LABORATORY TEST REPORT LTR 6158-2470

EVALUATION OF VERICODE LASER MARKED MATERIALS

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SUMMARY

Laboratory analysis was conducted on a number of metallic and non-metallic materials Vericode marked using a Nd:YAG laser as part of a joint project between RI-SSD and RI-Huntsville. Laboratory evaluation included visual and SEM examinations, along with metallographic examination of the laser effects on the substrate.

All of the metallic materials marked easily, and were characterized by a slightly roughened surface and discoloration which made the Vericode symbols easily machine readable. No cracking or substantial recast layers were observed in any of these materials, except for the titanium materials which exhibited shallow 'mud flat cracking'. Similar discolorations and surface roughening were achieved on some of the non-metallic materials, however some did not mark well. Those materials (acrylic, Nylon 101, Teflon and Macor) either burned, or did not provide Vericode markings with sufficient contrast to be readable.

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1.0 BACKGROUND

RI-Downey M&P is working on a cooperative test program with RI-Huntsville to evaluate the effect of laser Vericode marking on a variety of different materials. A total of 24 different materials (17 metallic and 8 non-metallic) were marked with a vericode symbol using a neodymium: yttrium aluminum garnet (Nd:YAG) laser by the Compressed Symbology Testing Laboratory in Huntsville. All 17 of the metallic materials marked clearly, however four of the eight non-metallic specimens were not readable. Those four materials were: acrylic, nylon, teflon and Maycor. The problems encountered with these materials can be attributed to lack of color pigment and material mass, which allowed the laser light beam to penetrate through and/or be absorbed by the material.

The M&P Failure Analysis Laboratory was requested to prepare metallographic cross-sections of the various specimens, quantifying the maximum depth of affected material.

2.0 OBJECTIVE

The objective of this portion of the Vericode Laser Marking Project was to evaluate the damage induced by the Nd:YAG laser during marking of a wide variety of metallic and non-metallic Orbiter materials. The intent was to identify and characterize the nature and extent of the damage so induced.

3.0 LABORATORY INVESTIGATION AND RESULTS

3.1 Visual Examination of Vericode Markings

Each of the specimens was examined macroscopically and with the aid of a stereomicroscope and photodocumented. All of the received samples and the laser produced vericode markings created on them are shown in Figure 1.

All of the metallic materials were clearly marked. Four of the eight non-metallic materials were not readably marked. In those materials, the acrylic appeared burned and the Nylon 101 exhibited only spotty markings. The Teflon exhibited no apparent marking, and the Macor exhibited only faint Vericode marking, which was insufficient in contrast to be machine readable.

3.2 SEM Examination of Laser Vericode Markings

Each of the machine-readable laser Vericode markings was examined using the scanning electron microscope (SEM) for greater detail and characterization of substrate effects. Representative photomicrographs were taken at 100X and at 300X, showing both the affected region and the immediately adjacent substrate surface for comparison.

3.2.1 Metallic Materials

In general, the aluminum materials exhibited a molten and resolidified surface modification readily discernible from the substrate control surface. While the resolidification patterns were distinct, there was no evidence of any cracking, either substantial or superficial, related to the laser marking. Refer to Figures 2 through 5 for typical examples of the surface modification.

The CDA copper specimen exhibited a fine structured recast layer, apparently significantly more shallow than observed on the aluminum specimens. No cracking, either superficial or deep was noted on the laser marked surface. Refer to Figure 6.

The steel specimens exhibited only a slight surface modification. This consisted of softening and rounding of the surface features in the marked region on the carbon steel specimens and a more distinct, but still shallow melt/softening pattern on the CRES specimens. The CRES specimens exhibited a slightly more distinct recast pattern from the traverse pattern of the laser. None of the specimens exhibited any identifiable cracking. Representative illustrations of each are provided in Figures 7 through 12.

The superalloy materials generally exhibited features very similar to those found on the CRES specimens, notably a slight recast pattern from the laser traverse. No indication of cracking was found on any of the specimens and the depth of the affected material appeared to be relatively shallow. Refer to Figures 13 through 15.

Both of the titanium materials exhibited a pattern of fine 'mud-flat' cracks on the laser marked surface. These cracks appeared to be generally superficial although no actual estimate of their depth could be made solely from SEM data. Refer to Figures 16 and 17.

3.2.2 Non-Metallic Materials

None of the acrylic, Nylon 101, Teflon, Macor specimens marked suitably for machine readability. Of these only the Macor exhibited any physical evidence which was examined using the SEM. All of the other materials are described below.

The Super Koropon painted aluminum specimen, Figure 18, exhibited a distinct delineation, with the laser marked area characterized by a very irregular texture. In this region the surface appeared broken up into a mixture of both larger and fine irregularly shaped particulates. No evidence of any cracking was discovered.

The neoprene rubber, Figure 19, was readily apparent as the laser marked region exhibited a roughened surface. The structure of the disrupted surface was generally fine, with no apparent cracking with a few longer troughs of greater damage located along the axis of laser travel.

The silicone rubber specimen, Figure 20, exhibited the same general type of surface modification as the neoprene rubber, but was substantially more uniform in texture. No

indication of any cracking was observed.

Lastly, the Macor specimen (which was not machine readable) was examined. As shown in Figure 21, the laser marked surface was substantially damaged, exhibiting sharp, although fine, surface roughness.

3.3 Metallographic Examination

Metallographic cross sections were prepared through each of the specimens bisecting the laser marked Vericode pattern. These were then ground and polished using standard metallographic techniques and examined at magnifications up to 1000X. Representative photographs were taken of any observed substrate damage and are attached to this report as Figures 22 through 41.

