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MATERIAL AND PROCESS ENGINEERING

Model No.: B200
Report No.: 23-359-005

Examination of B200 Super King Air N8170J Main Landing Gear Actuator, P/N 99-810057-653

Report Date: 05/05/2023

Prepared By: See Electronic Signature Sheet

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Revision History

<u>Letter</u>	<u>Date</u>	<u>Description</u>	<u>By</u>	<u>Approved</u>
		EC: 088113 Enovia: CACECO-180369		
-	05/05/23	Initial Release.	See Electronic Signature Sheet	
A	05/15/23	Removed Appendix B and incorporated case requirements from Drawing Notes into Table II and Table IV.	See Electronic Signature Sheet	

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References

Technical References

1. *Failure Analysis and Prevention - Failures of Gears.* American Society of Metals Handbook, Volume 10
2. Hawker Beechcraft Corporation – Manufactured Component Maintenance Manual – Landing Gear Actuators P/N 99-810057, 115-810021, 115-820046, and 50-820208

Industry Specifications

3. AMS 6260 Steel, Bars, Forgings, and Mechanical Tubing and Forging Stock 1.2Cr - 3.2Ni - 0.12Mo (0.07 - 0.13C) (9310)
4. ASTM E140 Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness
5. ASTM A370 Standard Test Methods and Definitions for Mechanical Testing of Steel Products.
6. AMS2759/7 Carburizing and Heat Treatment of Carburizing Grade Steel Parts

1.0 SUBJECT INFORMATION

On landing approach to Bay St Louis-Stennis International Airport, MS (KHSB), the pilot attempted to extend the landing gear. While attempting to extend the landing gear, the passengers heard a "loud bang," and the pilot reported that the gear would not extend. The pilot diverted to Gulfport-Biloxi International Airport, MS (GPT), and attempted to extend the landing gear manually but was unsuccessful as the system was jammed. The pilot landed without the gear fully extended, damaging the aircraft. No injuries were reported.

P/N:	99-810057-653	Model:	200 Super King Air
Part Description:	Main Landing Gear - Manual Actuator	A/C S/N:	BB-728
		Tail Number:	N8170J
Part Serial Number:	050425030	Hours in Service:	-

The suspect landing gear actuator was submitted for evaluation to determine the means of failure. The part was supplied by Florida Air Recovery, Jacksonville, FL for review.

2.0 EXAMINATION

Before examination, the Hawker Beechcraft Corporation Manufactured Component Maintenance Manual - Landing Gear Actuators P/N 99-810057 and 115-810021 was reviewed. A diagram was taken from the maintenance manual and merged with a table that defines each component in Figure 1. The terminology referenced in this report follows the nomenclature identified in Figure 1.

2.1 Received Condition

The assembly arrived packaged as shown in Figure 2. The assembly was carefully removed, and the exterior was documented along with any visible damage, reference Figure 3 and Figure 4. Before beginning the teardown of the assembly, a functional test was performed. The pinion gear shaft could only be turned about a quarter of a rotation and did not extend or retract the gear assembly. However, the actuator nut was able to rotate freely, indicating that the thread interface between the actuator nut and actuator screw remained functional.

2.2 Teardown

The removal steps provided in the maintenance manual were followed, starting with the removal of the Actuator Brake Assembly, as shown in Figure 5. There was one fastener that did not directly match the maintenance manual but did not appear to impact the function of the actuator brake assembly, reference Figure 6. Next, the boot was removed from the upper end of the screw housing, Figure 7. The clevis and spring were then removed from the Actuator Nut and followed by unscrewing the actuator nut from the assembly, Figure 8. The remaining housing bolts were removed, allowing the housing bottom and upper cover to be removed. The upper cross bolt and cap were removed to allow the actuator screw to be removed, as shown in Figure 9. The lower bearing was removed from the housing. Then, the upper bearing and screw housing (with driven gear) was pressed from the housing. Even with grease packed in the housing, there was visible damage present on the pinion gear, as shown in Figure 10. Finally, the pinion was pressed from the housing.

2.3 Analysis of Damaged Surfaces and Debris Collection

After completing the initial teardown, the grease covered components were cleaned ultrasonically with Acetone to break down any residual grease. The majority of the damage was contained inside the grease filled housing. Both gears as well as the inside of the actuator housing showed signs of damage. The

contents of the grease were inspected to find pieces of the broken teeth. Each of the bearings were cleaned and checked for wear. No significant wear patterns on the bearings were observed, and each bearing could rotate freely after cleaning. No damage was present on the main screw threads. The clevis and large spring showed no visible indications of damage. The brake assembly and components were fully intact and did not exhibit signs of abnormal wear. Figure 11 provides an exploded view of the assembly, with the majority of the components having been cleaned of grease.

2.3.1 Pinion/Drive Gear (115-810028-3)

Once the grease was removed from both gears, the part markings became visible. Both gears have similar scribed markings paired with their part number, 28606-31, indicating they are a matched set.

As shown in Figure 12, the pinion gear had 8 broken teeth, with the majority of the failures being localized to the root/fillet area of the teeth. Figure 13 and Figure 14 help illustrate the wear and breakage visible on the pinion gear. There were cracks present near the dedendum of the teeth still attached. The pinion gear had evidence of pitting along the pitch line of the teeth. Plastic flow was present along the addendum of the teeth. No discoloration was present on the surfaces of the teeth. Figure 15 contains a few of the broken teeth that have interior secondary fractures within the teeth. The different types of wear observed on the broken sections of the gear teeth are shown in Figure 16. Both Figure 17 and Figure 18 include SEM Images of the different types of wear observed.

After reviewing the damage, the gear was sectioned for further composition and microhardness analysis. The composition results are provided in Appendix A as part of Figure A-1 and are summarized in Table I.

Table I: Composition Analysis - Pinion Gear (9310)

Element	Measured	Material Requirements per AMS 6260	
	(% Weight)	Minimum	Maximum
Carbon (C)	0.11	0.07	0.13
Manganese (Mn)	0.47	0.40	0.70
Phosphorus (P)	0.009	-	0.025
Sulfur (S)	<0.005	-	0.025
Silicon (Si)	0.27	0.15	0.35
Copper (Cu)	0.11	-	0.35
Nickel (Ni)	3.33	3.00	3.50
Chromium (Cr)	1.23	1.00	1.40
Molybdenum (Mo)	0.11	0.08	0.15
Boron (B)	<0.0005	-	0.001

Note: Data was provided in Arrow Laboratory Report #e57xb093

To verify the case hardening of the gear, microhardness measurements were collected on an undamaged portion of several gear teeth. No wear was present near the wider end of the bevel gear teeth, as shown in Figure 19. A cross section was taken through the region defined by the dotted orange line in Figure 19 to obtain the microhardness measurements reported in the table below. The measured case hardness did not conform to the drawing requirements but the case depth did meet the drawing requirements. After hardness testing, the cross-section was etched with 2% Nital to reveal the case within the microstructure.

Table II: Microhardness Results – Pinion Gear

Distance from surface	Measured HK (500g)				Drawing Requirement: Case ≥ 58 HRC Effective Case Depth (0.010" – 0.020")		
(inches)	Spot 1	Spot 2	Spot 3	AVG	Hardness HK (500g)	Hardness (HRC)	Strength (ksi)
0.003"	586	572	588	582	690 min ¹	58 min	-
0.005"	592	596	585	591	542 min ²	50 min ²	-
0.010"	562	549	538	550			
0.015"	520	494	471	495			
0.020"	473	451	458	461			
0.025"	451	437	430	439	297 - 438 ¹	28 - 43 ³	130 - 200
0.030"	451	422	445	439			
0.035"	446	431	431	436			
0.040"	445	425	442	437			
0.045"	445	433	445	441			
0.050"	431	430	439	433			

Note: 1. Hardness conversion to HK (500g) from HRC per Table 1 of ASTM E140
2. Effective Case Depth Hardness Requirements per Section 3.6.1.2 of AMS2759/7
3. Strength to hardness conversion for ksi to HRC per Table 2 of ASTM A370

2.3.2 Driven Gear (115-810025-1 Braze Assy – Gear 115-810027-1)

The damaged driven gear retained most of its teeth, as shown in Figure 20. A combination of partial tooth breakage/cracks and plastic flow were the primary wear patterns on the driven gear, reference Figure 21. No discoloration was present on the surfaces of the teeth. The plastic flow was localized to the addendum of the gear teeth, but cracks were found in regions near or below the pitch line of the teeth.

After reviewing the damage, the gear was sectioned for composition and microhardness analysis. The composition results are provided in Appendix A as part of Figure A-2 and are summarized in Table III.

Table III: Composition Analysis - Driven Gear (9310)

Element	Measured	Material Requirements per AMS 6260	
	(% Weight)	Minimum	Maximum
Carbon (C)	0.11	0.07	0.13
Manganese (Mn)	0.56	0.40	0.70
Phosphorus (P)	0.008	-	0.025
Sulfur (S)	<0.005	-	0.025
Silicon (Si)	0.26	0.15	0.35
Copper (Cu)	0.03	-	0.35
Nickel (Ni)	3.15	3.00	3.50
Chromium (Cr)	1.15	1.00	1.40
Molybdenum (Mo)	0.12	0.08	0.15
Boron (B)	<0.0005	-	0.001

Note: Data was provided in Arrow Laboratory Report #e57xb094

To verify the case hardening of the gear, microhardness measurements were collected on an undamaged portion of a gear tooth. No wear was present near the base of the outside surface of the teeth, as shown in Figure 22. A cross section was taken through the region defined by the dotted purple line in Figure 22 to obtain the microhardness measurements reported in the table below. The measured case hardness and depth did not meet the drawing requirements. The hardness tests did not indicate the presence of a case layer. Etching with 2% Nital, after hardness testing, did not reveal a case layer.

Table IV: Microhardness Results – Driven Gear

Distance from surface	Measured HK (500g)				Drawing Requirement: Case ≥ 58 HRC Effective Case Depth (0.012" – 0.025")		
(inches)	Spot 1	Spot 2	Spot 3	AVG	Hardness HK (500g)	Hardness (HRC)	Strength (ksi)
0.005"	411	408	403	407	542 min ²	50 min ²	-
0.010"	406	402	411	406			
0.015"	406	404	395	402			
0.020"	404	407	408	406			
0.025"	403	410	406	406			
0.030"	407	403	395	402	297 - 438 ¹	28 - 43 ³	130 - 200
0.035"	417	408	407	411			
0.040"	400	403	408	404			
0.045"	403	408	402	404			
0.050"	399	403	410	404			

Note: 1. Hardness conversion to HK (500g) from HRC per Table 1 of ASTM E140
 2. Effective Case Depth Hardness Requirements per Section 3.6.1.2 of AMS2759/7
 3. Strength to hardness conversion for ksi to HRC per Table 2 of ASTM A370

2.3.3 Actuator Housing (115-810023-3)

The vertical scoring/grooves in the inner bore, as shown in Figure 23, were made during the removal of the damaged driven gear. The secondary damage within the case is likely a result of the gear mesh fracturing/deforming resulting in secondary damage.

2.3.4 Grease Analysis

During the teardown, a sample of the grease was collected from the interior of the actuator after removing the screw housing from the actuator housing. The grease was evaluated using FTIR, and it was identified as Aeroshell 64. Figure 24 illustrates how the grease sample obtained from the actuator closely matched the Aeroshell 64 reference. Based on the peaks present within the Spectrum collected from the sample, the grease did not appear to be degraded.

