MACK T-12 RING ANALYSIS

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Performance you can rely on.

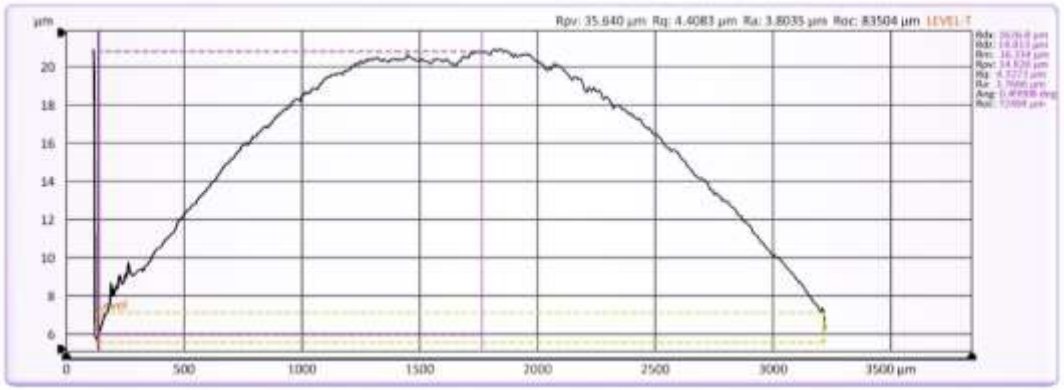
Mack T-12 Ring Batches

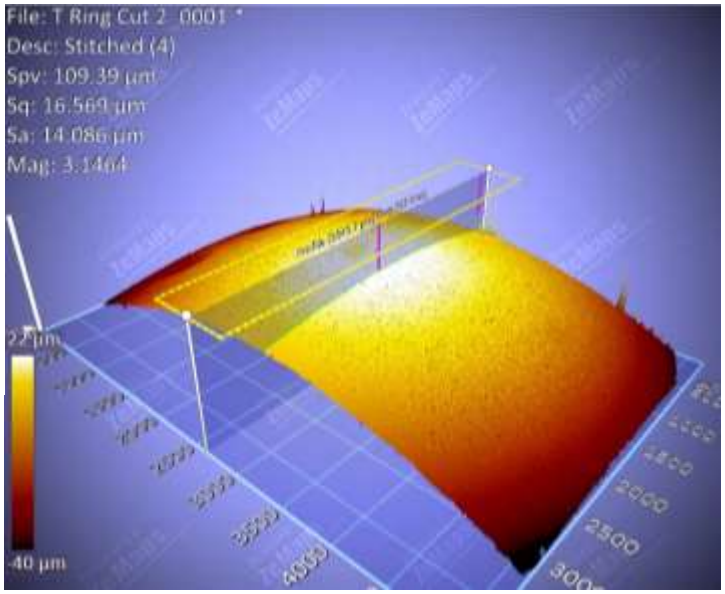
- Mack T-12 has recently gone through multiple parts batch changes
- The STWN (S liners, T top rings, W conrod bearing, N main bearings) batch of parts was exhausted in 2Q2013
- TUXO batch of parts was rejected by the industry for high liner wear and oil consumption
  - T liners were found to have high angle hone marks which were suspected of increasing the oil consumption.
  - This caused the engine test to be unavailable for 4 months.
- U liners were designed with a lower hone angle.
  - A limited batch of parts was fabricated
- The UUXO batch of parts was accepted by the industry with high correction factors since the liner wear and oil consumption still remained high and the test needed to be brought back online
- V liners were fabricated under similar specifications as the U liners and a large batch was made
- During this time there has been 3 liners batch changes and the rings have never been fully analyzed.