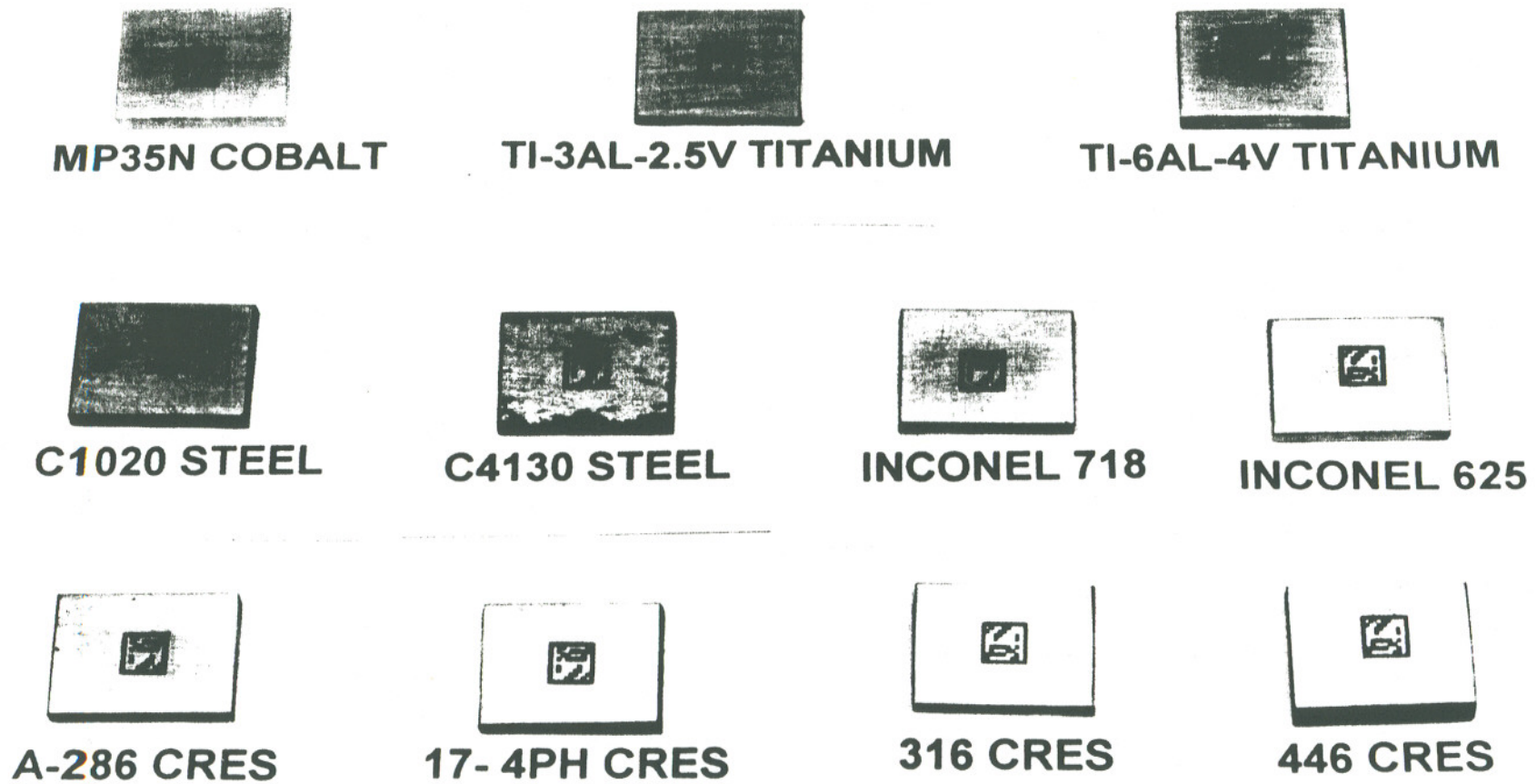
A summary of the maximum depth of substrate damage observed for each specimen is provided in Table I, along with any pertinent descriptive information.

4.0 SUMMARY

All of the metallic materials marked easily, and were characterized by a slightly roughened surface and discoloration which made the Vericode symbols easily machine readable. No cracking or substantial recast layers were observed in any of these materials, except for the titanium materials which exhibited shallow 'mud flat cracking'. Similar discolorations and surface roughening were achieved on some of the non-metallic materials, however some did not mark well. Those materials (acrylic, Nylon 101, Teflon and Macor) either burned, or did not provide Vericode markings with sufficient contrast to be readable.

