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Variant M4 Barrel Characterization

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ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
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15. SUBJECT TERMS

155mm, M777, Spiral Wear, Bore Debris, Bore Residue

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Variant M4 Barrel Characterization

S. B. Smith and C. Rickard

15 July 2009

1. Abstract

Four candidate barrels configurations were investigated in the as-received condition and after endurance testing. Each configuration was manufactured from one of two CrMoV steels and either button broach or hammer forge rifling.

The investigation noted rough chromium bore coatings, variations in coating thickness, and cracking in the substrate steel in the as-received barrels. Loss of Cr in the forcing cone, widespread Cu deposits, and damage to the rifling forward of the forcing cone was noted for all fired barrels.

The major difference in firing damage between the candidate barrels was the land wear mechanism. The button broached samples exhibited shear cracking at the land root, leading to eventual loss of material. The hammer forged barrels exhibited wear on the leading land edge, with gradual material removal and a shallowing of the land edge.

2. Background

Four candidate 5.56mm M4 barrel configurations, identified as 1 through 4, are being investigated. Each barrel is manufacture with one of two chrome-moly-vanadium steels and one of two rifling techniques. The barrel configurations are identified as follows:

Configuration 1: MIL-B-11595 CrMoV steel, button broached rifling (Standard M4 barrel).
Configuration 2: 32CrMoV12.10/1.7765 GKH steel, hammer forged rifling.
Configuration 3: MIL-B-11595 CrMoV steel, hammer forged rifling.
Configuration 4: 32CrMoV12.10/1.7765 GKH steel, button broached rifling.

One barrel of each configuration was analyzed in the as-received condition[1]. These as-received barrels were not un-fired, in that a small number of proof rounds have been fired through them as part of the manufacturing process.

Additional barrels of each configuration were subject to endurance testing at Aberdeen Proving Grounds. Testing involved firing M855 Ball, lot # LC-04E159-083, ammunition in a 120 round cycle (semi/burst/semi/burst). The weapon was lubed every 600 rounds and cleaned and inspected every 1200 rounds. The weapons and ammunition were conditioned at ambient temperature.

3. Procedure

The specimens provided were subjected to a characterization procedure based upon ARDEC-Benét Laboratory's established protocol for protective coatings. The specific characterization tests performed on these specimens include:

- Coating thickness measurements. Metallographic specimens are prepared of the sample in cross-section. The coating thickness is measured with a measuring optical microscope.
- Microstructure analysis. Metallographic specimens are prepared of the sample and etched for microstructure.
- Microhardness measurements. Metallographic specimens are prepared of the sample in cross-section and microhardness measurements are taken through the thickness of the coating and substrate.
- Surface analysis. The surface of sample sections are investigated with optical and electron microscopes.
- Adhesion testing. Groove testing and subsequent microscopic examination are performed on chamber sections.

The barrels were sectioned to facilitate analysis. Five sections were identified (see Figure 1) mirroring the locations used previously[1-3]. These locations for analysis are:

- Location 1 – chamber – ¼" ring section
- Location 2 – forcing cone – ½" longitudinal section
- Location 3 – 3" forward of the rear face of the tube (RFT) – ¼" ring section
- Location 4 – 9.5" RFT – ½" longitudinal section
- Location 5 – 10" RFT – ¼" ring section

This report will identify each sample with a series of numbers representing the barrel configuration (1 through 4) - unfired (1) and fired (2) condition – sample location (1: chamber, 2: forcing cone, 3: 3" RFT, 4: 9.5" RFT, and 5: 10" RFT) – and clock position (3, 6, 9, or 12 o'clock) when necessary. For example, sample 4-2-3-9 is barrel configuration 4, fired barrel, ring section 3" forward of the RFT, at the 9 o'clock position.

4. Data/Observations

4.1. Coating thickness measurements.

The three ¼" ring sections from each as-received and fired barrel (Location 1, 3, and 5) were metallographically mounted in cross-section and polished to a mirror finish. Chromium coating thickness measurements were made using an Instron Wilson-Tukon microhardness-tester with a measuring eye-piece. The range of measured thickness values are posted as Table 1.

US Army-ARDEC drawing #9349054 *Barrel and Barrel Extension Assembly for the M16 barrel* specifies in Note #21 that the thickness of electroplated chromium in the chamber (Location 1) should be between 7.6μm and 38.1μm (0.0003" to 0.0015"). The chamber of barrels 1-1, 1-2, 2-2, and 4-2 failed to meet this criterion entirely. The chambers of barrels 2-1, 3-1, 4-1, and 3-2 met this criterion on average, but all included localized areas that were below limit.

Note #21 also states that the chromium thickness in the rifled section of the barrel should be greater than 10.2µm (0.0004"). All Location 3 and 5 samples, except 3-2-3, met this criterion on average; however most included localized areas that were below limit.

Thin chromium coatings in the chamber and non-concentric plating thicknesses are issues with each of the investigated barrels. These bore coating issues appear independent of the material and rifling configuration of the barrel. A thin chamber coating can cause premature wear, resulting in round chambering and extraction issues, headspace issues, etc. A thin or non-concentric bore coating will cause uneven barrel heating, resulting in uneven or premature wear and an associated loss of accuracy.

4.2. Microstructure analysis.

The three ¼" ring sections from each as-received and fired barrel (Location 1, 3, and 5) were metallographically mounted in cross-section and polished to a mirror finish. The samples were then etched with Nitol to reveal the steel microstructure. Representative images comparing the as-received and fired barrels are posed as Figures 2 through 5.

The microstructure of the two steels was indistinguishable. All fired barrels showed a tempering in the microstructure, when compared to the as-received steel. This is confirmed in section 4.3 *Microhardness.* Heat affected zones seen in the fired barrels are relatively thin and localized to wide cracks and surfaces where the chromium has been completely removed.

All fired barrels show extensive copper deposits and damage to the rifling lands, and the type of damage appears to be dictated by the rifling profile. The Configuration 1 and 4 button broach barrels had large deposits of copper at the root of the lands; in addition to collecting copper and firing debris at surface cracks and disparities. The Configuration 2 and 3 hammer forged barrels have a rougher as-received surface. During firing, the rough surface tended to collect copper and debris in the surface troughs. For all fired barrels, the damage was heavier at Location 3 compared to Location 5.

