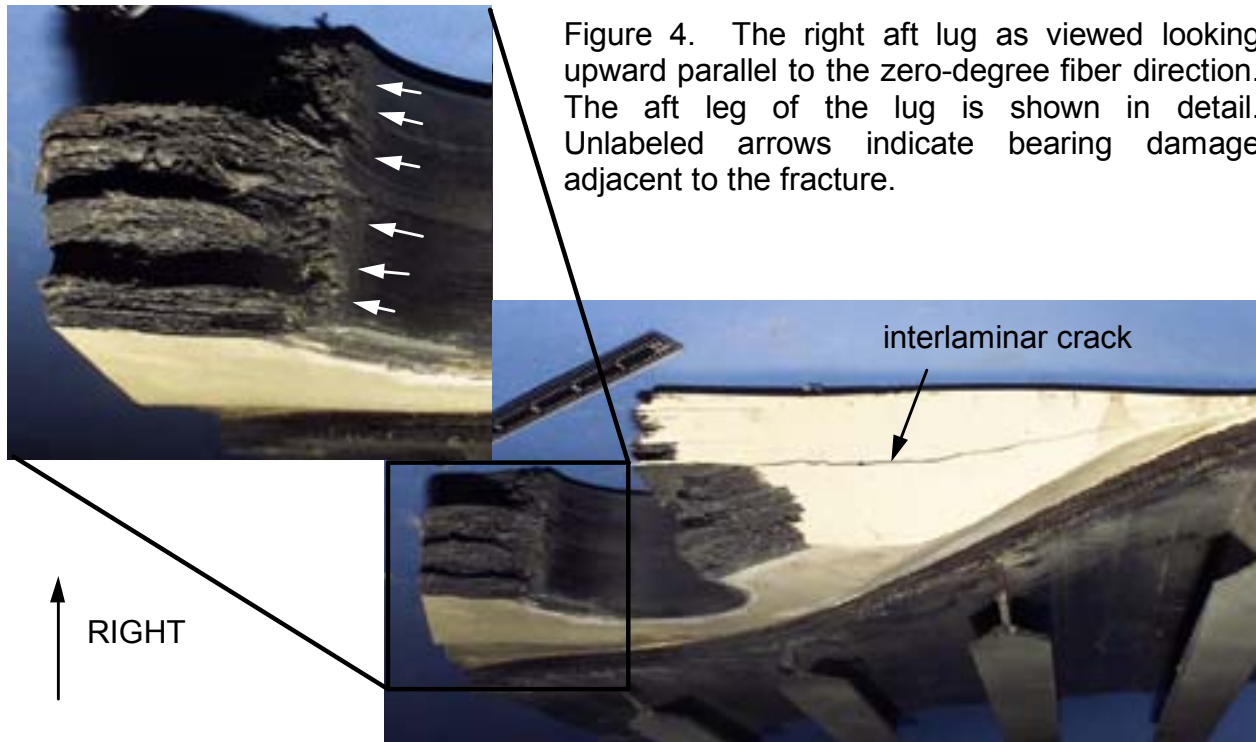
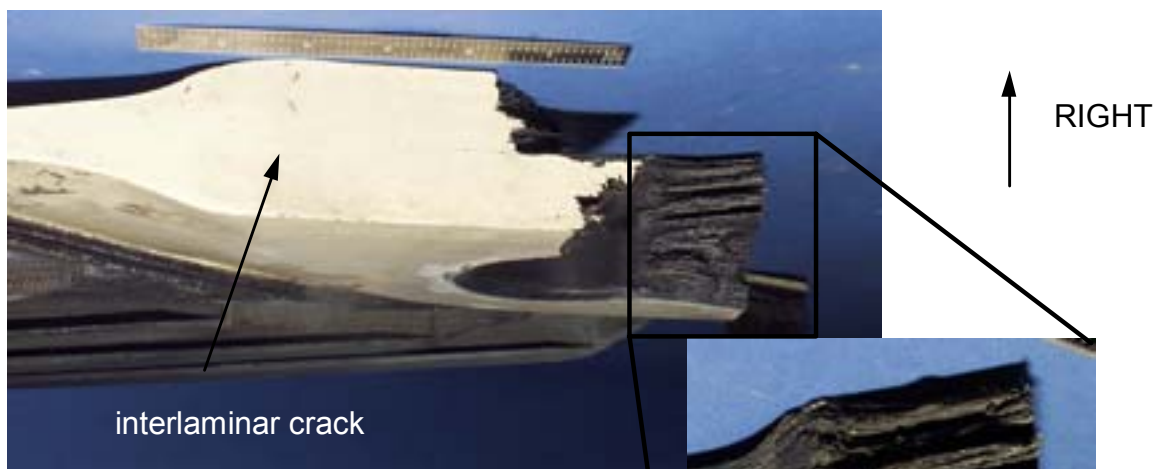


Figure 1. Engineering drawing of a typical lug cross section in the plane parallel to the zero-degree fiber direction.

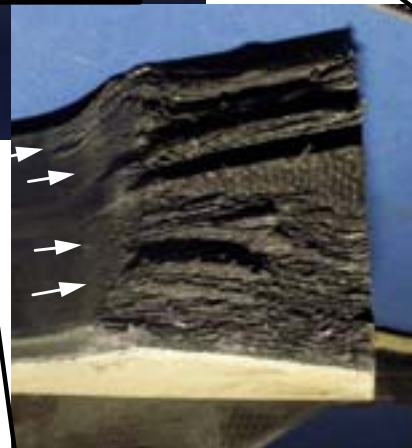


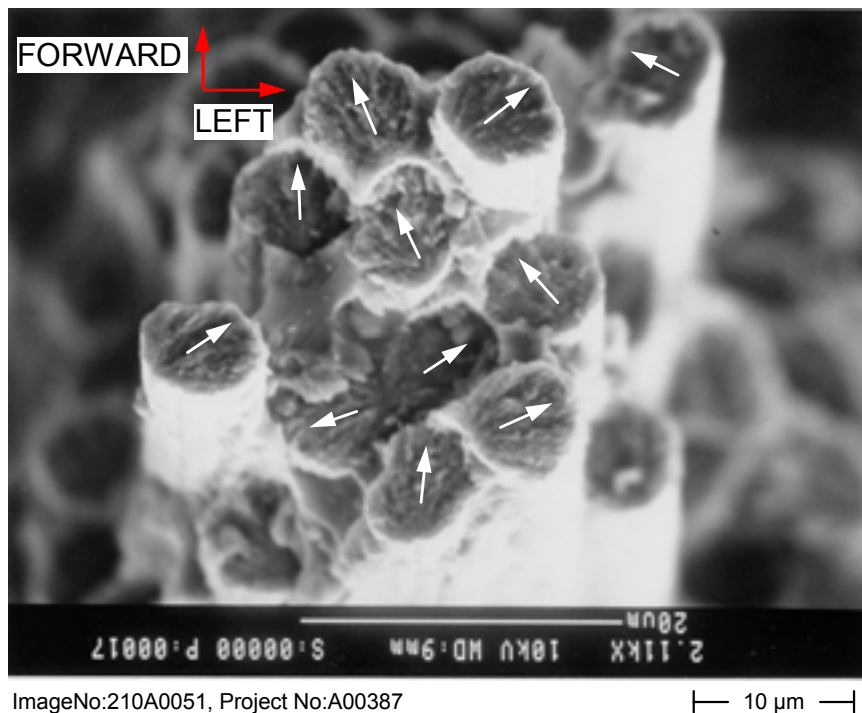
ImageNo:210A0039, Project No:A00387



ImageNo: 210A0040, Project No:A00387

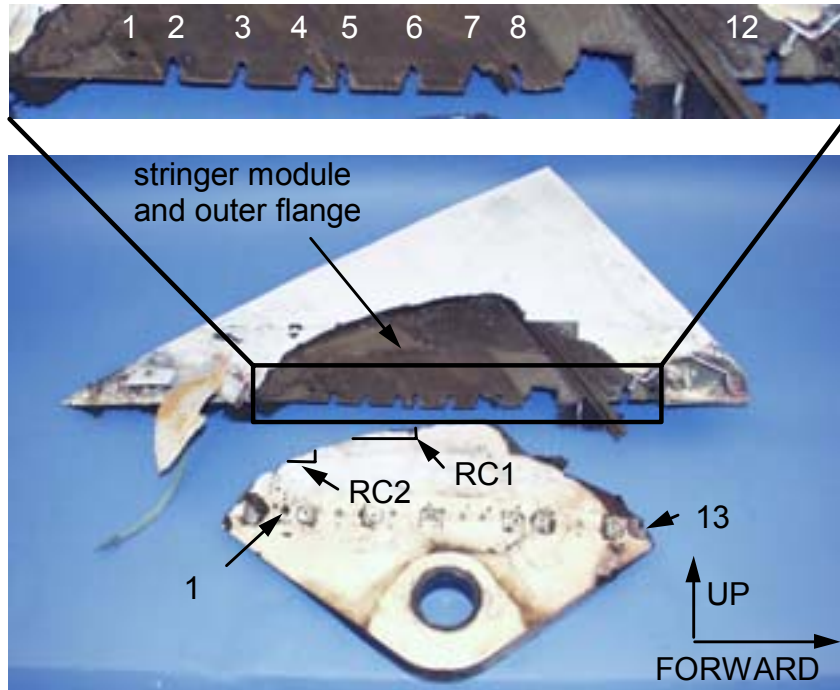
Figure 5. The right aft lug as viewed looking upward and forward. The fracture surface on the forward leg of the lug is shown in detail. Unlabeled arrows indicate bearing damage adjacent to the fracture.





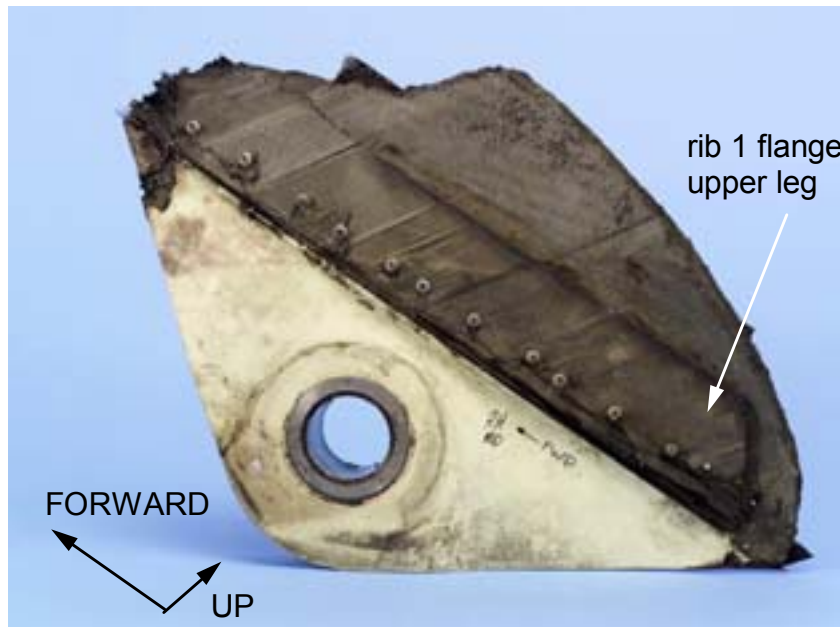
ImageNo:210A0051, Project No:A00387

Figure 8. Typical appearance of the fractured zero-degree fibers on specimen RA3-2 near the center of the total lug thickness. Arrows on fractured fibers indicate direction of fracture propagation through the fiber.