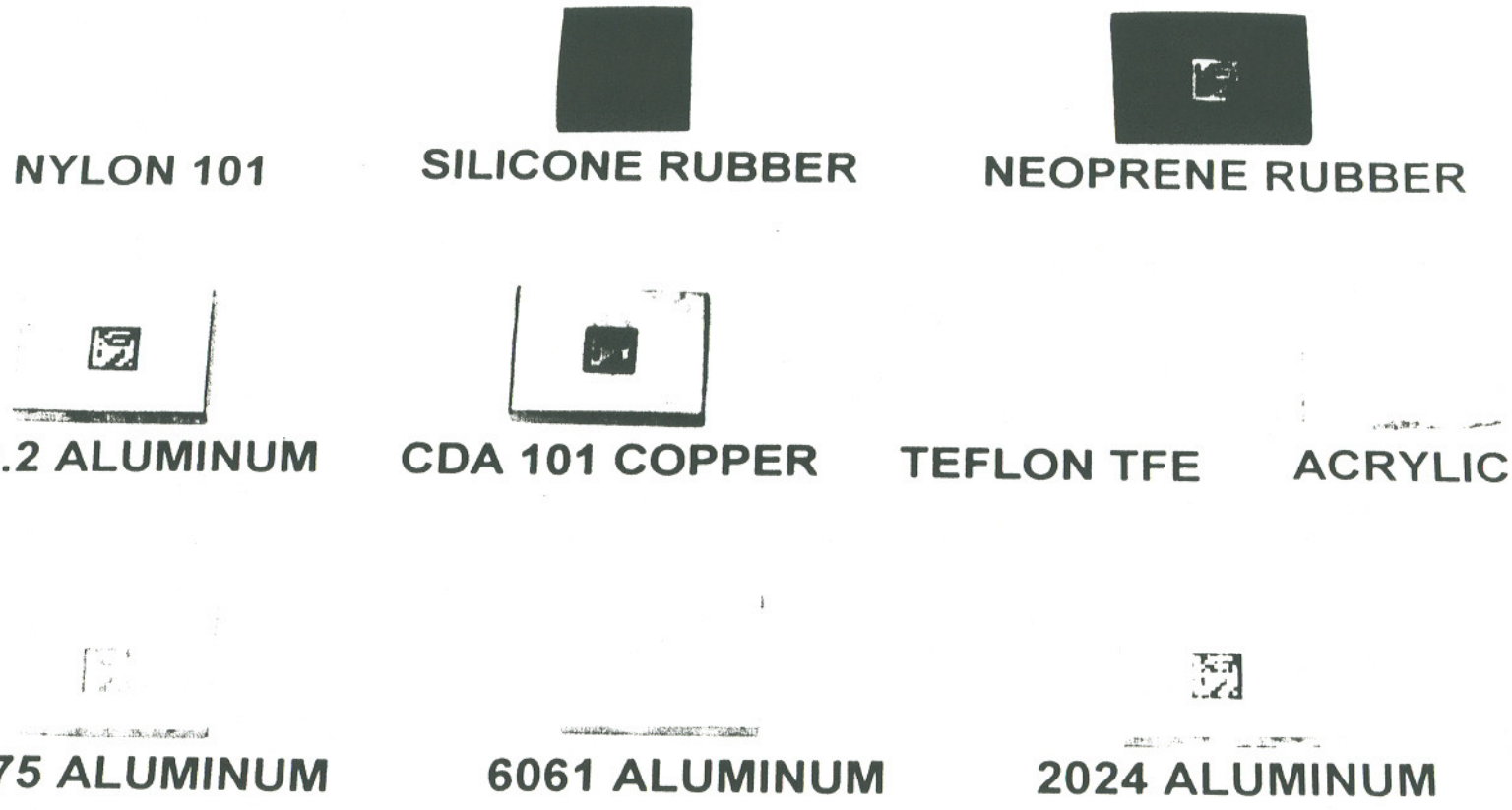
Table I.
Summary of Substrate Damage

Sample#	Material	Affected Depth (inch)	Remarks
001	2024 Aluminum	0.005	Deep/narrow mat'l erosion
002	6061-T6 Aluminum	0.001	Shallow/irregular mat'l erosion
003	7075 Aluminum	0.008	Sharp penetration as well as relief
004	356.2 Aluminum	0.004	Rounded/narrow mat'l erosion
005	CDA 101 Copper	0.001	Shallow,rounded mat'l erosion
006	C1020 Steel	<0.001	Very shallow affected region
007	C4130 Steel	none apparent	Surface discoloration apparent
008	17-4PH CRES	none apparent	
009	316 CRES	<0.001	Very shallow, irregular effect
010	446 CRES	0.001	Very shallow, somewhat irregular mat'l penetration
011	A-286 CRES	0.003	Irregularly shaped penetration
012	Inconel 625	0.001	Irregular, shallow affected region
013	Inconel 718	0.001	Shallow, irregular affected region
014	MP35N	none apparent	Mostly surface discoloration
015	Ti-6Al-4V	none apparent	Mostly surface discoloration
016	Ti-3Al-2.5V	<0.001	Superficial, irregular penetration
017	Super Koropon Painted Aluminum	0.004	Sharp, narrow penetration and relief
018	Acrylic	-	Mat'l burned through
019	Nylon 101	-	
020	Teflon TFE	none apparent	Insufficient surface contrast
021	Gr/Ep Composite	none apparent	
022	Neoprene Rubber	0.005	Rounded, smooth penetration
023	Silicone Rubber	0.003	Rounded, smooth penetration
024	Macor	0.006	Smooth, but slightly irregular penetration



VERICODE MARKED MATERIALS

Figure 1a. Overall view of the titanium and steel based specimens showing the applied vericode markings. All exhibit distinct, readily readable markings. (approx. 1X)



VERICODE MARKED MATERIALS

Figure 1b. Overall view of the aluminum, copper, and non-metallic materials. All of the metallic materials are well marked, but the nylon, Teflon, and acrylic materials are not readable. (approx. 1X)

