

NATIONAL TRANSPORTATION SAFETY BOARD

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



February 23, 2022

MATERIALS LABORATORY FACTUAL REPORT

Report No. 21-033

A. ACCIDENT INFORMATION

Place : Eveleth, Minnesota
Date : July 5, 2020
Vehicle : Piper PA32, N4079R
NTSB No. : CEN20LA263
Investigator : John Brannen, AS-CEN

B. COMPONENTS EXAMINED

Pieces of an engine driven fuel pump and drive coupling

C. DETAILS OF THE EXAMINATION

On July 5, 2020, about 1100 central daylight time, a Piper PA-32-300, N4079R, was substantially damaged when it was involved in an accident near Eveleth, Minnesota. The airplane was operated as a Title 14 Code of Federal Regulations Part 91 personal flight. Shortly after establishing cruise parameters, the engine lost all power. Attempts to restart the engine were not successful. The pilot executed a forced landing into wooded area and as a result, the pilot and passenger received minor injuries and the aircraft was substantially damaged. A portion of the engine driven fuel pump and pieces of the fuel pump drive coupling were received by the NTSB Materials Laboratory for further examination.

The as received components are shown in figure 1 with the fractured fuel pump drive coupling (outlined by a yellow dashed box) placed in approximate operational position relative to the adjacent fuel pump. An identification plate riveted to the side of the fuel pump indicated a part number RG17980D and serial number B-8647 020. The drive coupling was fractured into two pieces at the reduced diameter section approximately 0.1 inch from the shoulder of the splined end along a plane transverse to the axis of rotation. Other components shown in figure 1 outlined by a white dotted line were submitted and included a fragment of safety wire with a lead seal, a tapered section retaining ring, and a flat washer.

Figure 2 shows a closer side view of the fractured drive coupling. One piece contained a splined end, the other piece contained a tongue end designed to fit within a groove in the fuel pump shaft when assembled. Wear marks were observed on successive flanks on one side of the spline grooves as evidenced by smooth shiny depressions which resembled polished metal. These areas extended radially from a well-defined step at approximately mid-flank to the crest and spanned approximately 85% of the face width from the engine side of the spline. Three examples visible in figure 2 are indicated by white arrows. Wear marks on the opposite side of the spline grooves were less pronounced. The tongue portion of the drive coupling exhibited a shiny, reflective, and battered wear mark on the contact face indicated by the yellow bracket in figure 2. A similar mark was observed on the opposite side and

opposite face of the tongue (not visible in figure 2). A matching wear pattern was observed in the fuel pump shaft groove, one side of which is shown in figure 3 and highlighted by a yellow bracket.

The drive coupling fracture surface was cleaned using ultrasonic agitation and a mild soap and water solution followed by acetone to facilitate viewing under a 4X – 80X zoom stereomicroscope. The fracture surface was relatively flat with a dull-gray swirled appearance. The outer edge was smoother and exhibited evidence of smearing. Features that resembled ratchet marks¹ were observed at several locations around the edge of the fracture surface as indicated by yellow arrows in figure 4. Further cleaning by immersion in an ambient bath of Evapo-Rust® cleaner was employed to facilitate higher magnification examination using a scanning electron microscope (SEM). A rougher, slightly off-center region with a swirled appearance showed evidence of microvoid coalescence² in the form of parabolic dimples as shown in the SEM fractograph on the left in figure 5, which was consistent with torsional overstress loading at final separation. Adjacent to this rough central region, outlined by a yellow dashed line in figure 4, was an area which exhibited a brighter, faceted appearance. Closer examination of this region revealed river patterns³ and fracture features consistent with transgranular cleavage fracture propagating towards the rougher central region. Finer elongated dimples, as shown in the SEM fractograph on the right in figure 5, were observed at approximately mid-radius in the region between the outer edge and rougher central region which was consistent with mode II (in-plane) or III (out-of-plane) shear loading. Areas of the fracture surface near the edge were examined more closely under high magnification and no features indicative of fatigue, such as striations, were observed but the morphology was generally smeared.

The surface of the reduced section of the drive coupling adjacent to the fracture surface exhibited a small degree of bending deformation, indicated by curved white arrows in figure 6, and circumferential secondary cracks, the largest examples indicated by straight yellow arrows. A cross section view of the reduced section revealed relatively short crack profiles extending into the shaft from the outer surface as shown in figure 7. The largest crack observed was approximately 0.009 inch below the fracture surface and was approximately 80 microns (0.003 inch) in length. Microhardness indentation measurements were consistent with a through hardened component and averaged 405 HK which when converted in accordance with ASTM E 140, corresponded to approximately 40 HRC or 182 ksi tensile strength. X-ray fluorescence spectroscopy (XRF) confirmed the coupler material to be consistent with a low alloy steel, predominantly iron with less than 2% each of other common alloying elements such as chromium, manganese, molybdenum, and nickel detected.

¹ Ratchet marks are slight vertical steps in the fracture that link slightly offset planes of progressive cracking at an 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. Ratchet marks are more commonly observed in cyclic loading scenarios.

² Microvoid coalescence is a fractographic term describing ductile fracture that occurs through the formation and coalescence of microvoids along the fracture path. The fracture surface of such a ductile fracture appears dimpled when observed at high magnification and usually is most clearly resolved when viewed in a scanning electron microscope.

³ River pattern is a term used in fractography to describe a characteristic pattern of cleavage steps running parallel to the local direction of crack propagation on the fracture surfaces of grains that have separated by cleavage.

The fuel pump was later disassembled to examine the interior. The pump drive shaft was not easily rotated by hand and, once freed, only moved approximately 90° before seizure. Prior to disassembly, it was observed that the gasket between the pump housing and valve housing protruded as much as 0.076 inch from the exterior of the pump as shown in figure 8. Upon separation of the valve housing from the pump housing, the gasket exhibited regions of permanent set on the interior contact area evidenced by raised features around the outer perimeter and inner circular area as indicated by red arrows in figure 8. The pump gaskets were consistent with unmodified original equipment.⁴ The bypass valve guide was removed from the valve housing to reveal the bypass valve. No spring was present between the bypass valve guide and the bypass valve. Figure 9 shows the opposite side of the bypass valve guide as shown in figure 8, the bypass valve guide port, and both sides of the bypass valve. Circular shaped contact marks were observed around the outer edges of the bypass valve guide and circular shaped rub marks around both sides of the bypass valve evidenced by a dull lighter colored band. The rub mark on one side of the bypass valve was relatively centered about a 0.32 inch diameter circle and extended to the outer edge of the circular valve which was approximately 0.392 inch in diameter as measured using a digital microscope. The rub mark on the other side of the bypass valve was off-center about a 0.33 inch diameter circle and extended to the outer edge of the circular valve resulting in an observed rub mark band width ranging from 0.018 inch to 0.042 inch. The inner edge of the bypass valve port contact area was measured to be approximately 0.330 inch. The outer diameter of the bypass valve port and the inner diameter created by the bypass valve guide prongs both measured approximately 0.405 inch.

The valve cover assembly was removed from the valve housing to expose the safety relief valve assembly, as shown in figure 10, which consisted of a valve affixed to a gasket. A portion of the valve was covered in a reddish orange powdery substance consistent with iron oxide (rust). The portion of the valve retained in the valve housing was less covered with rust and a ring-shaped area on the tapered portion of the valve which interfaced with the valve seat on the housing was predominantly free of rust. No visible cracks or tears were observed in the gasket material.

The pump vanes, rotor, pump shaft, and inner housing were exposed after removal of the valve housing, and all appeared intact. A reddish-brown substance consistent with rust was present on the inner housing wall, the vanes, and significant portions of three of the four rotor quadrant sidewalls. The rotor quadrants were labeled A-D for the purpose of this report. A discolored dark brown-gray region emanated from the base of the rotor along the integral pump drive shaft, consistent with localized thermal damage/heat tint. XRF confirmed the fuel pump shaft material to be consistent with a low alloy steel, predominantly iron with less than 2% each of other common alloying elements such as chromium, manganese, molybdenum, and nickel.

