

NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594



February 21, 2017

MATERIALS LABORATORY FACTUAL REPORT

Report No. 17-022

A. ACCIDENT INFORMATION

Place : Fairbanks, Alaska
Date : September 30, 2016
Vehicle : Helio Courier, N6464V
NTSB No. : ANC16LA067
Investigator : Brice Banning, AS-ANC

B. COMPONENTS EXAMINED

Tail wheel frame.

C. DETAILS OF THE EXAMINATION

An overall view of the submitted tail wheel frame is shown in figure 1. The frame component included two arms extending forward of a flanged downtube. As installed on the airplane, the submitted frame was attached to the airframe at the forward ends of the arms and to a shock absorber on the aft side of the downtube. The steering axle for the tail wheel was housed in the downtube.

The left arm was fractured from the downtube and was deflected downward relative to the right arm. The corner brace between the left arm and the downtube was buckled and cracked. The brace tube between the two arms was fractured from the right arm with a fracture through the welded pad at the attachment point, and a flat sheet brace at the lower sides of the arms was bent with a crack along the bend. One of the ears for attaching the shock absorber on the aft side of the downtube was also fractured from the downtube.

A visual inspection of the frame was completed, and features observed on the fractured frame were compared to a photograph of an exemplar frame supplied by the investigator in charge. The fracture through the left arm was near the weld attaching the arm to the downtube. Most of the weld around the circumference of the arm had a uniform weld bead pattern, but additional weld bead material was observed at the upper side of the arm as indicated in figure 2. A weld was also observed along the left side of the arm as indicated in the left image in figure 3. The weld in figure 3 continued below the angle brace, indicating the angle brace was applied after the weld in the side of the arm. A weld at this location was not observed on the right arm. A weld at this location was also absent from the exemplar tail wheel frame shown in the right image in figure 3.

The corner braces for the left and right arms each measured 0.068 inch thick. The lower edge of each corner brace was manufactured with an L shape to form a flange at the lower edge (see figure 3). The width of the lower flange on the right arm corner brace as measured from the outboard face of the brace to the inboard edge of the flange was 0.456 inch. The width of the lower flange on the left arm varied along its length due to the buckling deformation that reduced the bend radius and affected the overall geometry of the part. Width measurements of the lower flange on the left corner brace ranged between 0.400 inch and 0.438 inch relative to the deformed outboard face. Although measurements for the lower flange on the left brace were lower than that of the right brace, some or all of the observed difference may be attributed to deformation associated with buckling.

A close inspection with optical magnification revealed a potential crack indication at the toe of the weld between the intact right arm and the downtube as shown in figure 4. The feature was located at the upper side of the arm and had a linear shape with orange oxide stain consistent with a crack.

The fracture surfaces where the brace tube between the arms had separated from the right arm were examined. The fracture features had matte gray features on slant planes consistent with ductile overstress fracture. Fracture features where the shock absorber attachment ear fractured from the downtube also had features consistent with ductile overstress fracture. No evidence of preexisting cracks were observed on these fractures.

The left arm remained attached to the rest of the frame by portions of the buckled corner brace at the side of the arm and by the bent sheet at the lower side of the arm. A cut was made in the corner brace up to the tip of the crack, and the left arm was pulled from the rest of the frame while fracturing a remaining intact ligament in the lower brace, thereby exposing the fracture in the arm. After an initial examination, the fracture surfaces were cleaned with acetone in an ultrasonic cleaner. Images of the exposed fracture surface were taken after cleaning.

Most of the arm fracture had a matte gray fracture on slant planes consistent with ductile overstress fracture. However, a portion of the fracture surface at the upper inboard side of the arm had a fracture in a plane perpendicular to the surface across most of the fracture. A dashed line in figure 5 indicates the region of fracture mostly perpendicular to the surface. A close inspection revealed small shear lips at the edges of the perpendicular fracture, consistent with overstress fracture, but in a material with lower fracture toughness than other areas where fracture occurred in a slant plane across the thickness of the arm wall.

Two areas, labeled A and B in the detail image in figure 5 had a no shear lips at the surface. Closer views of these areas are shown in figures 6 and 7. The areas were oxidized with smooth curving boundaries, consistent with fatigue. Ratchet marks¹ were

¹ A ratchet mark is a small step in the fracture surface formed when two adjacent fatigue cracks originate on slightly offset planes.

observed associated with both cracks, consistent with multiple fatigue origins at each crack location. Brackets in figures 6 and 7 indicate the length of the fatigue crack at the surface, and dashed lines indicated the fatigue crack depth at the time of fracture. Fatigue crack A was 0.144 inch long and 0.016 inch deep. Fatigue crack B was 0.038 inch long and 0.006 inch deep.

Fracture through the left arm also initiated in areas of overstress fracture where small shear lips were observed at the edge of the fracture. Unlabeled arrows in figure 5 indicate fracture initiation in areas where no fatigue cracks were observed. The fatigue cracks initiated at the toe of the weld, but the overstress fracture initiation occurred in the weld.

The next step in the examination was to expose the crack indication in the right arm. A transverse cut was made through the downtube in a plane near the centerline of the arms from the aft side of the downtube and forward into the right arm. Next a cut was made upward through the right arm just forward of the welded attachment, removing the lower portion of the arm. The downtube flange was then clamped in a vice, and the right arm was pulled downward, producing a lab fracture. After an initial examination of the fracture, the fracture surface was cleaned using acetone.

An image of the upper end of the lab fracture in the right arm after cleaning is shown in figure 8. A portion of the fracture surface at the upper side of the arm where the crack indication was observed was on a plane perpendicular to the surface and was oxidized with curving crack arrest lines, features consistent with fatigue. A bracket in figure 8 indicates the length of the crack, which measured 0.576 inch long. A dashed line indicates the extent of the fatigue crack propagation, which had a maximum depth of 0.066 inch. The remainder of the fracture surface had matte gray features on slant planes across the thickness of the arm wall.

An area of the right arm exposed by the fracture of the brace tube attachment was tested using a Thermo Scientific Niton XL3t-980 x-ray fluorescence (XRF) alloy analyzer. The alloy analyzer identified the material as most likely AISI 4130 steel.

Next, a metallographic examination of the welds attaching the right arm and left arm to the downtube and the weld at the side of the left arm was completed. To facilitate the metallographic examination, the downtube was further cut into pieces as shown in figure 9, where the faces that were prepared from each weld are indicated. Each cross-section was mounted, polished, and etched with 4% nital². After the microstructural examination was complete, the samples were repolished to remove the etch and then tested using a Vicker's microhardness tester.

An overall view of the cross-section through the weld attaching the right arm to the downtube is shown in figure 10. The fatigue crack surface is indicated and was located at the toe of the weld. A secondary crack was also noted in the cross-section as indicated. The arm and downtube had a structure consistent with tempered martensite (see

² A solution consisting of 4 percent of concentrated nitric acid in methanol.

figure 11). The surfaces of the weld both at the interior and exterior sides of the weld also had a microstructure appearing similar to that of the arm wall and downtube, likely a mix of bainite and some martensite. The core area of the weld showed a mix of ferrite and bainite as shown in figure 12. The microstructure showed a transition from the surface microstructure to that of the core as shown in figure 13.

A Vicker's hardness map for the right arm weld is shown in figure 18. The arm and the downtube had hardnesses in the range of 45 HRC to 49 HRC (442 HV 0.5 to 499 HV 0.5). The surfaces of the weld had a hardness of up to 50 HRC (518 HV 0.5). In the core, the hardness was generally lower with a minimum hardness of 21 HRC (243 HV 0.5).