2.3.5 Upper and Lower Bearings

The Lower bearing was removed in pieces due to its design utilizing a floating bearing cage. The components were cleaned of grease and visually inspected for damage, reference Figure 25. The Upper Bearing was pressed from the screw housing and then inspected. The bearing cage prevented any non-destructive teardown of the bearing. Visual inspection of the assembled bearing was done after cleaning, and no immediate indicators of wear or damage were present, reference Figure 26.

3.0 FINAL OBSERVATIONS / CONCLUSIONS

Completion of the examination produced the following conclusions:

- The initial component failure originated between the straight bevel gear set.
- Breakage of the teeth from the pinion varied in fracture surface and location. The individual teeth that broke off have different features in comparison to the 6 adjacent teeth that were broken.
 - The individual broken teeth show cracking features that would have developed progressively before failure.
 - The group of adjacent broken teeth have evidence of shear overload and tensile overload indicating the failure was abrupt and possibly related to shock overloading.
 - Due to smearing that occurred during the final stages of mechanical failure it obscures additional evidence to the failure modes present.
- The broken teeth recovered from the pinion gear have internal secondary cracks.
- The driven gear teeth were plastically deformed and cracked along the tip of the addendum as it smeared against the broken section of pinion teeth. Additional cracks were observed near the root of the driven gear but cannot be confirmed as either a result of fatigue or overload cracking.
- The appropriate grease was used and abundant within the housing.
- Both the pinion and driven gears were confirmed to be the correct alloy per the drawing requirements.
- The pinion gear has effective case hardening to the appropriate depth but does not meet the drawing requirements for minimum case hardness.
- The driven gear did not have evidence of case hardening and does not meet the drawing requirements for both effective case depth and minimum case hardness.

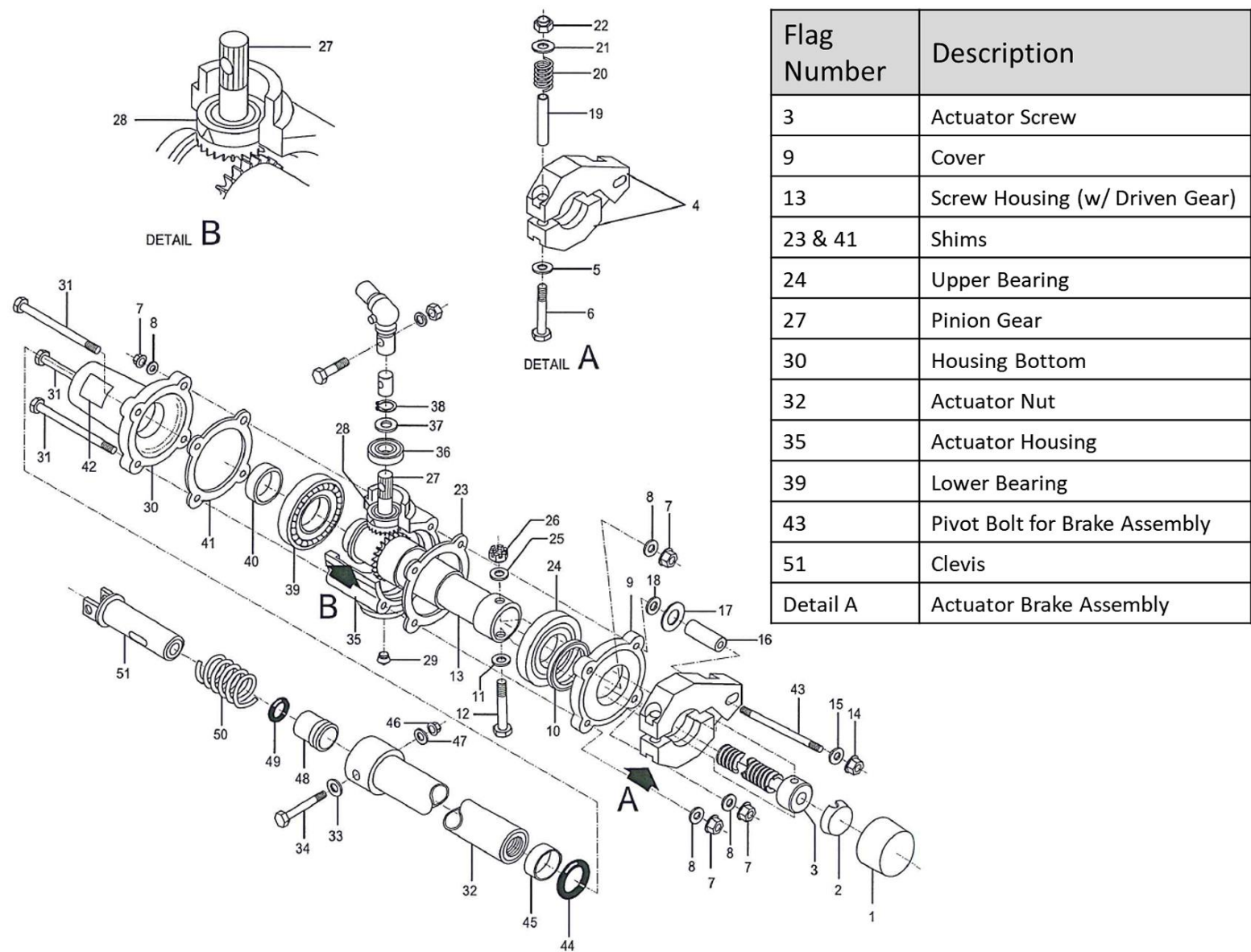


Figure 1: Exploded view taken from maintenance manual, page 32-31-01



Figure 2: Packaging used to ship actuator assembly

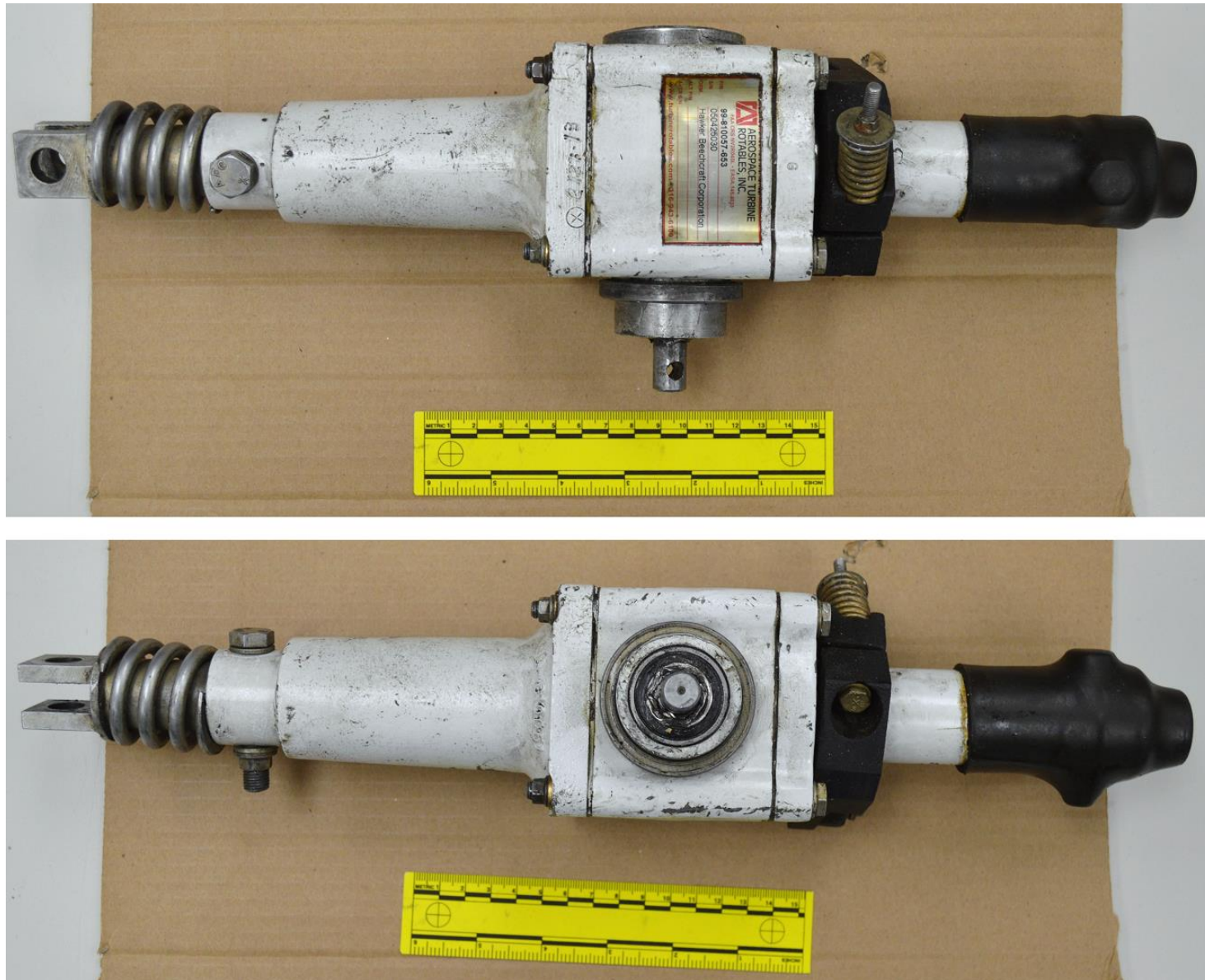


Figure 3: Overview images of exterior of gear actuator assembly as-received (Mag x0.4)