The vanes were removed from their respective slots in the rotor for closer examination. The sides of the vanes which interfaced with the rotor slot sidewalls were relatively smooth

⁴ Part names and configuration referenced from Lycoming Mandatory Service Bulletin No. 539A dated November 22, 2000, a reprint of Crane Lear/Romec Service Bulletin RG17980-73-001, an alternate means of compliance with Crane Lear/Romec SB 101SB020 first issued July 8, 1997. The service bulletin introduced pump design enhancements that provide improved relief valve housing sealing characteristics.

and featureless. The ends of the vane which interfaced with the pump inner housing are shown in figure 11 with the labels identifying the adjacent rotor quadrant. Smeared material transfer marks and other oxidized particles were observed, consistent with adhesive wear and ferrous wear debris.

Figure 12 shows a photograph looking along the pump drive shaft at the rotor with the vanes removed. The yellow dashed line highlights the boundary of the thermal damage/heat tint observed on the shaft emanating from the rotor end. Closer examination of the outer surface of the rotor quadrants revealed wear debris present on the lower portions of quadrants A and C nearest quadrant B and over the majority of quadrant B. Energy dispersive x-ray spectroscopy (EDS) was performed in the vicinity of one of the larger wear debris particles identified by the black arrow in figure 12. The spectra acquired from areas indicated by yellow boxes in the electron image at the top left in figure 13 are shown overlaid at the bottom of the same figure. The larger yellow box in the electron image corresponded to a portion of the rotor surface relatively free of wear debris. The smaller yellow box corresponded to an area on the particle of interest. A white dashed box was used to highlight the location of the wear particle of interest in the field of view. The other inset images in figure 13 are elemental dot maps acquired over the same field of view showing where the elements iron (Fe), aluminum (Al), silicon (Si), carbon (C), and titanium (Ti) were detected and the white dashed box outlining the location of the particle of interest was reproduced on each map. These elements showed the greatest degree of contrast between the particle location and the surrounding rotor surface. The yellow dot map shows detection of iron (Fe), the predominant element contained in the fuel pump shaft and rotor. The area where the particle was located was essentially devoid of yellow, consistent with a foreign non-ferrous particle. Higher concentrations of carbon, aluminum, chlorine, silicon, and titanium were detected over the area of the particle which were consistent with common elements found in soil minerals. Other elements detected as indicated by smaller peaks in the spectra were consistent with elements found in soil minerals and common alloying elements in steel.

The fuel pump drive shaft was cleaned using a soft bristled brush and mild detergent followed by ultrasonic cleaning in acetone. Figure 14 shows a view of the rotor after cleaning with a portion of the outer surfaces of quadrants B and C visible. The black dashed line highlights the boundary of the rougher area where wear debris were observed. Above this region, the outer surface of the rotor was smoother and exhibited a pattern of parallel circumferential machining marks. Yellow arrows identify examples of larger pits observed on the outer surface of the rotor. These locations were observed more closely using SEM. The area on the slot face of quadrant B, indicated by a red bracket, exhibited a shinier appearance with angled gouges, consistent with abrasive wear. This surface interfaced with a pump vane when assembled.

Figure 15 shows a top view of the fuel pump rotor looking down the shaft axis. Around this central image are views of the slot faces and top surface of the corresponding rotor quadrants which exhibited similar evidence of abrasive wear and gouges as shown in the previous figure. The yellow lines in the central image indicate the slot faces where abrasive wear and gouges were observed and correspond to the faces being viewed in the adjacent images. The relative lengths of the yellow lines indicate the approximate maximum length over which the shinier gouged surface was observed from the outer edge to the central hub. On the slot surface of rotor quadrant A facing B, the gouged area extended approximately

0.076 inch from the outer edge inward. Similarly, for rotor quadrant B slot surface facing C, rotor quadrant C slot surface facing D, and rotor quadrant D slot surface facing A, the equivalent measurements were 0.276 inch, 0.206 inch, and 0.201 inch, respectively. The length of the chamfer feature between the top surface of the rotor and the gouged slot faces tapered slightly from the rotor center to the outer surface, consistent with more material loss due to wear closer to the outer surface. This was readily observed on slot faces of quadrant B (facing C) and of quadrant D (facing A) shown in the bottom and top images in figure 15, respectively. The white and red dashed lines and corresponding arrows in the central and lower images indicate an example of the observed taper.

The pits and missing material observed on the outer surface of the rotor as identified in figure 14 were examined more closely using SEM. Figure 16 shows a lower magnification view of one of the pits and the surrounding outer surface of the rotor. The area within the red dashed line including the pit was spalled from the rotor surface. A higher magnification view of the area highlighted in the yellow dashed box is shown to the right. A relatively flat crack path and features consistent with fatigue striations were observed emanating adjacent to the pit. The yellow dashed arrows indicate the general direction of progression of these fatigue features and a ledge feature was observed near the end of the arrows where fracture features were more obscured. The fatigue crack continued to progress under the rotor surface. The subsurface fatigue cracking mechanism and observed pitting/spalling was consistent with contact fatigue wear. Figure 17 shows a secondary electron image from another area of spalled material between the rotor sidewall and base. Features consistent with fatigue striations were observed near this location as well as shown in the higher magnification secondary electron image on the right in figure 17.

Michael Meadows
Materials Engineer

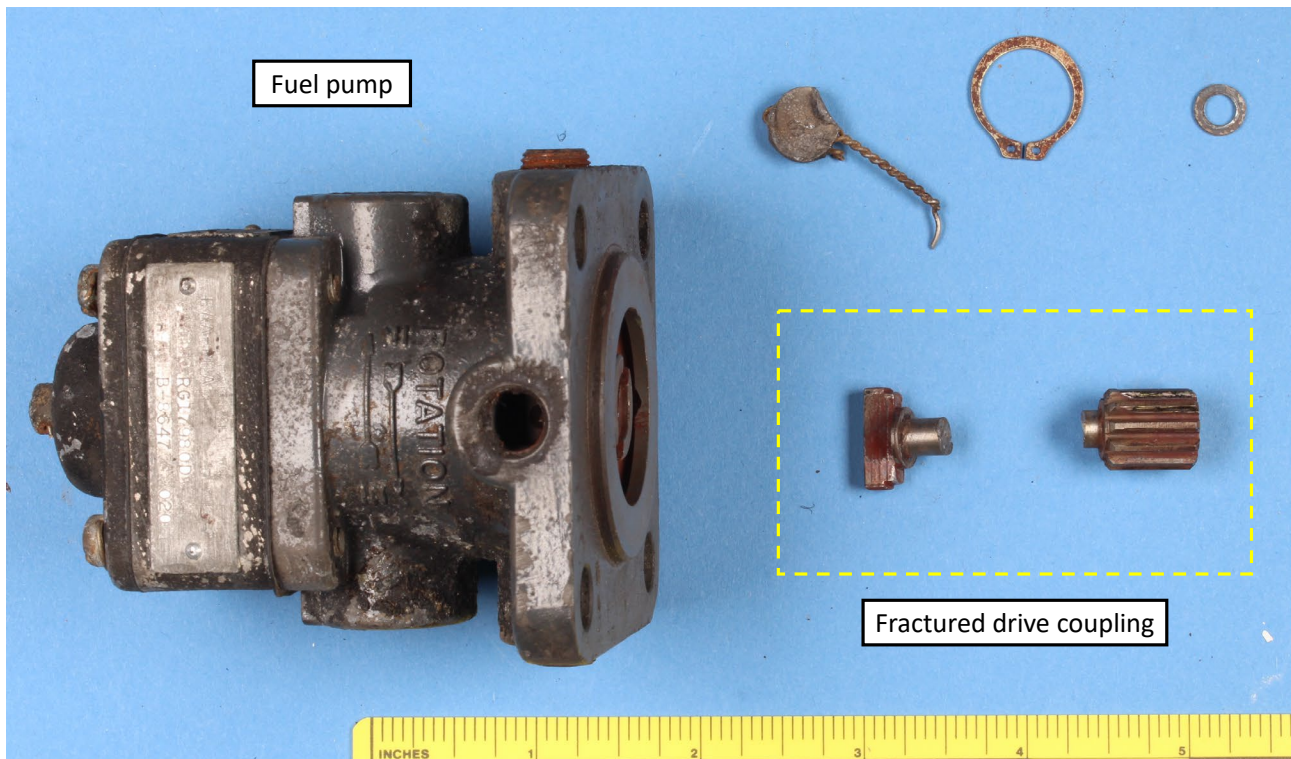


Figure 1: A photograph of the as received components.