An overall view of the cross-section through the weld attaching the left arm to the downtube is shown in figure 15. The weld cross-section showed two weld beads. The first weld had a geometry and microstructure that appeared similar to that observed on the right arm weld, and a representative image of the core microstructure is shown in figure 16. The weld cross-section also showed a second weld bead located at the forward end of the first weld overlayed onto the first weld. The second weld bead had porosity as indicated in figure 15. The fracture at the location of this cross-section occurred through the second weld bead and was within the region with relatively small shear lips. The surface and toe of the second weld bead had microstructures similar to that of the arm and downtube consistent with bainite and some martensite, and the core of the weld had a mix of ferrite and bainite as shown in figure 17.

A Vicker's hardness map for the left arm weld is shown in figure 18. The arm and the downtube showed a relatively uniform hardness of 46 HRC to 48 HRC (453 HV 0.5 to 485 HV 0.5). The surfaces of the first and second weld showed a maximum hardness of 49 HRC (493 HV 0.5). In the core of the first weld, the hardness was generally lower with a minimum hardness of 23 HRC (252 HV 0.5). The core of the second weld had a minimum hardness of 29 HRC (295 HV 0.5).

The weld in the left side of the left arm had a uniform appearance throughout the weld bead, and a typical image is shown in figure 19. The root of the weld intersected a crack emanating from the interior surface of the arm as shown in figure 20. A dashed line in figure 20 indicates the boundary of the weld root.

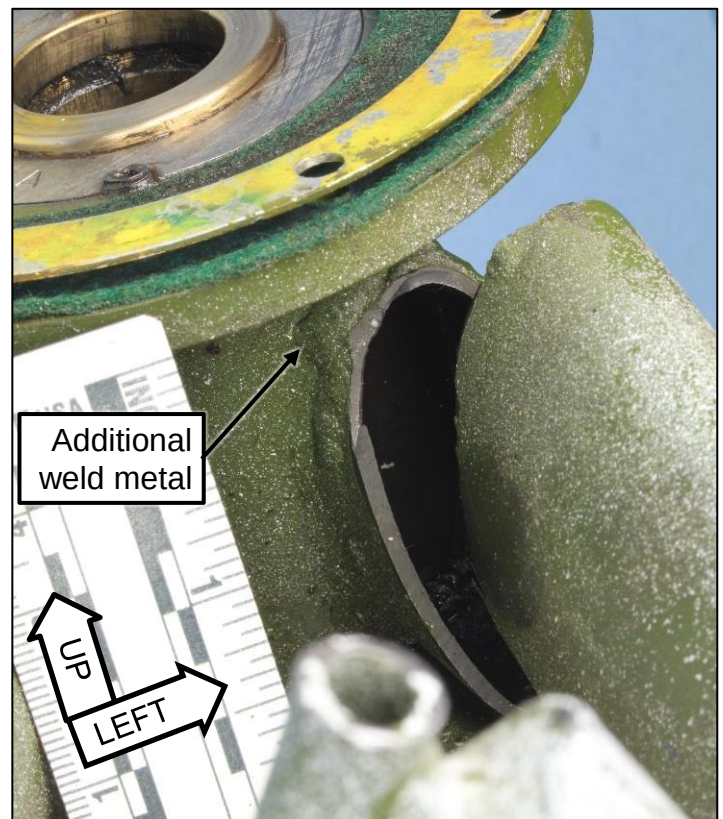
A Vicker's hardness map for the left arm side weld is shown in figure 21. The minimum value at the core of the weld was higher than that observed in the right and left arm attachment welds, and the scale shown at the bottom of figure 21 reflects that difference. Most of the arm and weld area had a hardness of approximately 48 HRC (480 HV 0.5). The maximum hardness in the heat-affected zone near the root of the weld was 50 HRC (513 HV 0.5). The minimum hardness was near the center of the weld bead and had a minimum value of 45 HRC (446 HV 0.5).

Matthew R. Fox
Senior Materials Engineer



Figure 1. Overall view of the fractured tail wheel frame.

Figure 2. Close view of the fracture in the left arm adjacent to the welded joint with the downtube.



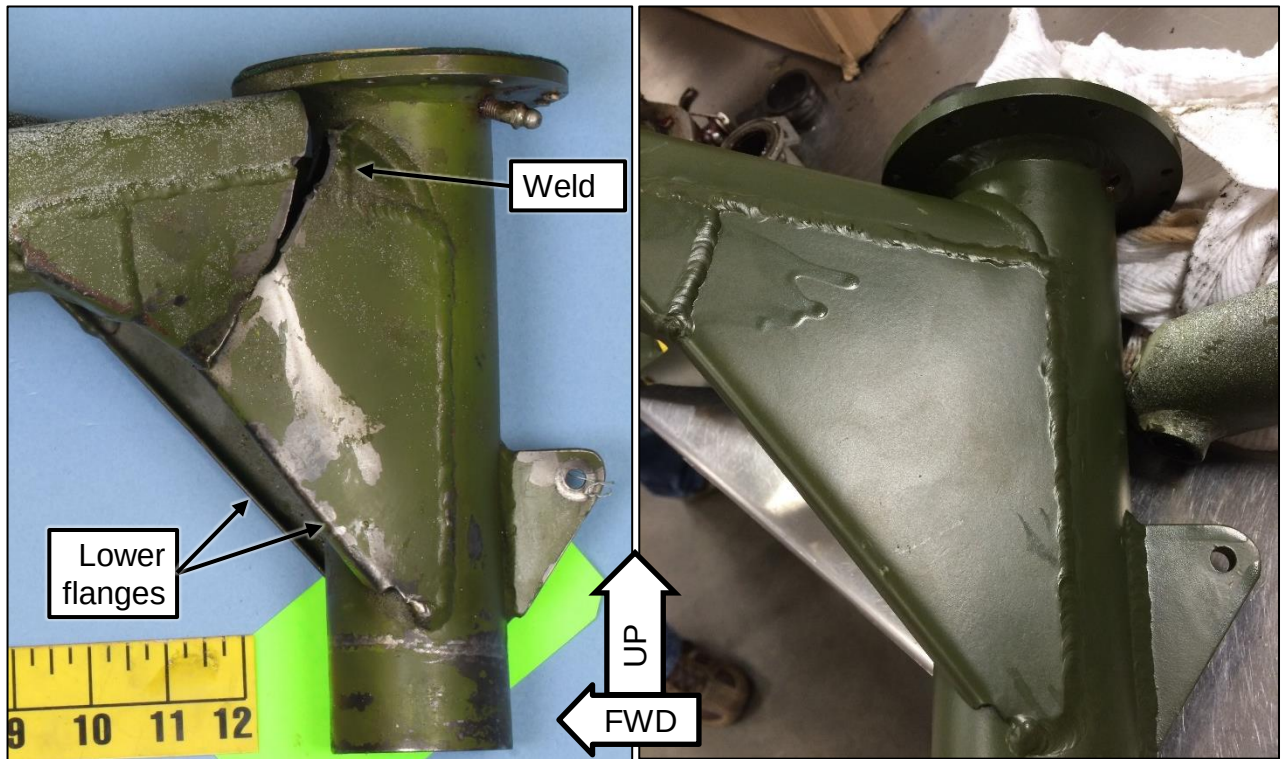


Figure 4. Views of the incident tail wheel frame (left image) and an exemplar frame (right image). The weld indicated on the incident frame was present only on the left side of the left arm of the incident frame.