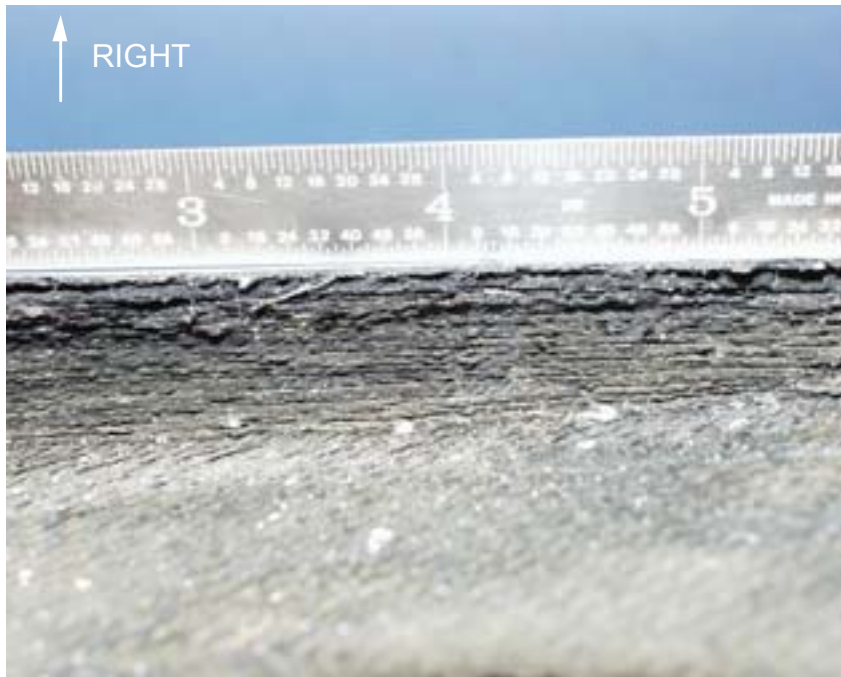
ImageNo:209A0282, Project No:A00387

Figure 9. Overall view of the right center lug pieces viewed from the right with the upper photograph showing details of the rib 1 fastener hole tearouts in the stringer module and outer flange layers.



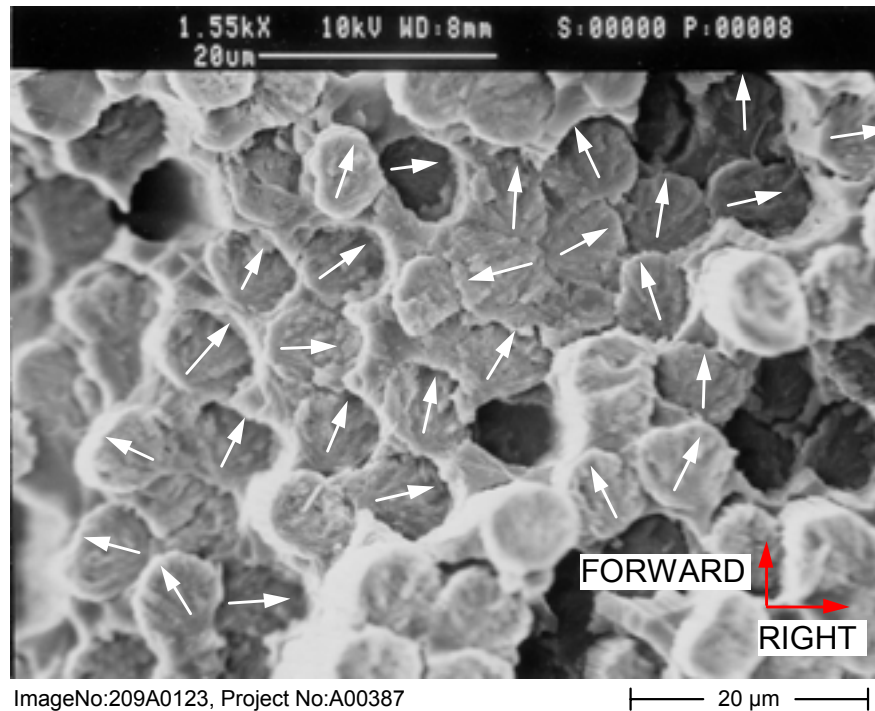
ImageNo: @ImageNo/2@, Project No:A00387

Figure 10. Overall view of the right center lug, lower piece, looking from the left.



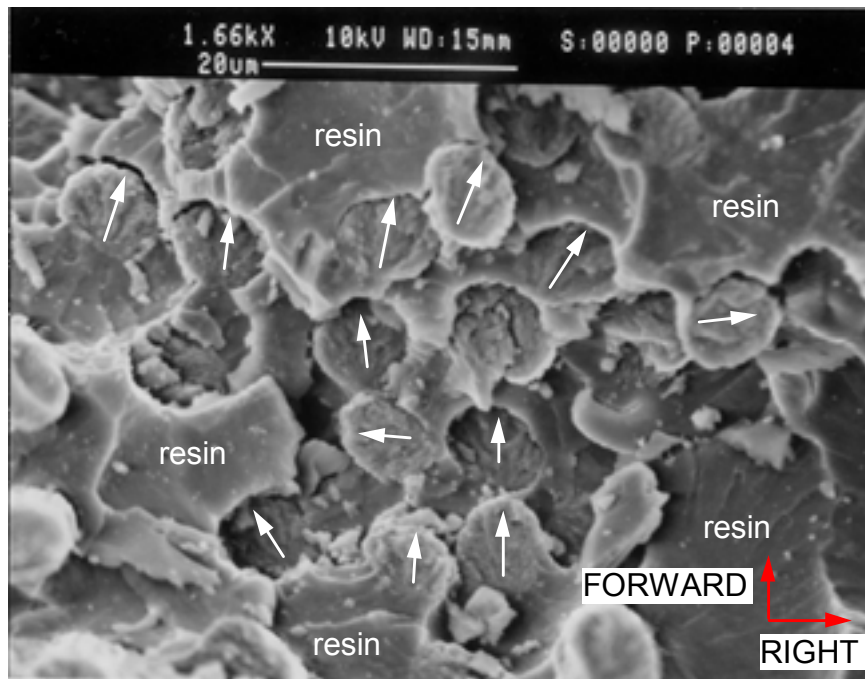
ImageNo:209A0307, Project No:A00387

Figure 11. Right center lug upper fracture surface viewed looking upward parallel to the zero-degree fiber direction.



ImageNo:209A0123, Project No:A00387

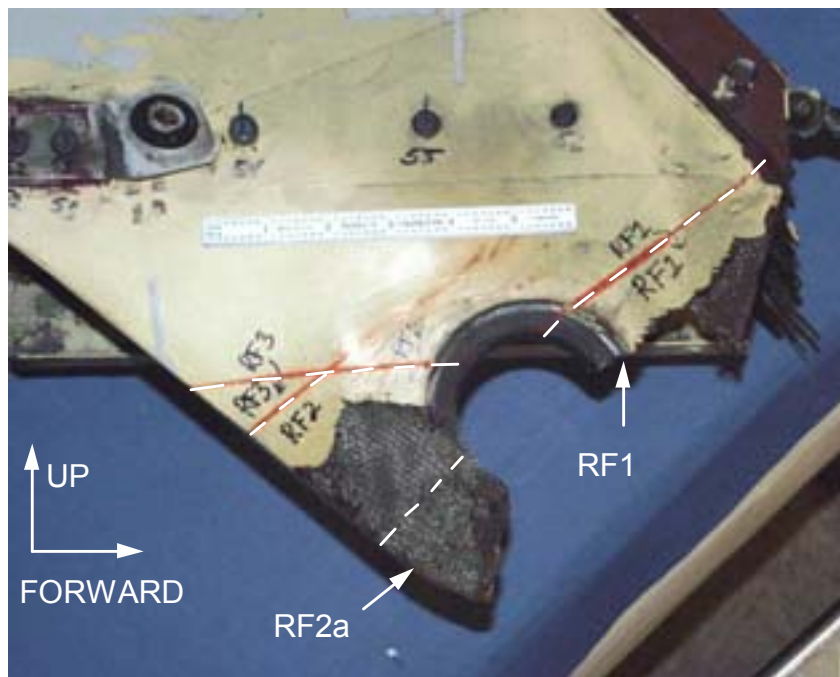
Figure 12. Typical appearance of the fractured zero-degree fibers on specimen RC2 near the exterior surface. Arrows on fractured fibers indicate direction of fracture propagation through the fiber.



ImageNo:209A0118, Project No:A00387

20 μm

Figure 13. Typical appearance of the fractured zero-degree fibers on sample RC1 near the exterior surface. Arrows on fractured fibers indicate direction of fracture propagation through the fiber.



ImageNo: 209A0417, Project No:A00387

Figure 14. Overall view of the right forward lug upper fracture area. Dashed lines indicate locations where cuts were made.

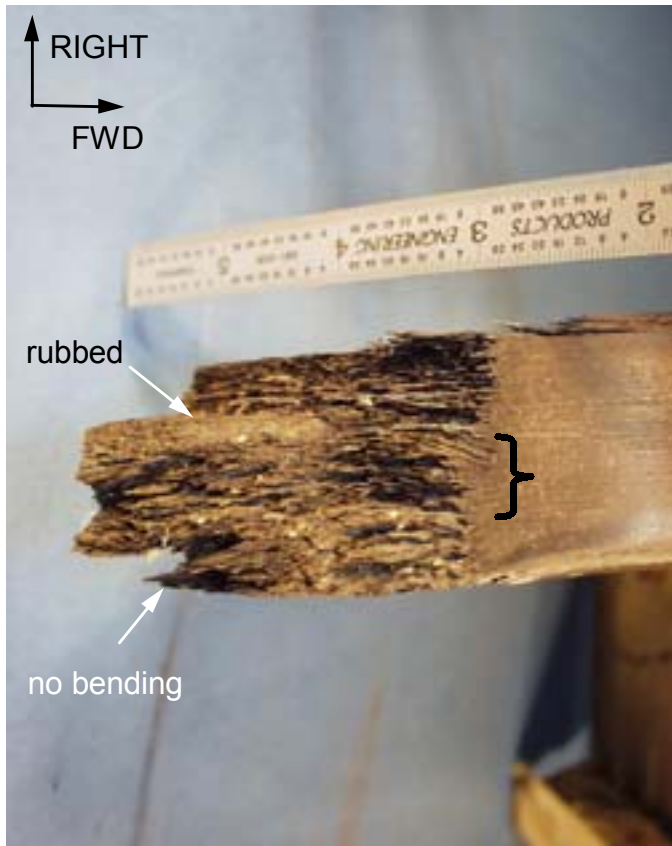
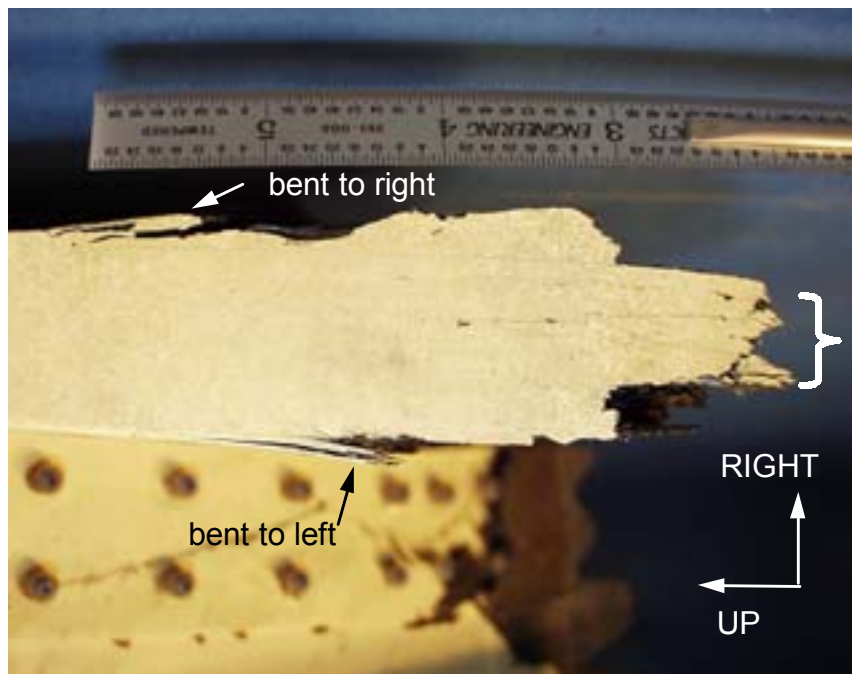