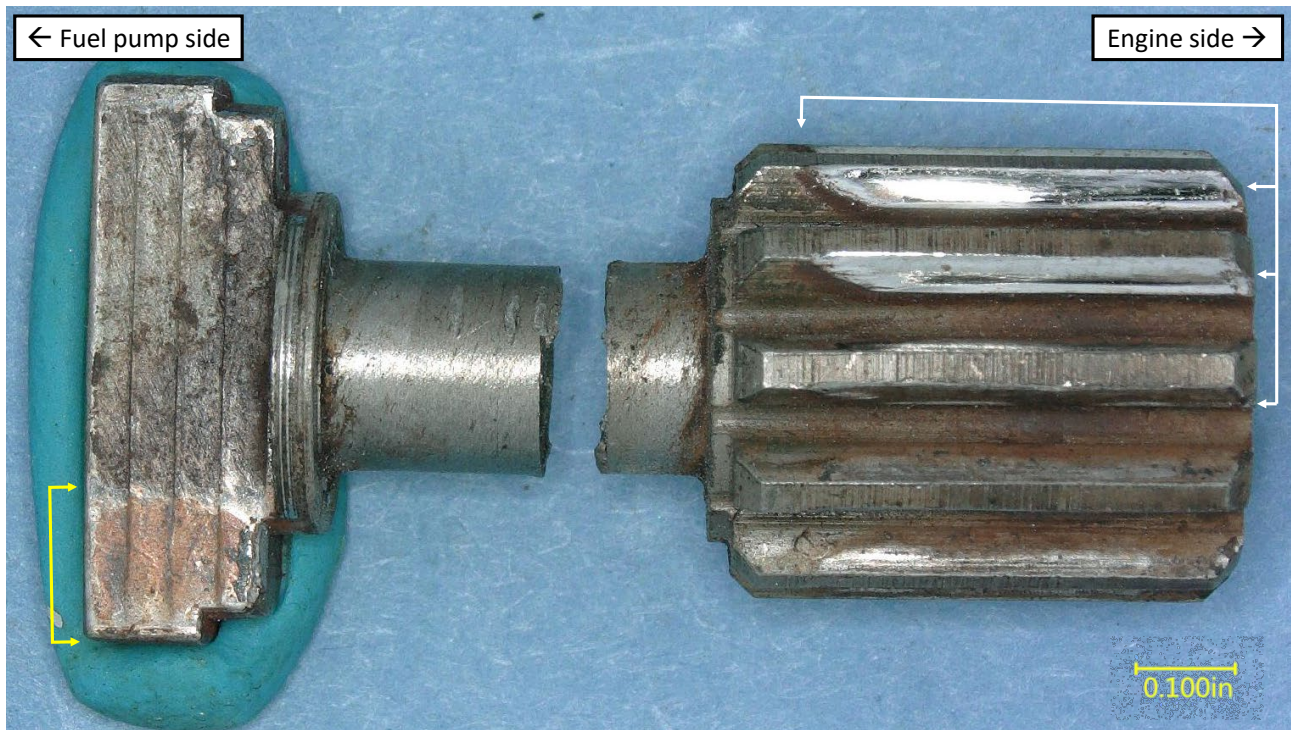


Figure 2: A digital microscope image showing a side view of the fractured drive coupling. Wear marks observed on one side of the spline grooves on the engine side are indicated by white arrows. A wear mark observed on the tongue at the fuel pump side is indicated by yellow arrows. A similar mark was observed on the opposite face at the other end of the tongue (not visible in this photograph).

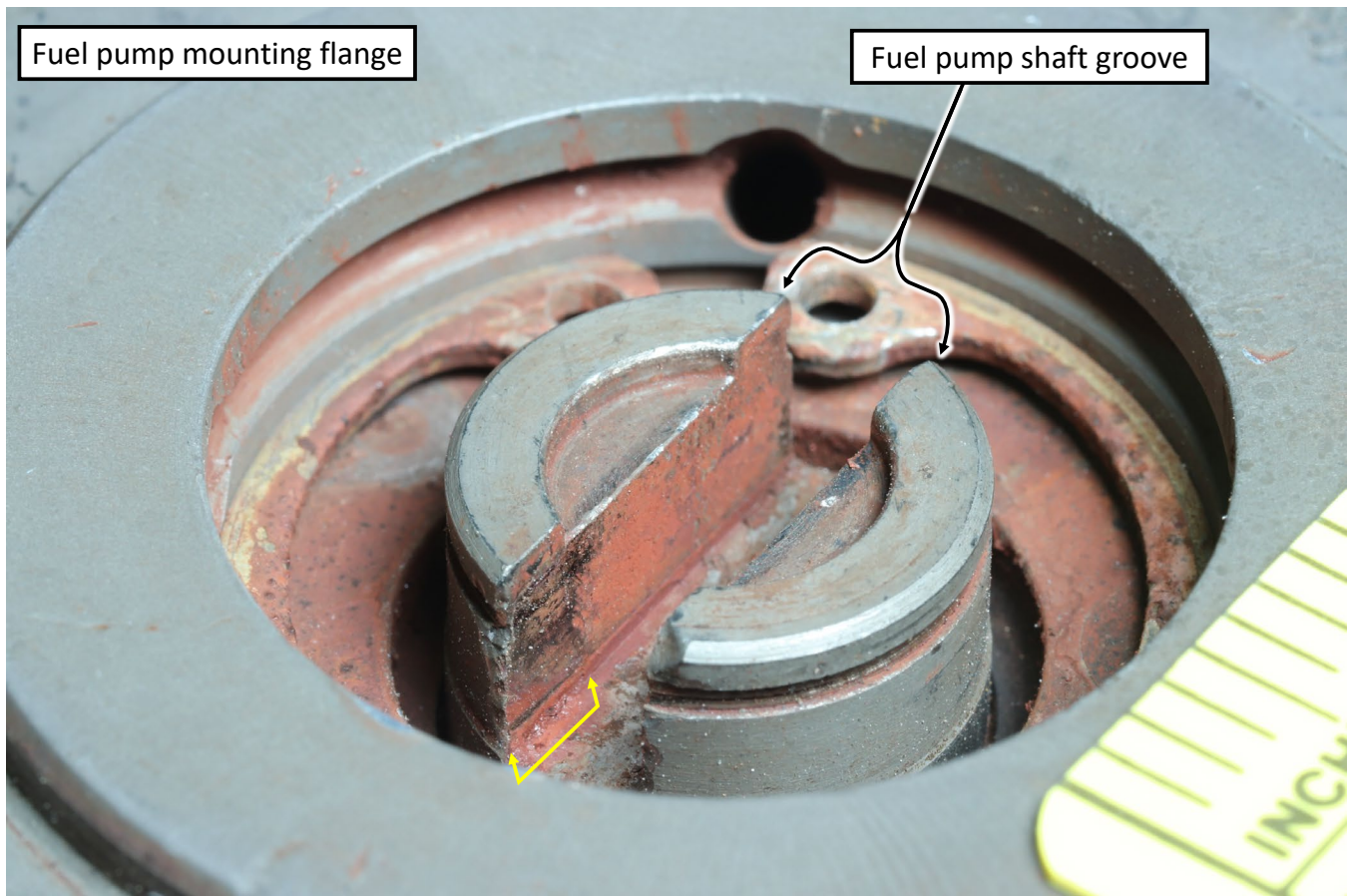


Figure 3: A photograph showing the fuel pump drive shaft component installed in the fuel pump. The yellow bracket indicates the boundaries of a wear mark observed on the groove face which coordinates with the mark observed on the tongue surface of the fractured drive coupling. A similar mark was observed on the opposite face at the other end of the groove (not visible in this photograph).