The Configuration 1 and 4 button broach barrels exhibited a limited amount of cracking in the steel in the as-received barrels. These cracks were relatively shallow and extended into the wall at a 45° angle from the bore surface at the root of the land. During firing, these 45° cracks initiated and extended at each land root, on both the driving and leeward side of the land. The location and orientation of the cracks suggest shear forces on the side of the land are the motivating force for cracking. In some instances, the driving and leeward side cracks of a land eventually linked up, and the land is completely removed.

The Configuration 2 and 3 hammer forged barrels showed deeper and more extensive cracking in the as-received barrels. However, the cracks were oriented perpendicular to the bore surface, and were not associated with a land corner. These cracks tended to occur in the middle of the land or groove surface. During firing, these cracks widened and extended further through the wall. Damage to the land was predominately wear to the driving side land wall. The driving side wall was worn down to a very shallow slope; while the leeward land side was relatively undamaged.

4.3. Microhardness.

Metallographically prepared cross-sectional samples were investigated for microhardness. Hardness values were measured from each barrel at Location 3 with an Instron Wilson-Tukon microhardness-tester using a Knoop indenter with a 200g load. Knoop hardness values where then converted to

Rockwell hardness numbers[4]. Readings were obtained for the steel substrate adjacent to the chromium bore coating. The chromium coating itself was too thin for an accurate hardness measurement. The range of converted hardness values are posted as Table 2.

The steel hardness values range from 40 to 47 HRc equivalent in the as-received barrels. There is no statistical difference in hardness noted between the as-received candidate barrels.

The steel hardness values range 33-40 HRc equivalent in the fired barrels. There is no statistical difference in hardness noted between the fired candidate barrels.

The 20% drop in hardness is due to the heat from firing tempering the steel material. This heat affect is confirmed in section 4.2 *Microstructure analysis*.

4.4. Surface analysis.

The two longitudinal sections from each as-received and fired barrel (Location 2 and 4) were cleaned in an alcohol solution and then investigated with a JEOL scanning electron microscope. Images of the samples are posted as Figures 6 through 9.

Surface imaging of the as-received Location 2 samples (Figure 6) shows a smooth and complete chromium coating. These samples are also used for coating adhesion testing; see section 4.5 *Adhesion testing* for more information.

Surface imaging of the fired Location 2 samples (Figure 7) shows two distinct wear bands in each of the barrel configurations. The first wear band occurs approximately 0.5mm rearward of the chamber/forcing cone junction. This approximate 1mm wide band exhibits extensive mechanical damage to the chromium through numerous axial scratches, dings, and dent. A small percentage of these scratches penetrate the chromium into the steel. The second wear band occurs approximately 0.25mm forward of the chamber/forcing cone junction. This approximate 1mm zone is a contiguous band where the chromium coating has been removed, revealing a belt of steel and corrosion/combustion products. Samples 1-2-2 and 2-2-2 have wider forward wear bands than 3-2-2 and 4-2-2. Sample 2-2-2 was also image with a large amount of combustion products adhered to the chamber/forcing cone junction area. These wear zone issues appear independent of the material and rifling configuration of the barrel.

Surface imaging of the as-received Location 4 samples (Figure 8) shows a textured bore surface. Samples 1-1-4 and 4-1-4, the button broached samples, exhibit shallow machining marks on the surface. These marks tend to follow the rifling profile of the bore. Samples 2-1-4 and 3-1-4, the hammer forged samples, exhibit a furrowed surface. Compared with the broached tube surface, these ruts are slightly deeper than the machining marks and align with the tube axis instead the rifling profile.

Surface imaging of the fired Location 4 samples (Figure 9) shows a cracked and contaminated surface. All the samples exhibit heat check cracking, and these cracks have been subsequently packed with copper and combustion products. The axial surface furrows on the hammer forged samples 2-2-4 and 3-2-4 are also filled with copper. The button broached samples 1-2-4 and 4-2-4 showed a large amount of copper adhered to the root of the driving side land; this driving-side copper build-up is not present in the hammer forged samples.

4.5. Adhesion testing.

The as-received Location 2 samples (Figure 6) were subjected to groove adhesion testing. A tungsten-carbide tool bit was scribed through the coating along the axis of the barrel. This groove was then analyzed for adhesive failure adjacent to the groove. No adhesive coating failure was identified.

Since electrodeposited chromium on steel has traditionally been a very well adhered coating, and no failure was noted during testing of the as-received samples, the fired samples were not subjected to the groove adhesion test.

5. Summary/Recommendation

Observations of note include:

- The variations in material and forming techniques appear to have no effect on the ability to electrodeposit chromium, or the quality or the plating. The chromium platting, itself, is thin in all barrel chamber sections and radially and axially non-uniform in thickness.
- The variations in material and forming techniques appear to have no effect on bore surface heating effects.
- The hammer forging produced an axially furrowed bore surface. This texture entraps copper and firing debris during firing.
- The button broached bore collects copper and firing debris at the root of the leading-edge land.
- Deep axially-perpendicular cracking is very prevalent in the as-received and fired hammer forged barrels.
- Leading edge wear is the predominate cause of land damage in the hammer forged barrels.
- Shear driven cracking from the root of the land is the predominate cause of land damage in the button broached barrels.

6. Acknowledgments

The authors are pleased to acknowledge the sample preparation provided by Mrs. A. Welty, RDAR-WSB-PA.

7. References

1) Smith, S. B., & Rickard, C. (2009). *Candidate M4 Barrel Characterization*. US Army-ARDEC.
2) Mulligan, C. P., Lee, S., Rickard, C., & Welty, A. (2007). *Comparison of electroplated chromium coatings applied to M4 and M16 barrels.* US Army-ARDEC.
3) Smith, S. B., & Rickard, C. (2008). *Characterization of HC Chromium Plated M16 Barrels from Two Manufacturers.* US Army-ARDEC.
4) Bauccio, M. (Ed.). (1993). *ASM Metals Reference Book* (3rd ed.). ASM International.