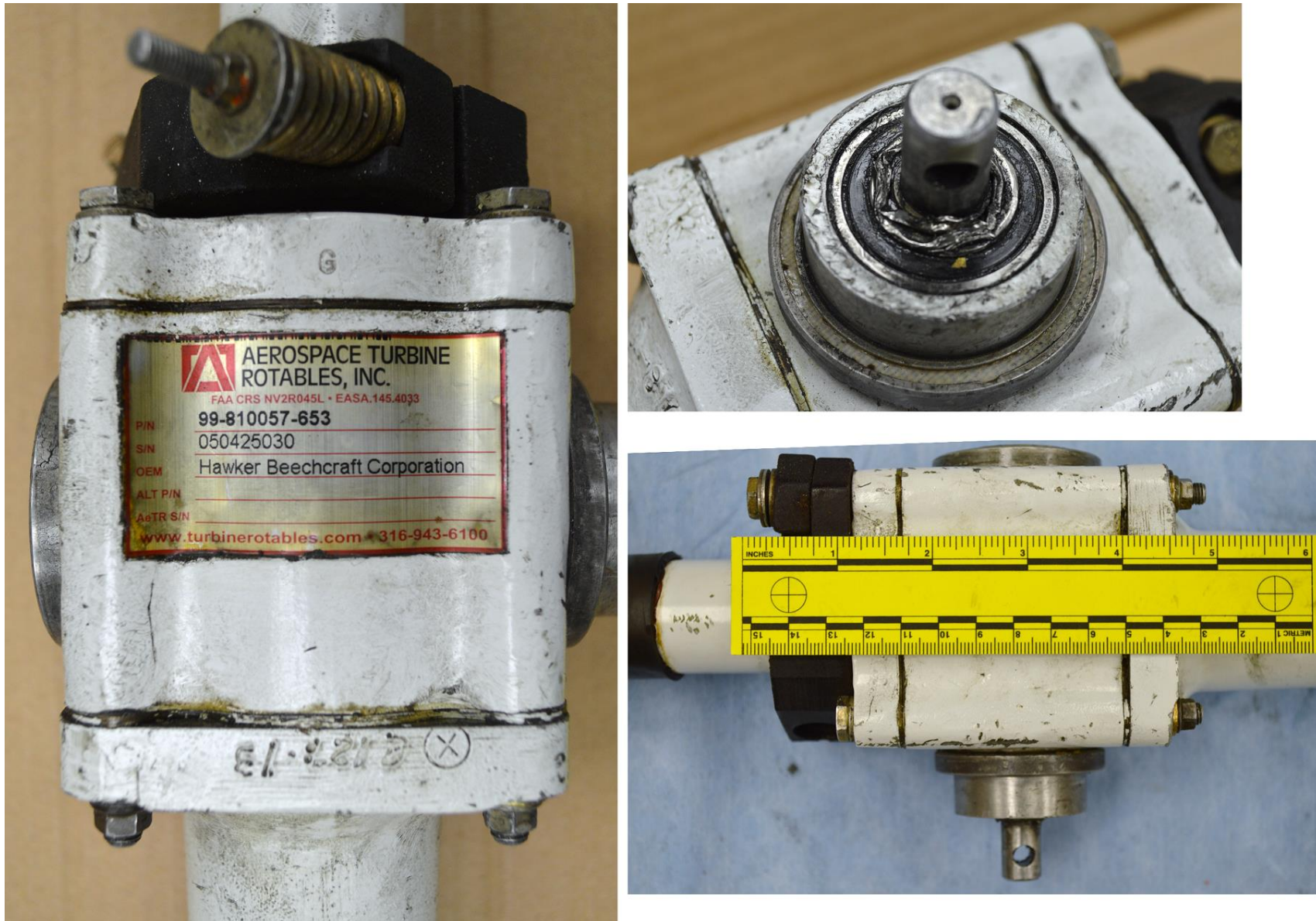


Figure 4: Additional Images of gear actuator assembly as-received

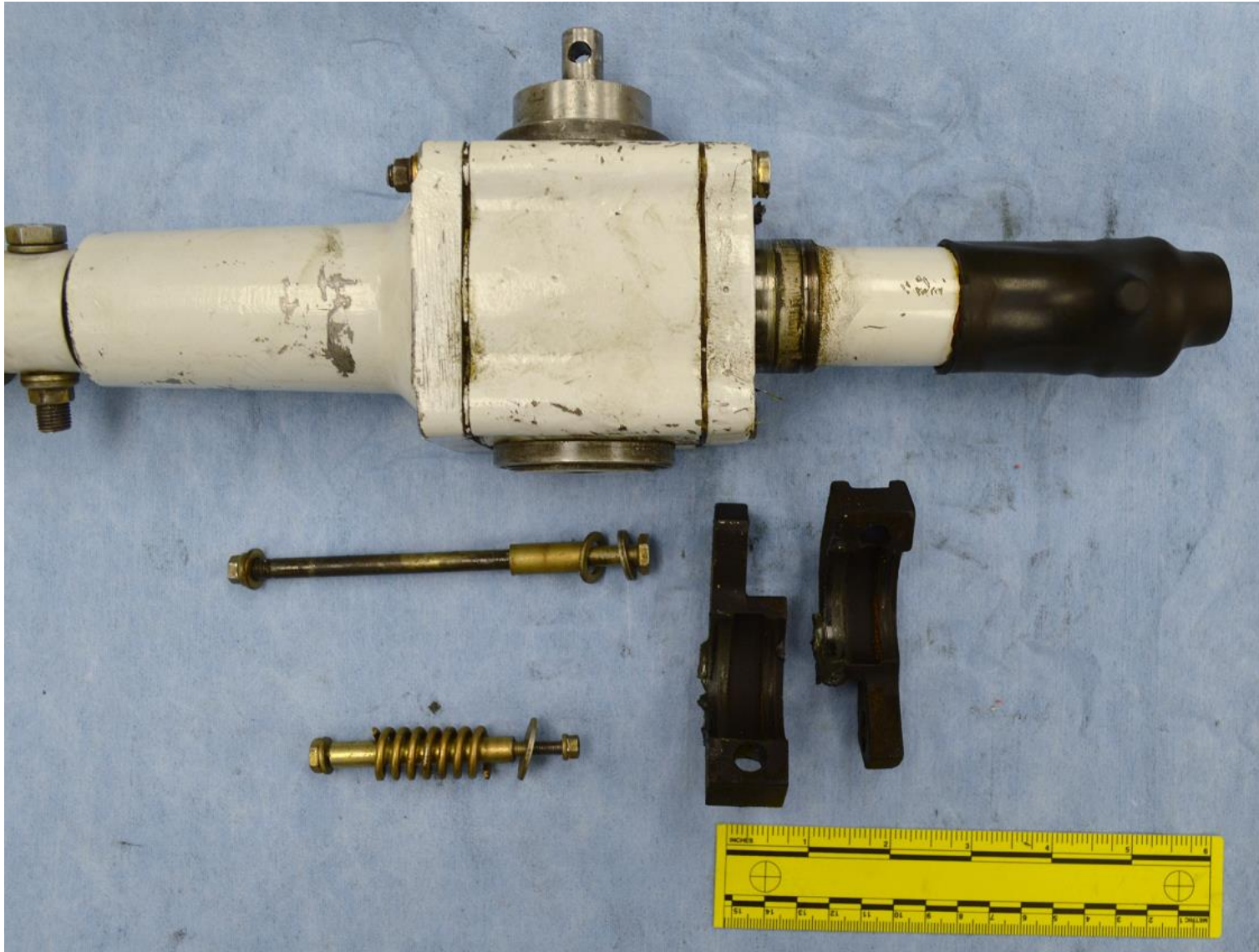


Figure 5: Removal of Brake Assembly (Mag x0.5)



Figure 6: Pivot Bolt for Brake Assembly (Mag x1.5)



Figure 7: Boot Removal (Mag x0.75)

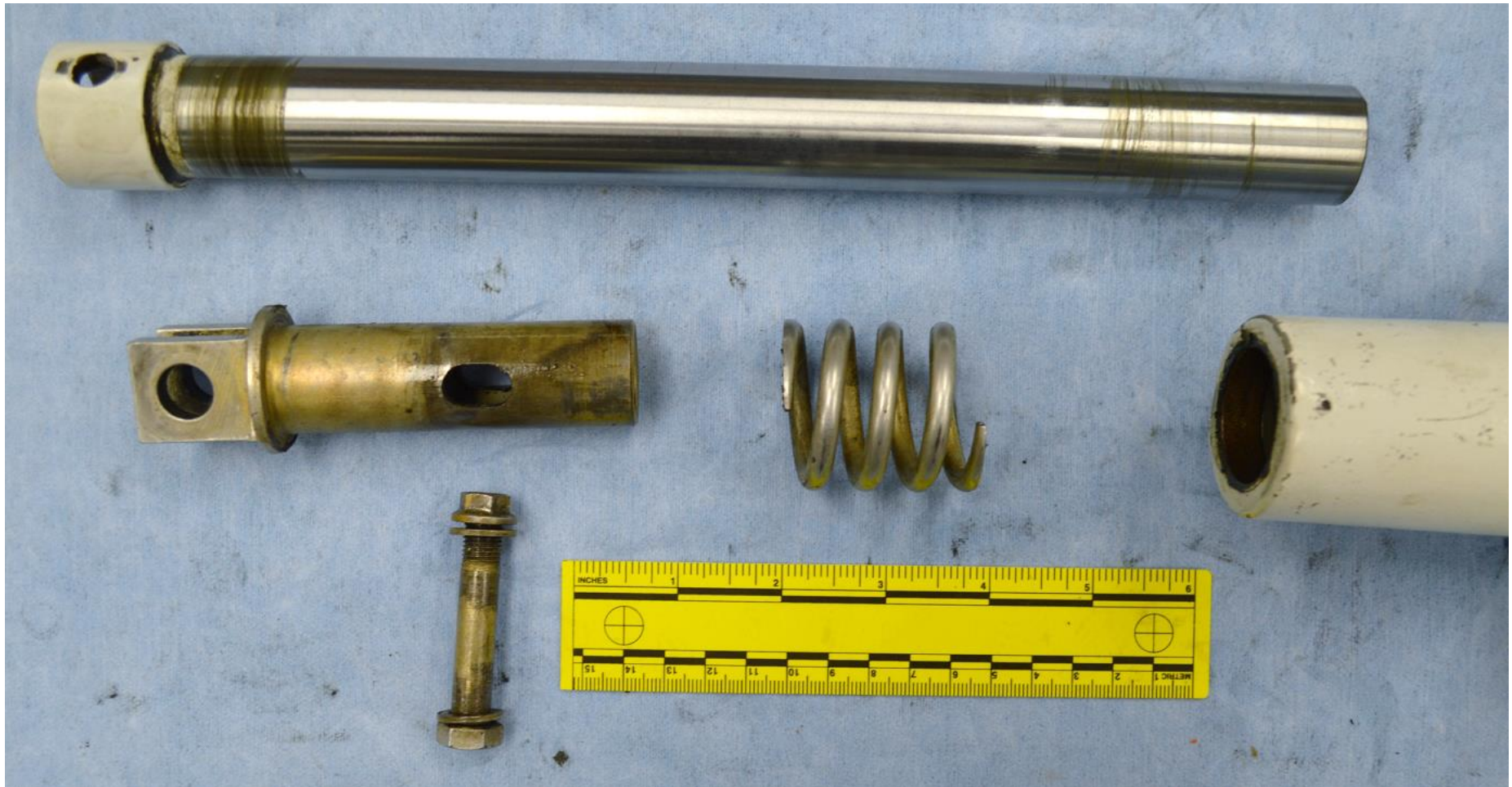


Figure 8: Fork and actuator nut removed from the housing. (Mag x0.6)