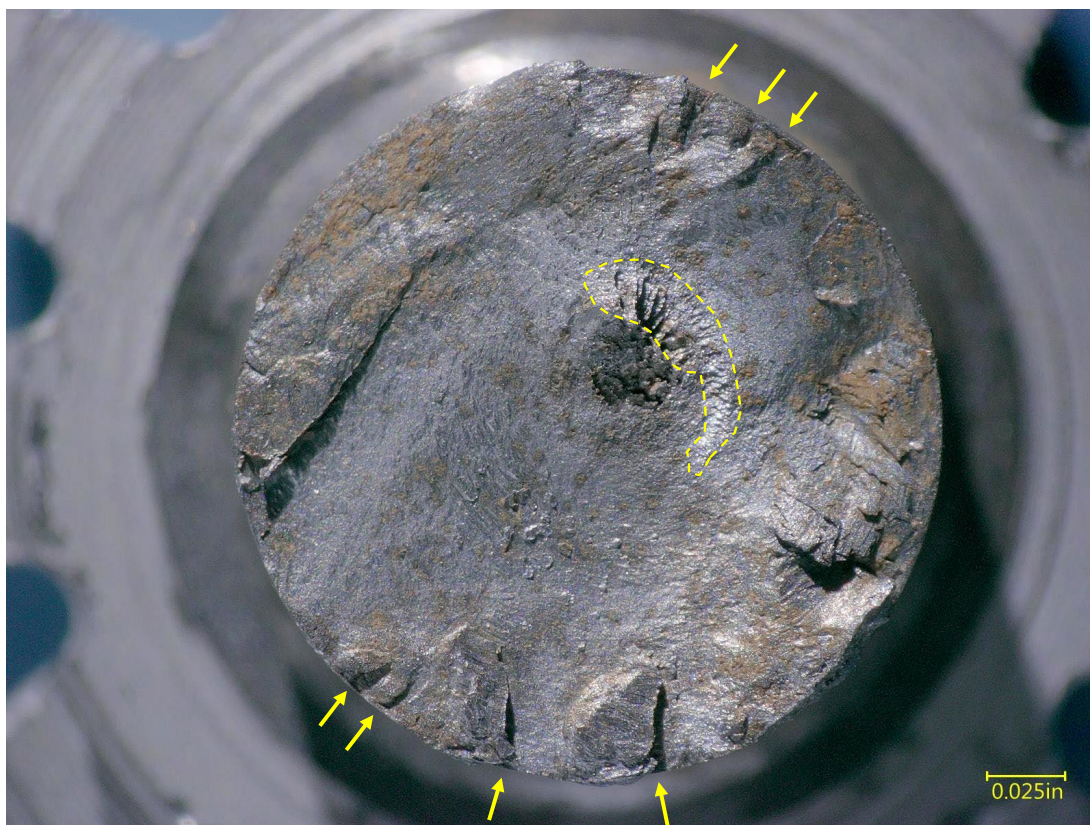


Figure 4: A digital microscope image of the drive coupling fracture surface (splined side). The fracture surface was relatively flat and on a plane transverse to the axis of rotation. A swirl pattern was apparent around a rougher region slightly off-center. Adjacent to the rougher region was a brighter faceted area as highlighted by the yellow dashed line. Smearing was observed generally around the surface near the outer edge. Features resembling ratchet marks were observed around the outer edge as indicated by yellow arrows.

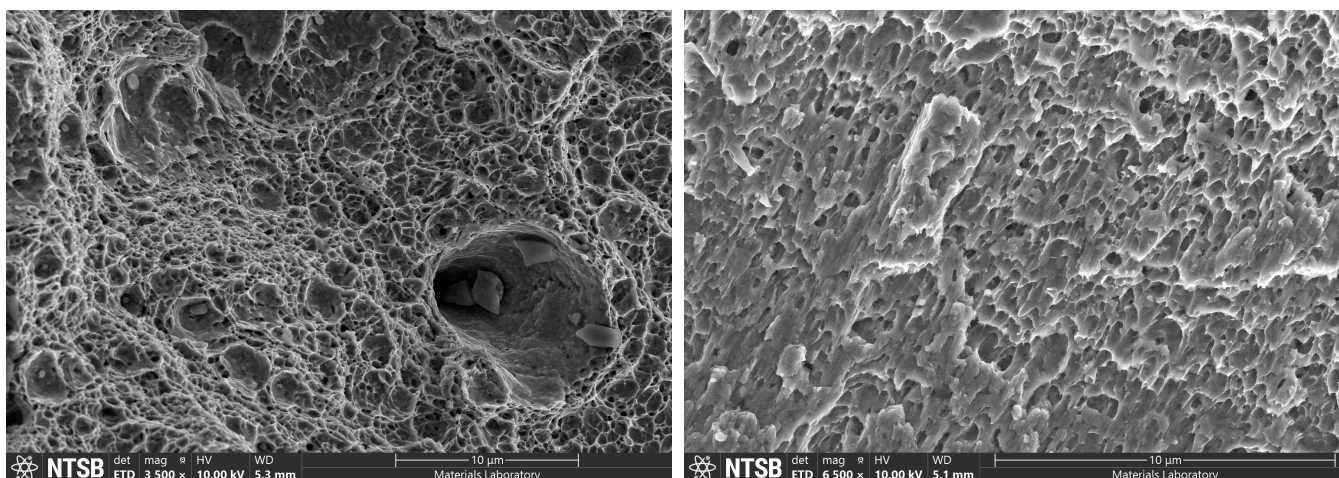


Figure 5: Left: A secondary electron image acquired from the drive coupling fracture surface in the rougher central region. Parabolic-shaped dimples were observed, features consistent with torsional overstress separation. Right: A secondary electron image showing elongated dimples observed on the drive coupling fracture surface at approximately mid-radius from the central axis to the outer surface, consistent with torsional-shear loading and overstress separation.

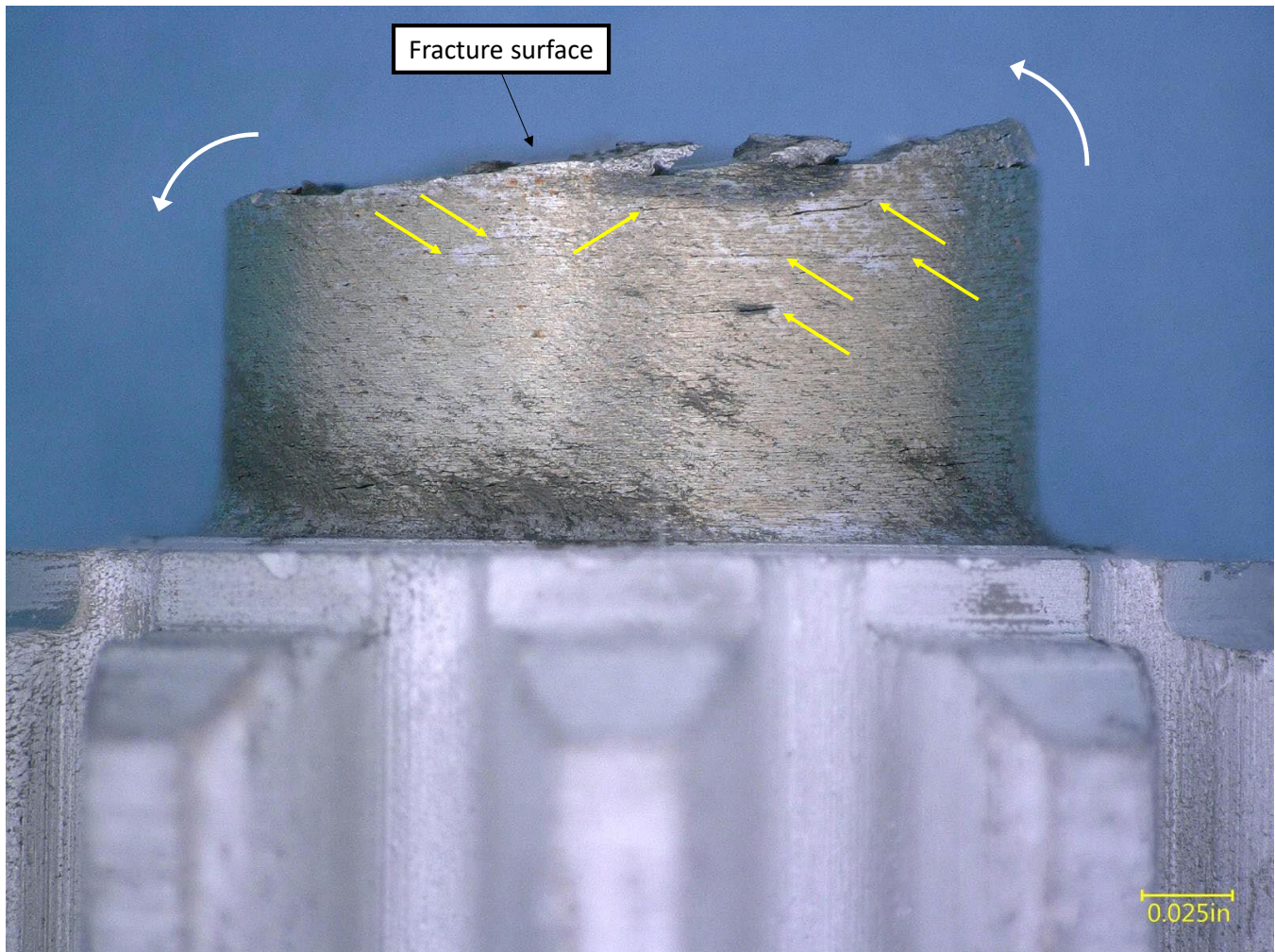


Figure 6: A digital microscope image of the drive coupling surface adjacent to the fracture surface. White curved arrows indicate bending deformation. Yellow arrows indicate relatively flat horizontal secondary cracks observed near the fracture surface.