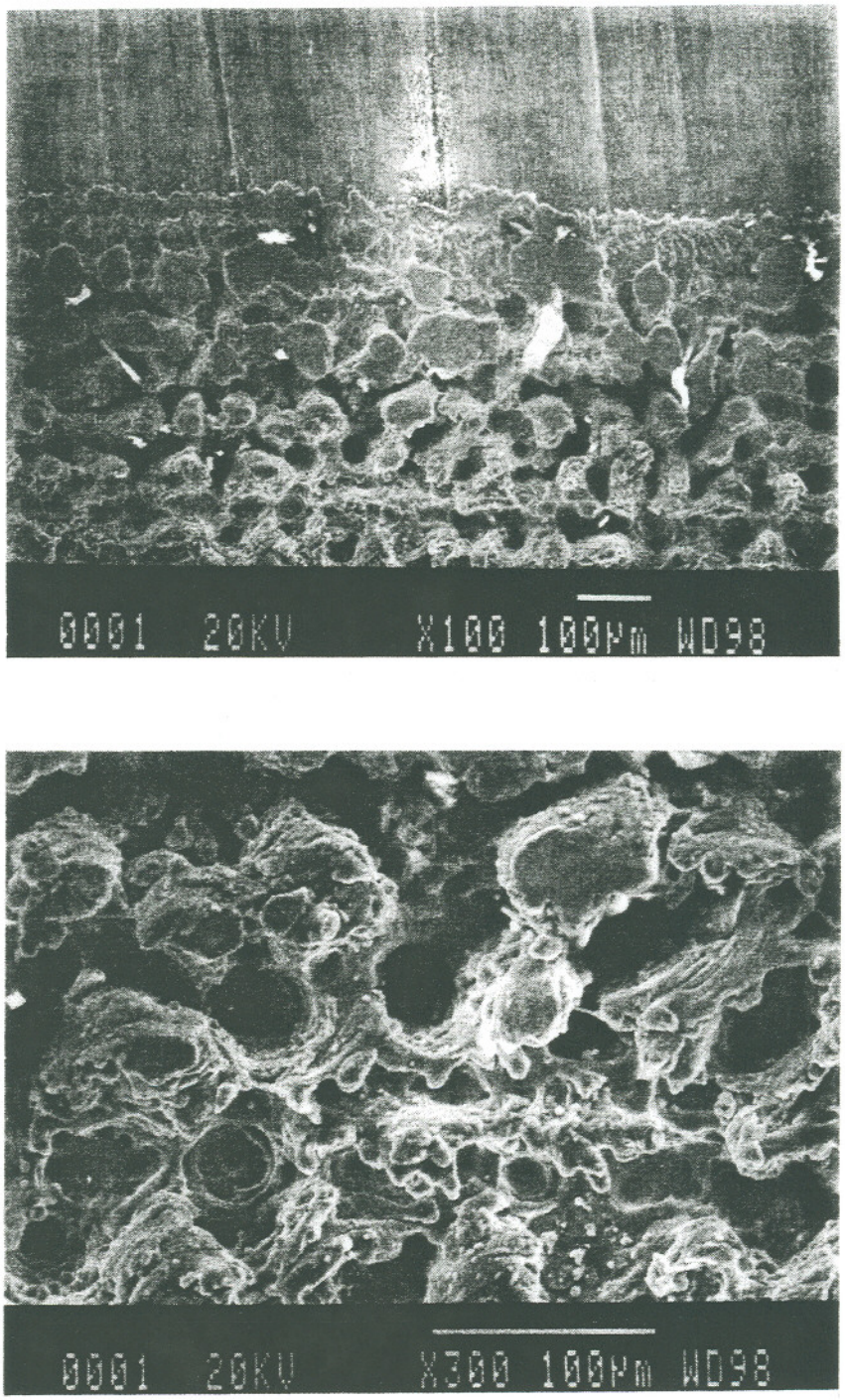


Figure 2. *2024 Aluminum* (100X & 300X)
Illustration of the effects of laser marking on the aluminum substrate. Note the distinct re-cast surface layer and roughness. No substrate cracking is apparent.

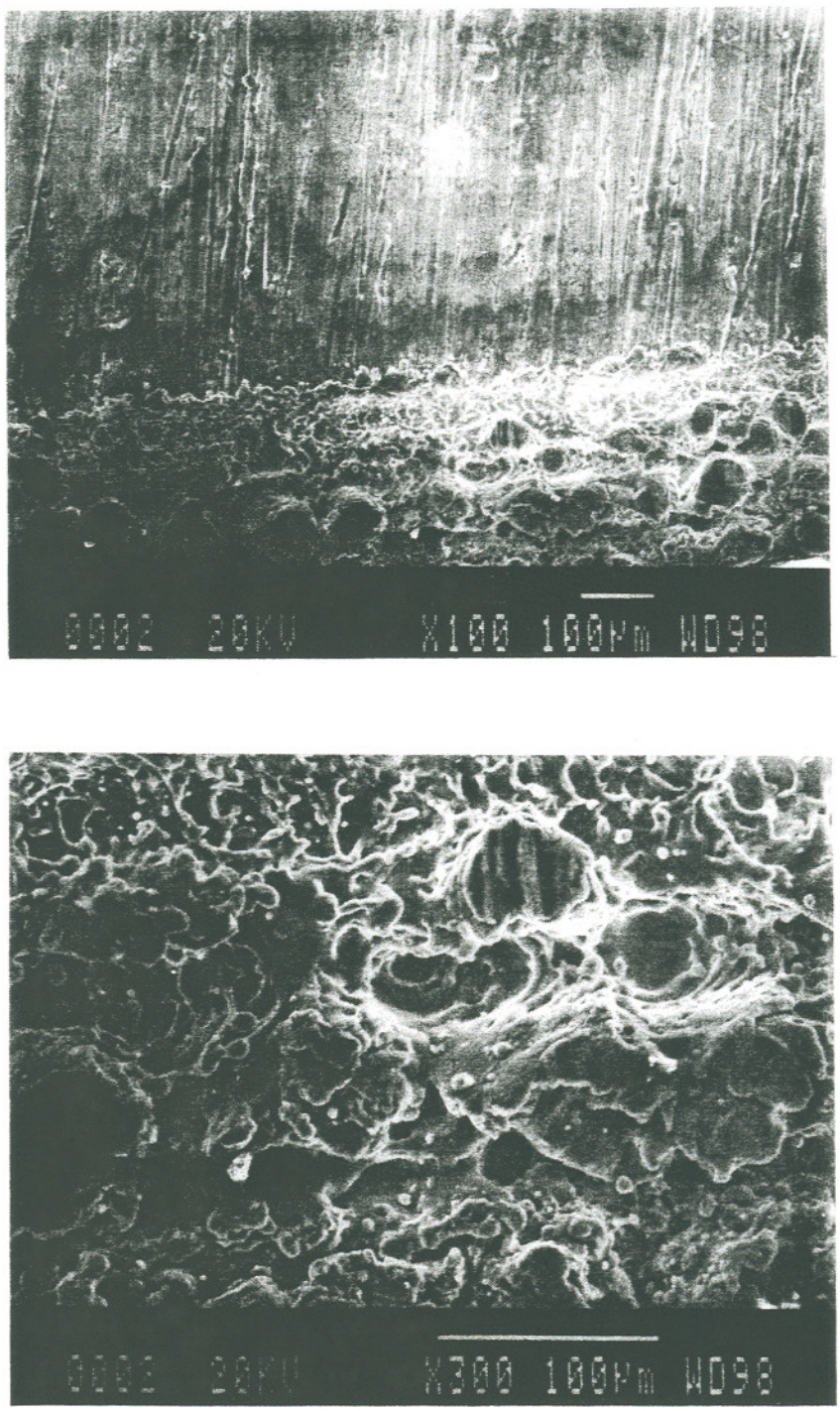
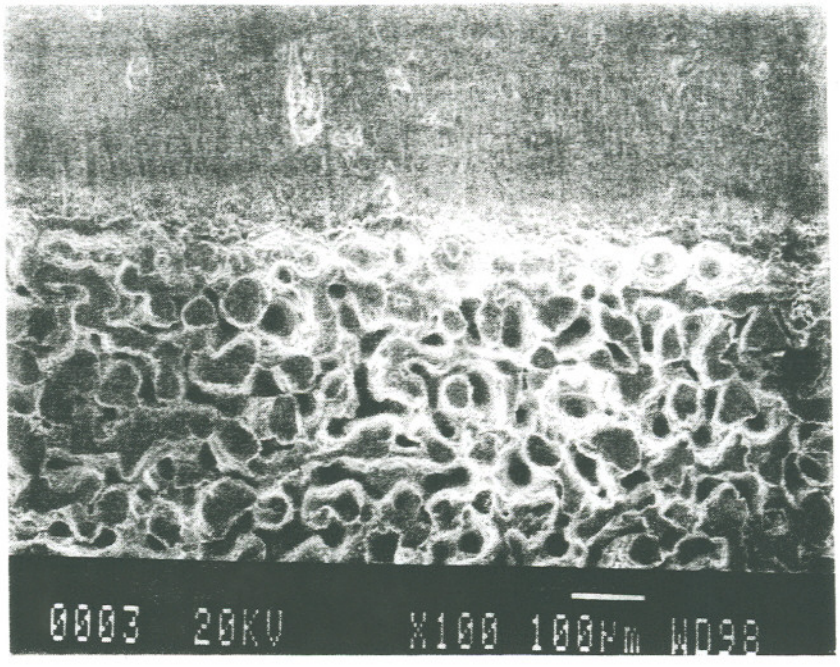