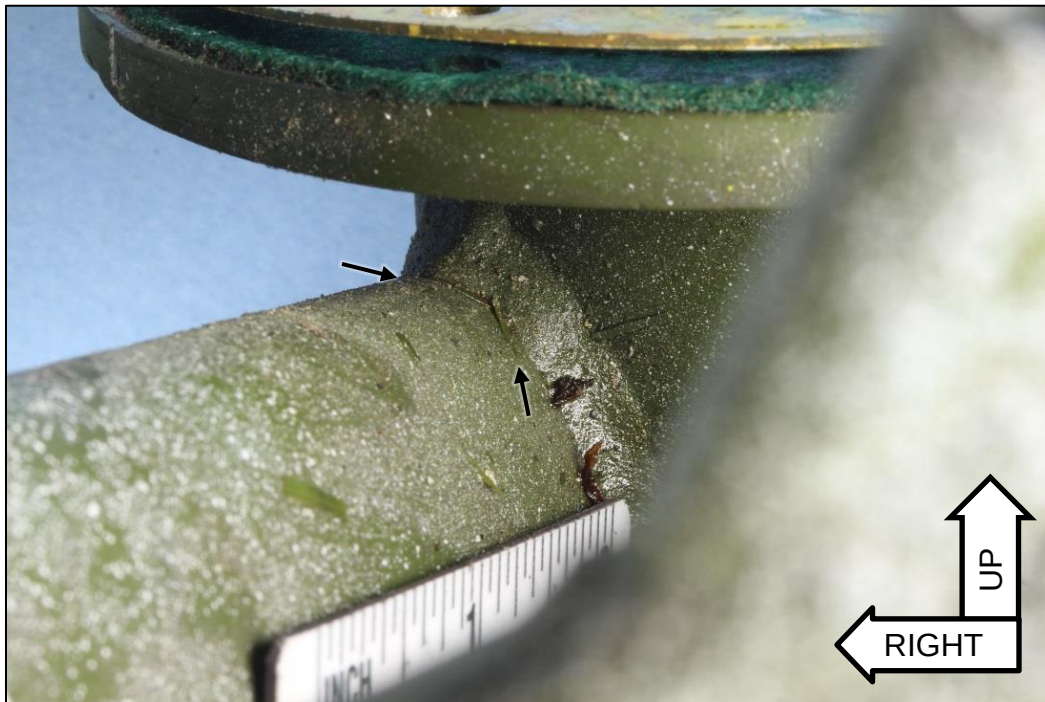


Figure 3. Upper side of the right arm showing a crack indication at the toe of the weld between the unlabeled arrows.

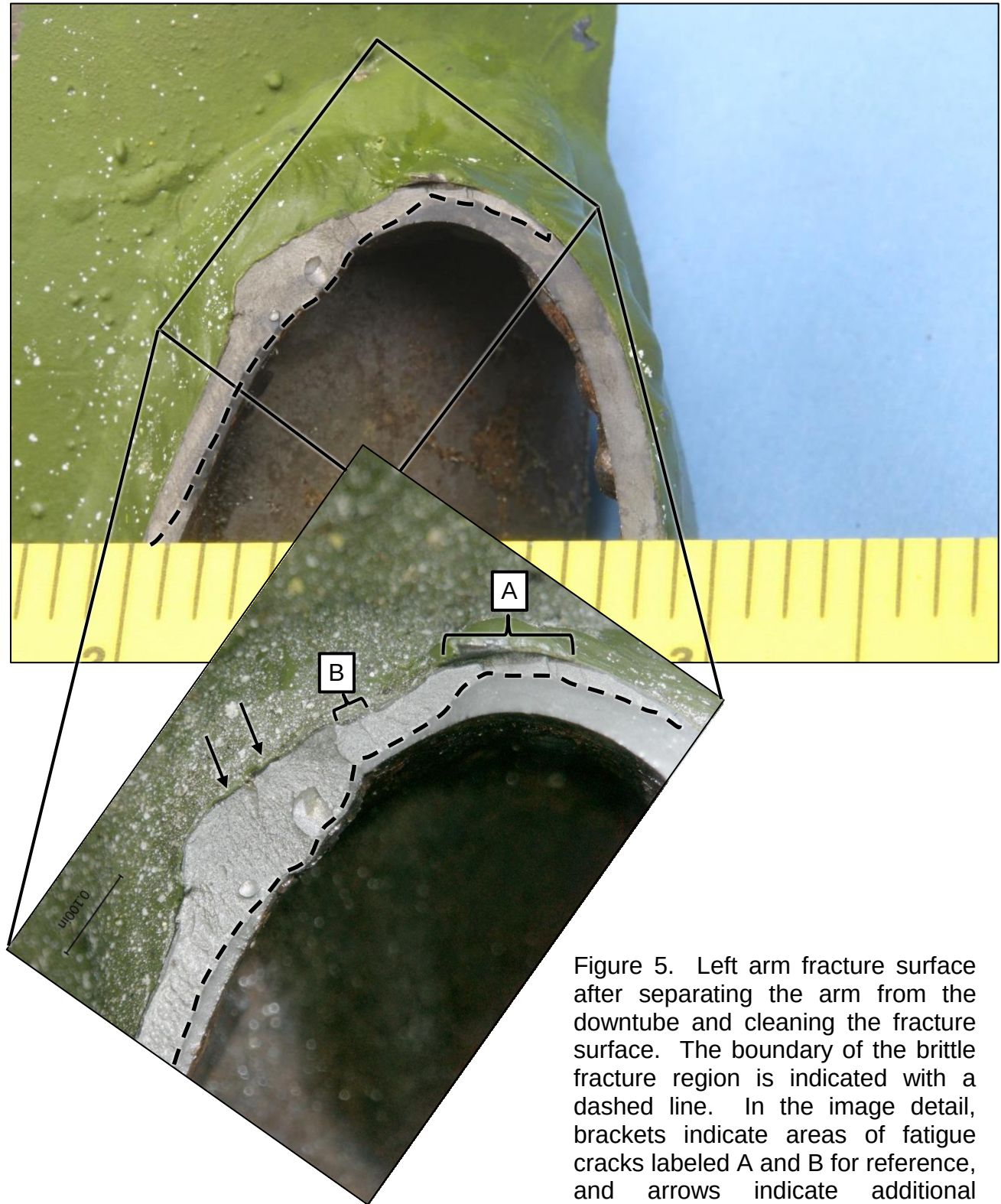


Figure 5. Left arm fracture surface after separating the arm from the downtube and cleaning the fracture surface. The boundary of the brittle fracture region is indicated with a dashed line. In the image detail, brackets indicate areas of fatigue cracks labeled A and B for reference, and arrows indicate additional fracture initiation areas.



Figure 6. Closer view of fatigue region A on the left arm fracture (see figure 5). A bracket indicates the extent of the fatigue region, and a dashed line indicates the fatigue boundary.