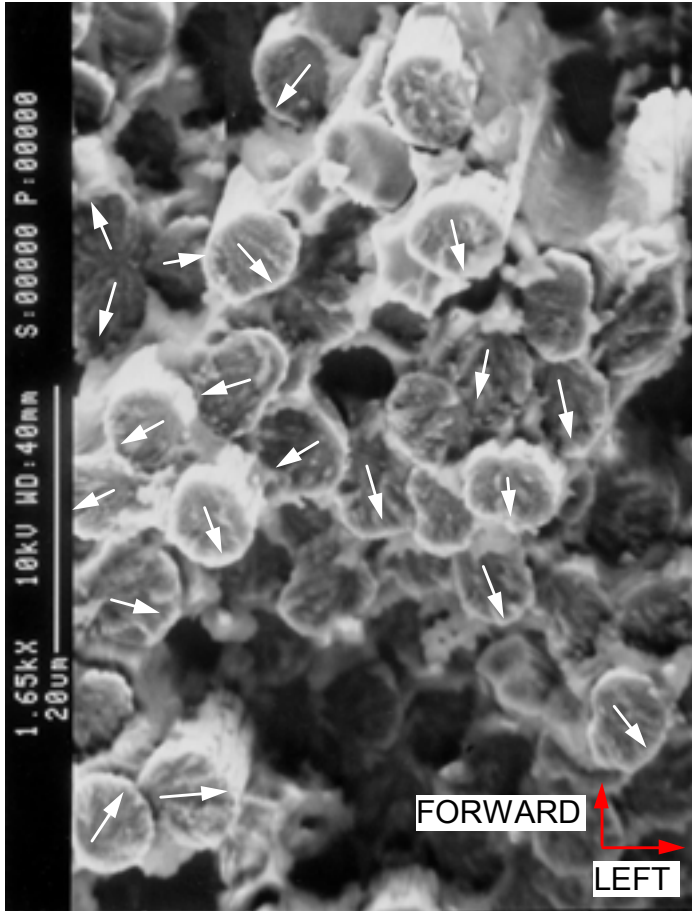
Figure 15. Direct view of the right forward lug, aft leg looking upward and aft. The bracket indicates fiber ends bent to the right.

ImageNo:209A0419, Project No:A00387

Figure 16. The aft surface of the right forward lug above the fracture through the aft leg, showing delaminations. View is looking upward and forward. The bracket indicates fiber ends bent to the left.



ImageNo: 209A0418, Project No:A00387

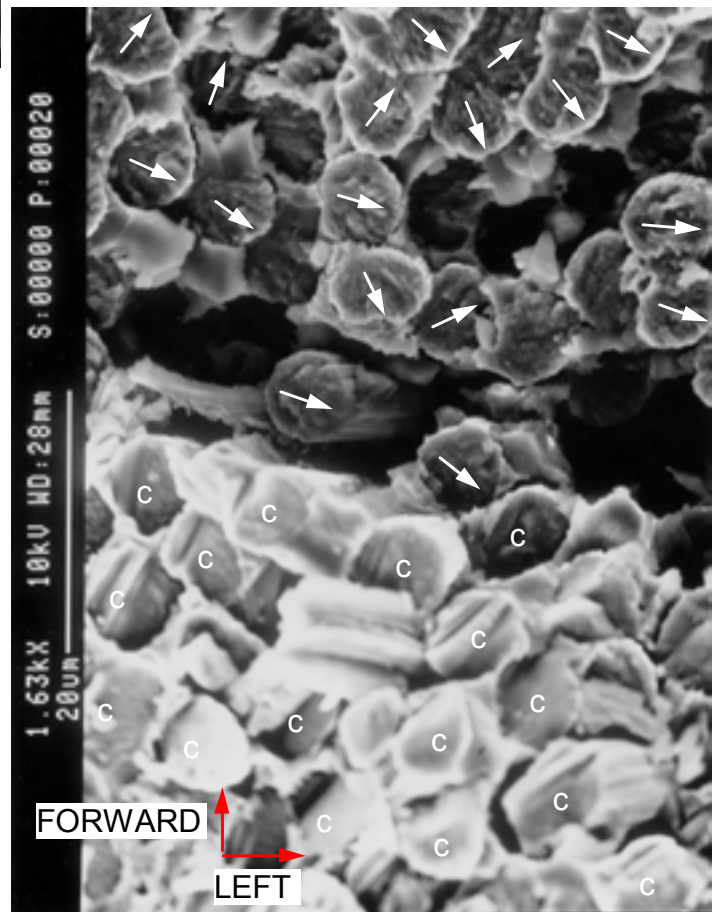


ImageNo: 209A0439, Project No:A00387

10 µm

Figure 21. Typical appearance of the fractured zero-degree fibers on sample RF2a near the exterior surface. Arrows on fractured fibers indicate direction of fracture propagation through the fiber.

Figure 22. Typical appearance of the fractured zero-degree fibers on sample RF2a near the forward and center portions of the fracture. Arrows on fractured fibers indicate direction of fracture propagation through the fiber.



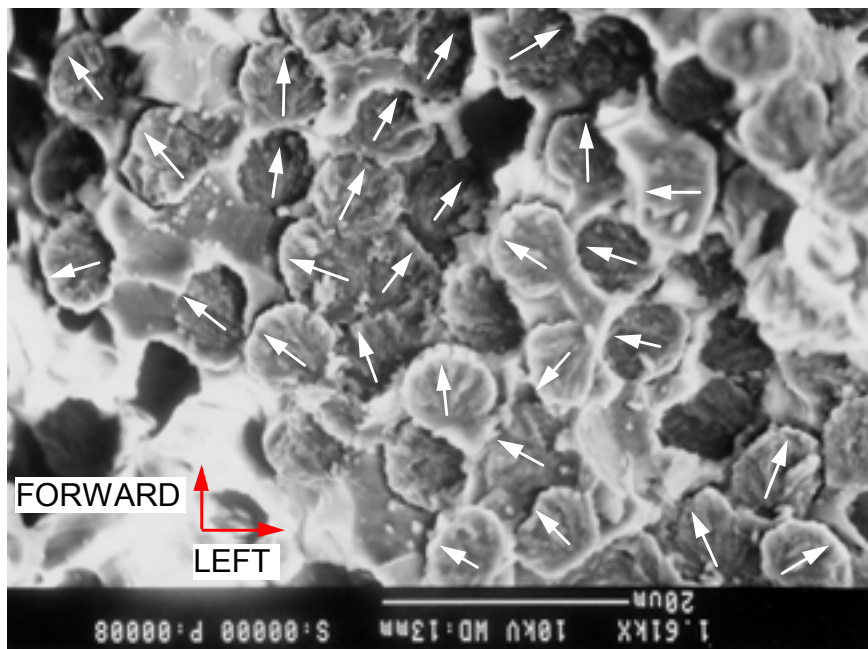
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10 µm



ImageNo:209A0416, Project No:A00387

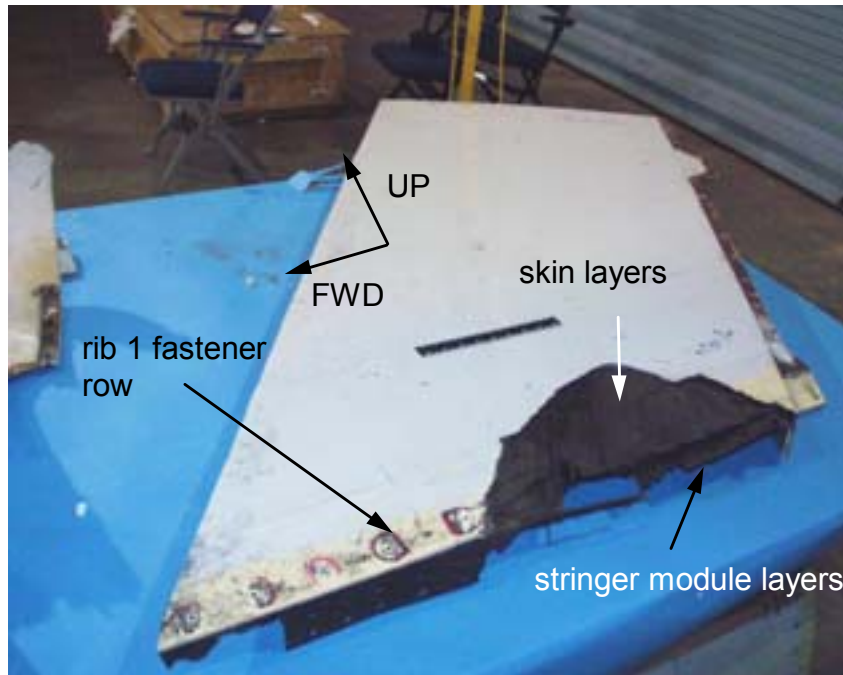
Figure 23. Fracture surface on the forward leg of the right forward lug, View is looking upward parallel to the zero-degree fiber direction.



ImageNo:209A0436, Project No:A00387

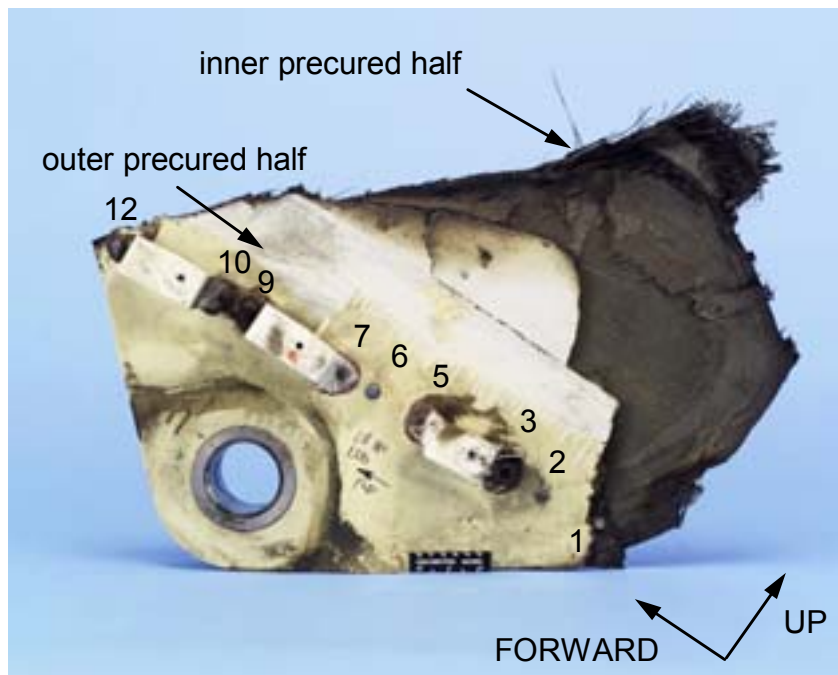
20 μm

Figure 24. Typical appearance of the fractured zero-degree fibers on sample RF1 near the outer and aft portions of the fracture. Arrows on fractured fibers indicate direction of fracture propagation through the fiber.