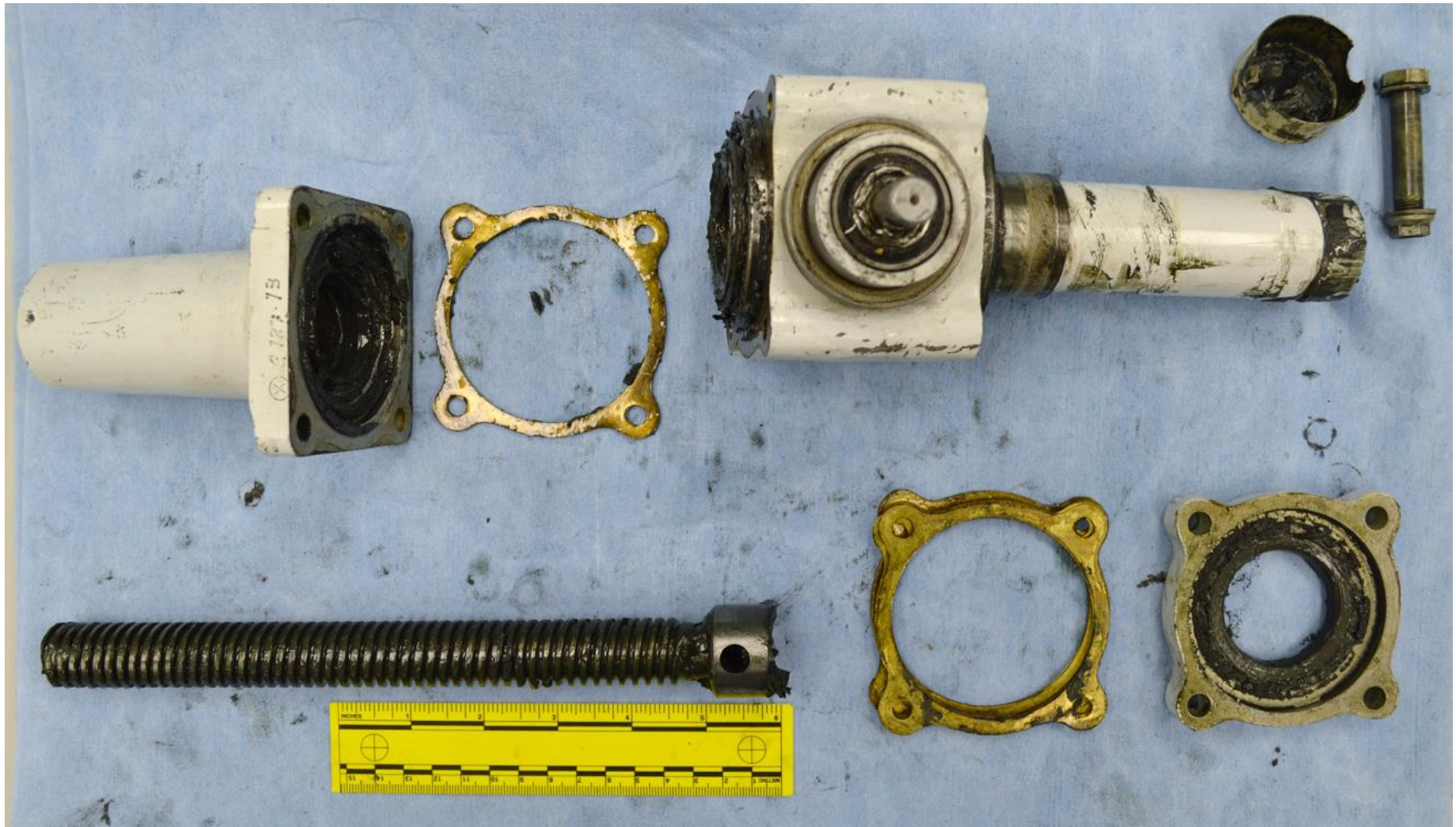


Figure 9: Housing ends and actuator screw removed from the housing. (Mag x0.5)



Figure 10: Housing with grease after removal of screw housing and upper bearing

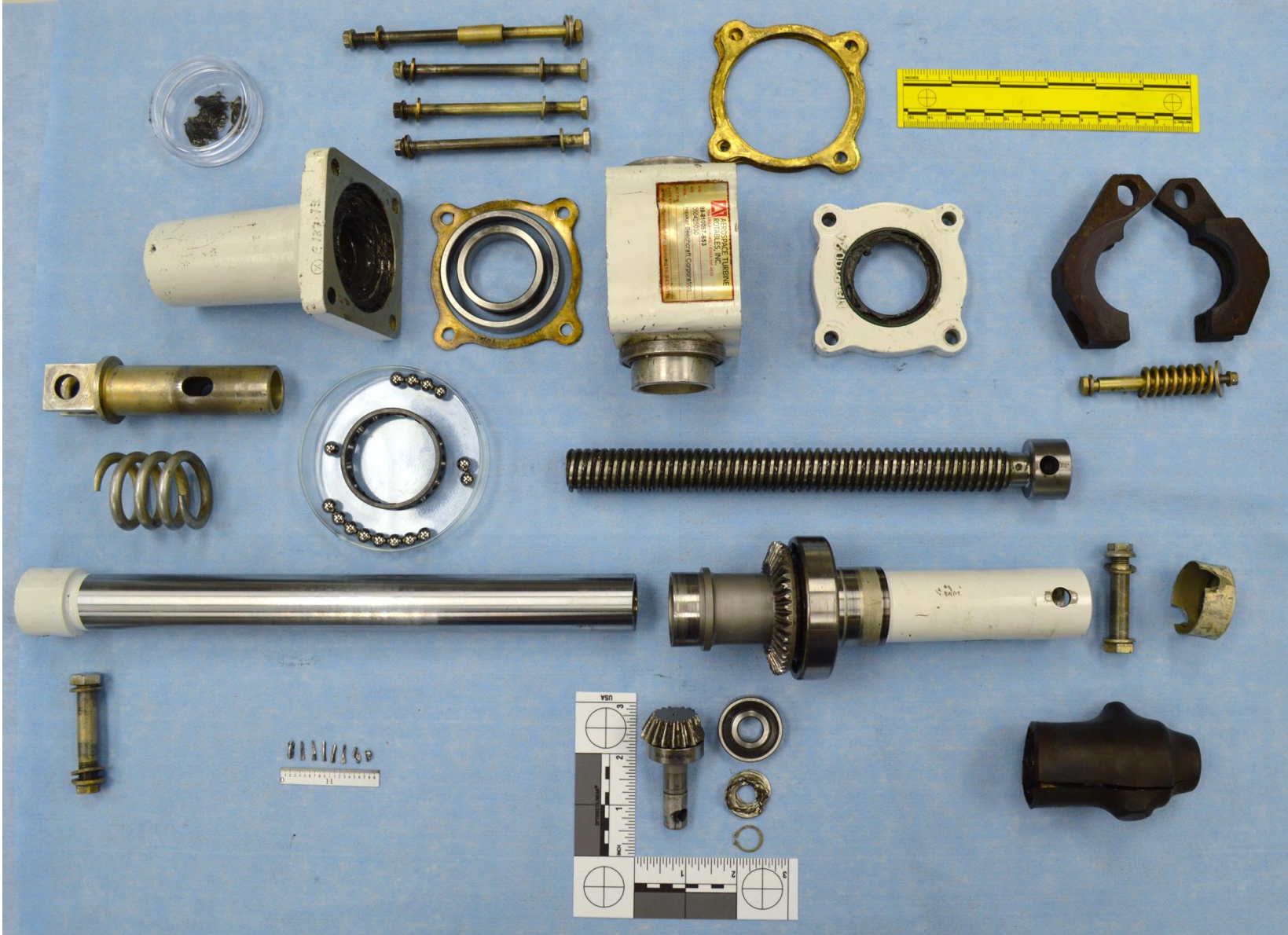


Figure 11: Fully Disassembled Gear Actuator (Mag x0.3)



Broken Gear Teeth



Figure 12: 115-810028-3 Drive Gear and Broken Gear Teeth

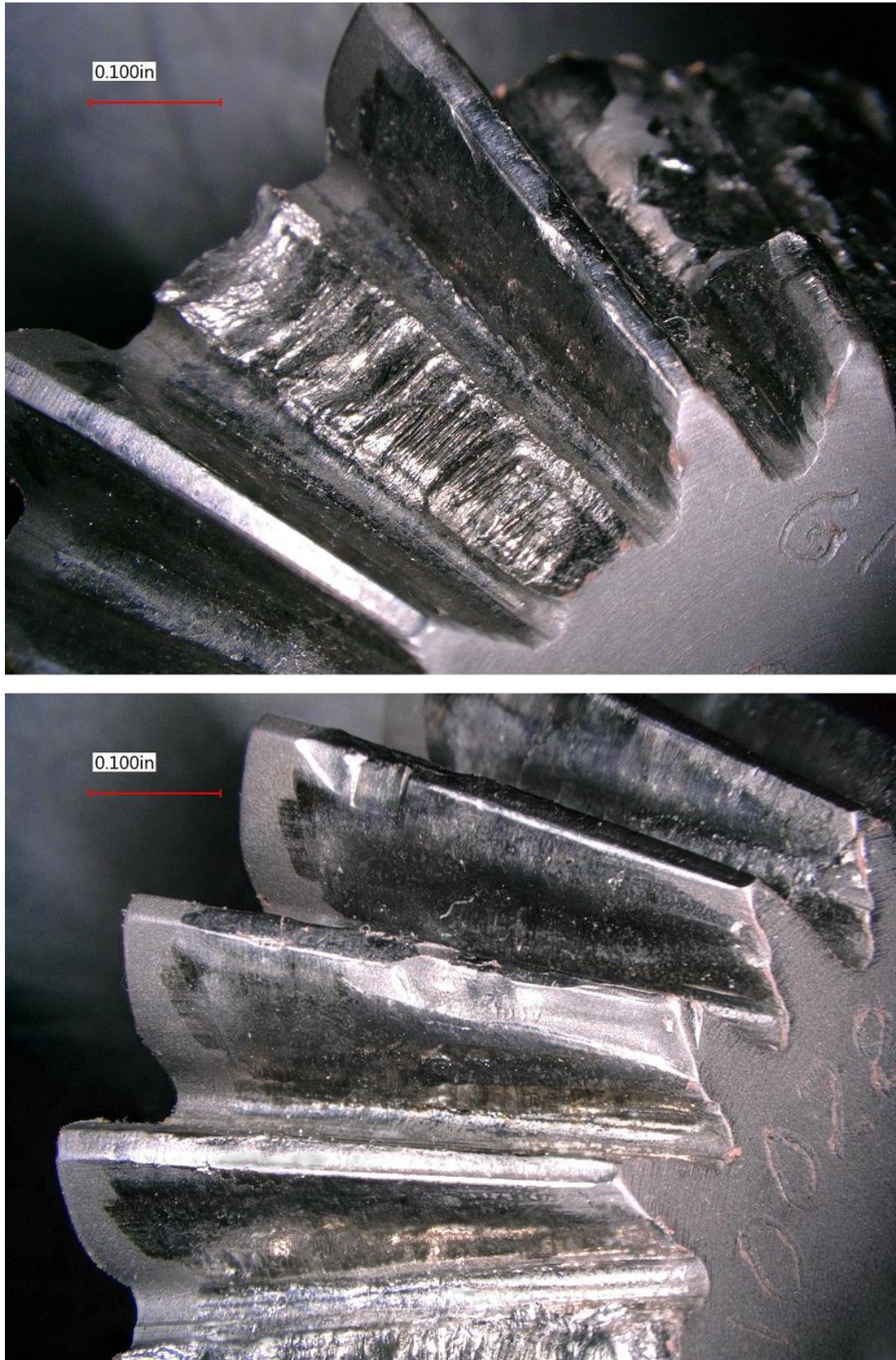


Figure 13: Visible Wear on Drive Gear Teeth. (Mag x8)

Types of Wear:

Plastic Flow

Cracking

Pitch Line Pitting

Flaking

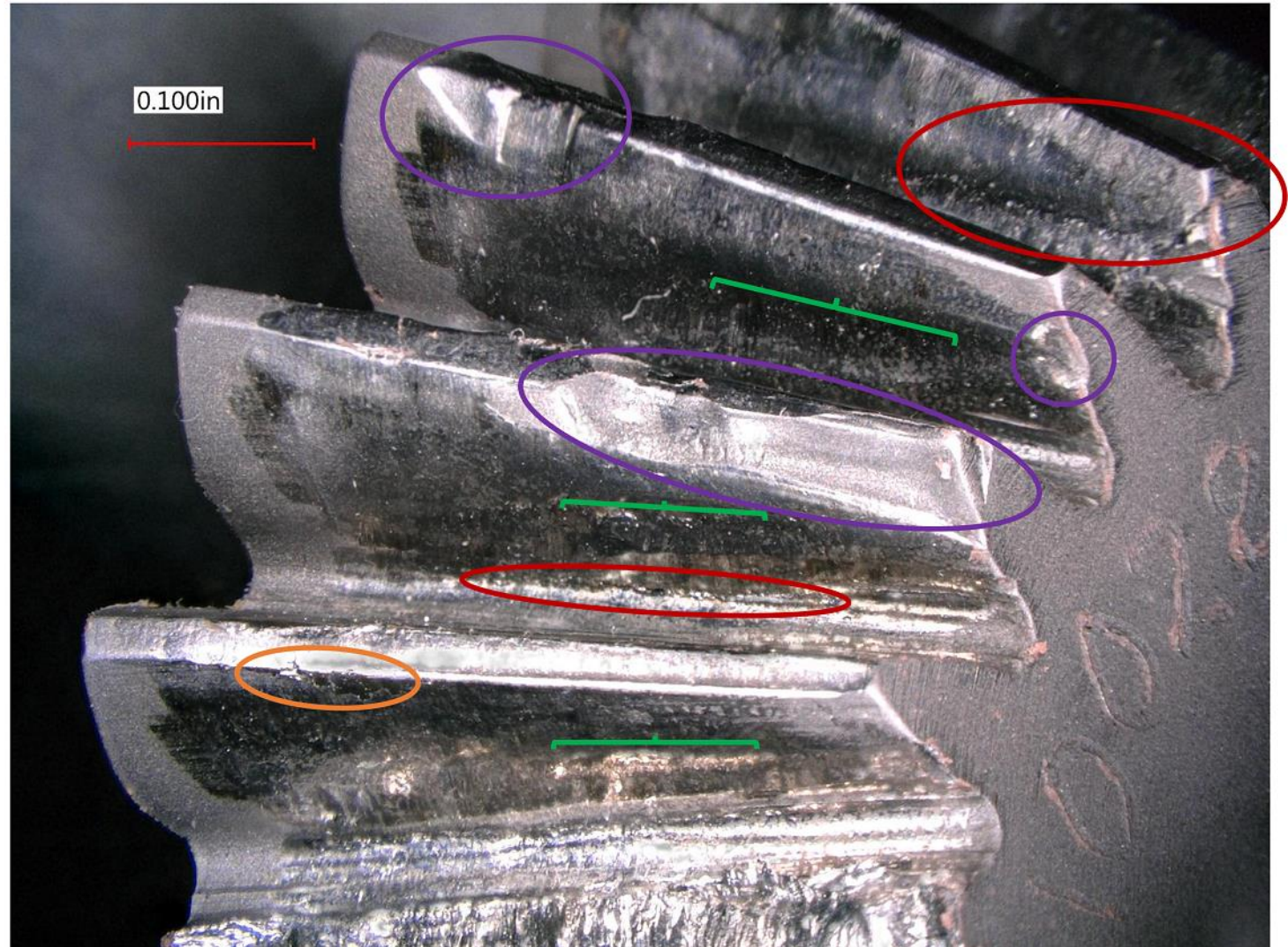


Figure 14: Different Types of Wear Visible on Teeth attached to Drive Gear. (Mag x10)

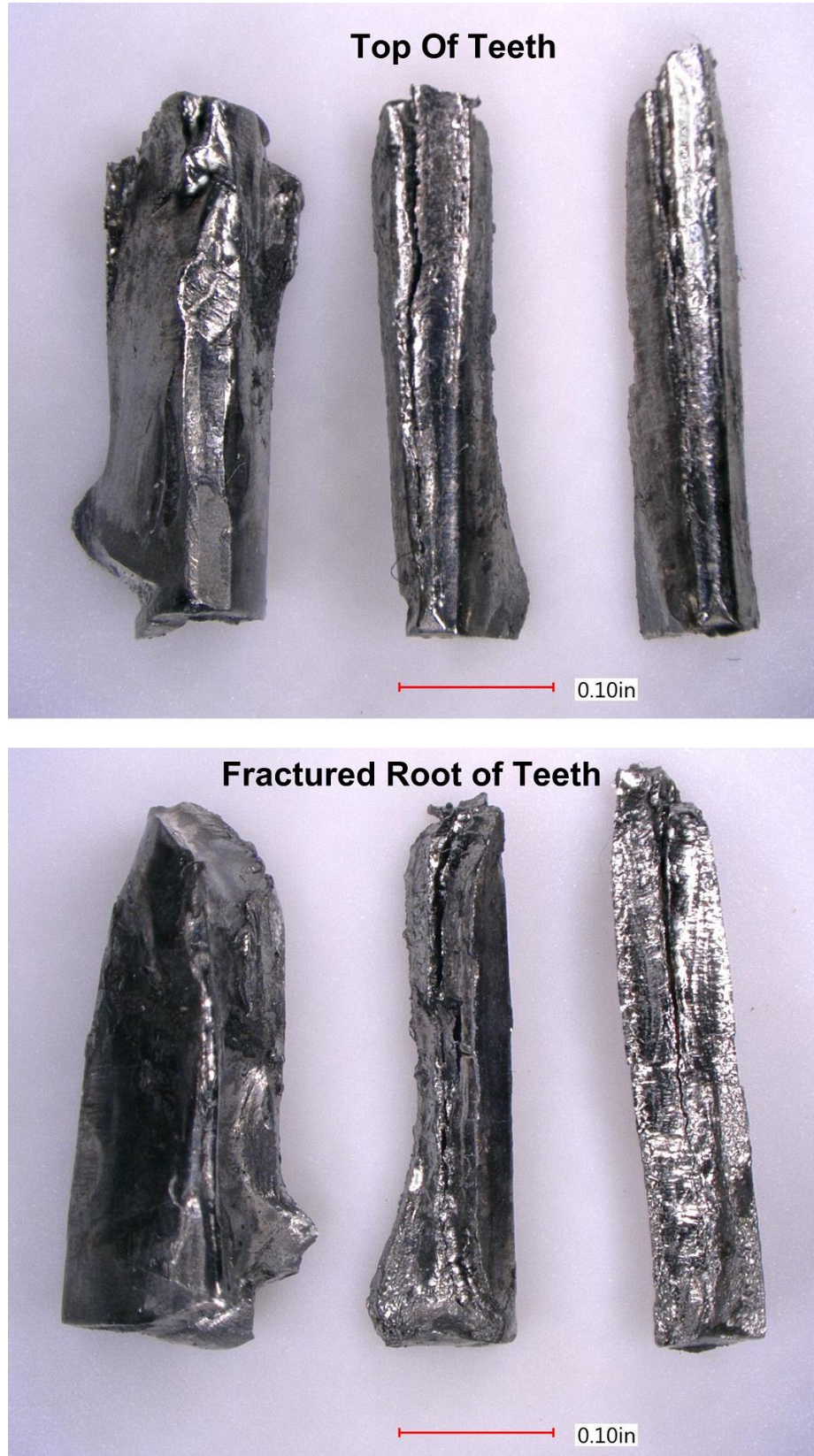
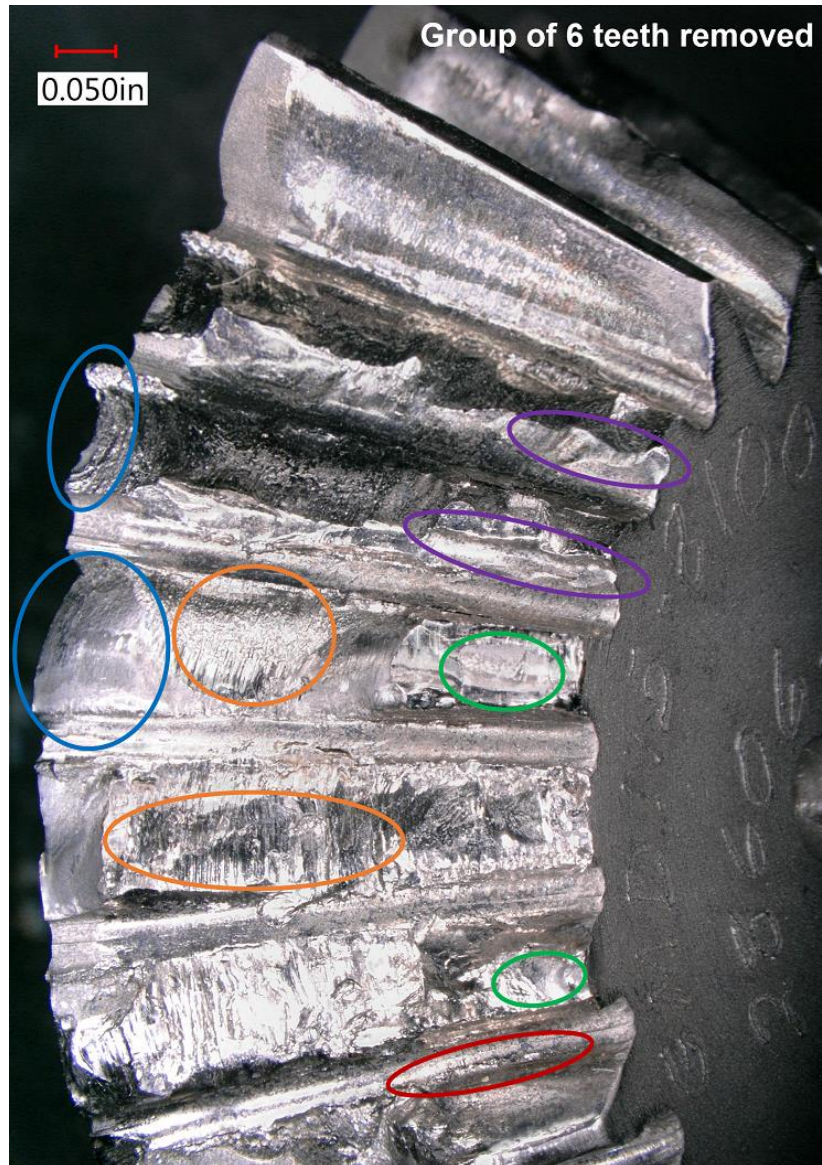


Figure 15: Different Types of Wear Visible on Fractured Teeth from the Drive Gear. (Mag x8)



Types of Wear observed:

Plastic Flow

Cracking

Shear Overload

Smearing

Mixed Shear & Tensile Overload



Figure 16: Different Types of Wear Visible on Drive Gear Where Teeth are Missing.