Ring Batches Analyzed

- used top ring – Tested in T12 on 6/13/2005
- “N” used top ring – Tested in T12 on 11/5/2008
- “P” used top ring – Tested in T12 on 9/3/2007
- “S” new top ring – Used in the Mack T-11 to reduce oil consumption (SSWN)
- “T” new top ring – Used in the STWN batch of parts
- “U” new top ring – Used in the TUXO, UUXO, VUXO batches of parts

Top Ring Barrel Rise





Top Ring Batch	Barrel Rise (µm)
S	24.7 – 25.8
T	11.1 – 14.9
U	13.5 – 14.8

- Barrel rise is shallower for the T and U rings than the S ring

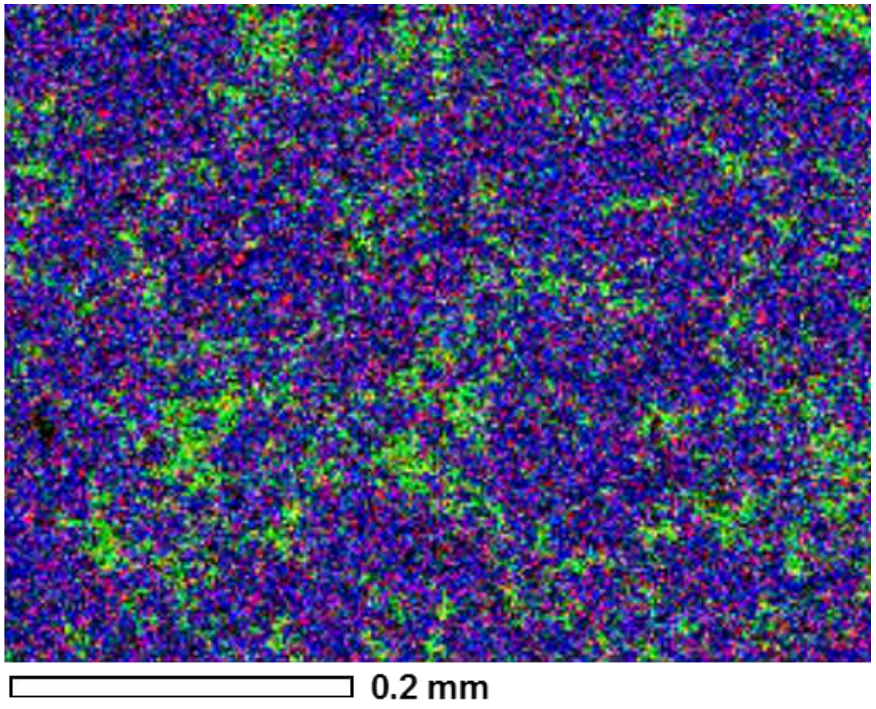
Top Ring Coating Elemental Analysis

Element	"?" Ring Mole %	"N" Ring Mole %	"P" Ring Mole %	"S" Ring Mole %	"T" Ring Seg 1 Mole %	"T" Ring Seg 2 Mole %	"U" Ring Seg 1 Mole %
Cr	**32.48**	**40.92**	**29.54**	**41.42**	**30.68**	**25.59**	**19.09**
Mo	2.18	1.60	1.92	1.88	2.01	1.67	1.46
Ni	**11.00**	**8.91**	**10.13**	**7.99**	**8.73**	**6.64**	**5.05**
Al	**0.22**	**0.62**	**1.20**	**0.25**	**0.54**	**6.88**	**16.91**
C	42.65	41.43	42.09	42.39	48.22	46.48	48.81
O	8.17	4.51	11.18	5.18	7.50	10.05	7.65
Si	0.27	0.18	1.06	0.55	0.77	0.60	0.79
Zn	0.64	0.40	0.48	0.35	0.59	0.38	0.25

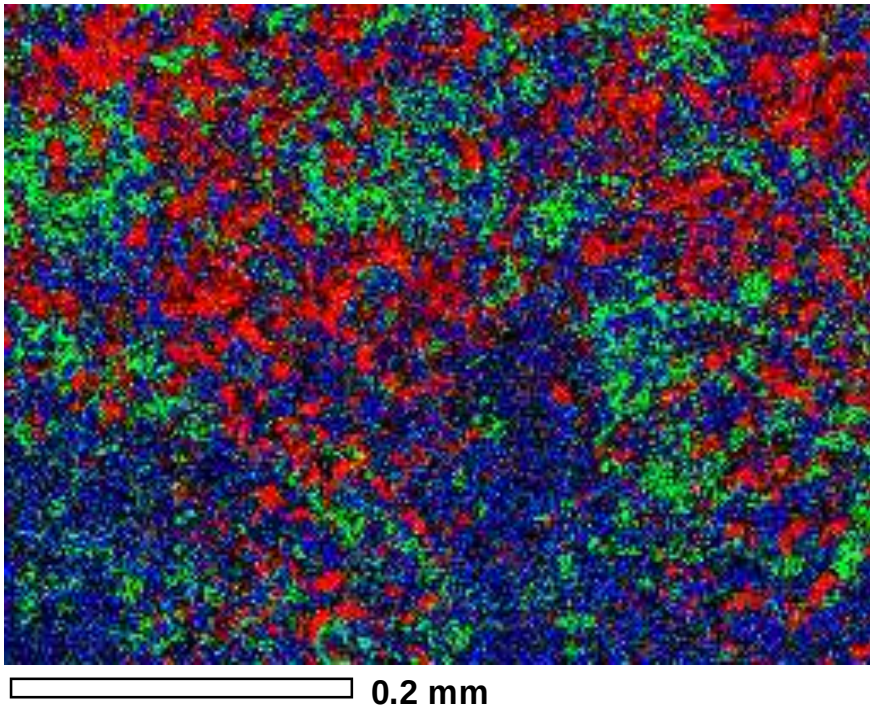
- The amount of aluminum in the coatings rose drastically in the T and U batches
- Concurrently the amount of chromium and nickel were reduced in the coatings