Figure 3. *6061-T6 Aluminum* (100X & 300X)
Note the re-cast surface layer and associated roughness. No evidence of substrate cracking can be seen.



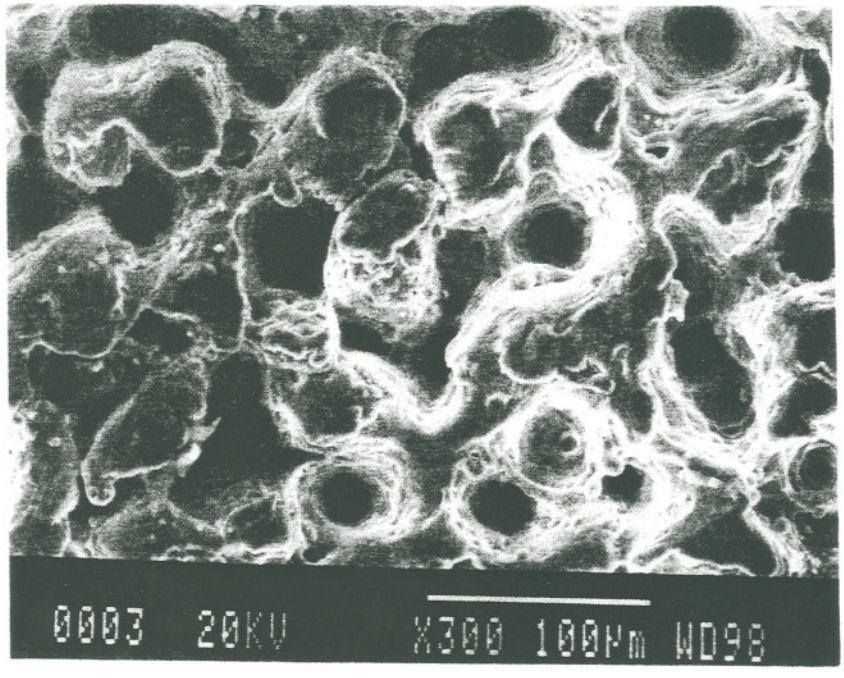


Figure 4. *7075 Aluminum* (100X & 300X)
Significant surface roughness from melting and re-cast of the surface layer are evident, but no cracking is visible.