ImageNo:209A0398, Project No:A00387

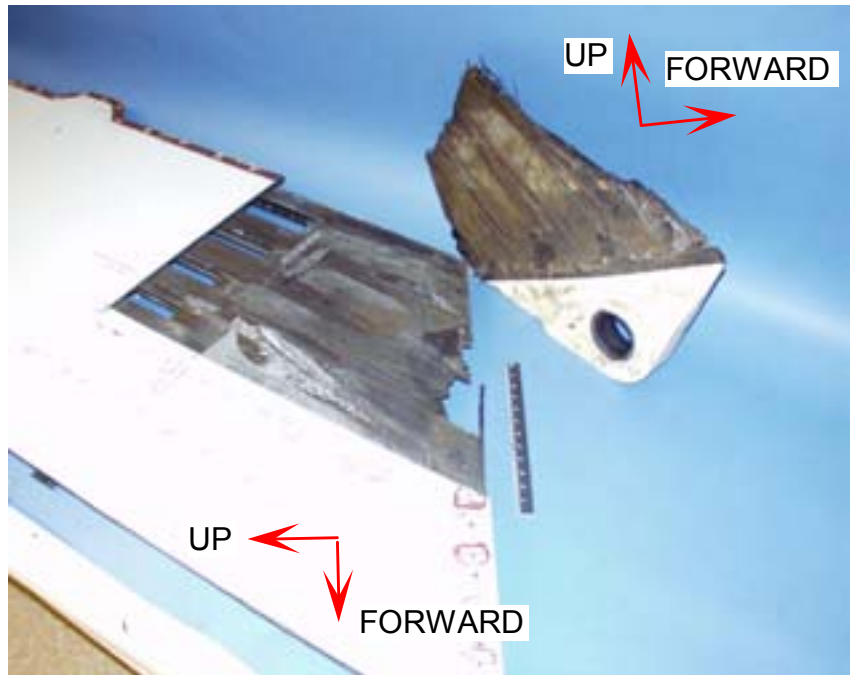
Figure 25. Overall view of the upper skin panel piece containing the upper portion of the fracture at the left aft lug, viewed looking up and to the right.



ImageNo: 209A0395, Project No:A00387

Figure 26. Overall view of the lower piece of the left aft lug, viewed looking to the right.

Figure 27. Mating fracture surfaces between the inner precured lug layers and the interior stringer structure of the left aft panel after cutting the skin panel section.



ImageNo: 209A0283, Project No:A00387



Figure 28. Inner surface of the vertical stabilizer left side skin section at the left aft lug after cutting from the upper skin panel piece. The lower portion of this interlaminar surface mates to the outer surface of the inner precured lug half.

ImageNo:210A0003, Project No:A00415

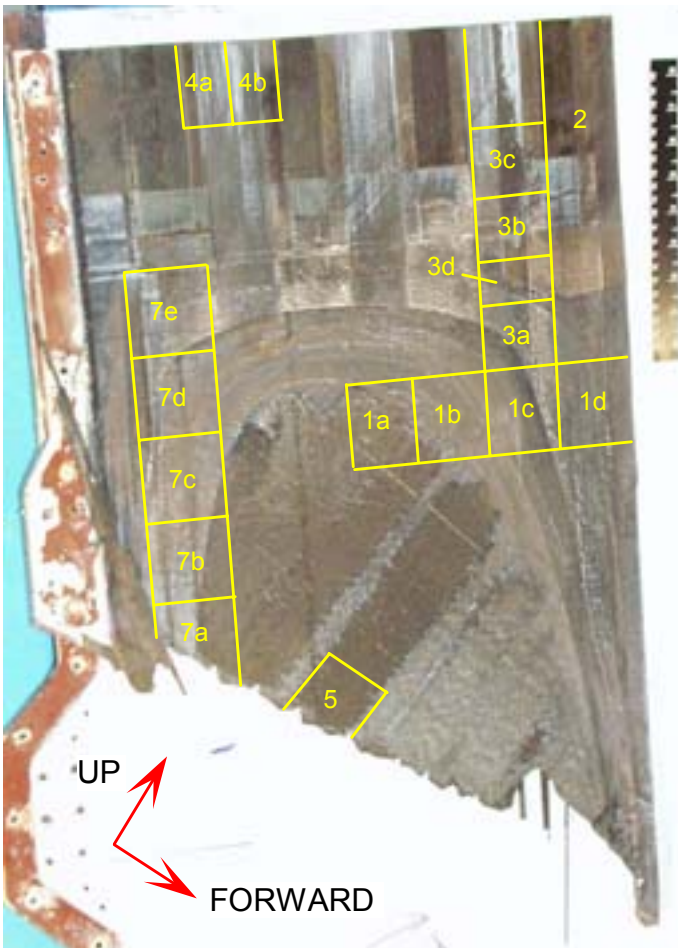
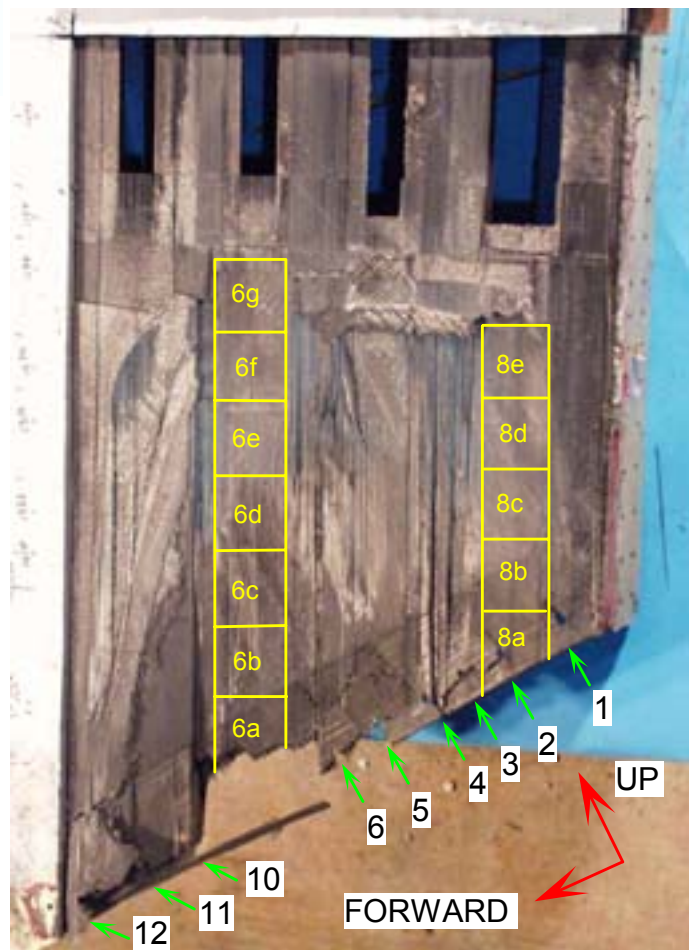


Figure 29. Specimens cut from the left aft skin section for examination using SEM.

ImageNo:210A0003, Project No:A00415

Figure 30. Specimens cut from the lower end of the left aft upper skin panel piece for examination using SEM. Rib 1 fastener holes are numbered at the bottom of the part.



ImageNo: 210A0004, Project No:A00415

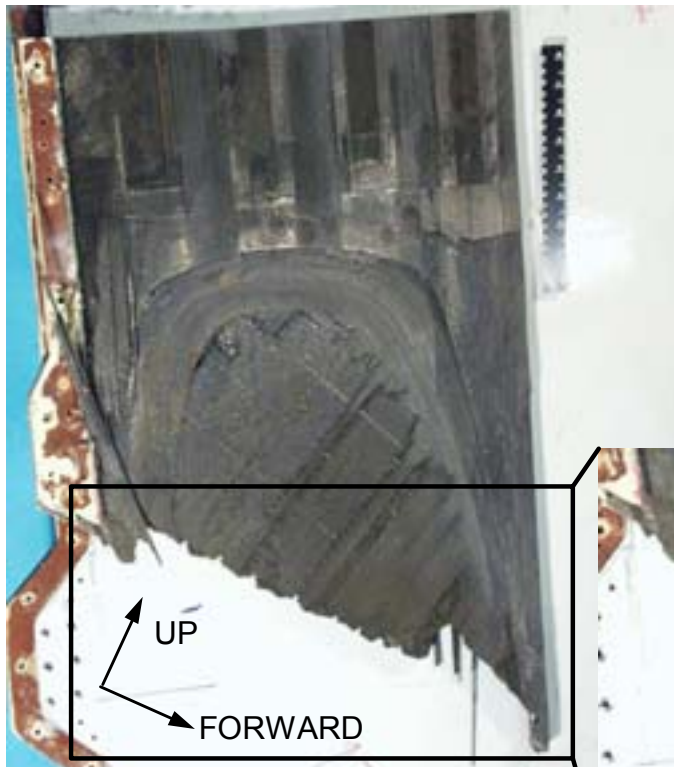
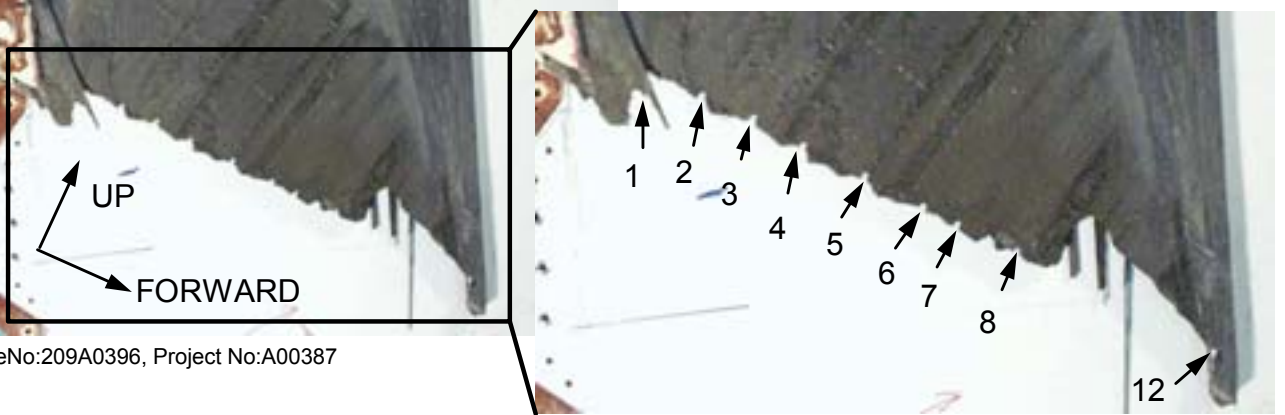


Figure 31. The interior surface of the vertical stabilizer skin section at the left aft lug fracture area after cutting from the upper skin panel piece. Inset photograph shows the numbered rib 1 fastener holes.

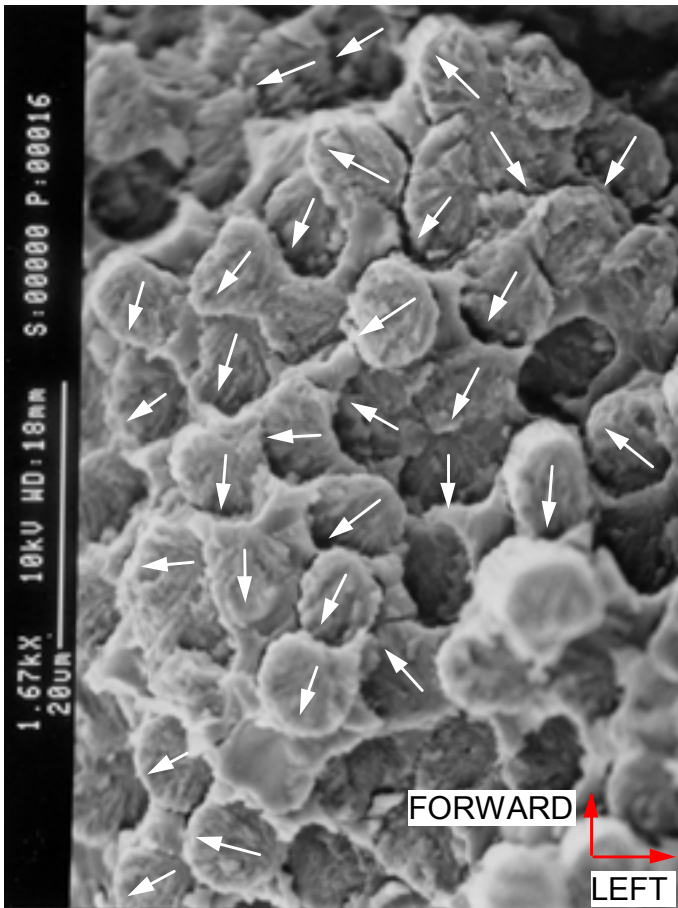
ImageNo:209A0396, Project No:A00387



ImageNo:209A0403, Project No:A00387

10 mm

Figure 32. Vertical stabilizer skin fracture at a rib 1 fastener hole in the vicinity of the left aft lug, viewed looking upward.