As-Received				
ID#	12 o'clock (microns)	3 o'clock (microns)	6 o'clock (microns)	9 o'clock (microns)
1-1-1	6.5	5	5.5	5.5
1-1-3	15	15	16.5	10
1-1-5	5-15	10-15	16-16.5	10
2-1-1	5	5-10	10-15	5
2-1-3	15	15	6.5-15	5-15
2-1-5	5-10	2.5-15	10	10
3-1-1	5	10	2.5-11.5	5-15
3-1-3	15	15	15	20
3-1-5	5-20	10	10-15	5-10
4-1-1	5-15	10	10-20	10-25
4-1-3	15-25	15	15	15-25
4-1-5	11.5	10-11.5	5-15	10-15

Fired				
ID#	12 o'clock (microns)	3 o'clock (microns)	6 o'clock (microns)	9 o'clock (microns)
1-2-1	5	3.5	5	3.5
1-2-3	10	10-11.5	10-12.5	10
1-2-5	10	9-10	9-10	9-10
2-2-1	5	2.5	3.5	5
2-2-3	10	15	10	15
2-2-5	10	6	6	6
3-2-1	6	10	9	5-6
3-2-3	5	5	5	5
3-2-5	6-10	10	5-6	10
4-2-1	5	2.5	5	3.5
4-2-3	20	10	10	10
4-2-5	9	8-9	10	8-10

Table 1: Chromium Thickness Measurements.

As-Received			Fired	
ID#	HRc		ID#	HRc
1-1-3	40-47		1-2-3	33-35
2-1-3	40-45		2-2-3	37-39
3-1-3	43-47		3-2-3	35-40
4-1-3	43-47		4-2-3	33-35

Table 2: Steel Hardness Measurements.