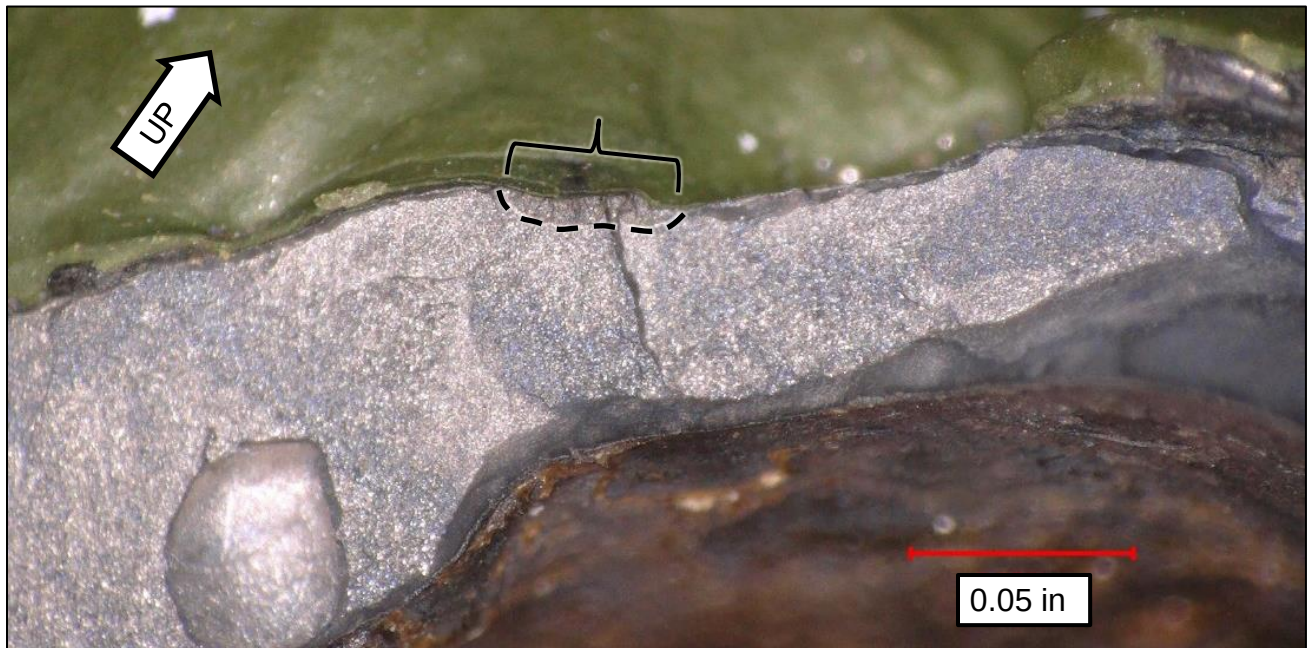


Figure 7. Closer view of fatigue region B on the left arm fracture (see figure 5). A bracket indicates the extent of the fatigue region, and a dashed line indicates the fatigue boundary.

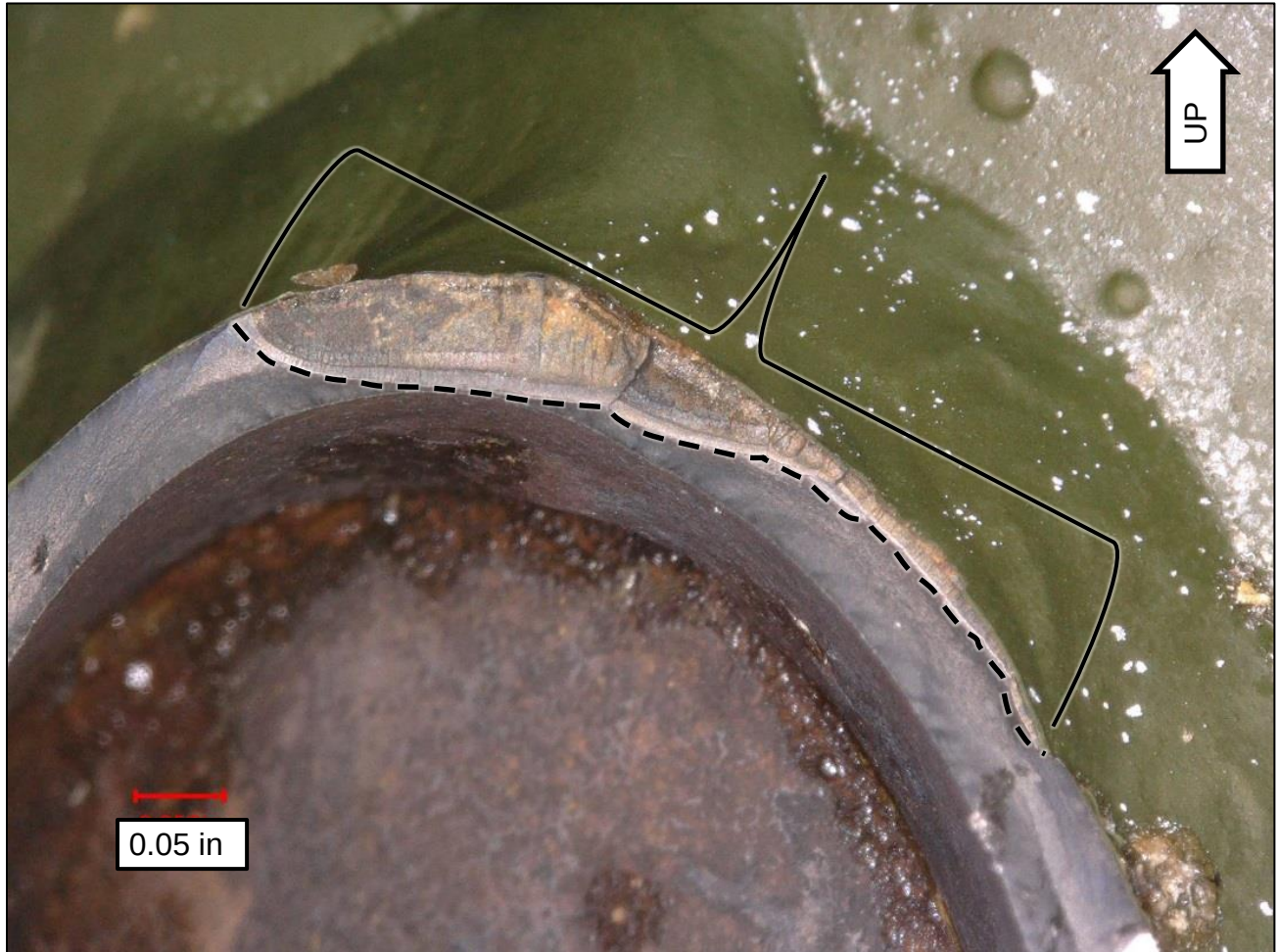


Figure 8. Close view of the fracture surface after the crack in the right arm was opened in the laboratory. A bracket indicates the extent of the fatigue crack, and a dashed line indicates the fatigue boundary.