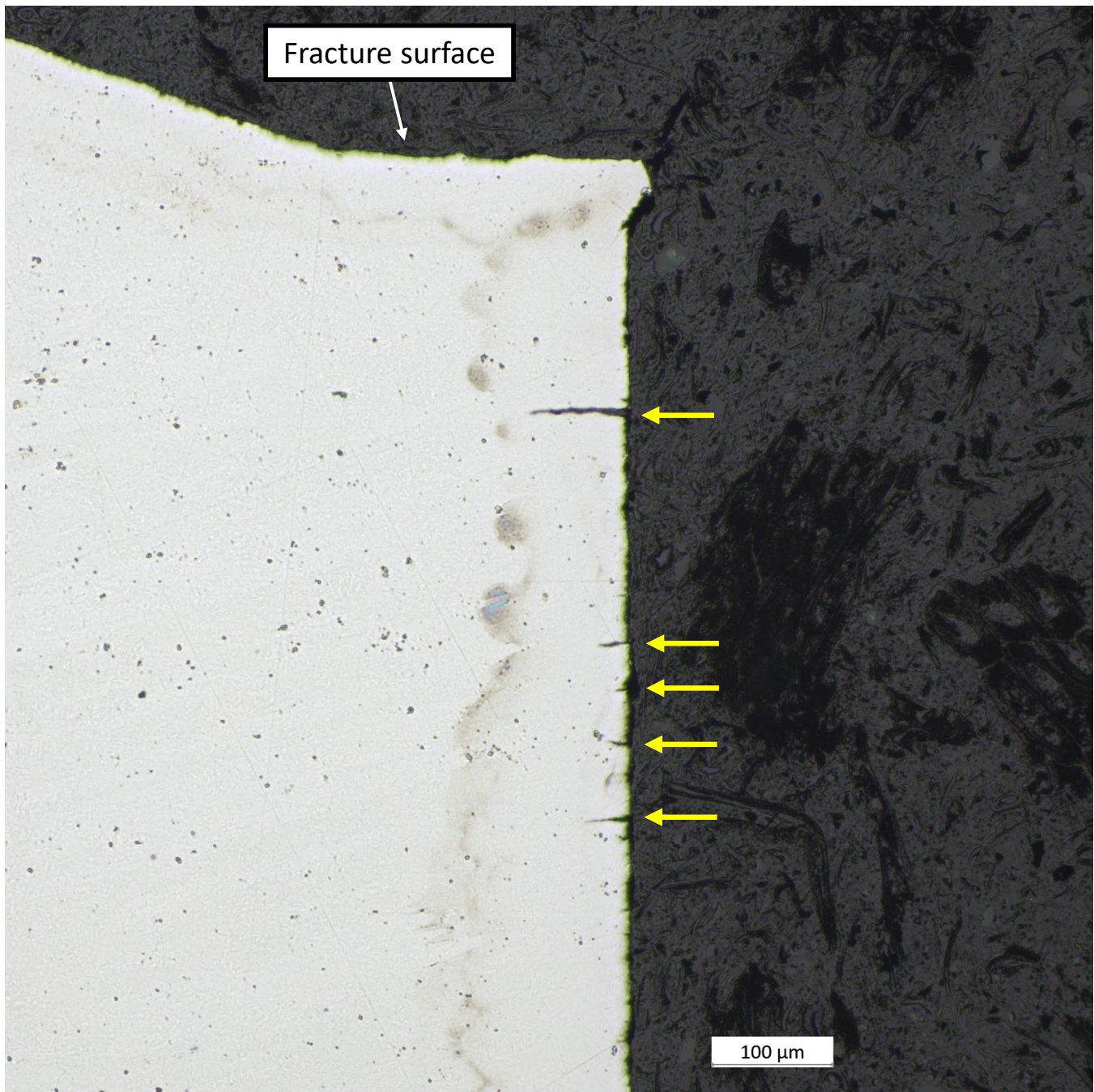


Figure 7: A bright-field metallographic cross section view through the drive coupling reduced section near the fracture surface. Secondary cracks observed extending into the drive coupling from the outer surface, as indicated by yellow arrows, were relatively flat. The maximum observed crack length was approximately 80 μm (0.003 inch). 2% Nital Etch.

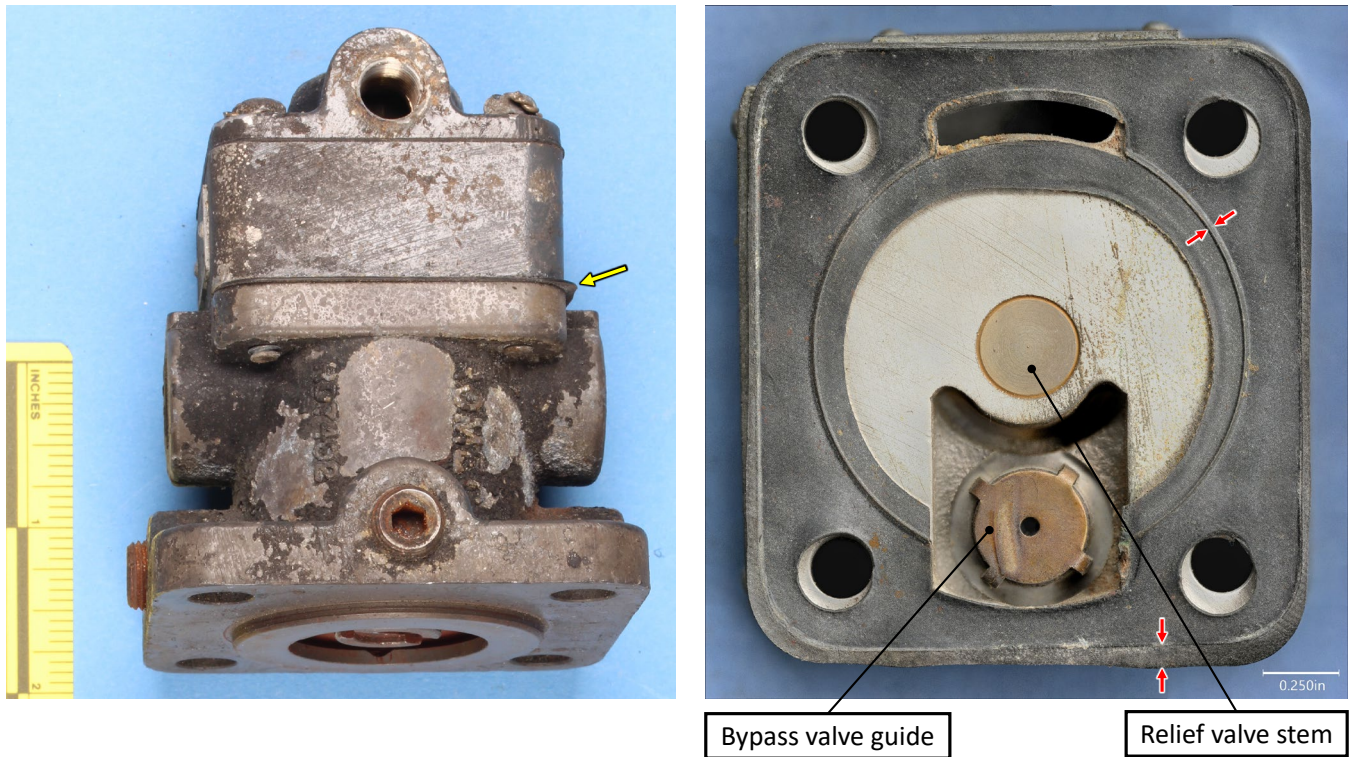


Figure 8: Left: A photograph showing a view of the fuel pump prior to disassembly. The protruding gasket is indicated by a yellow arrow. Right: A digital microscope image (stitched montage) showing a view of the relief valve housing and gasket at the pump housing interface after disassembly. Red arrows indicate examples of raised features consistent with a permanent set condition observed in the gasket material.