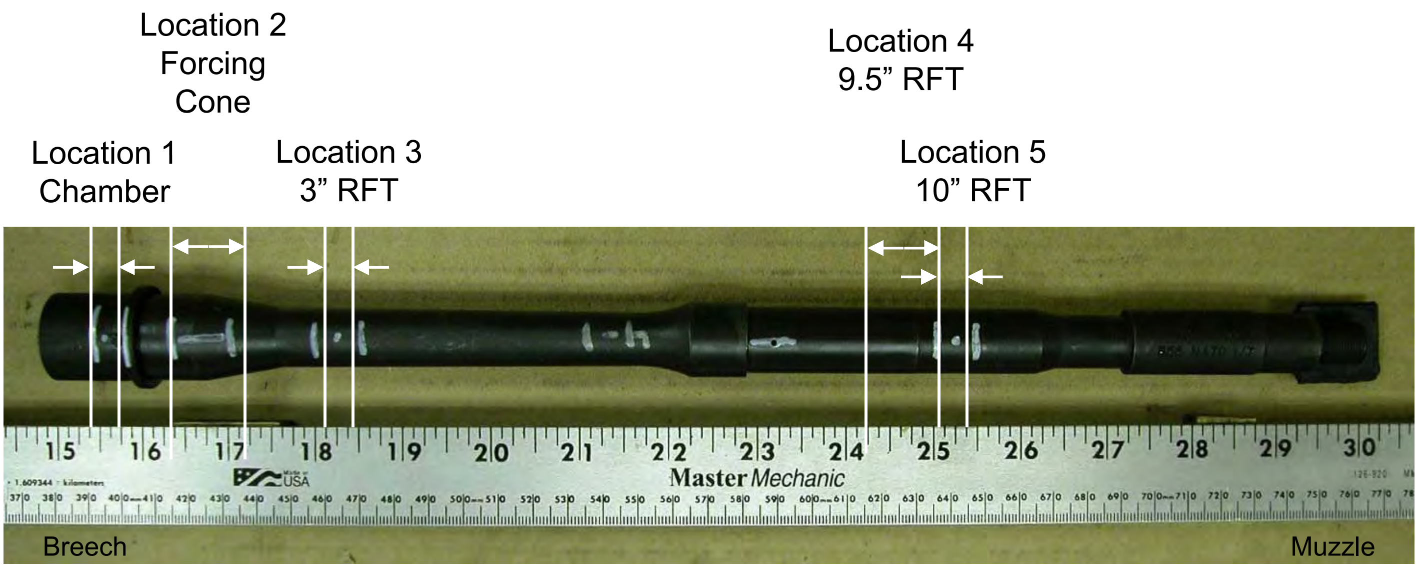


Figure 1: M4 Barrel Cut Plan

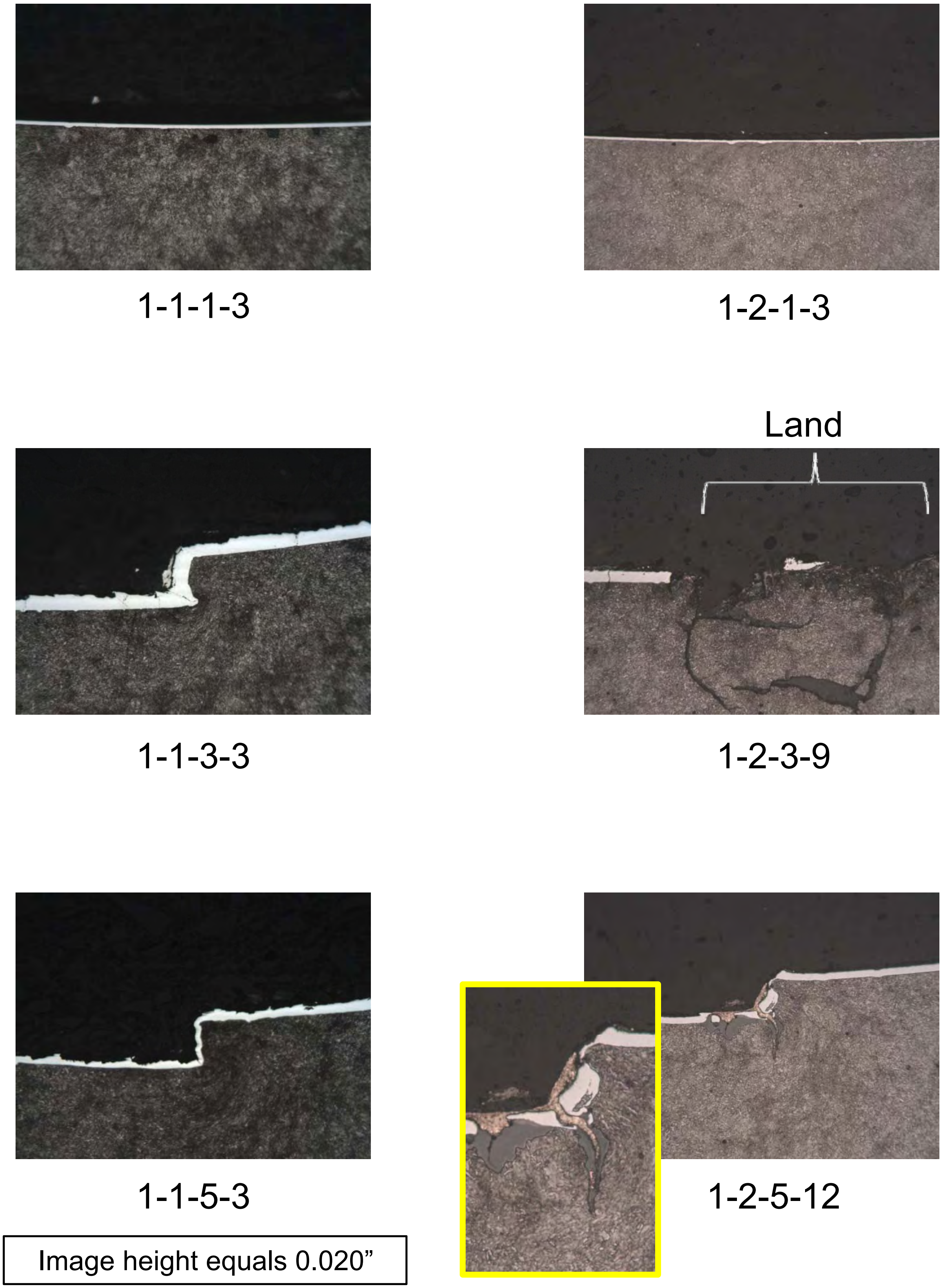


Figure 2: As-received and Fired Configuration 1 Cross-sections

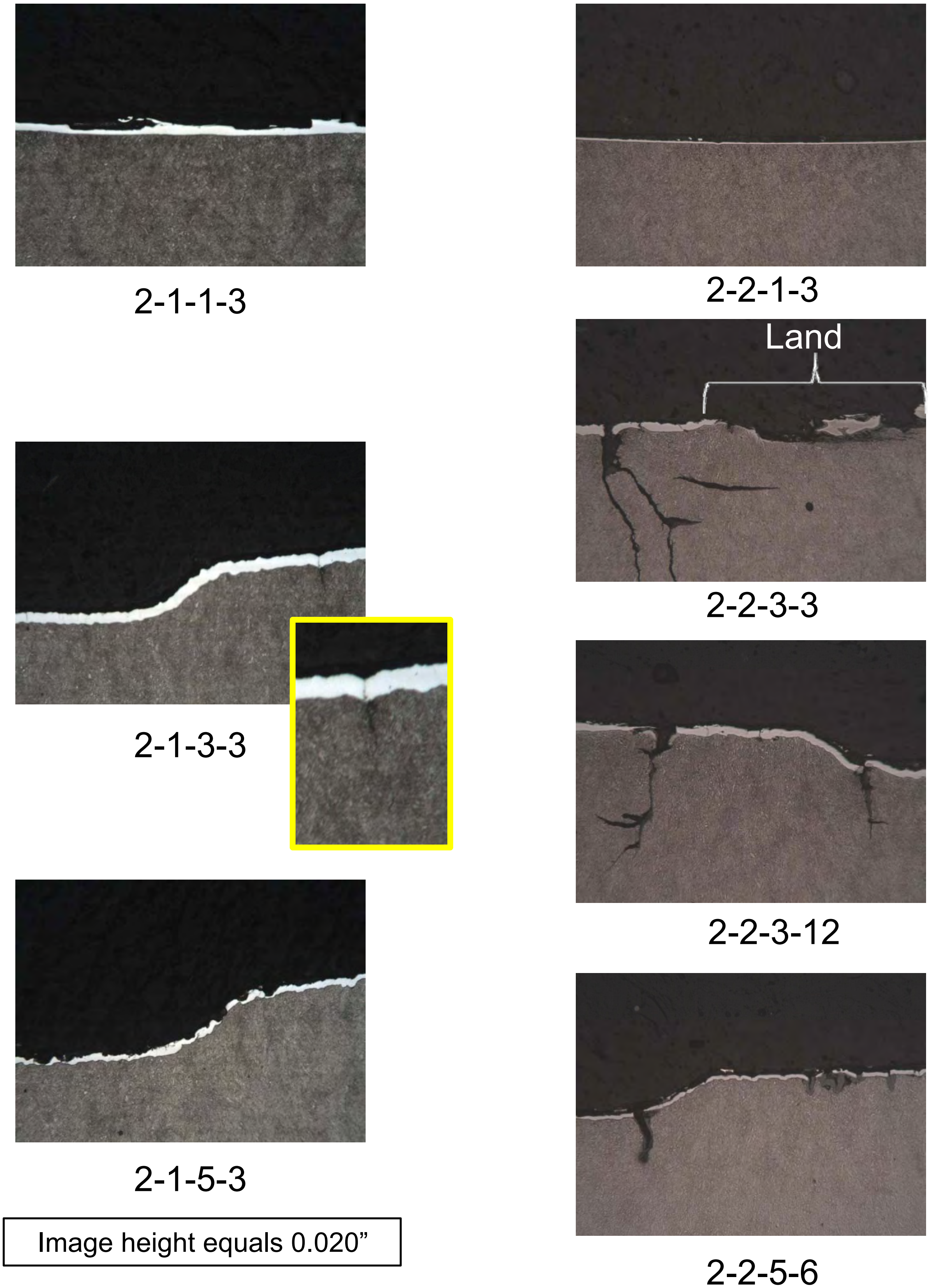
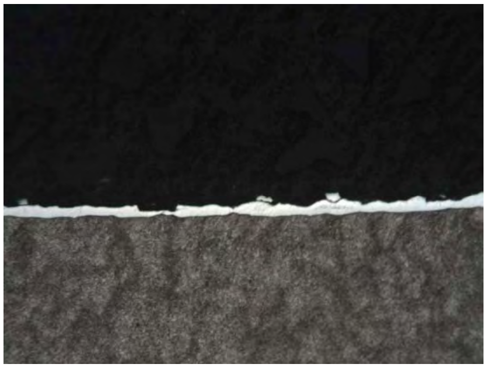
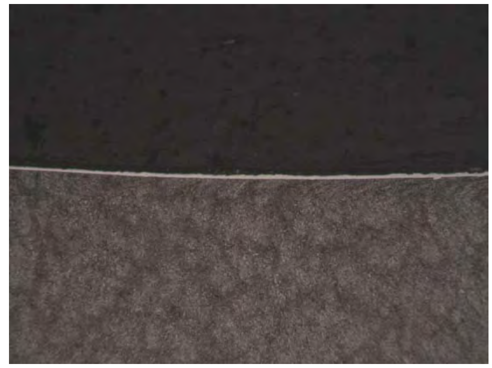