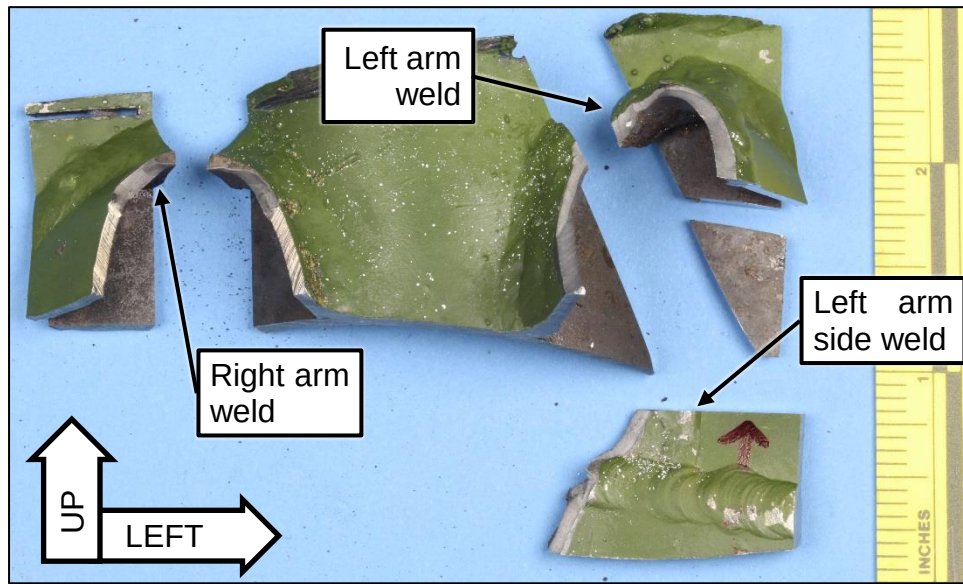
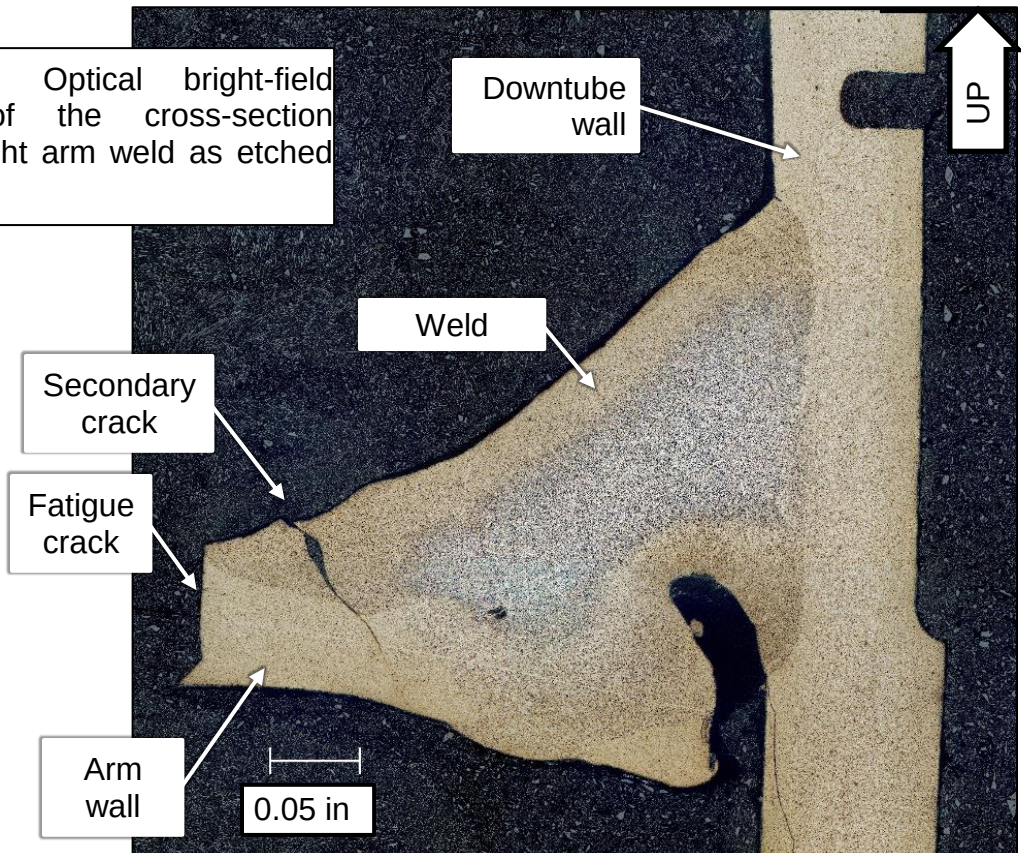


Figure 9. Downtube and arm pieces after sectioning for metallographic examination. Labels indicate surfaces that were mounted and examined in cross-sections through three welds.

Figure 10. Optical bright-field micrograph of the cross-section through the right arm weld as etched with 4% nital.



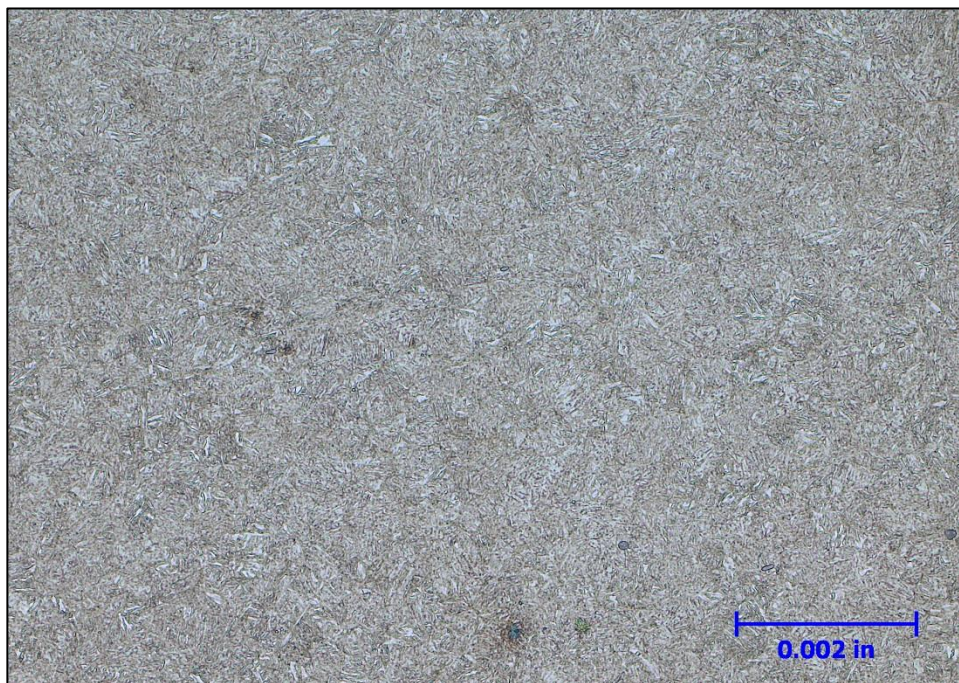


Figure 11. Optical bright-field micrograph of typical arm wall microstructure consistent with tempered martensite (4% nital etch).

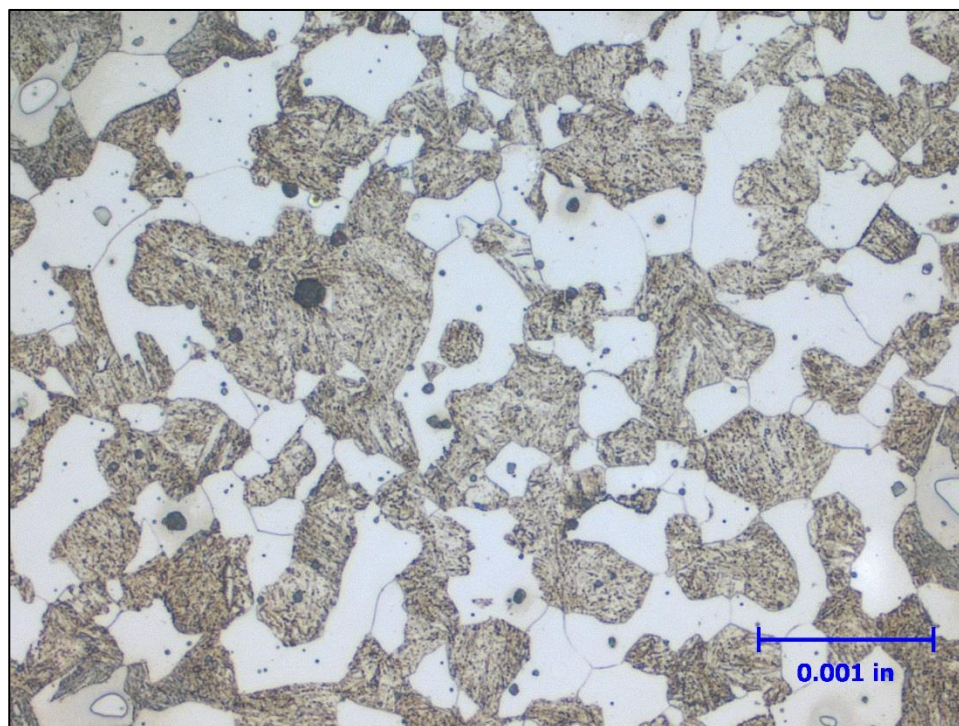


Figure 12. Optical bright-field micrograph of typical microstructure in the core portion of the weld showing a mix of ferrite (white) and bainite (brown) etched with 4% nital.