Figure 9: Digital microscope showing a view of the opposite side of the bypass valve guide as viewed in the previous figure after disassembly (upper left), the bypass valve port on the valve housing (lower left), and both sides of the bypass valve (upper and lower right). Circular off-center contact marks are evident around the outer edge of the bypass valve guide surface. Circular shaped rub marks were evident around the perimeter of the bypass valve on both sides as evidenced by a dull lighter appearance.



Figure 10: A digital microscope image showing a tilted view of the relief valve assembly (right) removed from the valve housing (left). A reddish orange powdery substance consistent with rust was observed covering the valve near the valve seat interface.



Figure 11: Digital microscope images of the fuel pump vane edges as removed from their relative rotor quadrant position (A-D). Material transfer and debris were observed consistent with adhesive and abrasive wear mechanisms.

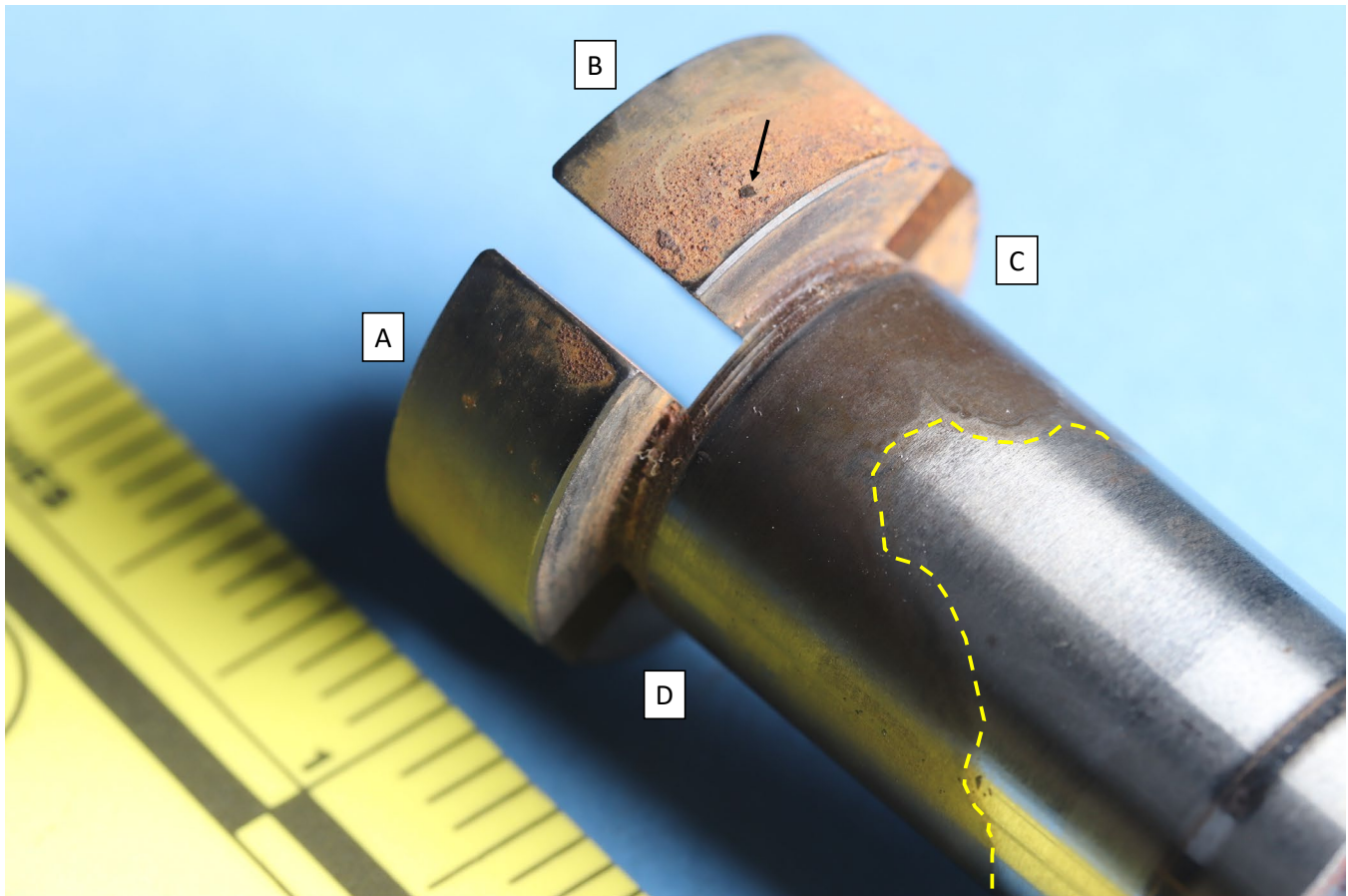
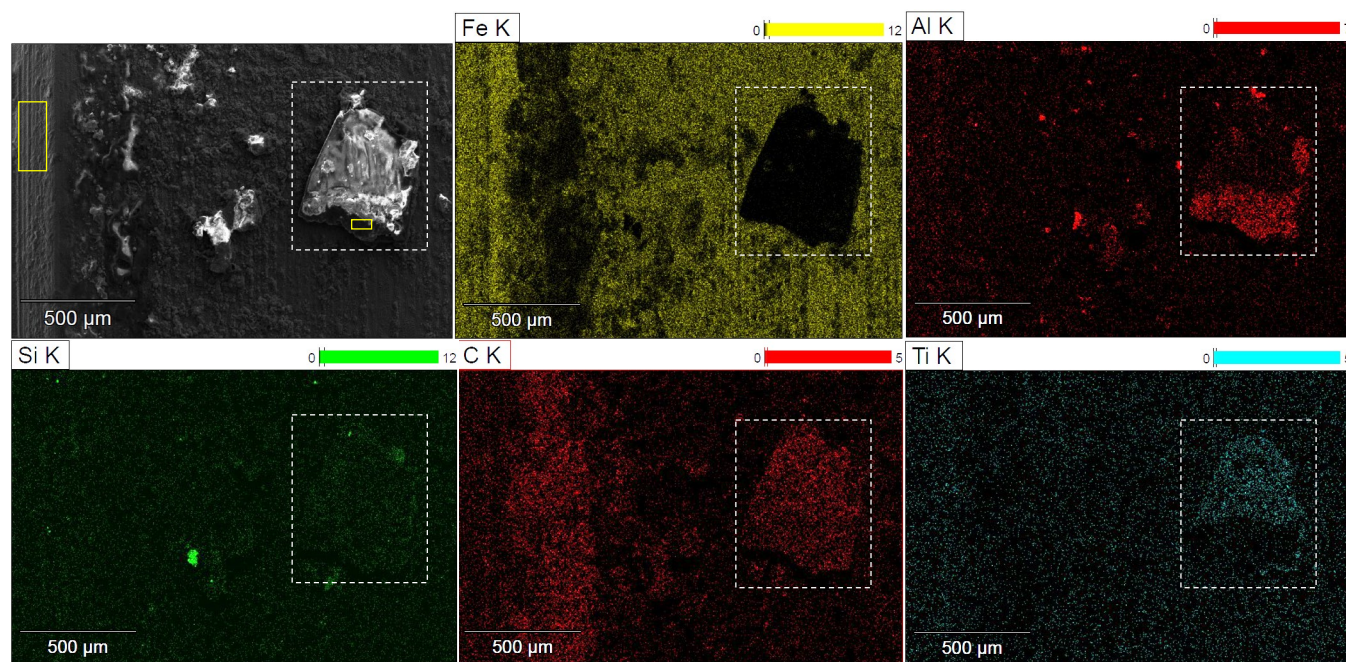


Figure 12: A photograph of the fuel pump rotor and a portion of the shaft. The pump vanes were removed from the slots between lettered rotor quadrants. Wear debris were observed on the sidewalls of rotor quadrants A, B, and C and an example of a larger wear debris particle is indicated by the black arrow. The yellow dashed line highlights the boundary of the dark region observed on the shaft which emanated from the rotor, consistent with thermal damage/heat tint.