Top Ring Coating Elemental Analysis

"S" ring



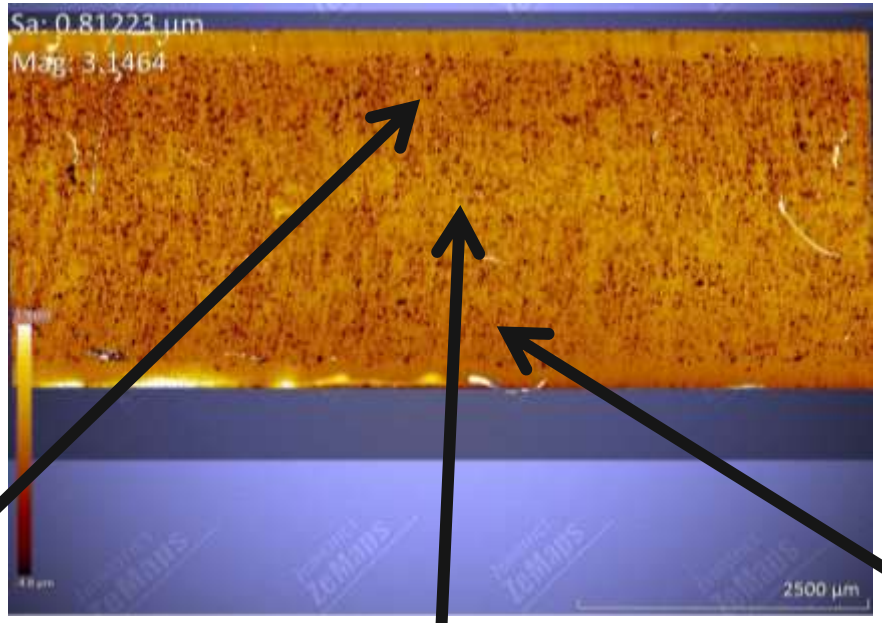
"U" ring



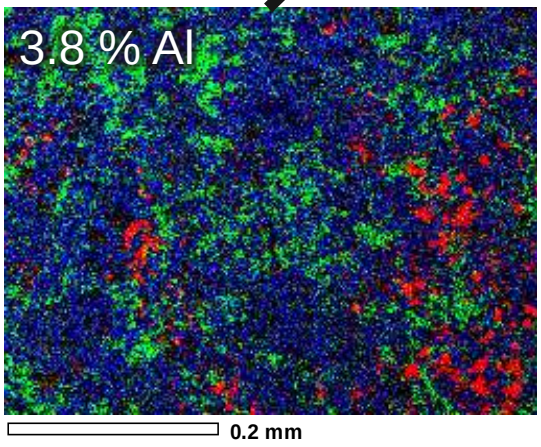
Red = Al, Blue = Cr, Green = Mo

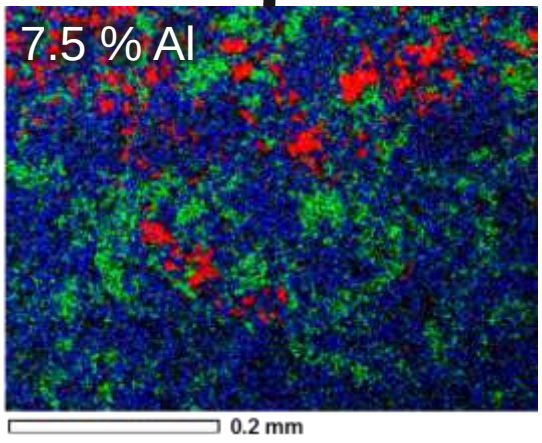
- Large aluminum domains have been found in the U batch rings that were not present in most previous ring batches