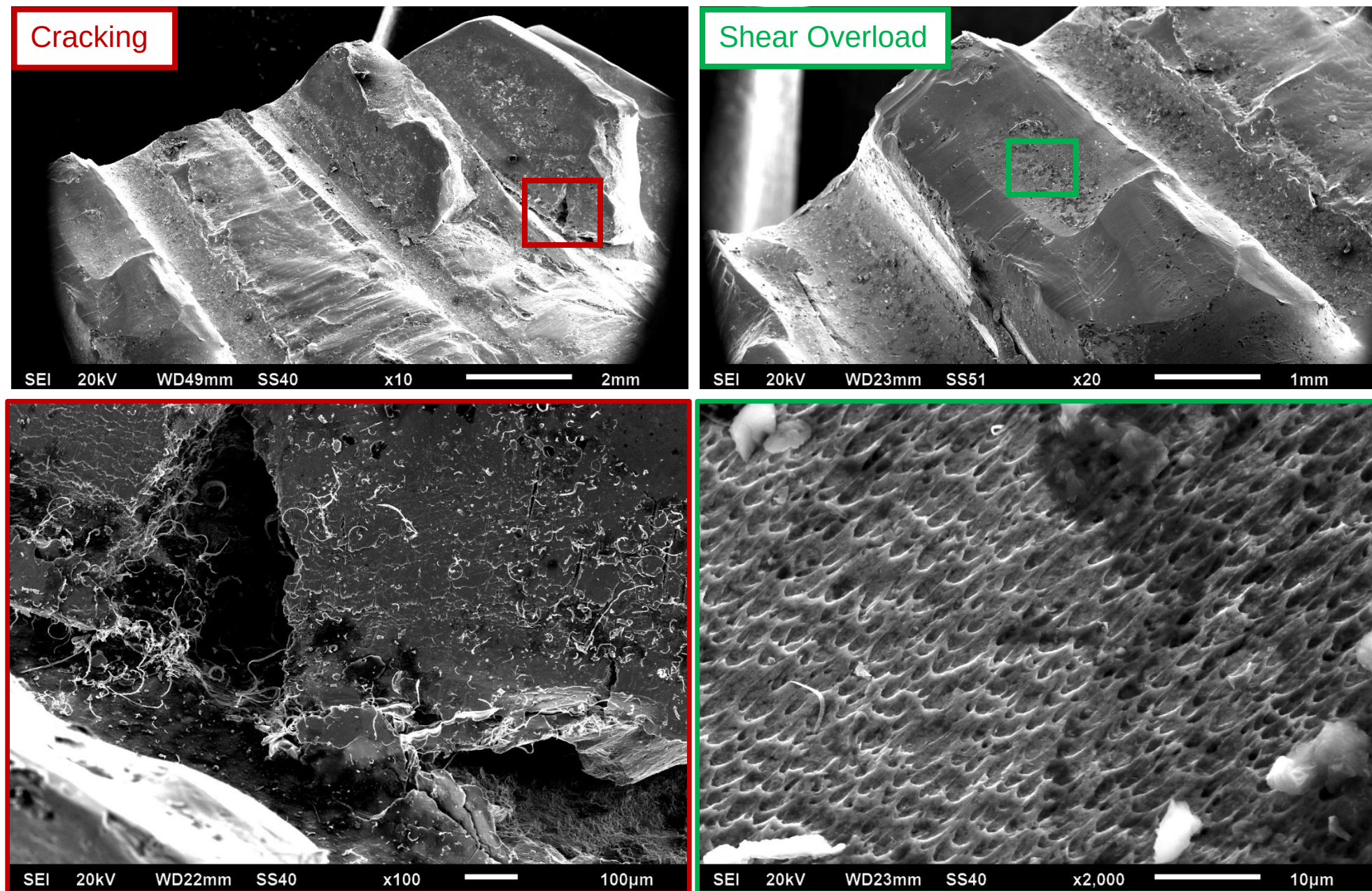


Figure 17: SEM Images of Different Types of Wear Visible on Drive Gear Where Teeth are Missing - Part 1

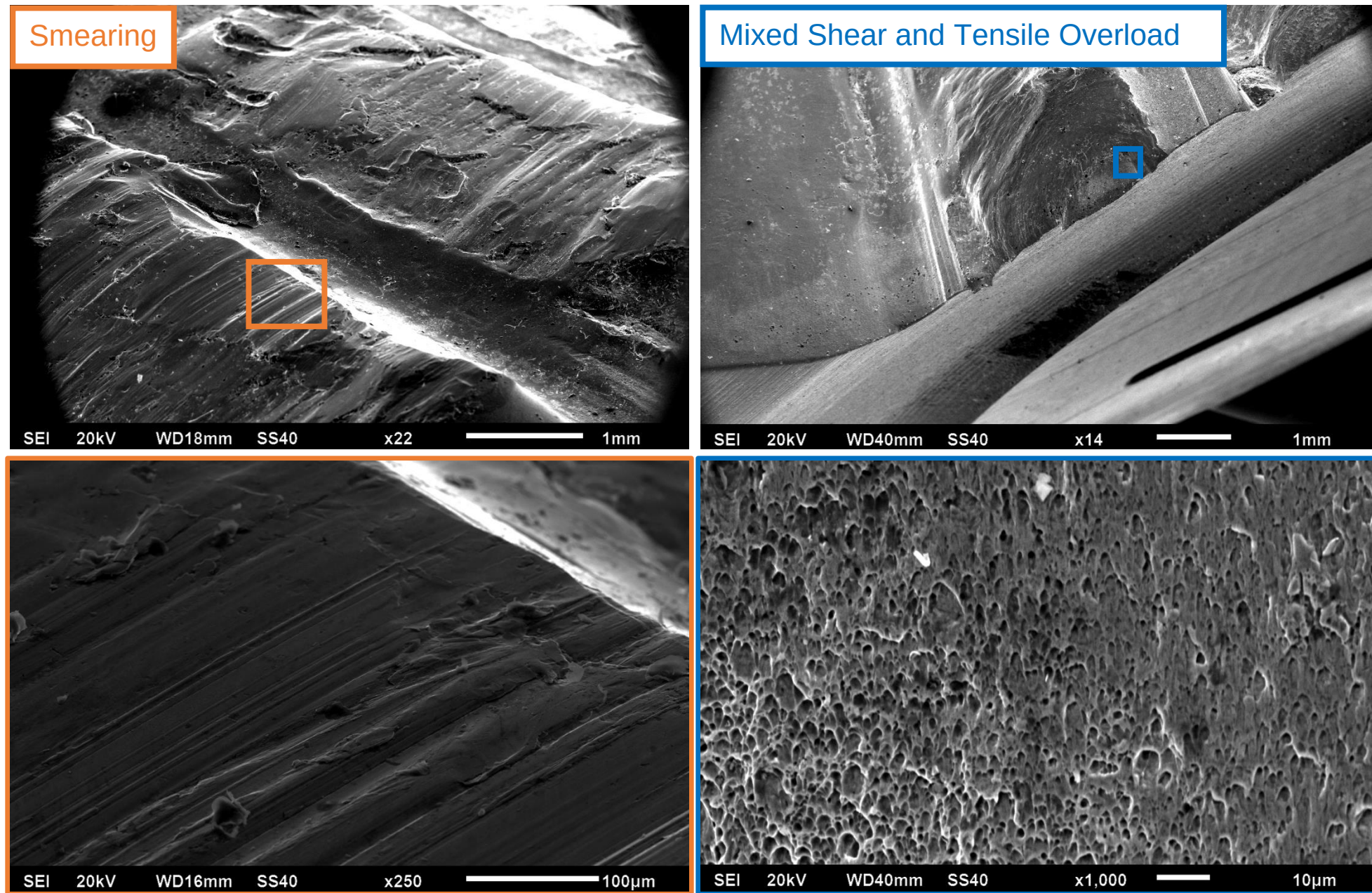


Figure 18: SEM Images of Different Types of Wear Visible on Drive Gear Where Teeth are Missing - Part 2

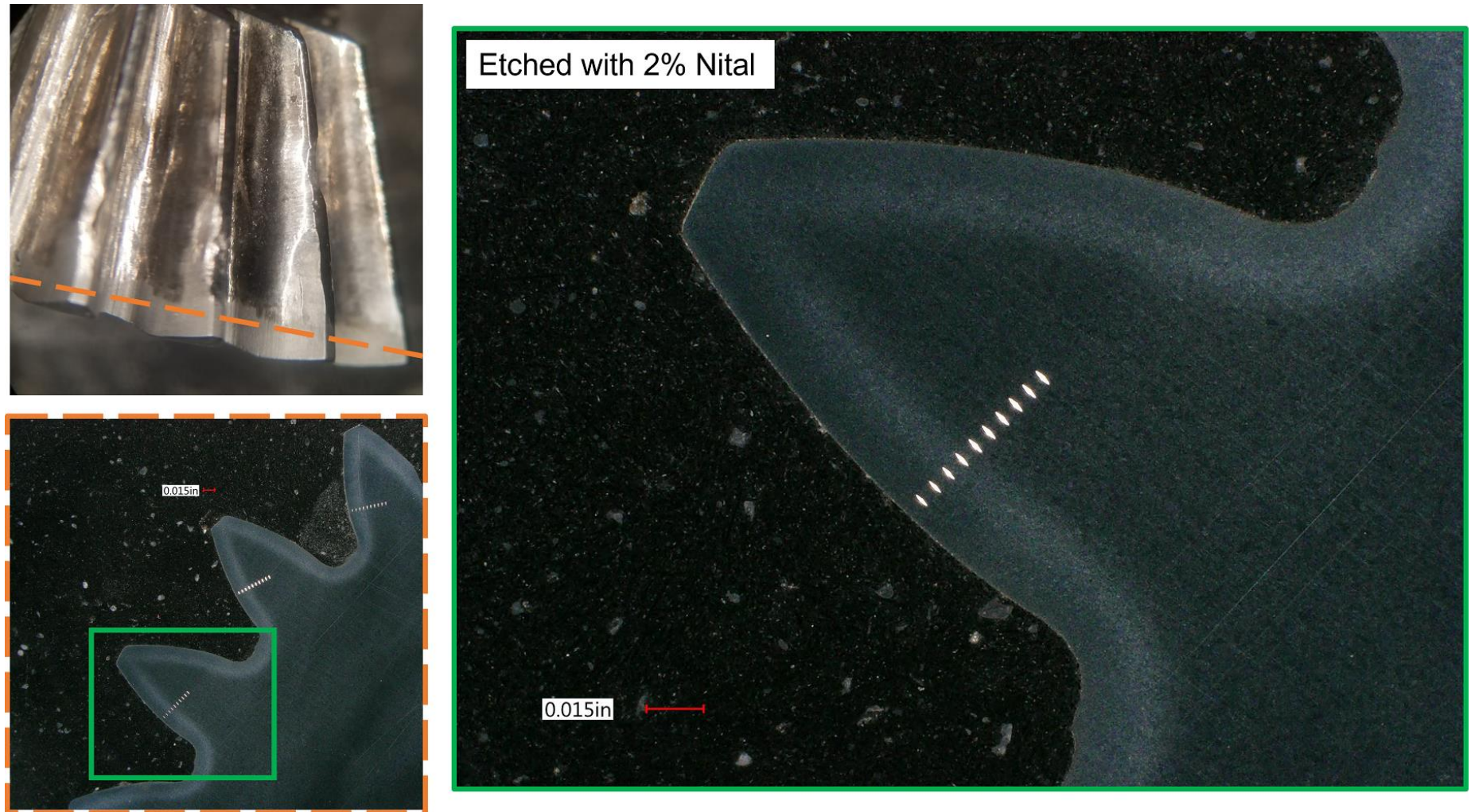


Figure 19: Drive Gear Cross-section and Microhardness Testing (115-810028-3)



Figure 20: 115-810025-1 Driven Gear with damaged Gear Teeth. (Mag x2)