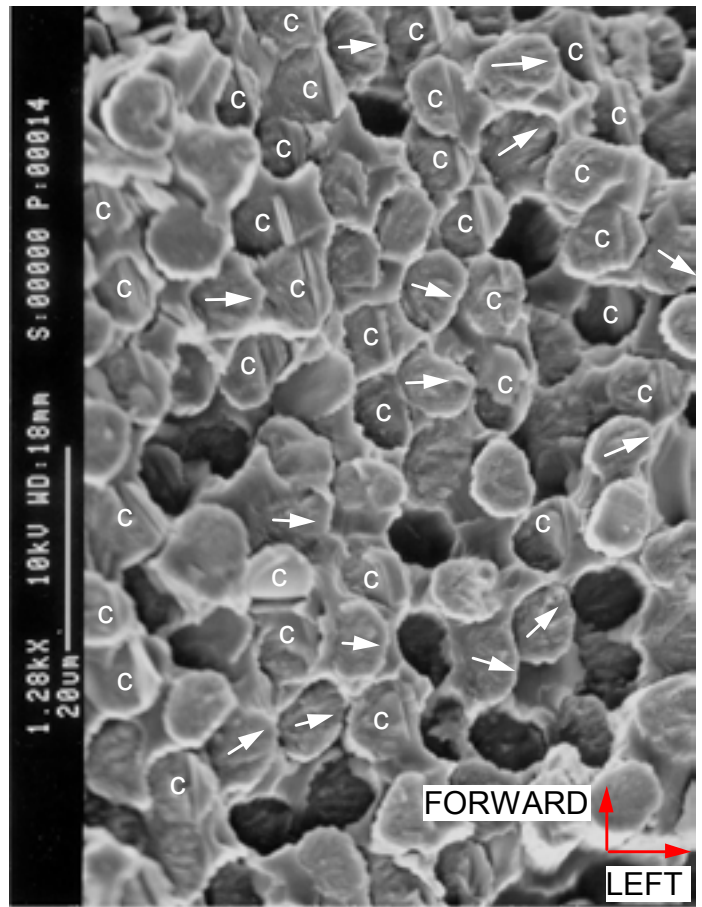


ImageNo: 209A0112, Project No:A00387

10 μ m

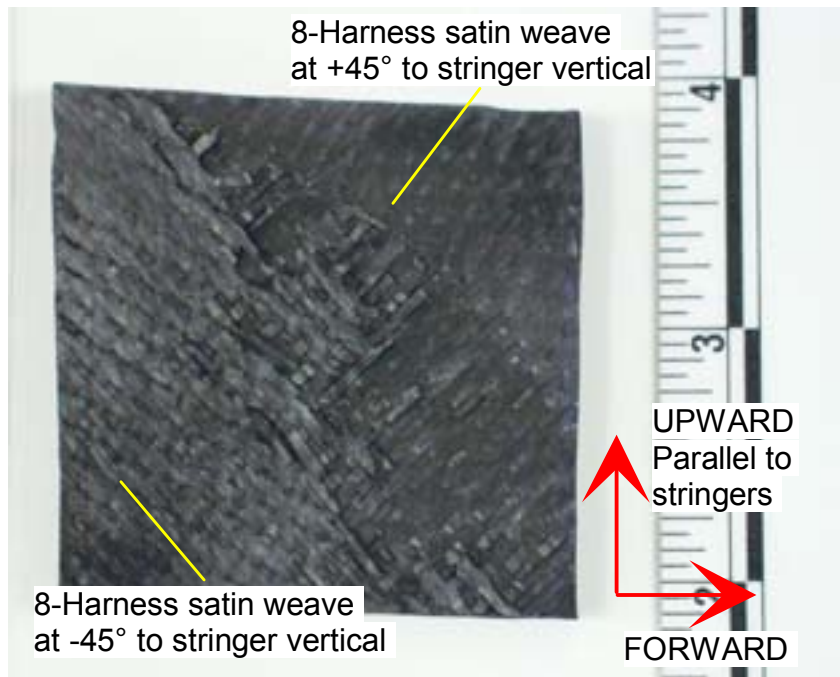
Figure 33. SEM photograph with arrows indicating the direction of tensile crack propagation on the ends of zero-degree fibers from the inside edge of specimen LA5a.

Figure 34. SEM photograph from the center of specimen LA5a. Arrows indicate the direction of tensile crack propagation and labels "c" indicate compressive failure on the ends of zero-degree fibers.



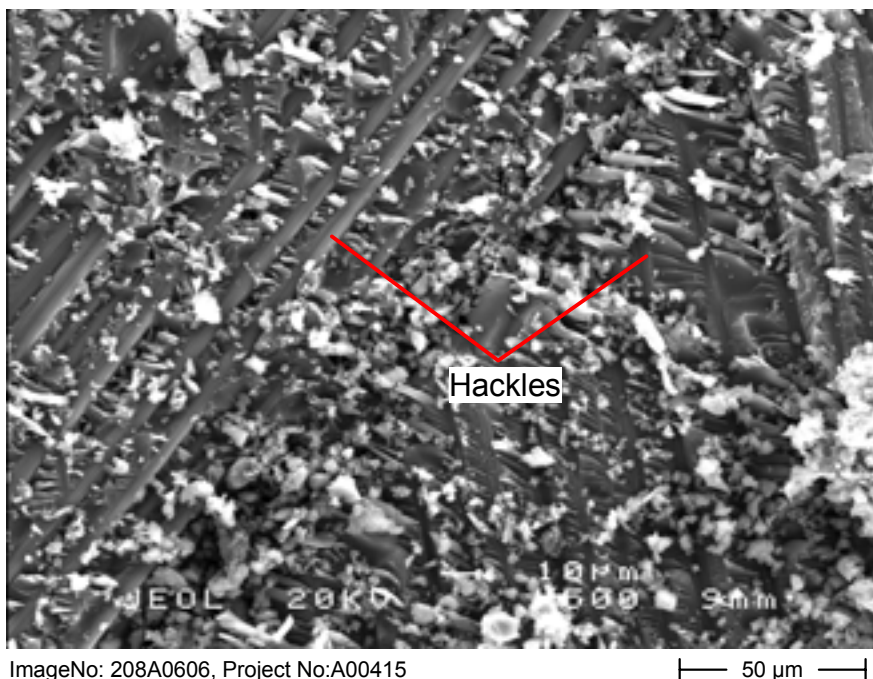
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20 μ m



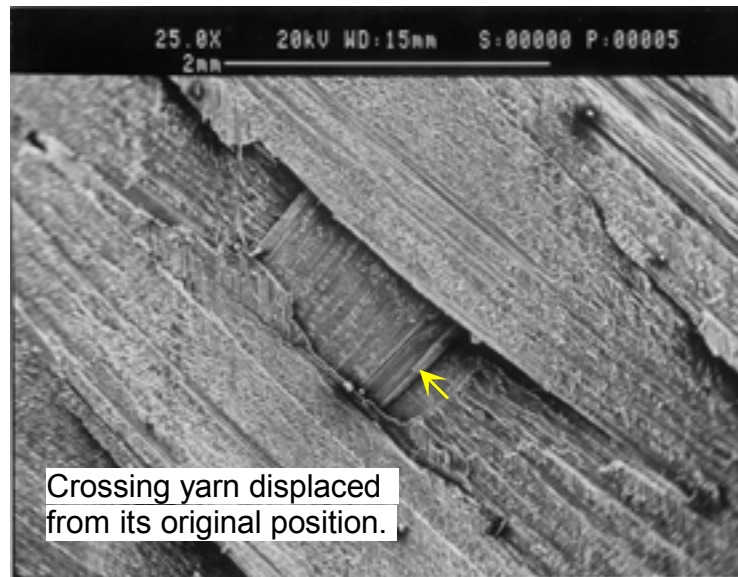
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Figure 35. Fracture surface of specimen LA1a.



ImageNo: 208A0606, Project No:A00415

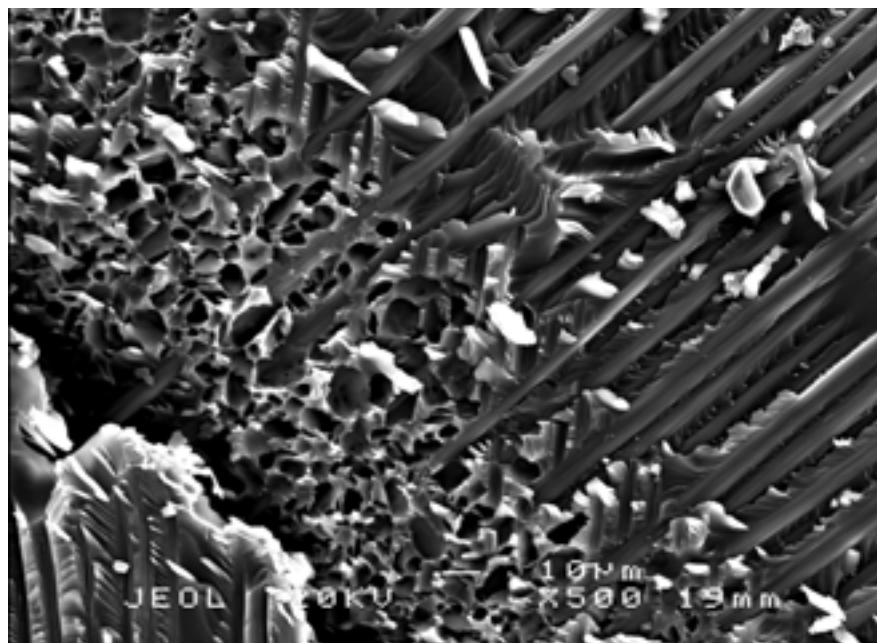
Figure 36. Example SEM photograph from the top forward area of specimen LA1a. Hackles are indicated between +45-degree fibers (left) and zero-degree imprints (right), pointing up and forward. Orientation as in figure 35.



ImageNo:208A0500, Project No:A00415

— 1 mm —

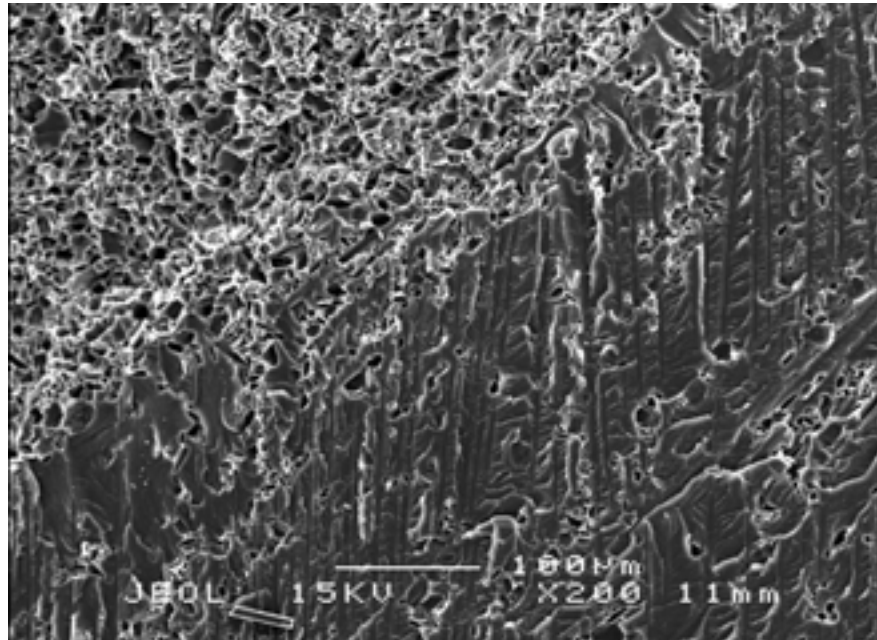
Figure 37. Specimen LA5 inner surface. An unlabeled arrow indicates a crossing yarn that was displaced from its original position. Orientation as in figure 35.