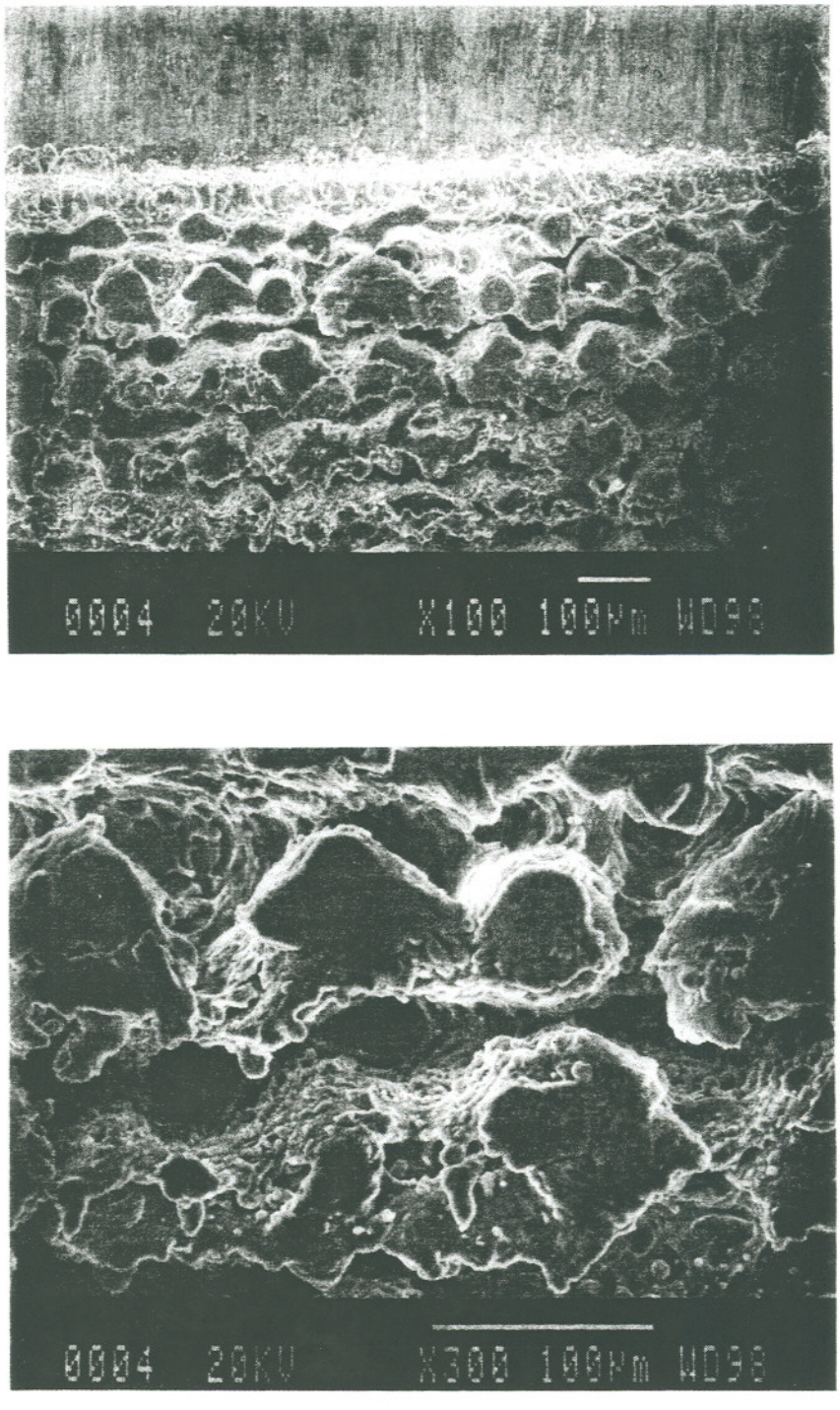


Figure 5. *356.2 Aluminum Casting* (100X & 300X)
Substantial surface re-cast has resulted in significant surface roughness, but no substrate cracking is evident.

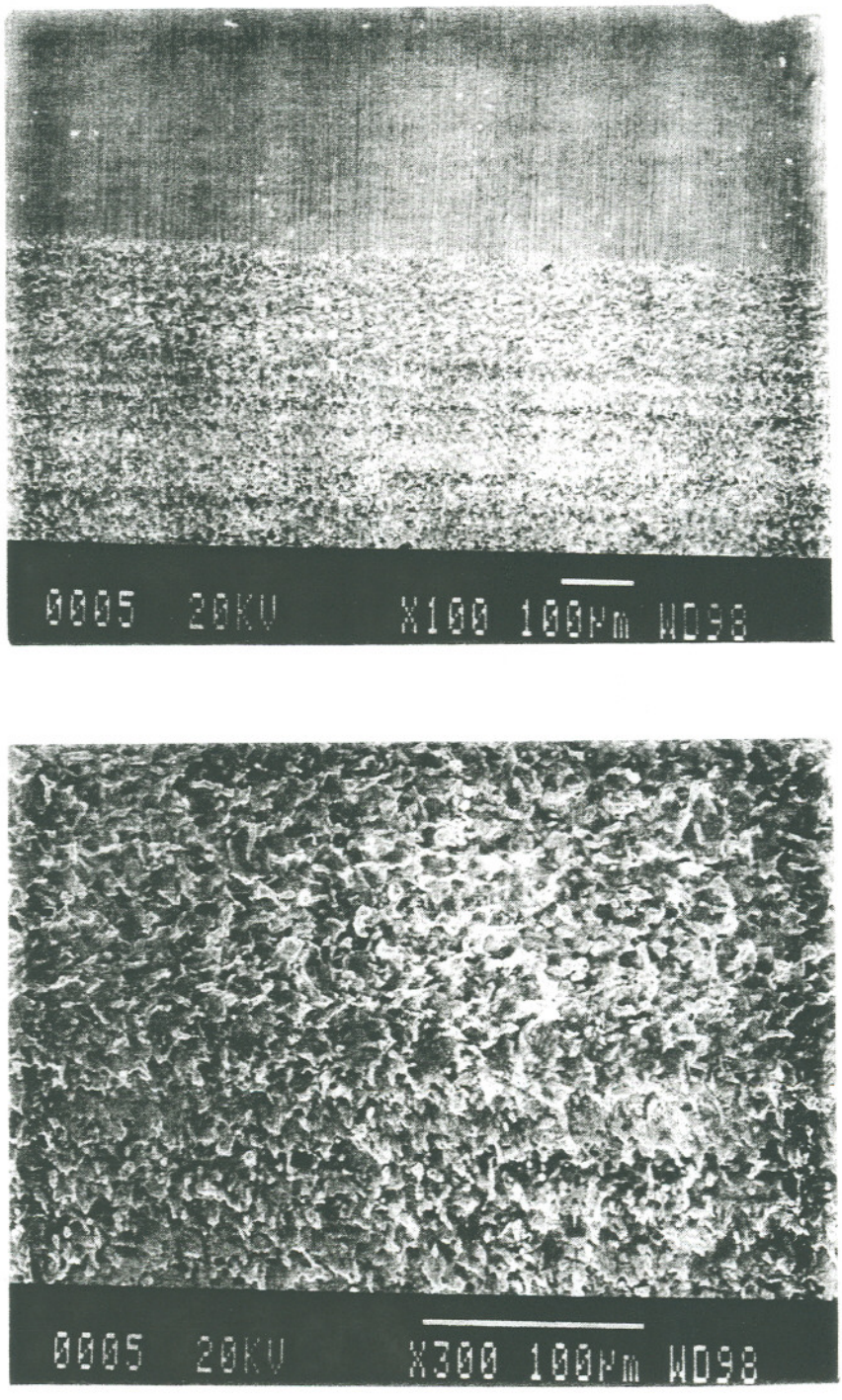


Figure 6. *CDA 101 Copper* (100X & 300X)
The readily visible surface re-cast layer is fine in texture, but exhibits no apparent substrate cracking. The texture is also very uniform.