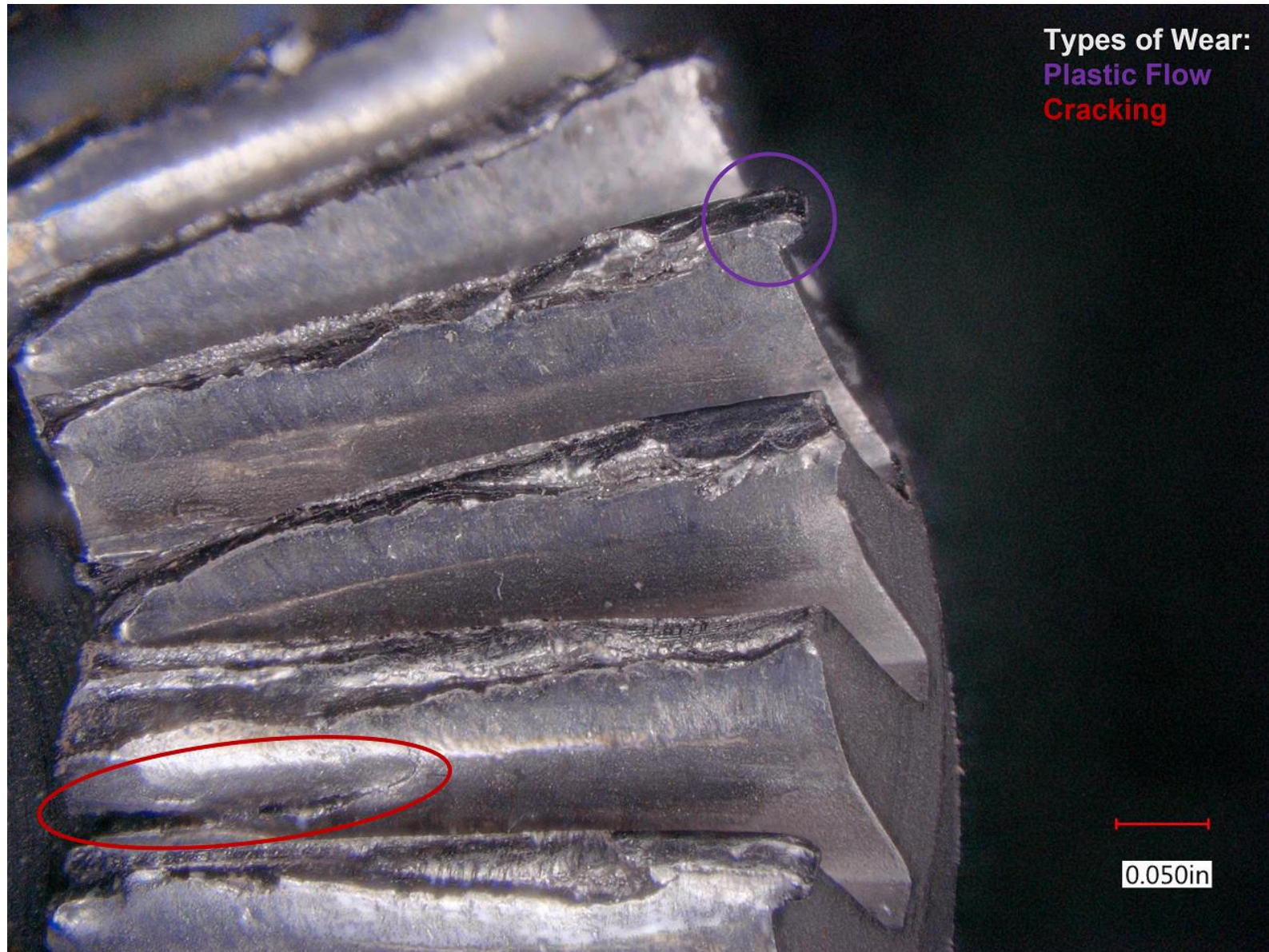


Figure 21: Different types of wear present on damaged teeth from the Driven Gear. (Mag x12)

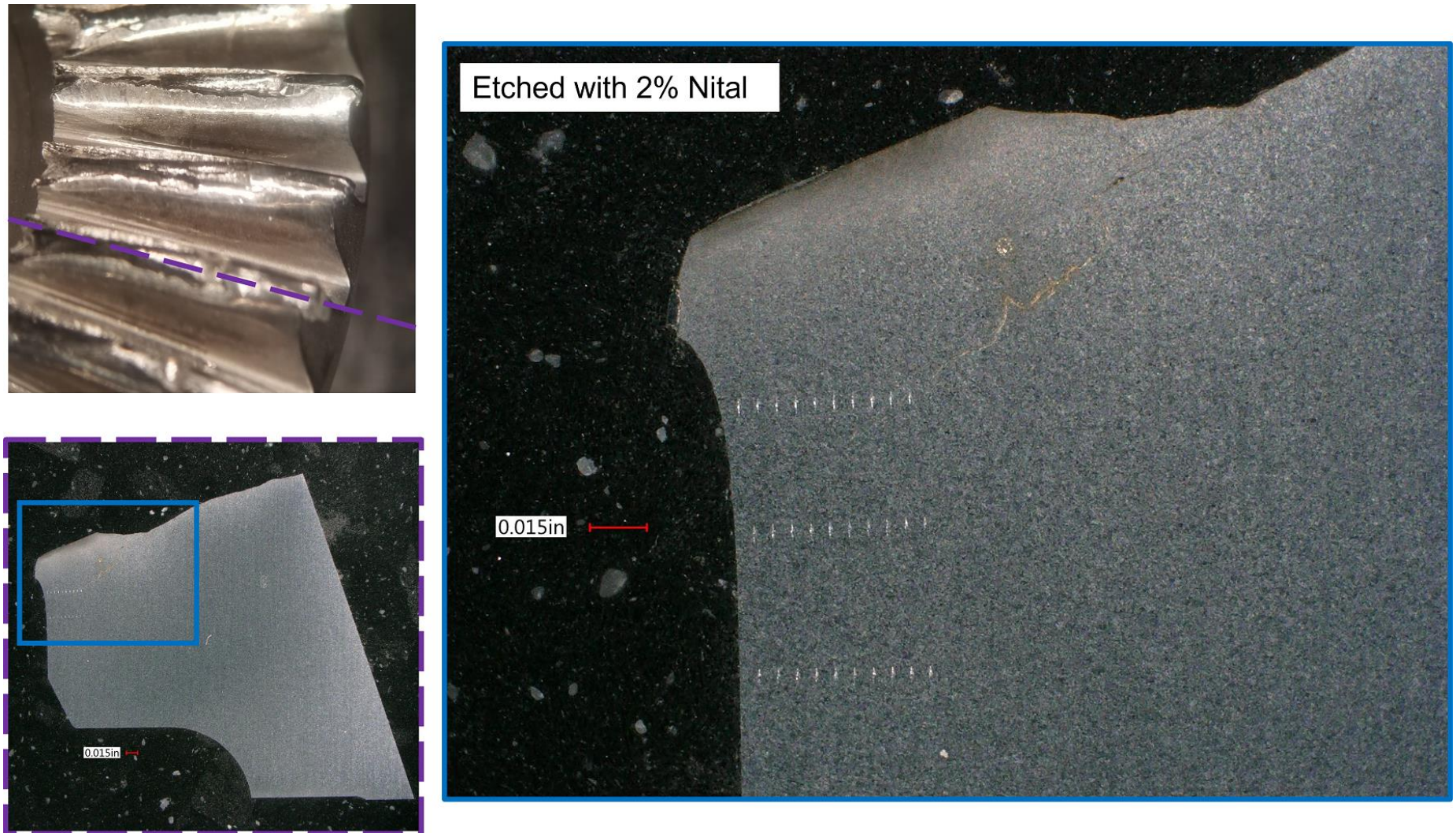


Figure 22: Driven Gear Cross-section and Microhardness Testing (115-810025-1).