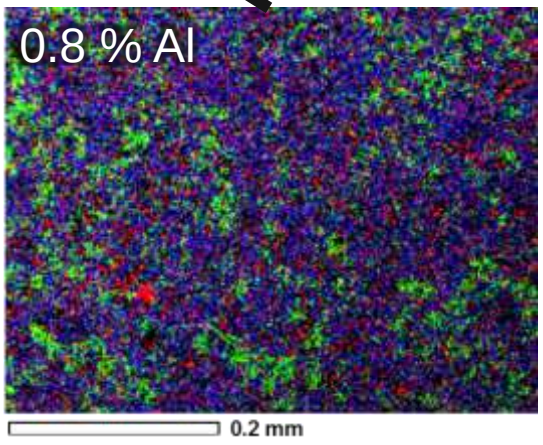
Aluminum Domain Uniformity
U-ring Segment 2



- Aluminum domains are not uniform in the coating

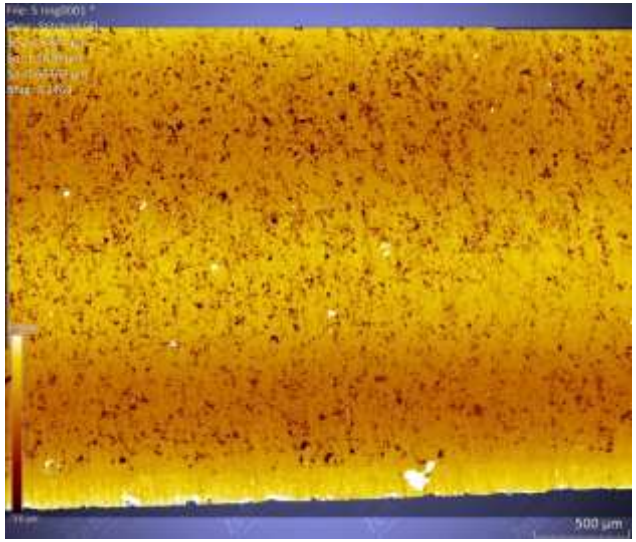




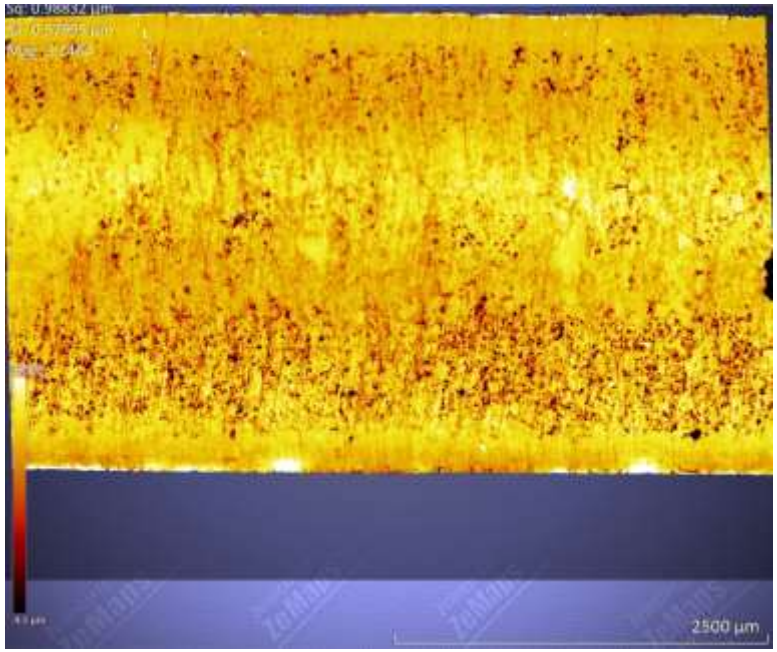


Top Ring Pore Density