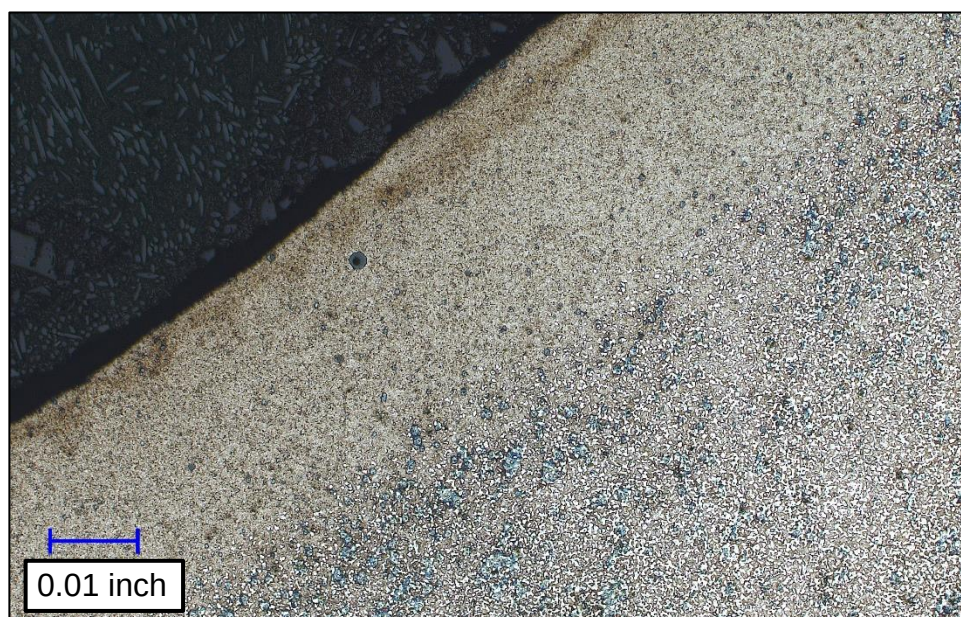
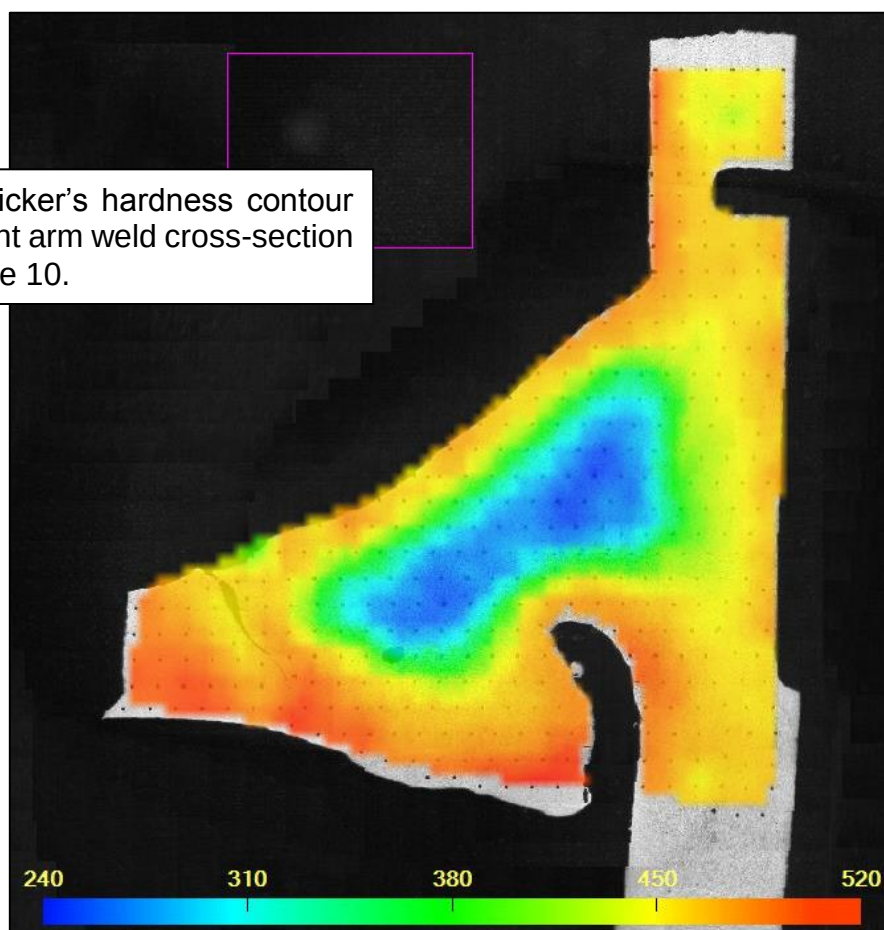


Figure 13. Optical bright-field micrograph of the surface of the right arm weld showing the transition from the surface microstructure to the core microstructure (4% nital etch).

Figure 14. Vicker's hardness contour map of the right arm weld cross-section shown in figure 10.



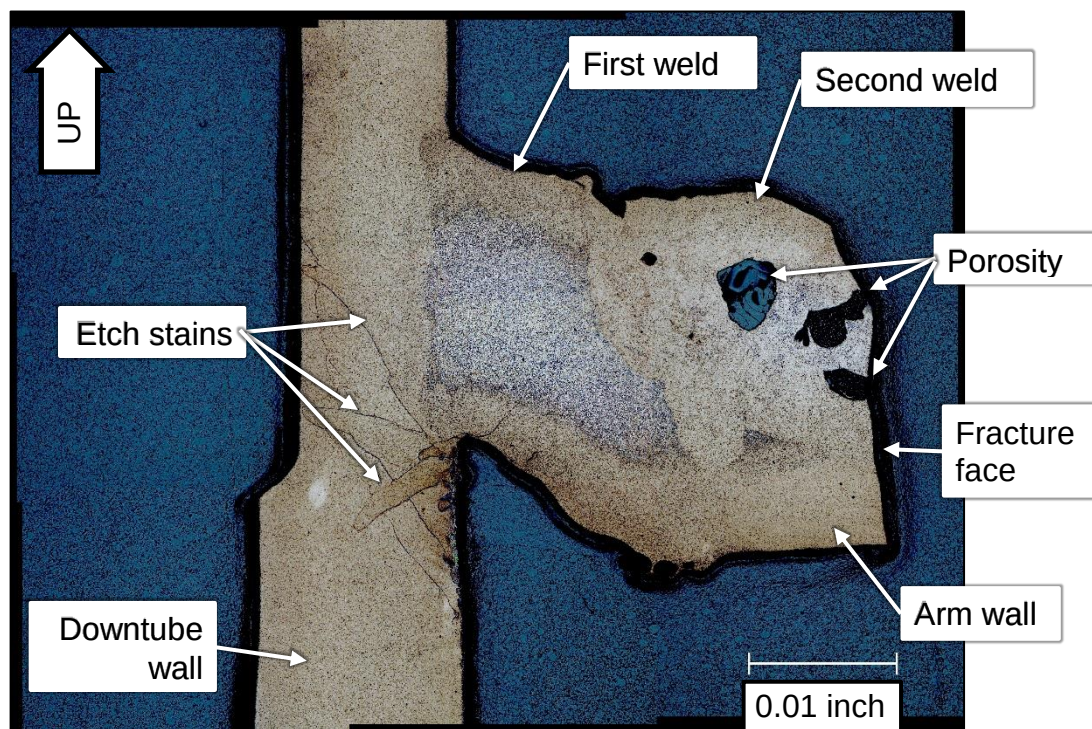


Figure 15. Optical bright-field micrograph of the cross-section through the right arm weld as etched with 4% nital.