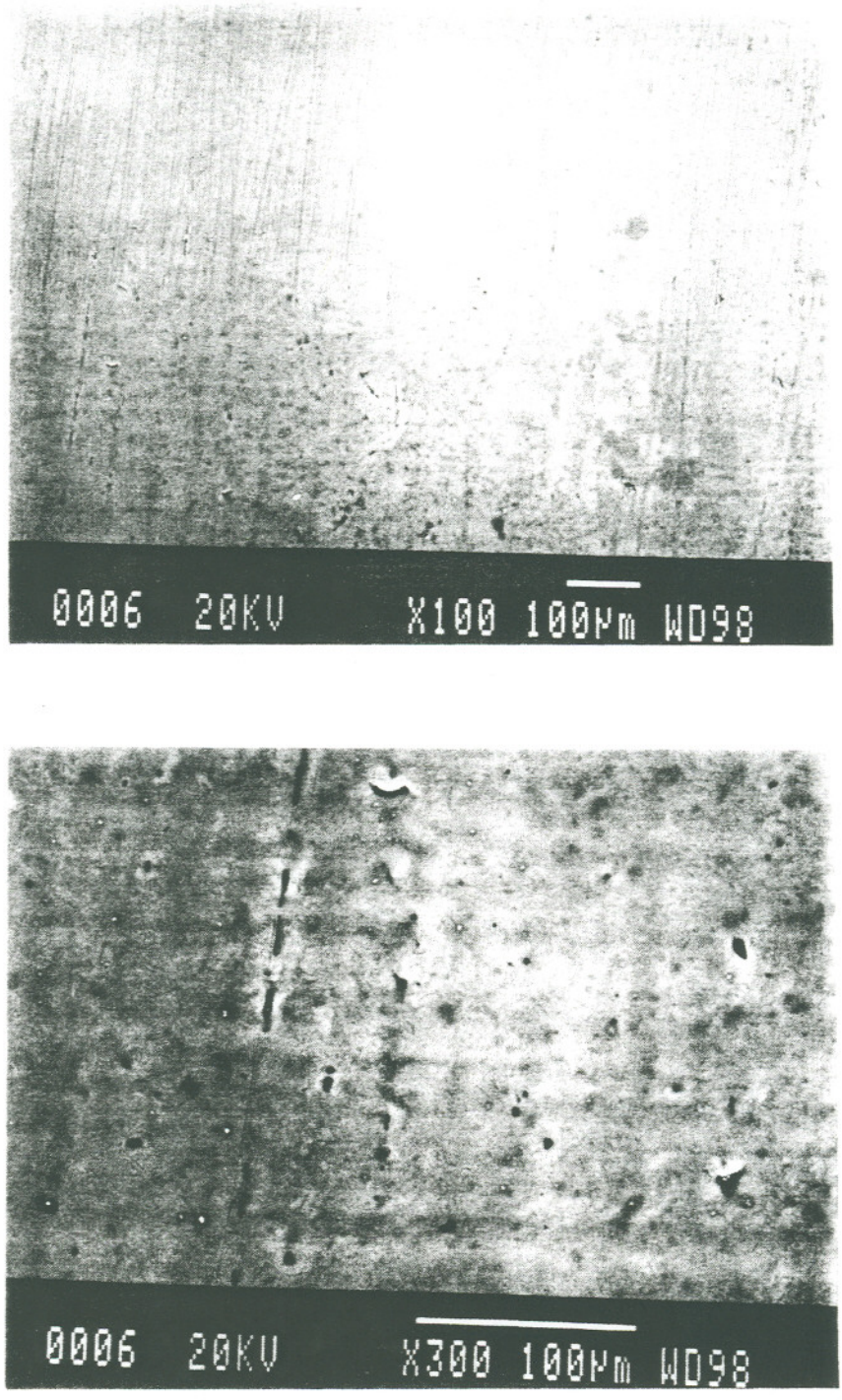


Figure 7. *C1020 Steel* (100X & 300X)
The laser marked surface region exhibits a smooth, undulating surface texture suggesting a very shallow re-cast depth. No indication of substrate cracking is apparent.

Figure 8. *C4130 Steel* (100X & 300X)
The surface texture in the marked region is similar to that of the C4130 steel, but does exhibit slightly more surface distress. No cracking was apparent.