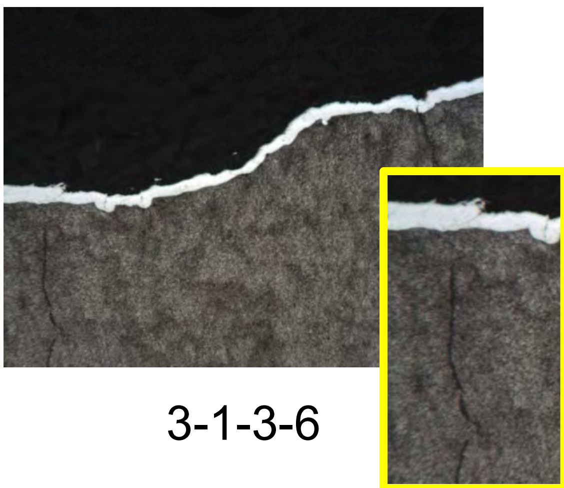
Figure 3: As-received and Fired Configuration 2 Cross-sections



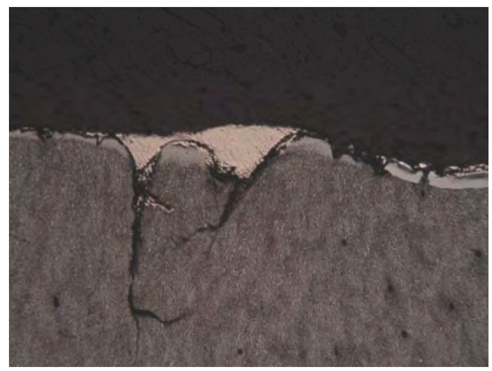
3-1-1-9



3-2-1-3



3-1-3-6



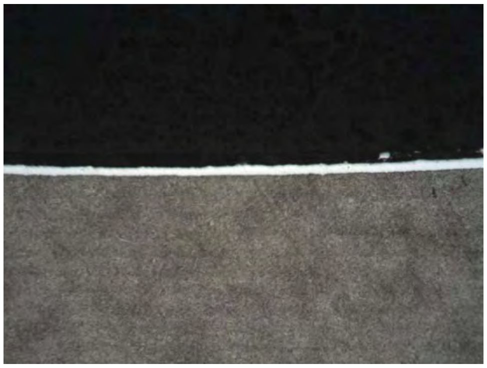
3-2-3-6

3-1-5-9

3-2-5-6

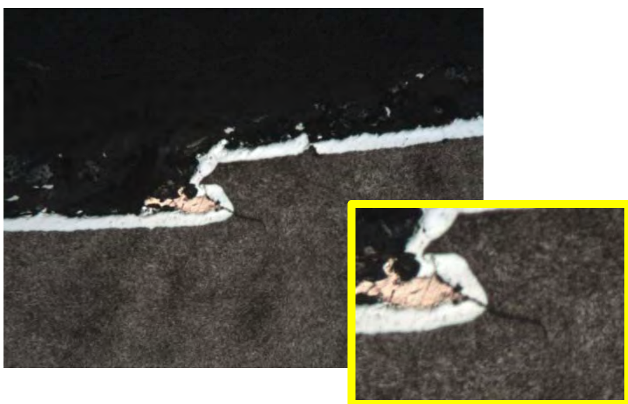
Image height equals 0.020”

Figure 4: As-received and Fired Configuration 3 Cross-sections

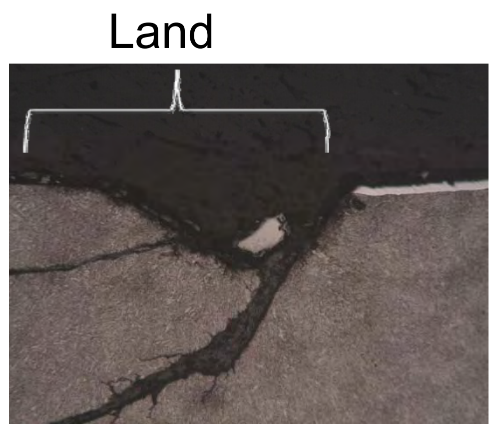


4-1-1-3

4-2-1-6



4-1-3-6



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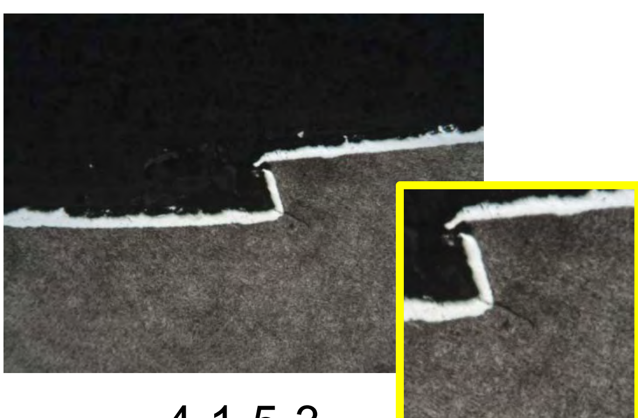
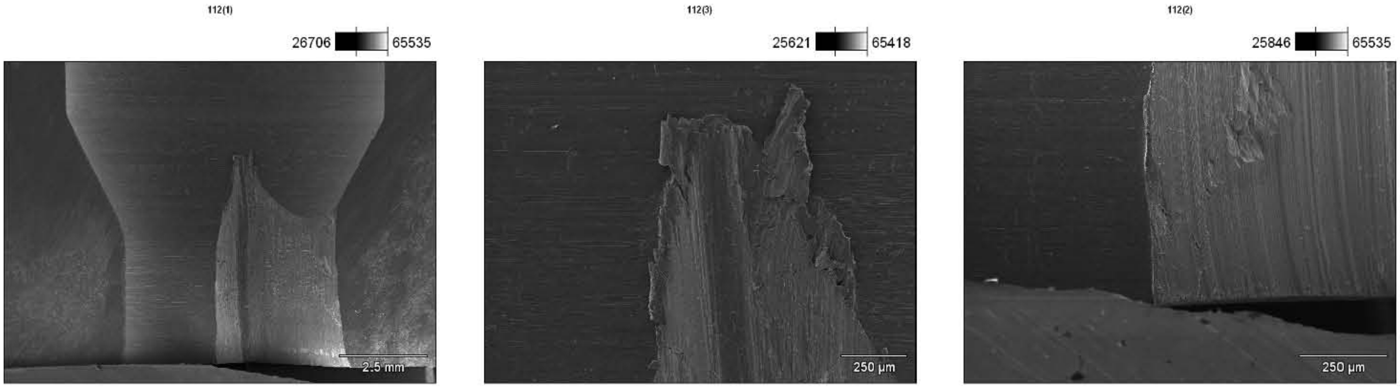