“S” ring



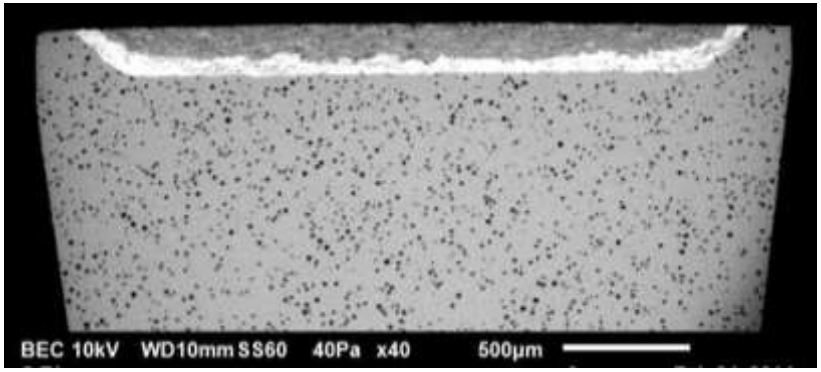
“U” ring

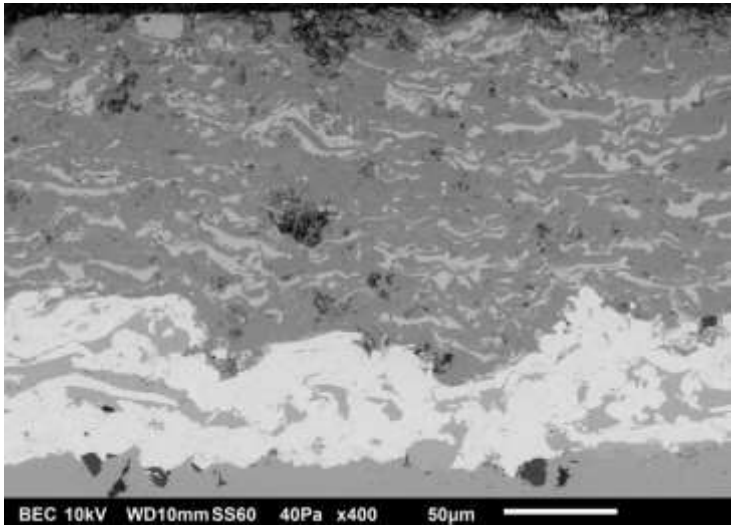


- Surface pores were more spaced out in in the S batch
- Surface pores have become more concentrated on one side of the ring in the U batch