Fuel pump rotor sidewall wear debris particle

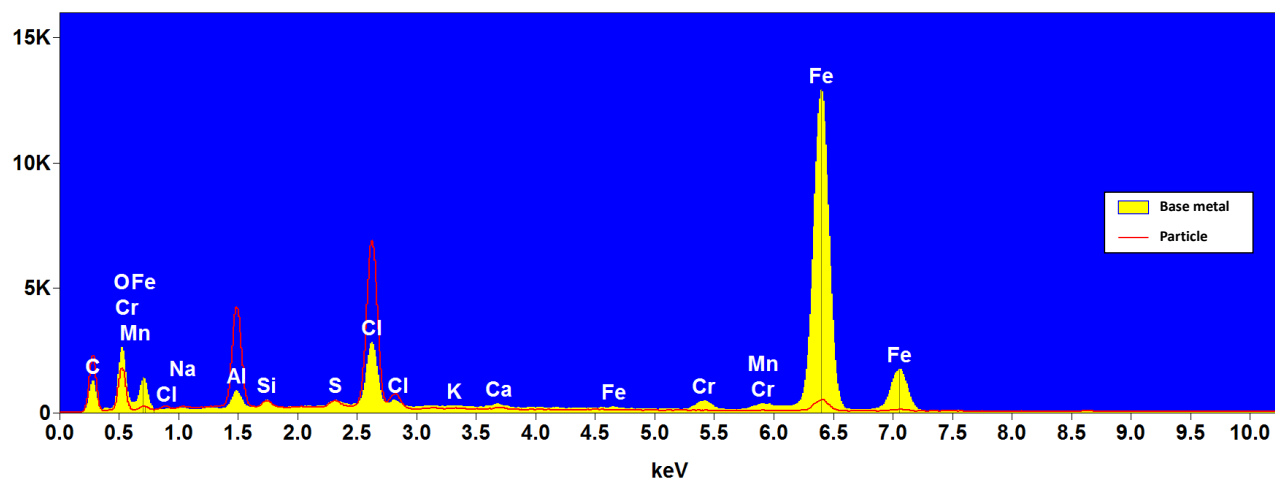


Figure 13: The upper left image shows a secondary electron image of a wear particle observed on the rotor sidewall of quadrant B. The yellow boxes indicate locations where the EDS spectra overlaid at the bottom of the figure were acquired. A dashed white box surrounds the particle location in the electron and elemental map images. Elemental maps from the same field of view as the electron image were generated to show compositional variation observed between the particle and surrounding rotor surface.

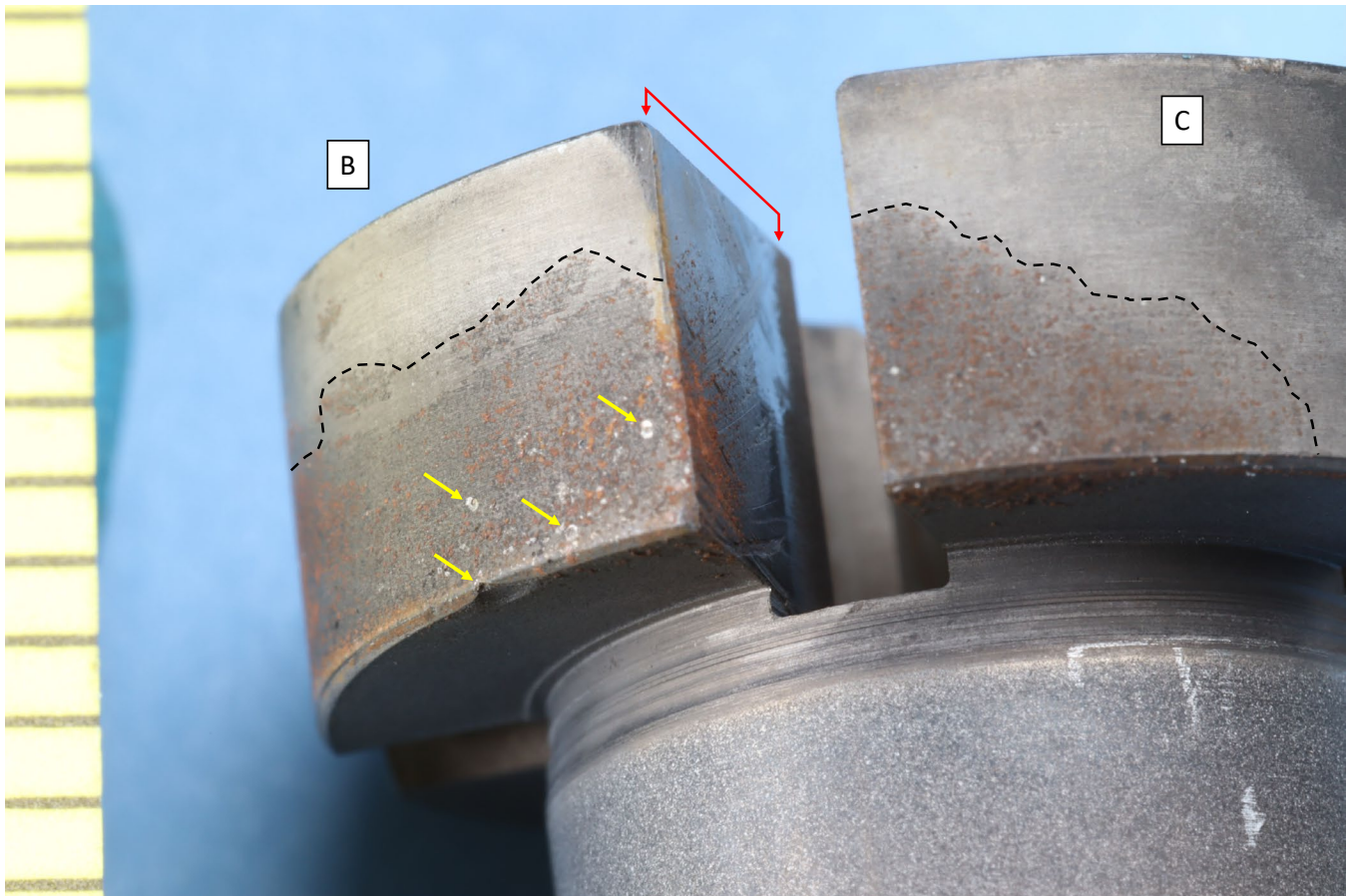


Figure 14: A photograph of the fuel pump rotor and vane slot between quadrants B and C after cleaning. The black dashed line highlights the boundary of the rougher area where wear debris were observed. Yellow arrows identify larger examples where pits and spalled material were observed. An area on the slot face of quadrant B bound by the red arrows was shinier in appearance and exhibited gouges.