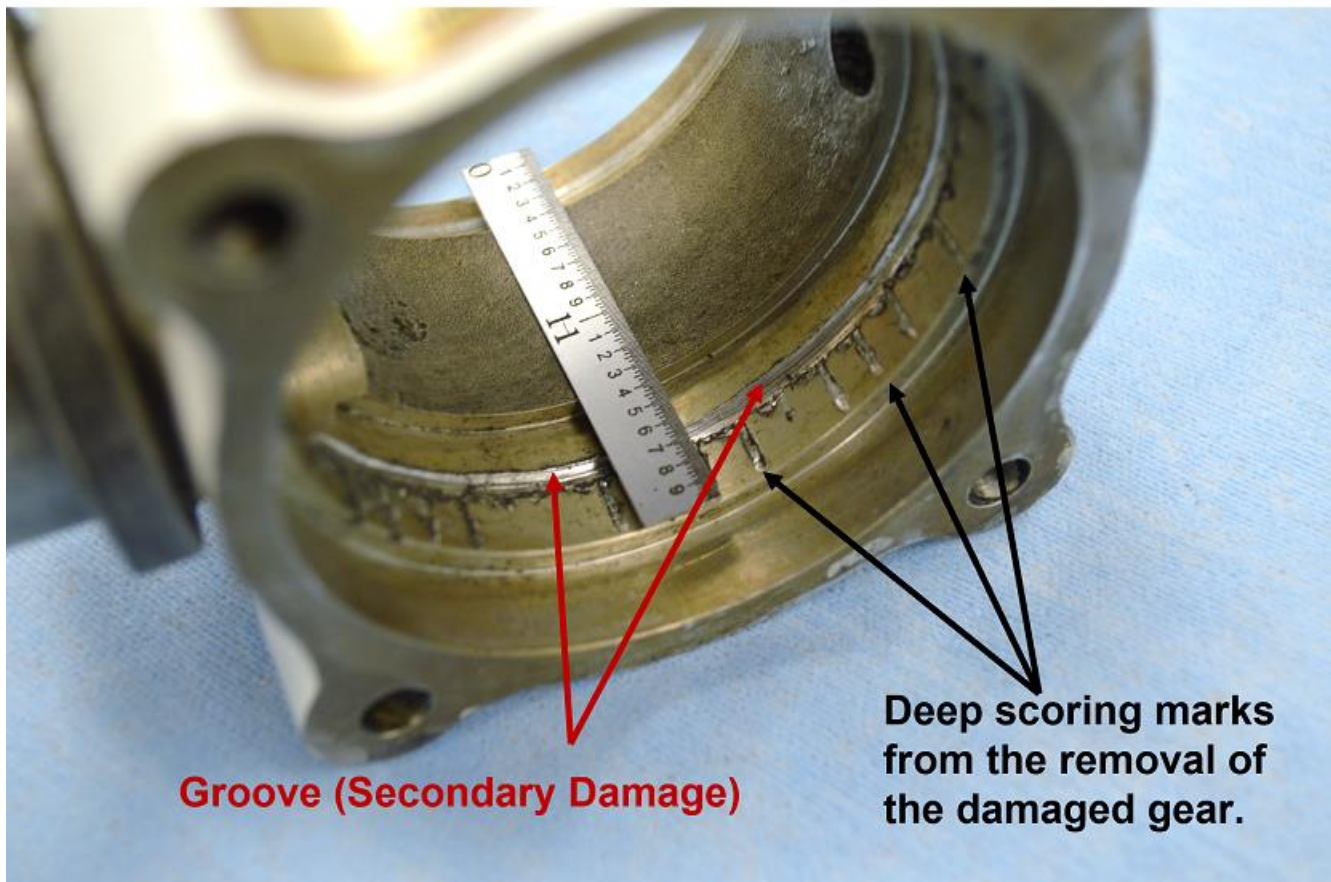
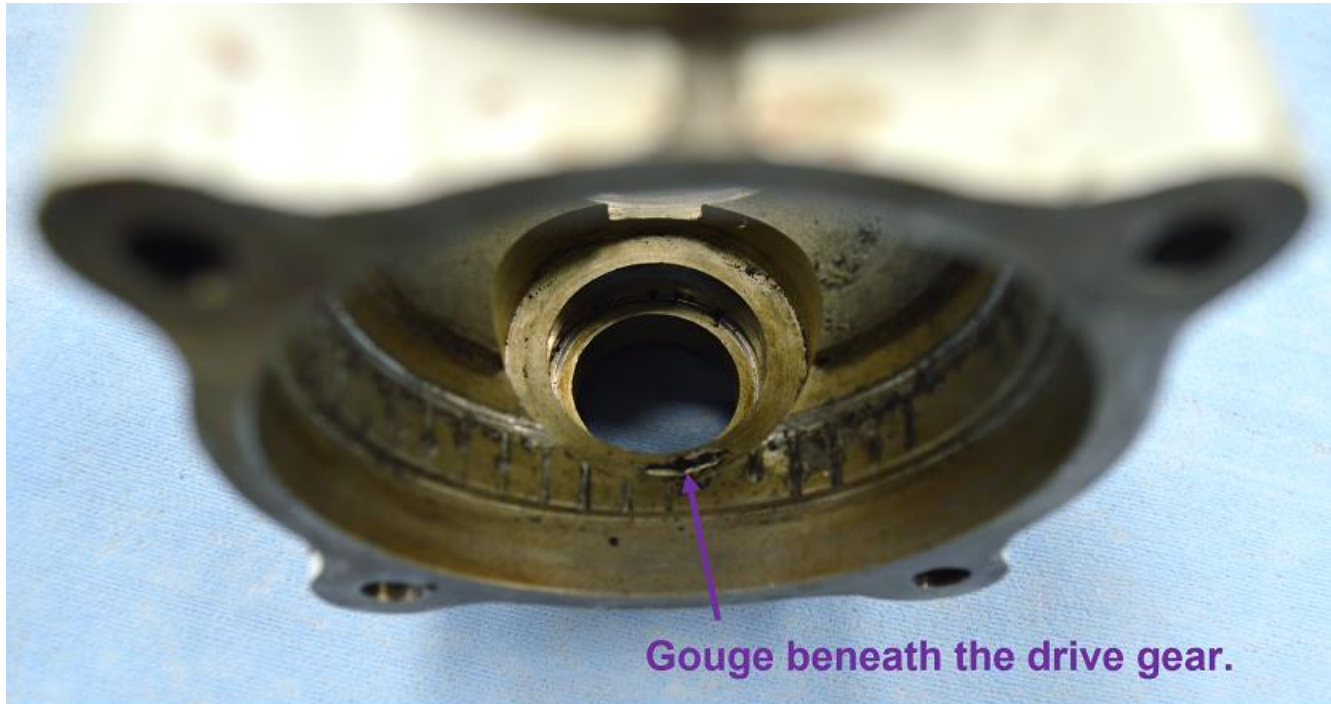


Figure 23: Visible damage inside the actuator housing.

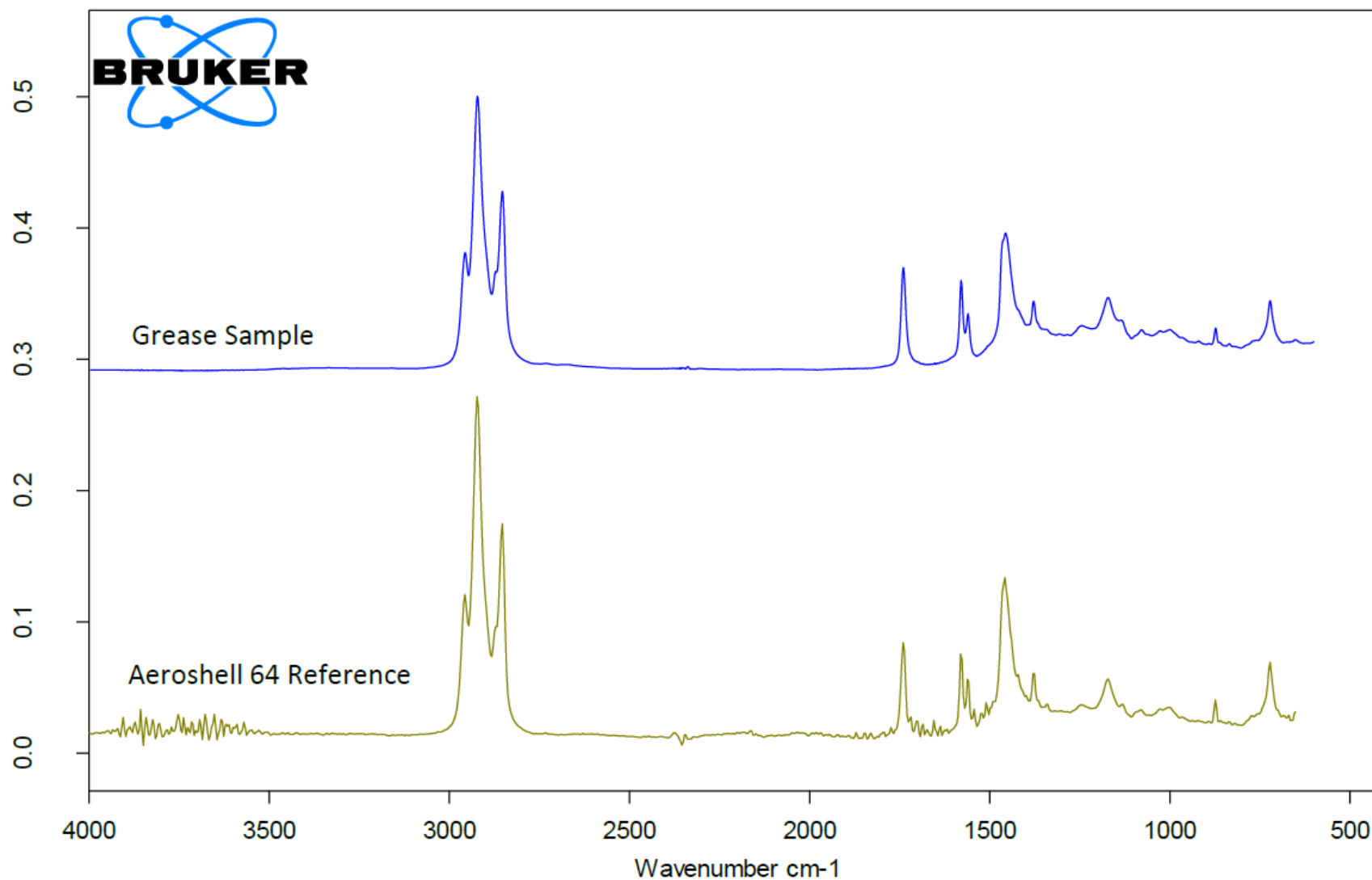


Figure 24: FTIR Analysis of Grease Sample



Figure 25: Lower Bearing removed from housing. (Mag x0.6)



Figure 26: Upper Bearing removed from housing. (Mag x0.6)

APPENDIX A ARROW LAB REPORTS

ARROW LABORATORY, INC.

Metallurgical Analysis and Testing

1333 N MAIN ST
WICHITA KS 67203
Fax: (316) 267-0171Attn: ALI EFTEKHARI
CESSNA AIRCRAFT CO
MATERIALS & PROCESSES

02-06-23

Page 1 of 1

LABORATORY REPORT #e57xb093

STEEL ANALYSIS

One 1/2" length of 1/2" Dia. bar was submitted and identified as:

9310 PER AMS 6260R

PART #810028-3

		Requirements
Carbon-----	0.11%	0.07 - 0.13%
Manganese-----	0.47	0.40 - 0.70
Phosphorus-----	0.009	0.025 max
Sulfur-----	<0.005	0.025 max
Silicon-----	0.27	0.15 - 0.35
Copper-----	0.11	0.35 max
Nickel-----	3.33	3.00 - 3.50
Chromium-----	1.23	1.00 - 1.40
Molybdenum-----	0.11	0.08 - 0.15
Boron-----	<0.0005	0.001 max

These results meet the requirements shown above.

Project Supervisor

Jennifer Unrein

JMU/mb

Rec'd 02-02-23

The sample or instrument was received in suitable condition for the tests performed at ambient lab conditions except as noted above.
Chemical Analysis of Carbon & Sulfur: Combustion/IR, Silicon: grav., Others: ICP/AA.
Tensile per ASTM E 8-21, E 557-15, or A 370-20. Hardness per ASTM E 10-18, E 18-20, E 384-17.
The recording of false, fictitious, or fraudulent statements or entries on the certificate may be punished as a felony under federal law.
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Figure A-1: Elemental Composition of 115-810028-3

ARROW LABORATORY, INC.

Metallurgical Analysis and Testing

1333 N MAIN ST
WICHITA KS 67203
Fax: (316) 267-0171Attn: ALI EFTEKHARI
CESSNA AIRCRAFT CO
MATERIALS & PROCESSES

02-06-23

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LABORATORY REPORT #e57xb094

STEEL ANALYSIS

One 3/8" length of 1-9/16" OD tube was submitted and identified as:

9310 PER AMS 6260R
PART #810025-1

		Requirements
Carbon-----	0.11%	0.07 - 0.13%
Manganese-----	0.56	0.40 - 0.70
Phosphorus-----	0.008	0.025 max
Sulfur-----	<0.005	0.025 max
Silicon-----	0.26	0.15 - 0.35
Copper-----	0.03	0.35 max
Nickel-----	3.15	3.00 - 3.50
Chromium-----	1.15	1.00 - 1.40
Molybdenum-----	0.12	0.08 - 0.15
Boron-----	<0.0005	0.001 max

These results meet the requirements shown above.

Project Supervisor

JMU/mb

Rec'd 02-02-23

Jel

The sample or instrument was received in suitable condition for the tests performed at ambient lab conditions except as noted above.
Chemical Analysis of Carbon & Sulfur: Combustion/IR, Silicon: grav., Others: ICP/AA.
Tensile per ASTM E 8-21, B 557-15, or A 370-20. Hardness per ASTM E 10-18, E 18-20, E 384-17.
The recording of false, fictitious, or fraudulent statements or entries on the certificate may be punished as a felony under Federal law.
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Figure A-2: Elemental Composition of 115-810025-1

From: Barclay, Jennifer [REDACTED]
Sent: Monday, May 22, 2023 2:54 PM
To: Abraham Laura [REDACTED]
Subject: CEN22LA138 - Actuator Exam

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Good afternoon Laura,

Attached is the report for the actuator exam conducted at Textron. The document is suitable for use in the public side of the docket. Apologies for the delay.

Have a great day!

Jennifer Barclay
Senior Air Safety Investigator, Air Safety Investigations
[REDACTED]

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