4-1-5-3

4-2-5-6

Image height equals 0.020"

Figure 5: As-received and Fired Configuration 4 Cross-sections



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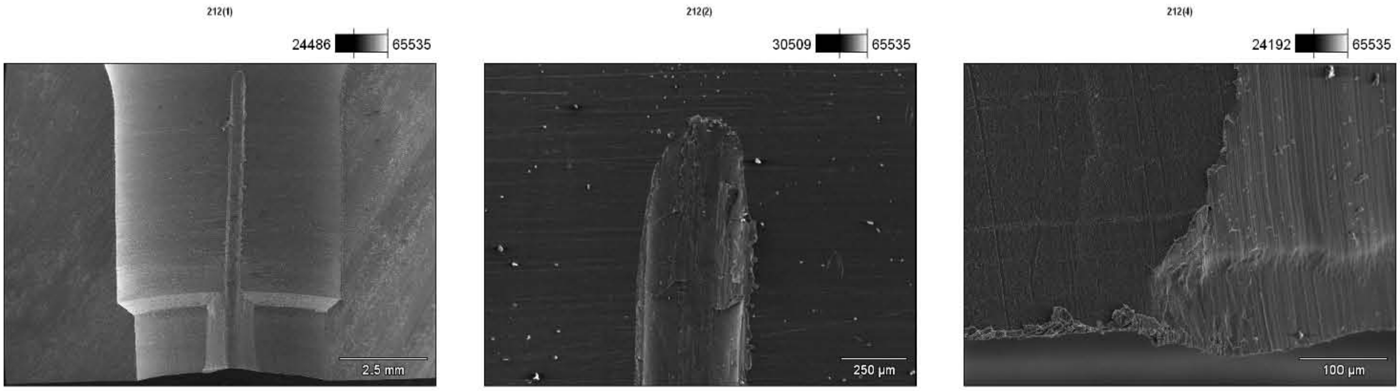

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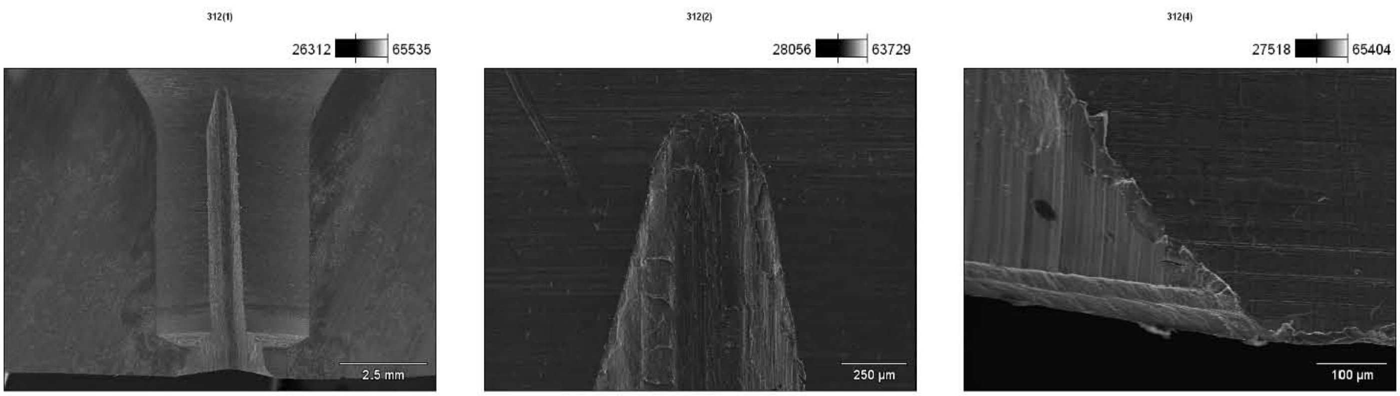

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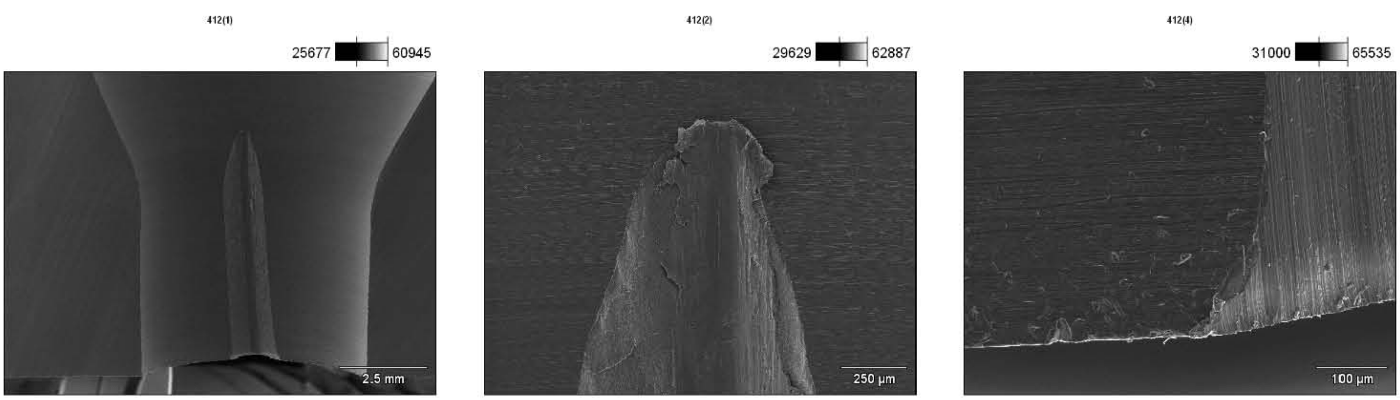