ImageNo: 209A0857, Project No:A00415

— 50 µm —

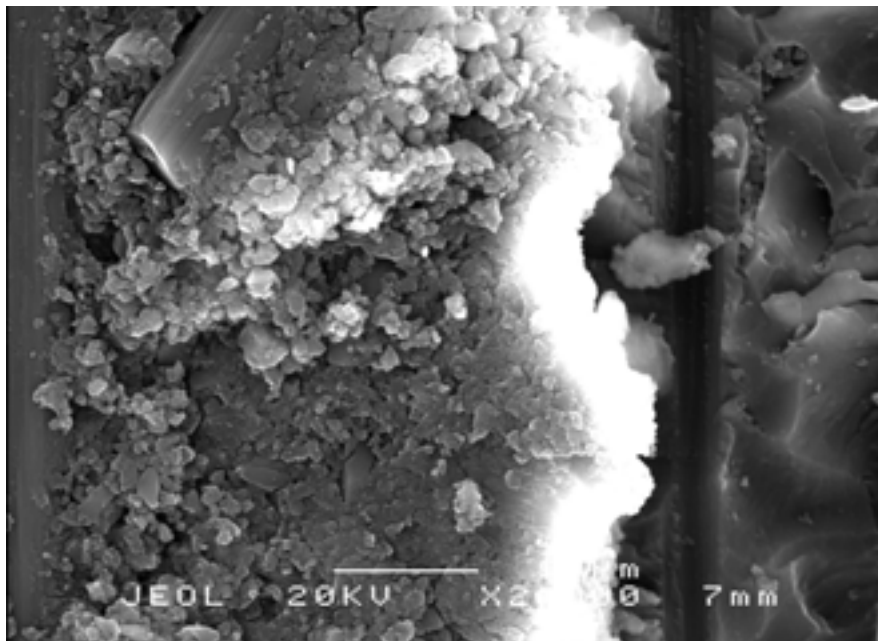
Figure 38. Microscopic matrix porosity in a region where yarns cross on specimen LA1b. The main yarn is at the upper right, with vertical imprints at the lower left. Orientation as in figure 35.



ImageNo:209A0861, Project No:A00415

200 μm

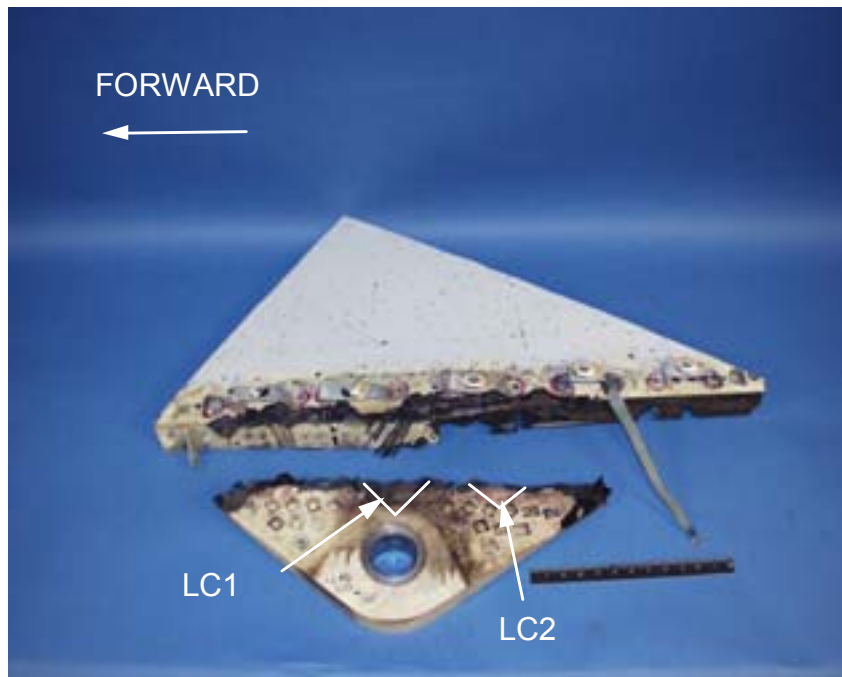
Figure 39. Microscopic matrix porosity on the outboard piece of LA1c. This porosity is shown at the upper left, with ill-defined hackles shown at the lower right. Orientation as in figure 35.



ImageNo: 209A0858, Project No:A00415

20 μm

Figure 40. Microscopic matrix granularity on the outboard piece of LA1c. A fiber fragment is shown at the upper left. Orientation as in figure 35.



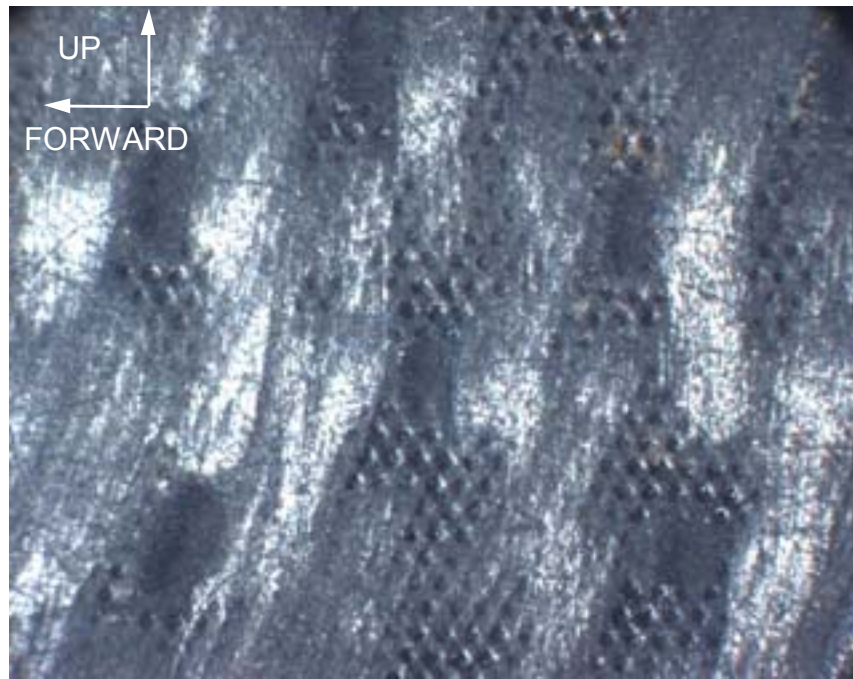
ImageNo:209A0587, Project No:A00387

Figure 41. Overall view of the two portions of the fractured structure at the left center lug viewed looking from the left.



Figure 42. Upper fracture surface at the left center lug, viewed looking upward parallel to zero-degree fibers.

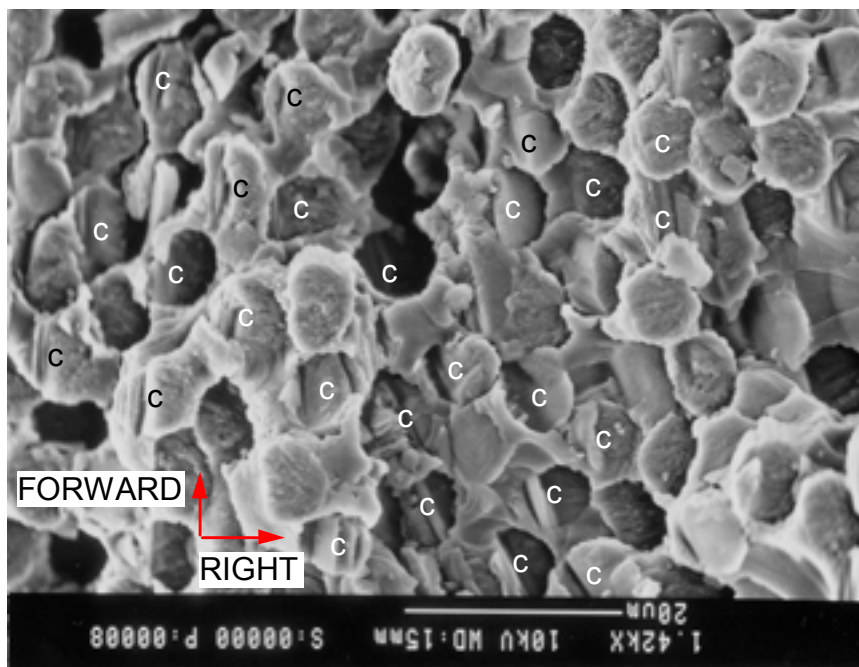
ImageNo: 209A0602, Project No:A00387



ImageNo: 209A0742, Project No:A00387

2 mm

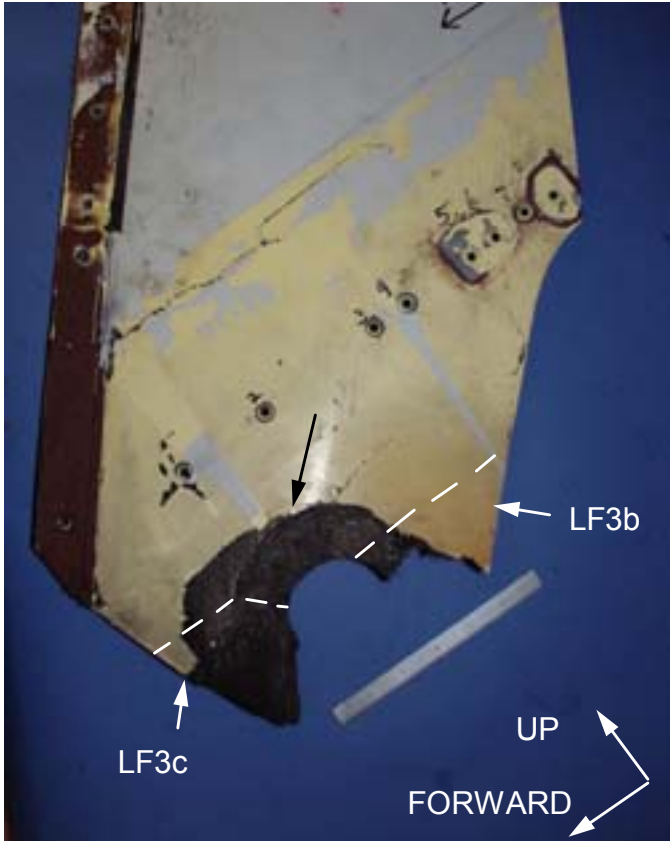
Figure 43. Translamellar fracture surface on the inboard piece of specimen LC2.