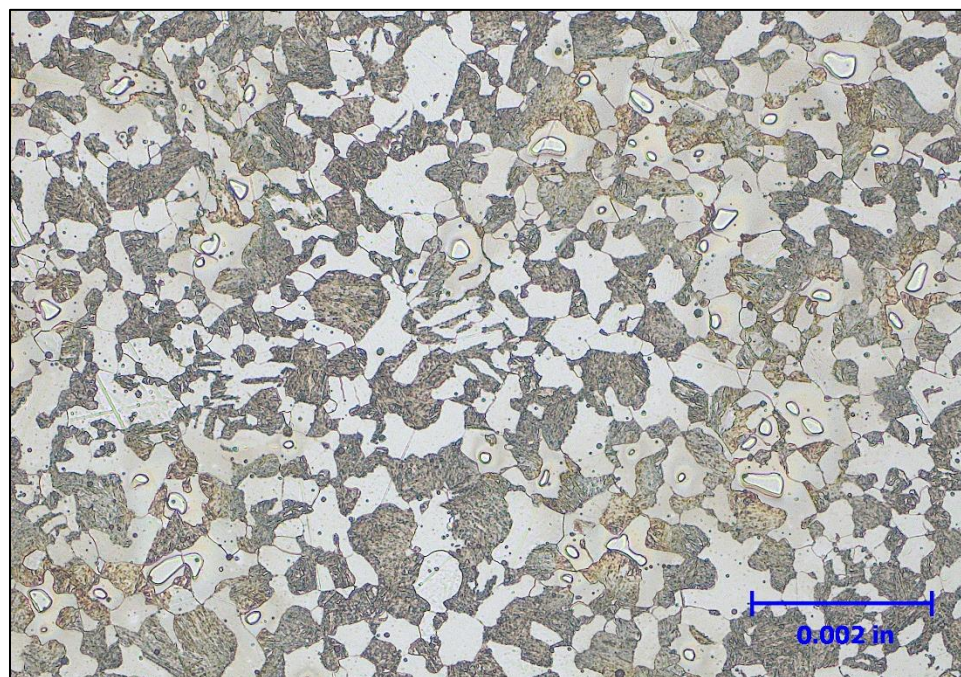


Figure 16. Optical bright-field micrograph of typical microstructure at the core of the left arm weld showing a mix of ferrite (white) and bainite (brown) as etched with 4% nital.

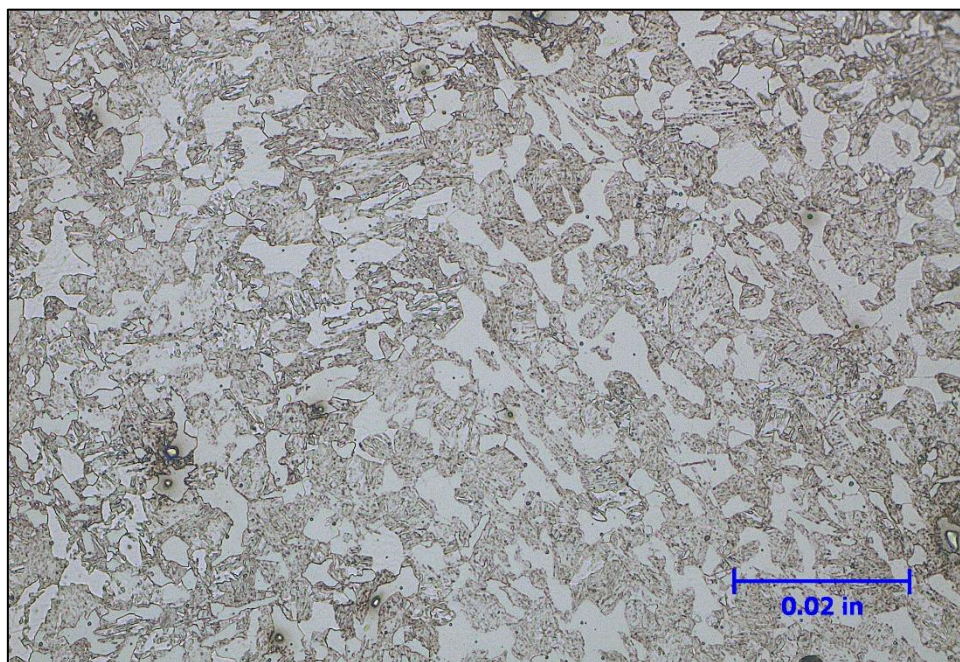


Figure 17. Optical bright-field micrograph of typical microstructure at the core of the second weld showing a mix of ferrite (white) and bainite (brown) as etched with 4% nital.

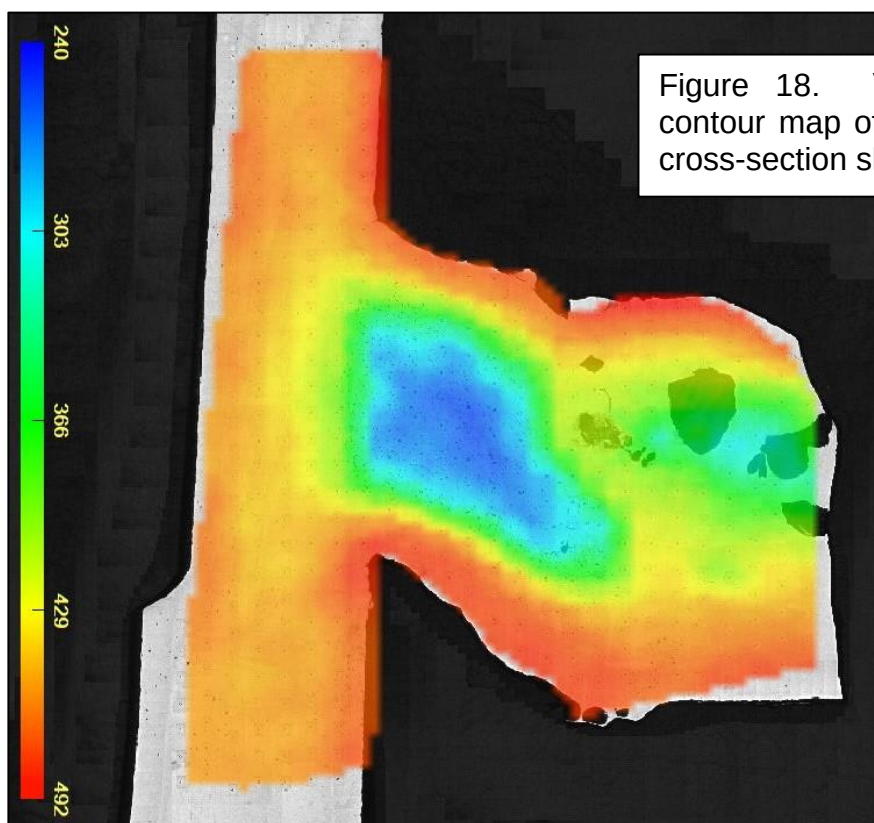


Figure 18. Vicker's hardness contour map of the left arm weld cross-section shown in figure 15.