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Figure 6: As-Received Forcing Cone Surface and Groove Images

ID# 1-2-2

ID# 2-2-2

ID# 3-2-2

ID# 4-2-2

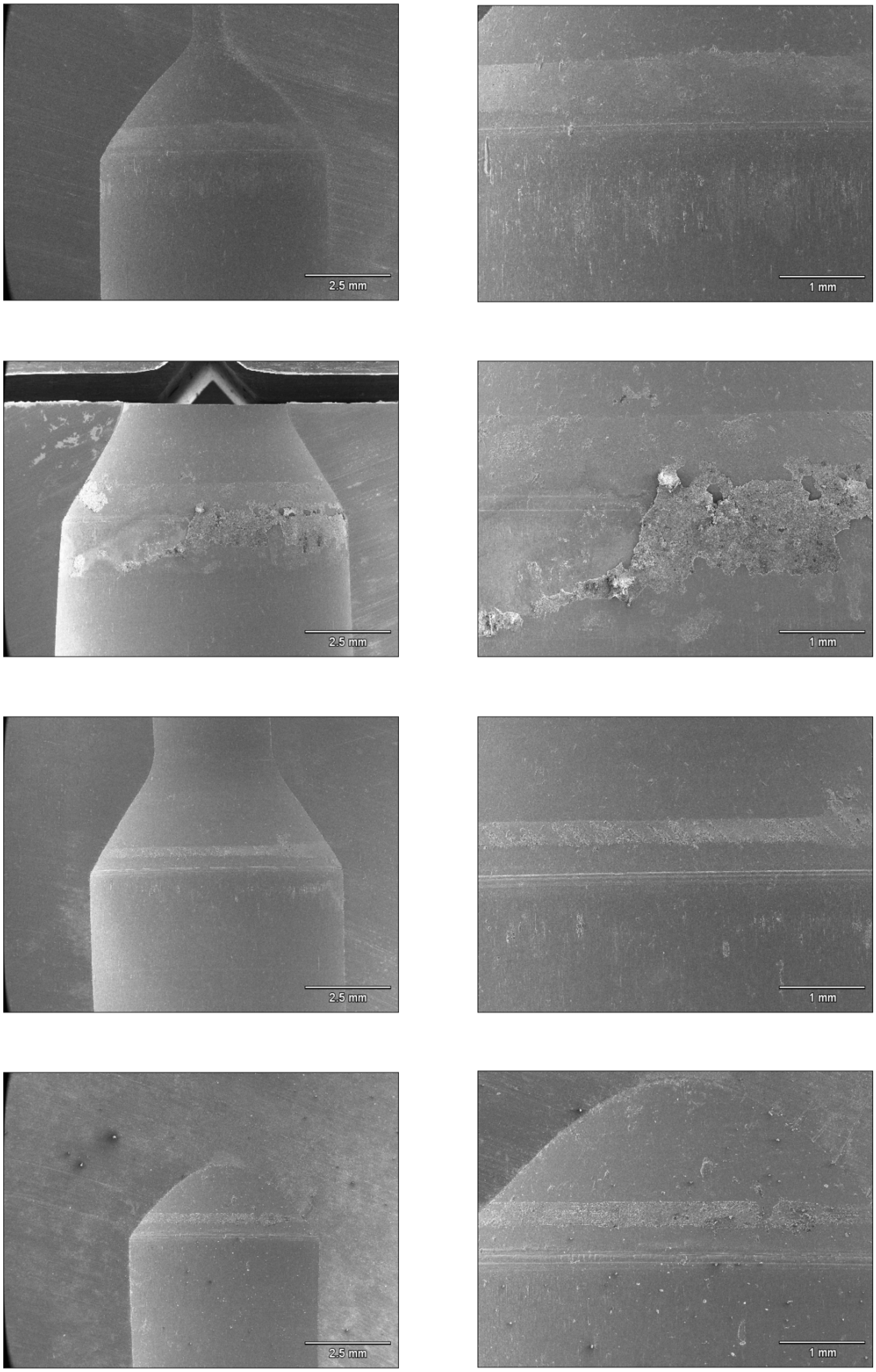

Figure 7: Fired Forcing Cone Surface Images