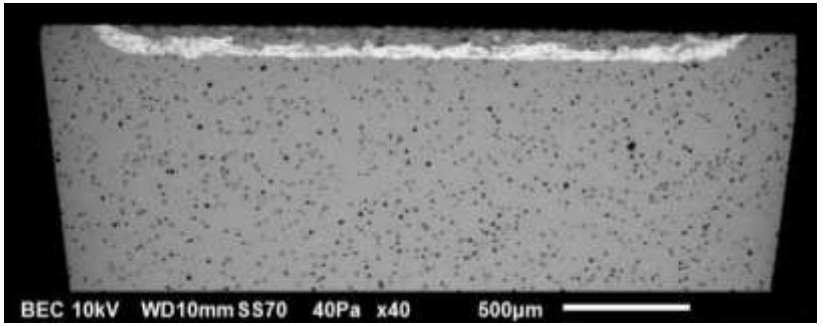
Cross Section Analysis of Rings

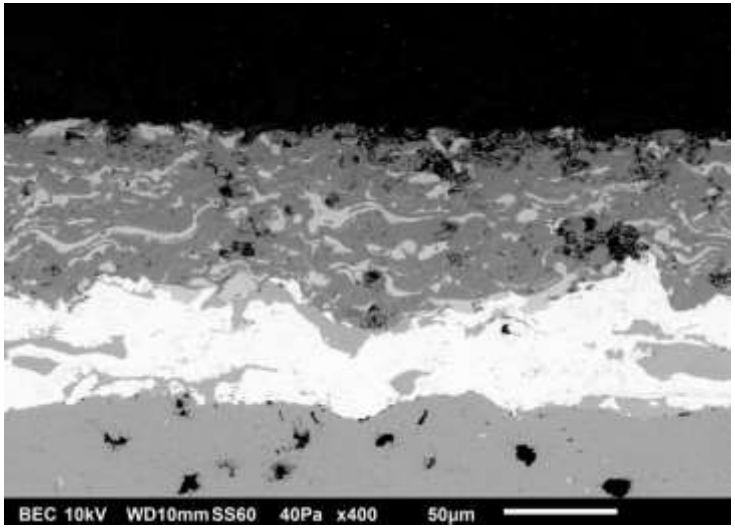
“S” ring





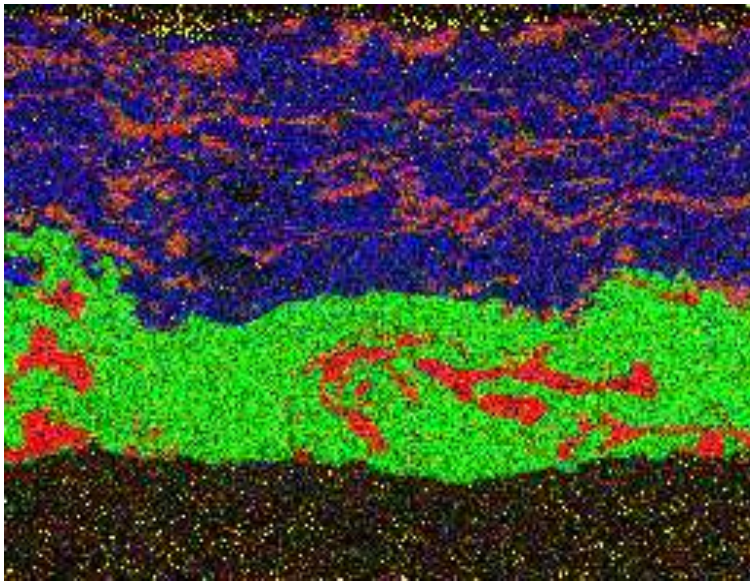
“U” ring

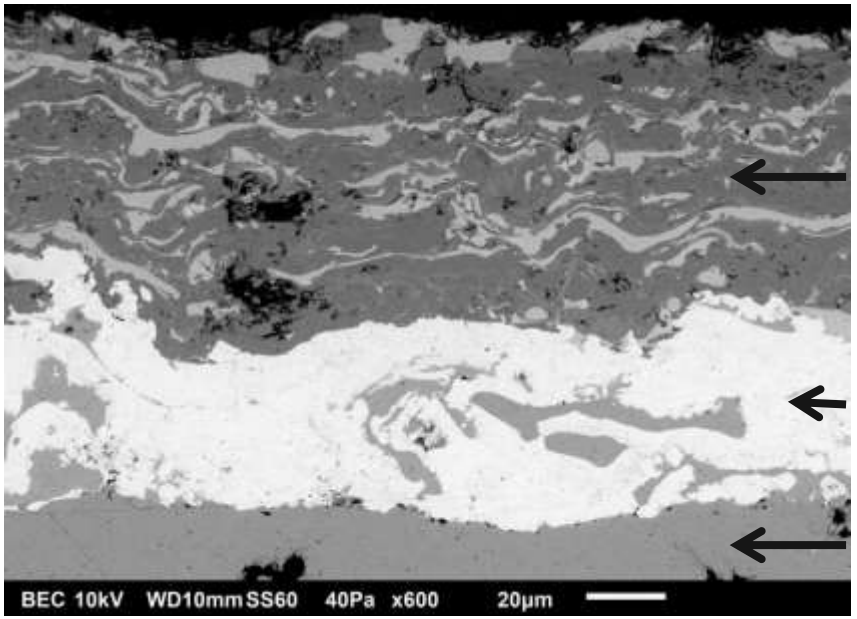




- Coating thickness has reduced from 200 to 127 µm in thickness

Cross Section Analysis
U-ring segment 1

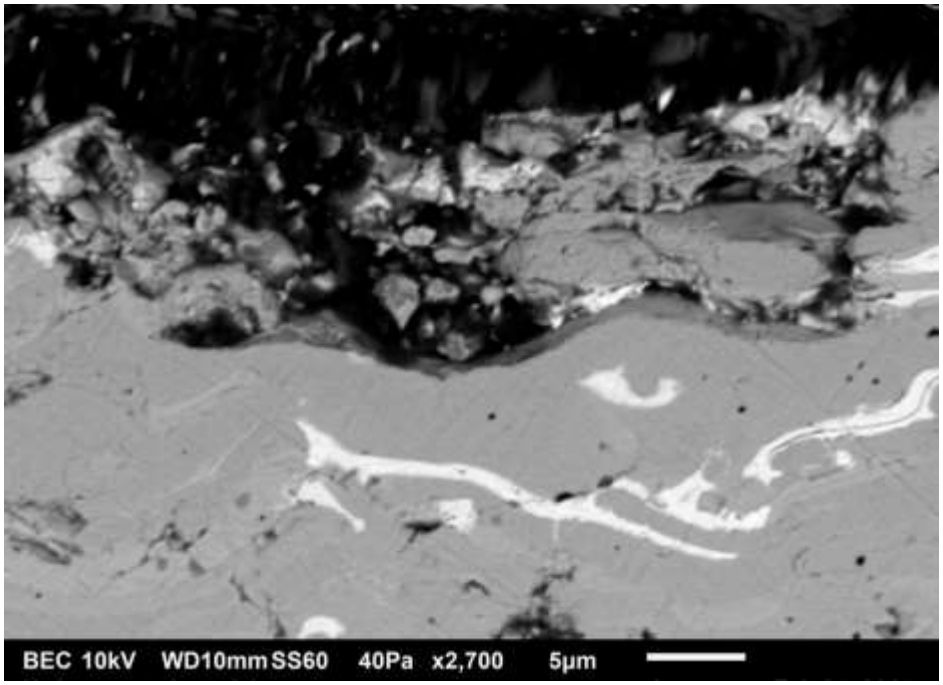


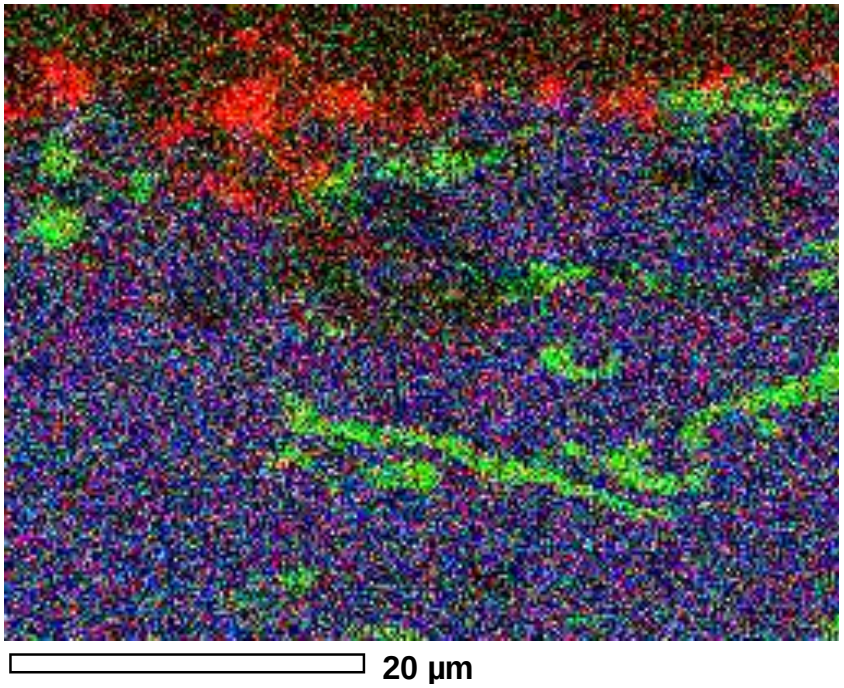


Yellow = Al, Red = Ni, Blue = Cr, Green = Mo

- Aluminum domains are not found throughout the coating they are only found at the surface

Cross Section Analysis
U-ring segment 1





Red = Al, Blue = Cr, Green = Mo

- Aluminum domains were found in the large surface pores structures
- These pore structures were greater in the U-ring than in the S-ring

Conclusion

- The formula for the ring coating has changed between batches
  - Aluminum domains were found at the surface of the coating concurrent with large structural pores in the surface
- The coating thickness has been reduced for the newest batch of rings
- The barrel rise has changed between batches
  - The barrel rise is about half as high T and U batches as it was in the S batch