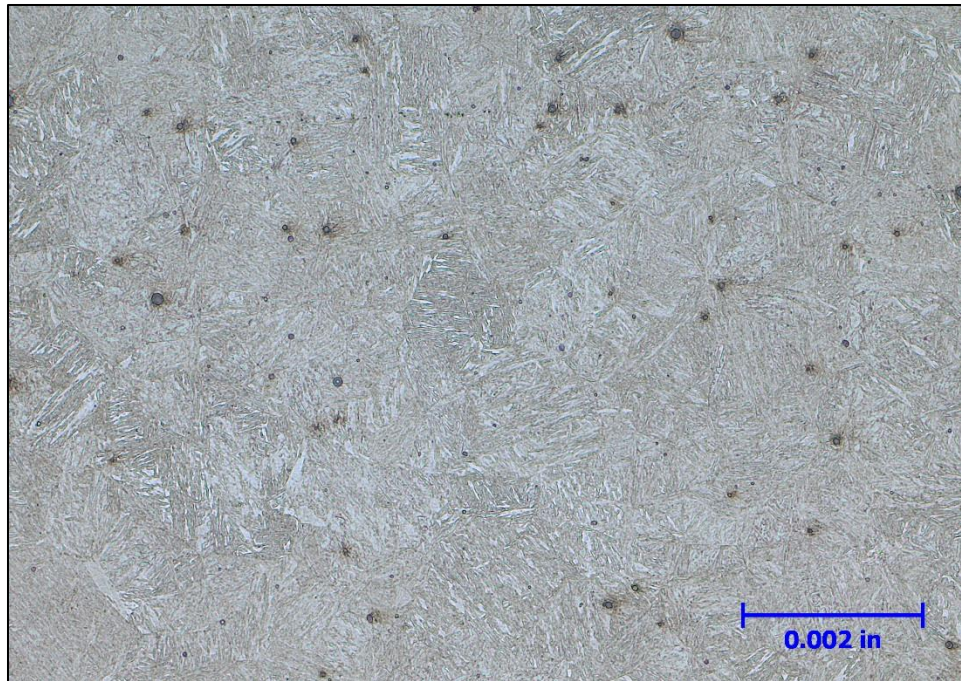


Figure 19. Optical bright-field micrograph of typical microstructure at the middle of the left arm side weld (4% nital etch).

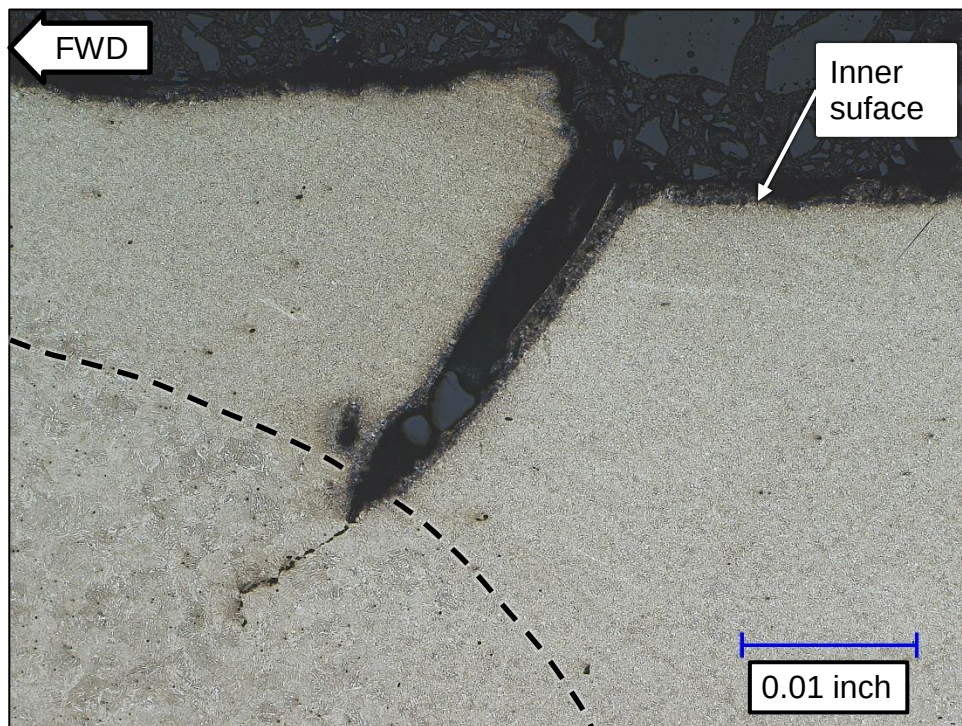


Figure 20. Optical bright-field micrograph of a crack emanating from the inner surface of the left arm near the root of the side weld (4% nital etch). A dashed line indicates the approximate boundary of the altered microstructure associated with the weld.

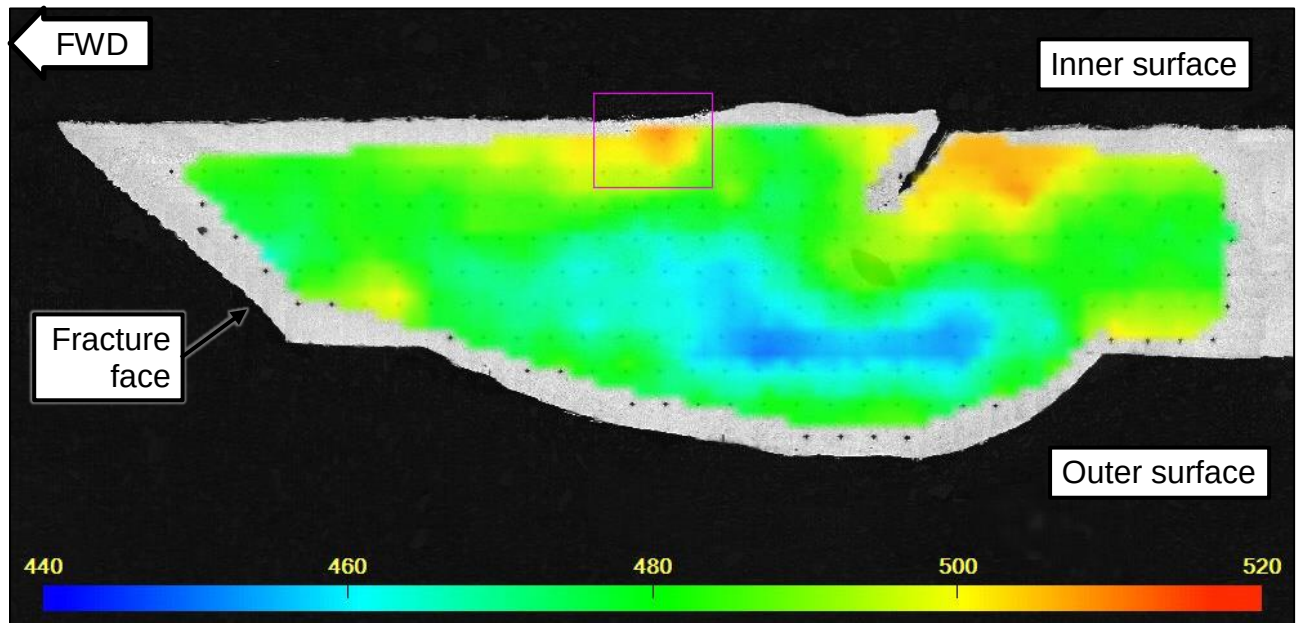


Figure 21. Vicker's hardness contour map of the left arm side weld cross-section. (Note the difference in scale relative to prior contour maps).