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ID# 2-1-4

ID# 3-1-4

ID# 4-1-4

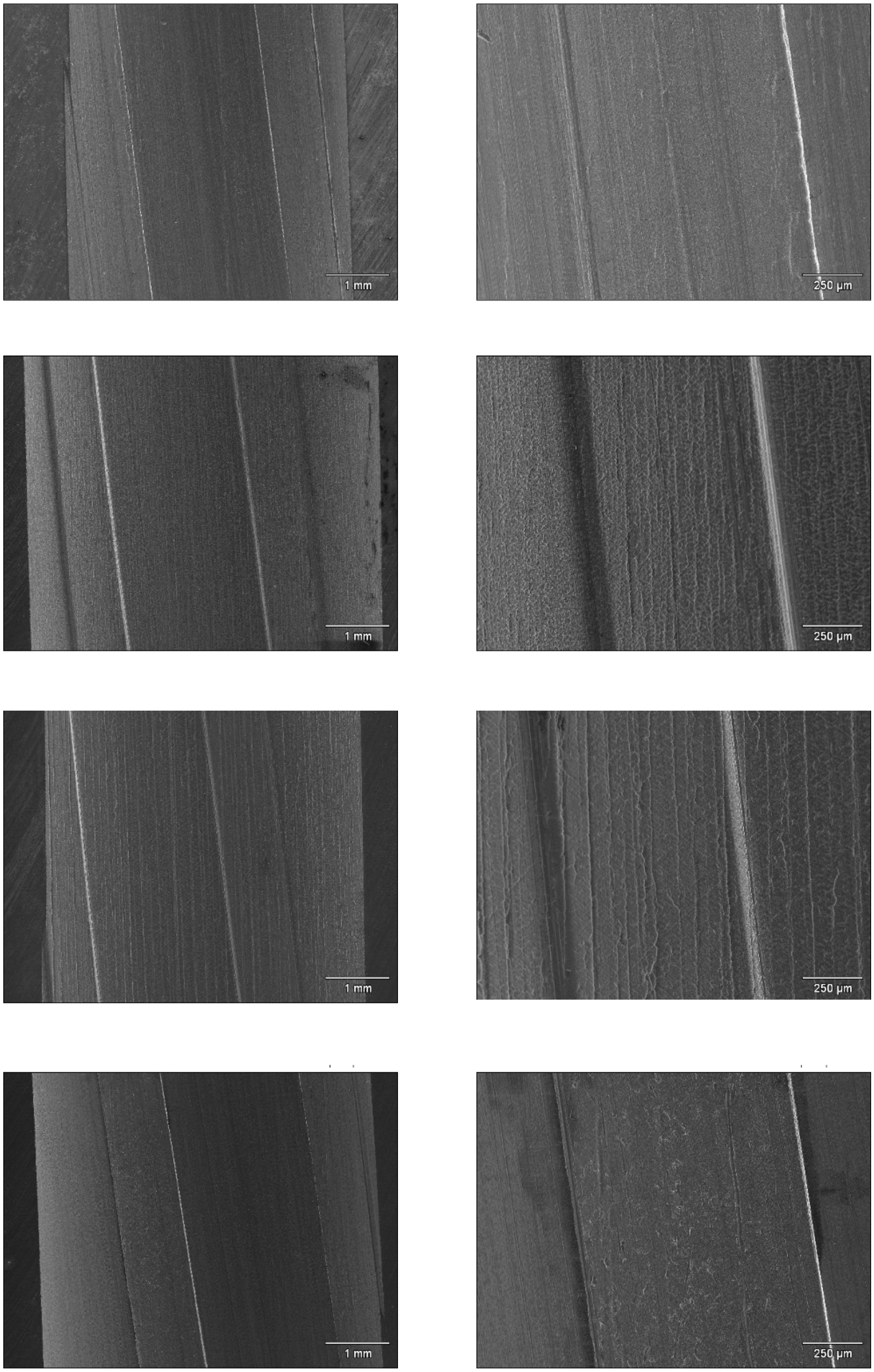

Figure 8: As-Received 9.5” RFT Surface Images

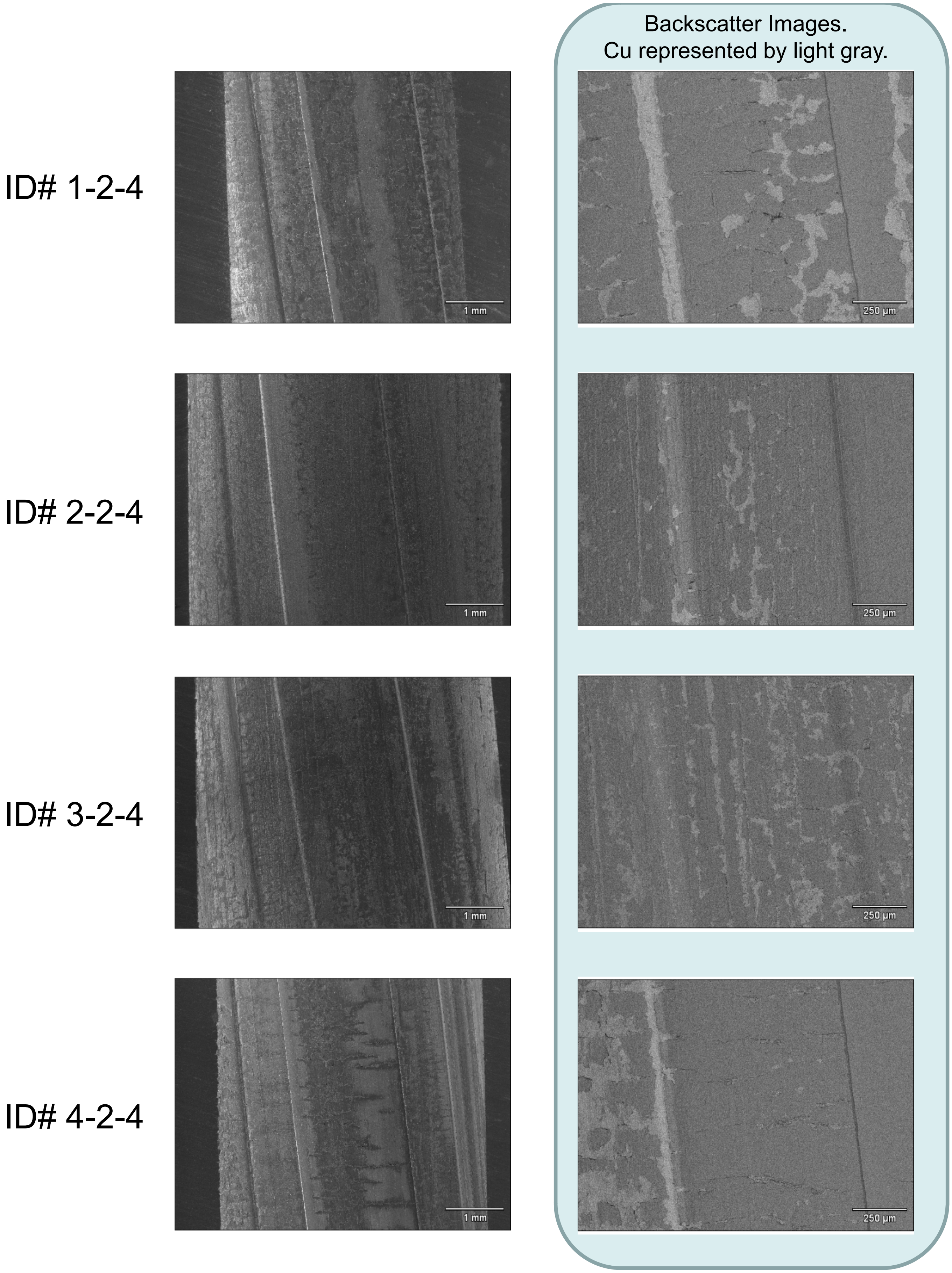

Figure 9: Fired 9.5” RFT Surface Images