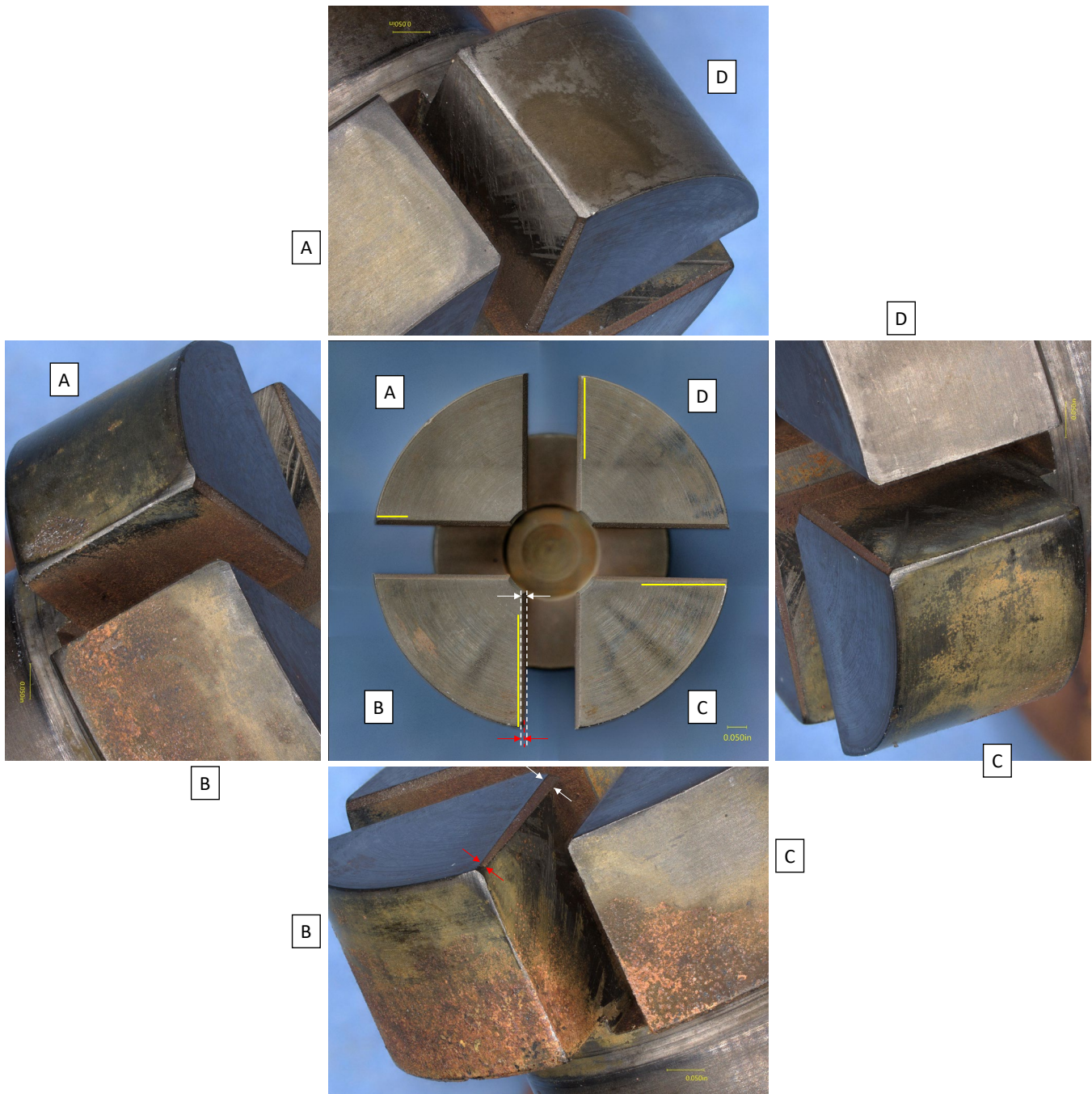


Figure 15: Digital microscope images of the fuel pump rotor and slot faces. The central image shows a view of the top surface of the rotor looking down the drive shaft. Yellow lines in the central image correspond to the slot face being viewed in the adjacent digital microscope images. The relative length of the yellow lines approximates the maximum extent of the gouging along the slot face. White and red arrows indicate an example of decreasing chamfer length between the top and sidewall surfaces from the central axis to the outer diameter on sidewalls where gouges were observed.

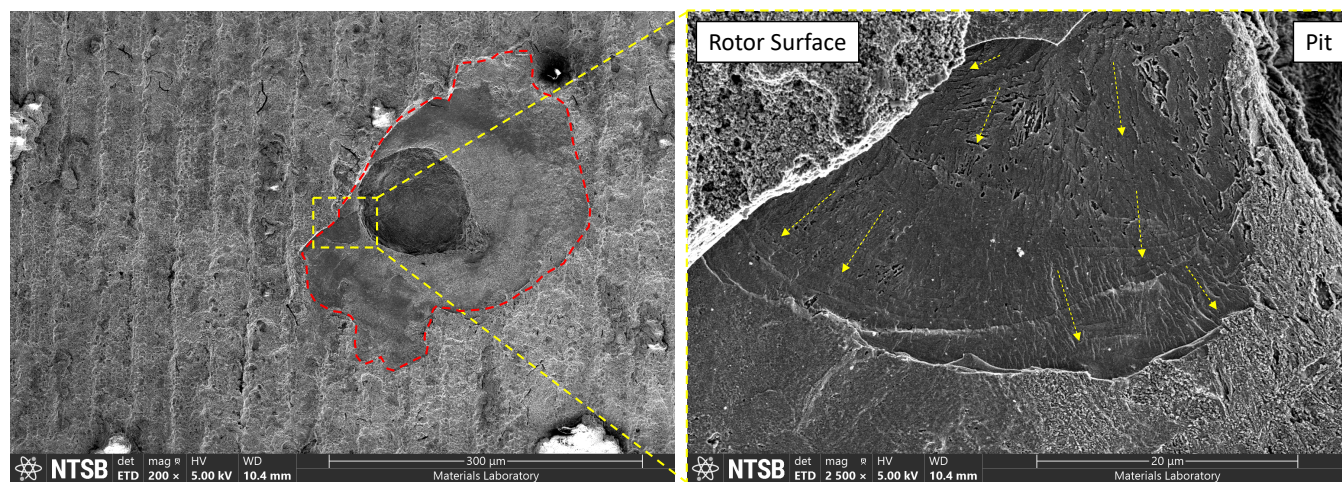


Figure 16: A secondary electron image of a pit observed on the rotor surface as identified in figure 10 is shown on the left. The area within the red dashed boundary exhibited spalled material. On the right is a higher magnification secondary electron image of the area in the yellow box showing features consistent with fatigue striations progressing near the pit along a surface approximately parallel to and beneath the rotor surface. Yellow arrows indicate the general direction of crack propagation which continued under rotor surface material that had not spalled.

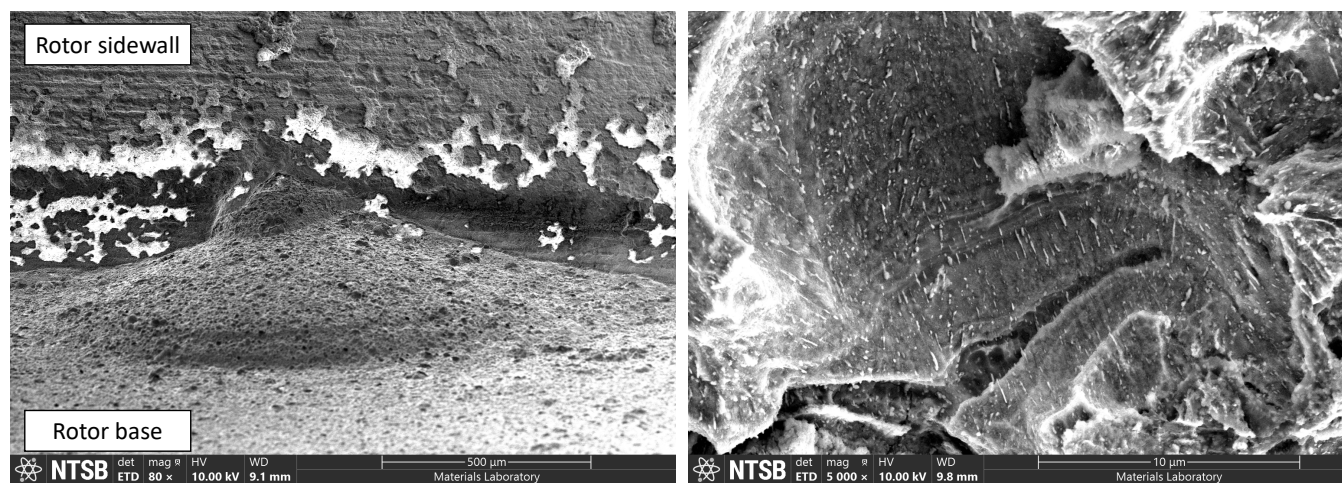


Figure 17: A secondary electron image of an area of spalled material observed at the corner of the rotor sidewall and base as identified in figure 14 is shown on the left. On the right is a higher magnification secondary electron image showing features consistent with fatigue striations, near the spalled material, progressing from lower right to upper left as oriented.