ImageNo:209A0586, Project No:A00387

20 μm

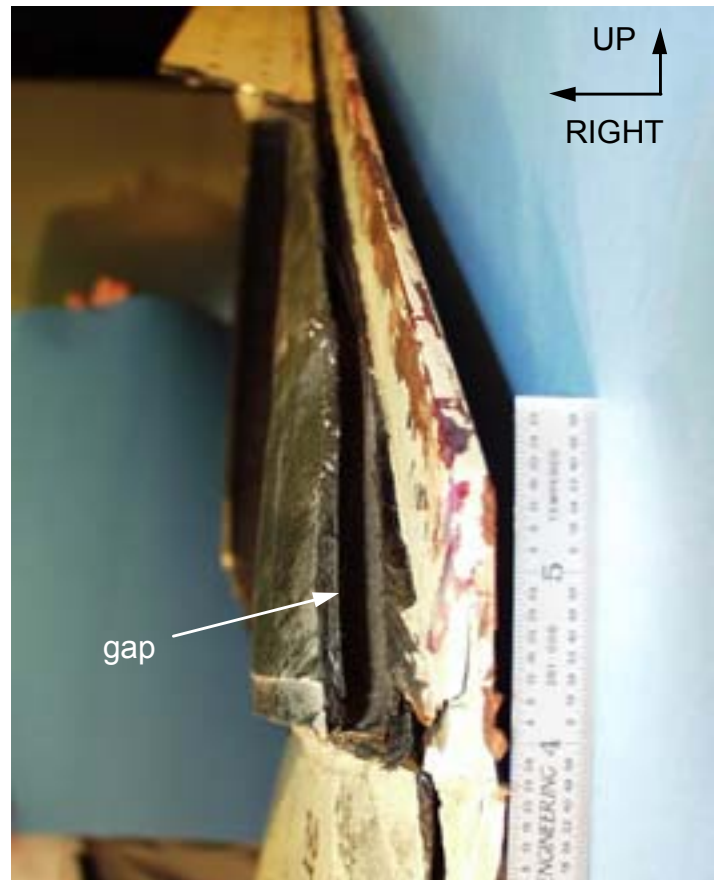
Figure 44. Translamellar fracture surface on the outboard piece from specimen LC2, with the fibers indicated by "c" containing features typical of chop marks.



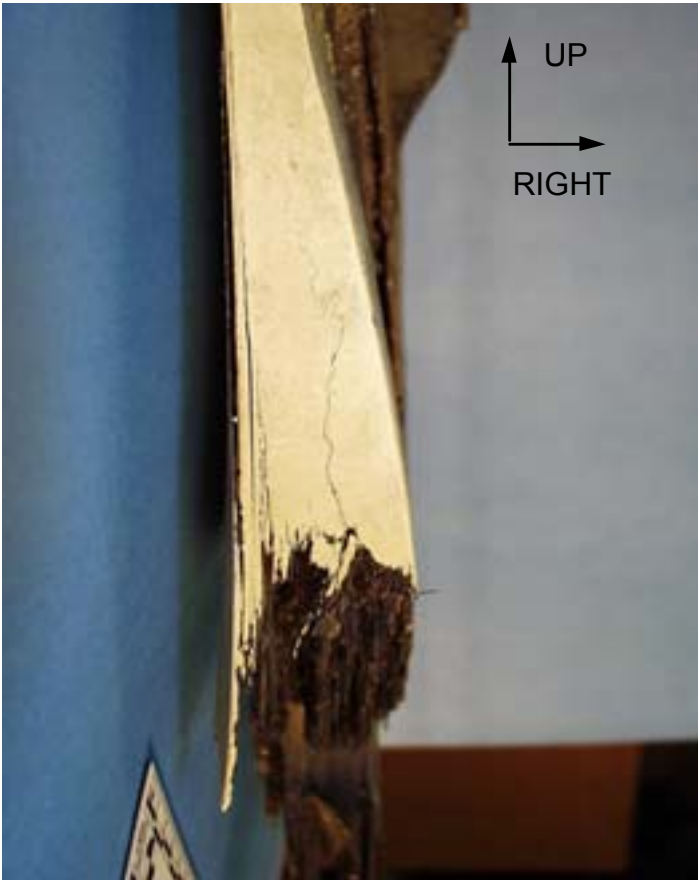
ImageNo:210A0041, Project No:A00387

Figure 45. Overall view of the left forward lug translaminar fracture. An unlabeled arrow indicates the upper end of the bearing indentation.

Figure 46. The visible gap at the forward lower end between the inner precured lug structure and the stringer outer flange structure as viewed looking aft.



ImageNo: 210A0071, Project No:A00387



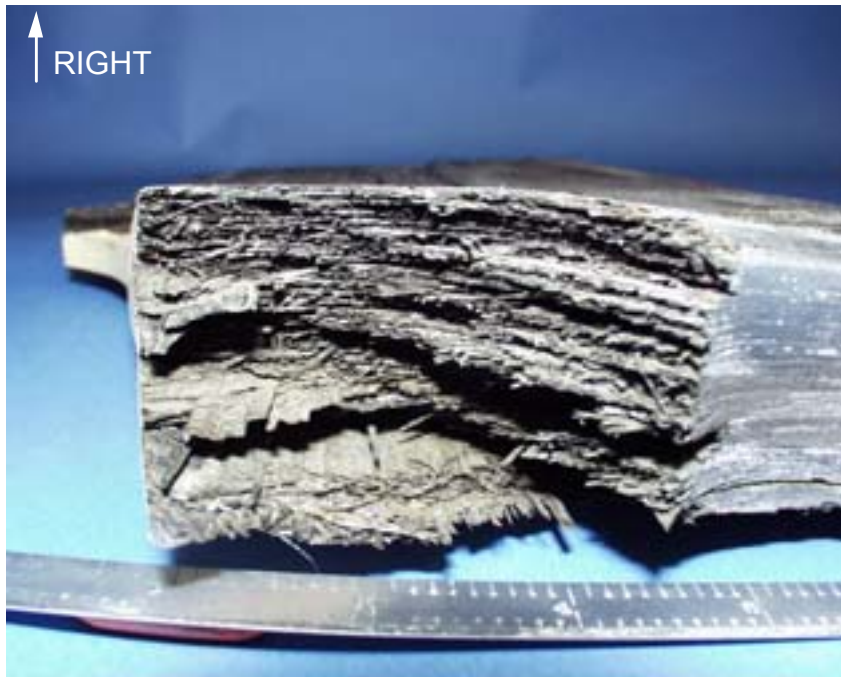
ImageNo:210A0045, Project No:A00387

Figure 48. View of the aft surface of the left forward lug.

Figure 48. View of the forward surface of the left forward lug.

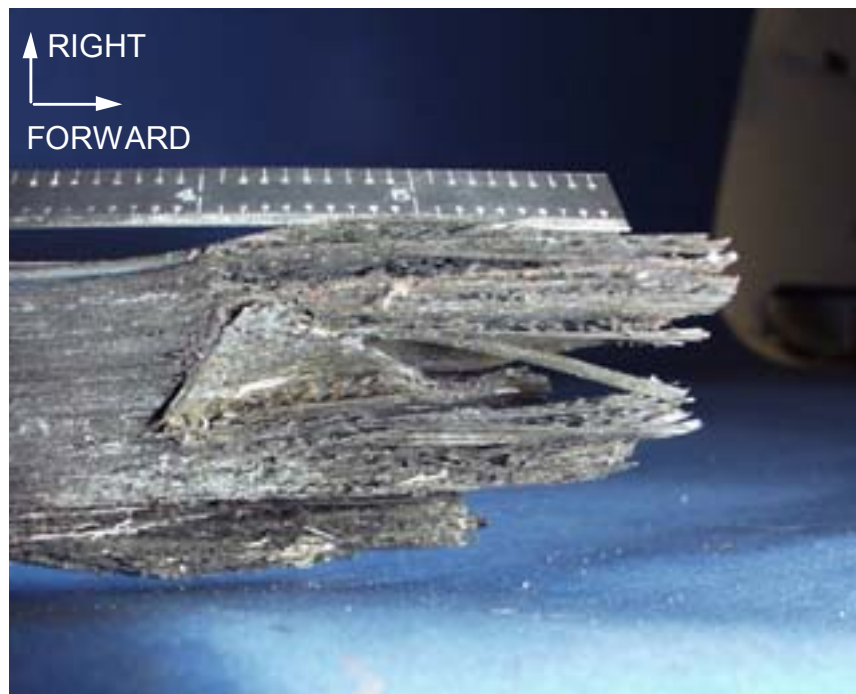


ImageNo: 210A0043, Project No:A00387



ImageNo:210A0044, Project No:A00387

Figure 50. Closer view of the left forward lug upper fracture surface, aft leg, as viewed looking upward parallel to the zero-degree fiber direction.



ImageNo: 210A0042, Project No:A00387

Figure 51. Closer view of the left forward lug upper fracture surface, forward leg, as viewed looking up.

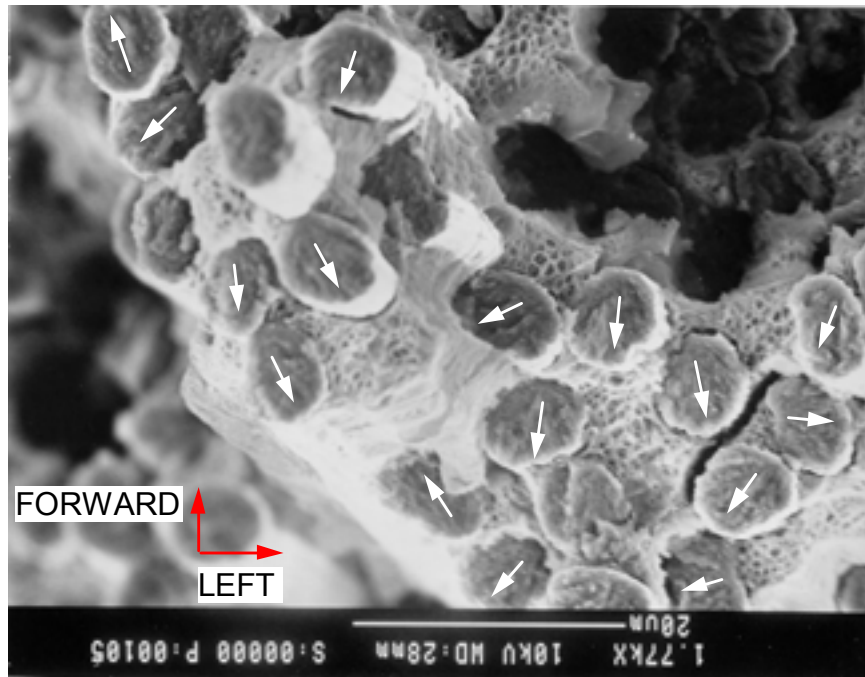
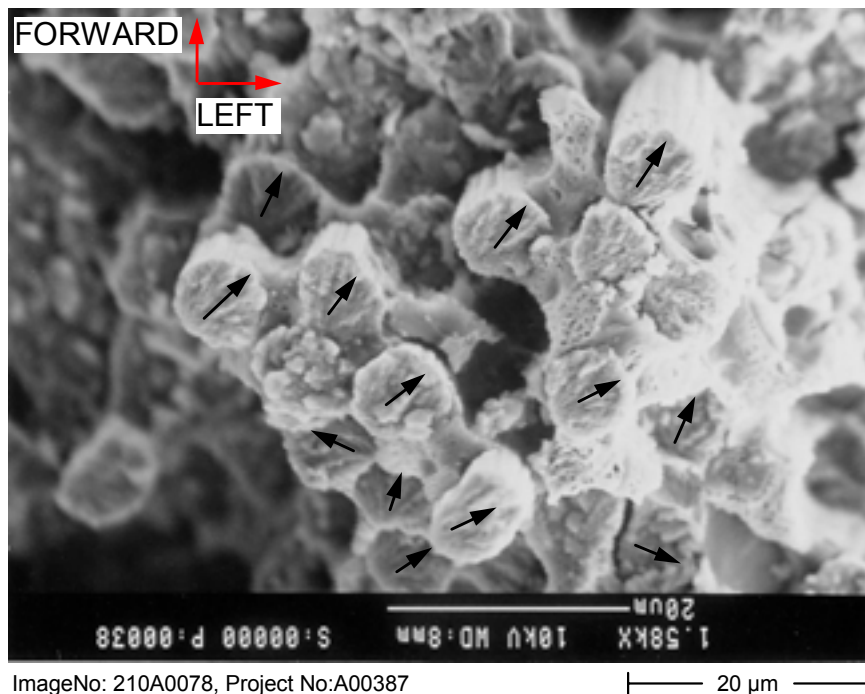


Figure 52. SEM photograph of the ends of zero-degree fibers from specimen LF3b. Arrows indicate fracture propagation direction in fibers with radial marks.



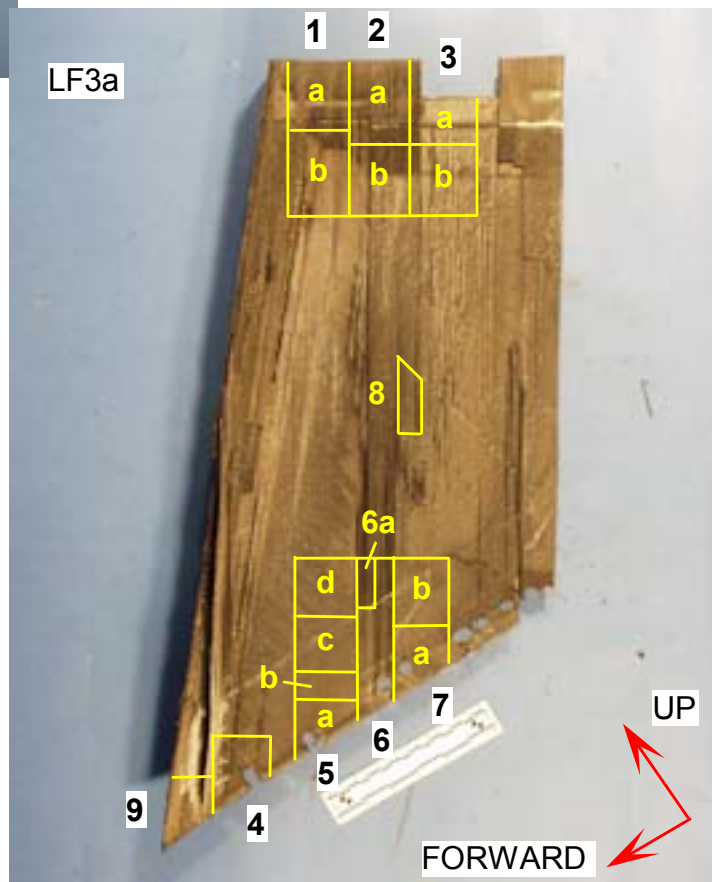
ImageNo: 210A0078, Project No:A00387 | 20 micrometers |
Figure 53. SEM photograph with arrows indicating the direction of tensile crack propagation on the ends of zero-degree fibers from the inboard center piece of specimen LF3c.



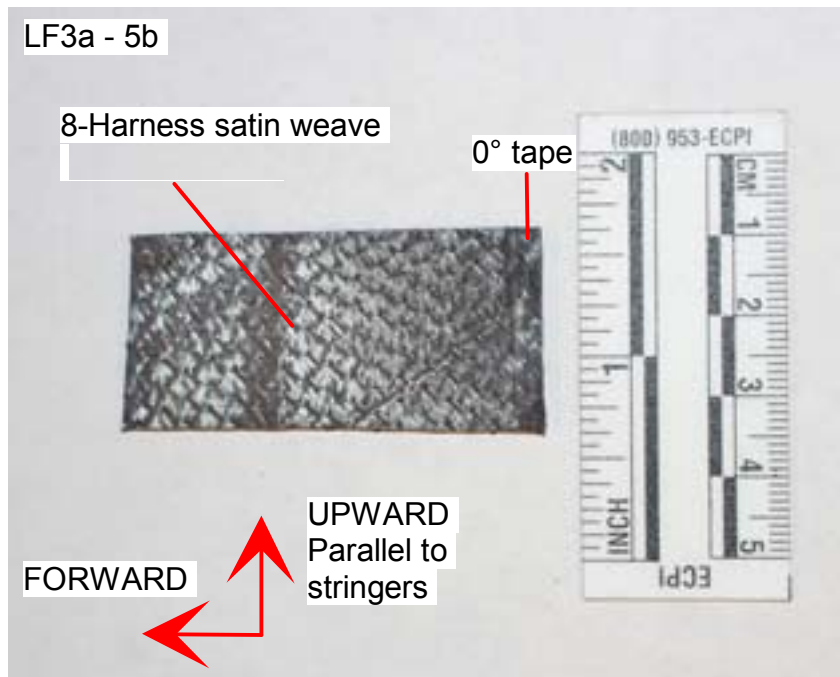
ImageNo:210A0031, Project No:A00424

Figure 54. Mating pieces after cutting to expose the interlaminar fracture above the left front lug. Arrows indicate UP and FORWARD for the main pieces LF2 and LF3.

Figure 55. Specimens cut from section LF3a for examination in the SEM.



ImageNo: 210A0032, Project No:A00424



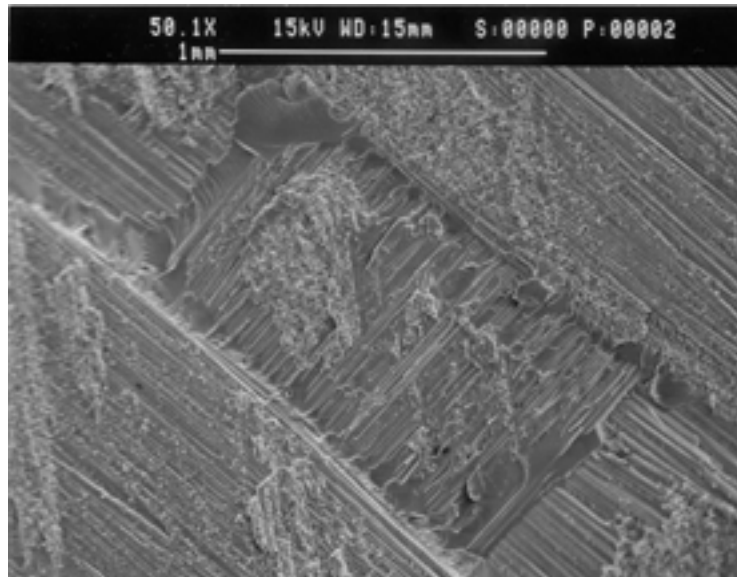
ImageNo:209A0603, Project No:A00424

Figure 56. Fracture surface from specimen LF3a-5b.



ImageNo: 209A0353, Project No:A00424

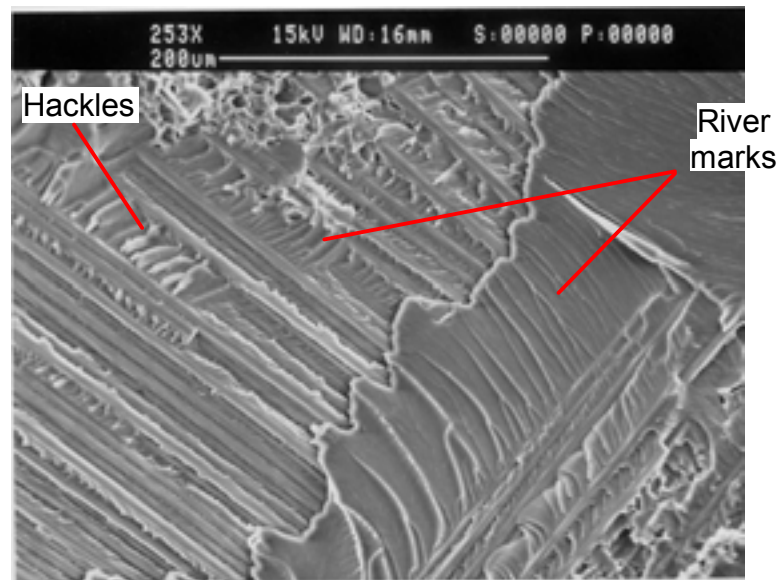
Figure 57. Example SEM photograph from the top forward corner of specimen LF3a-5b. Hackles indicated point up and forward, and river marks also point generally up and forward. Orientation as in figure 56.



ImageNo:209A0604, Project No:A00424

— 500 μ m —

Figure 58. A view of the center of specimen LF3a-5c showing a yarn crossing in the woven fabric. Orientation as in figure 56.



ImageNo: 209A0605, Project No:A00424

— 100 μ m —

Figure 59. Higher magnification view of the upper left corner of the yarn crossing shown in figure 58. Orientation as in figure 56.

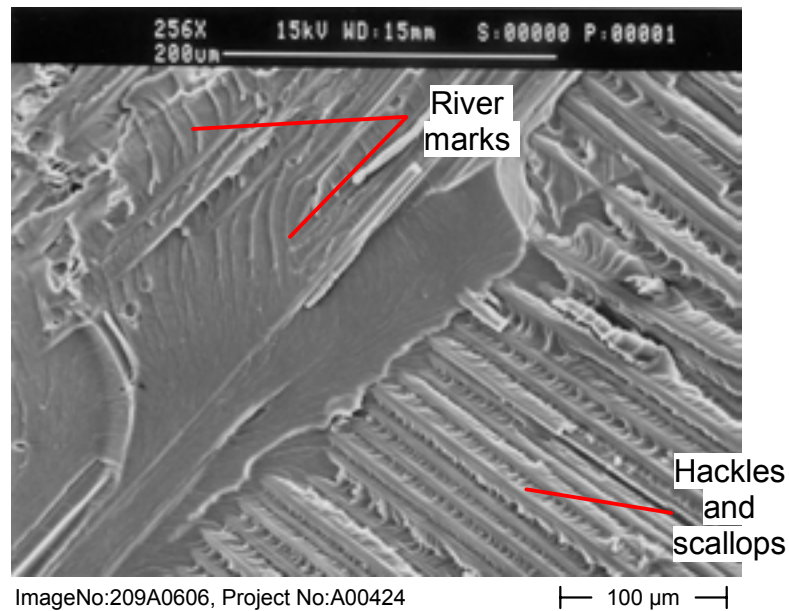


Figure 60. Higher magnification view of the lower right corner of the yarn crossing shown in figure 58. Orientation as in figure 56.

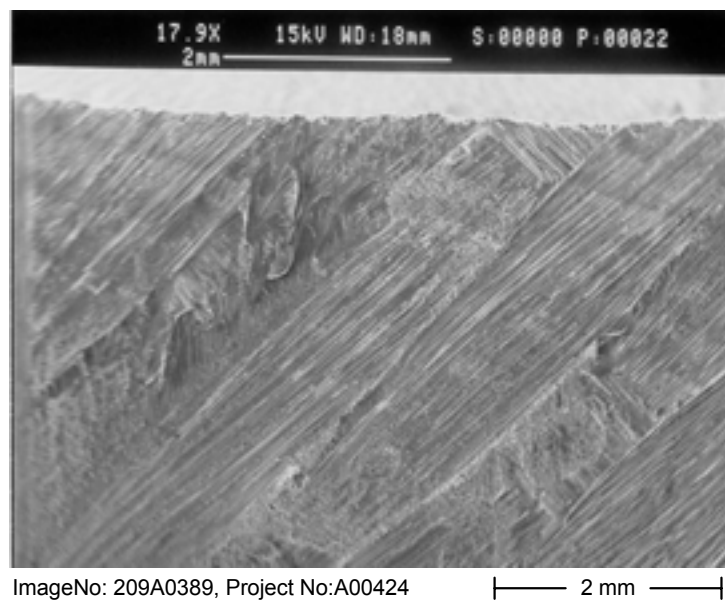


Figure 61. Faint bands at the top forward edge of section LF2b-1 indicate the direction of crack propagation upward and aft. Orientation as in figure 56.