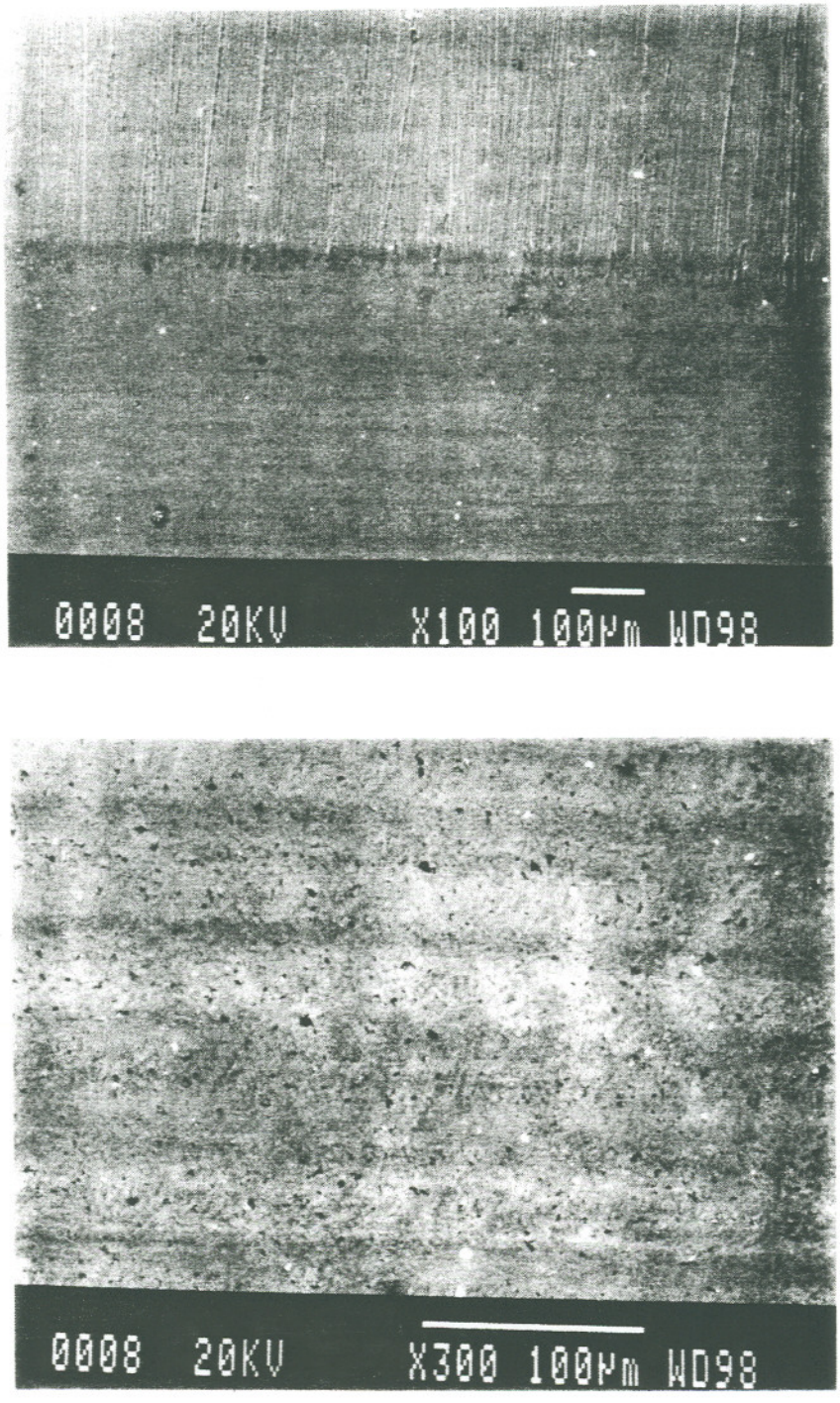


Figure 9. *17-4PH Steel* (100X & 300X)
As with most of the steels, the affected region appears to be very shallow. While the surface is generally smooth, it is slightly 'pock-marked', but without cracking.

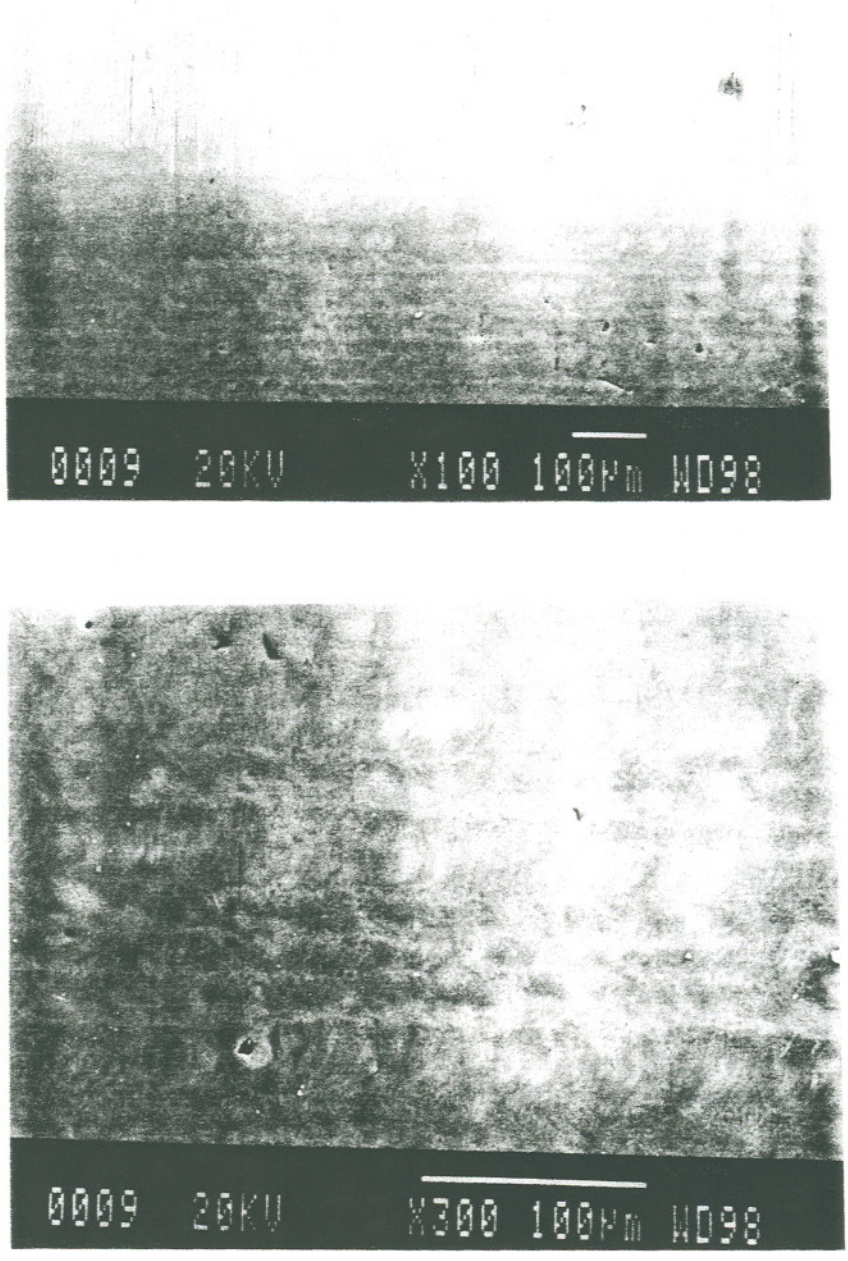


Figure 10. *316 CRES* (100X & 300X)
The surface of the marked area was very smooth, exhibiting the fine periodic structure of the laser pulsing. No substrate cracking was observed.

Figure 11. *446 CRES* (100X & 300X)
The surface of the marked area was generally smooth, but with some indication of the path of the laser travel over the specimen surface. Again, no cracking was noted.

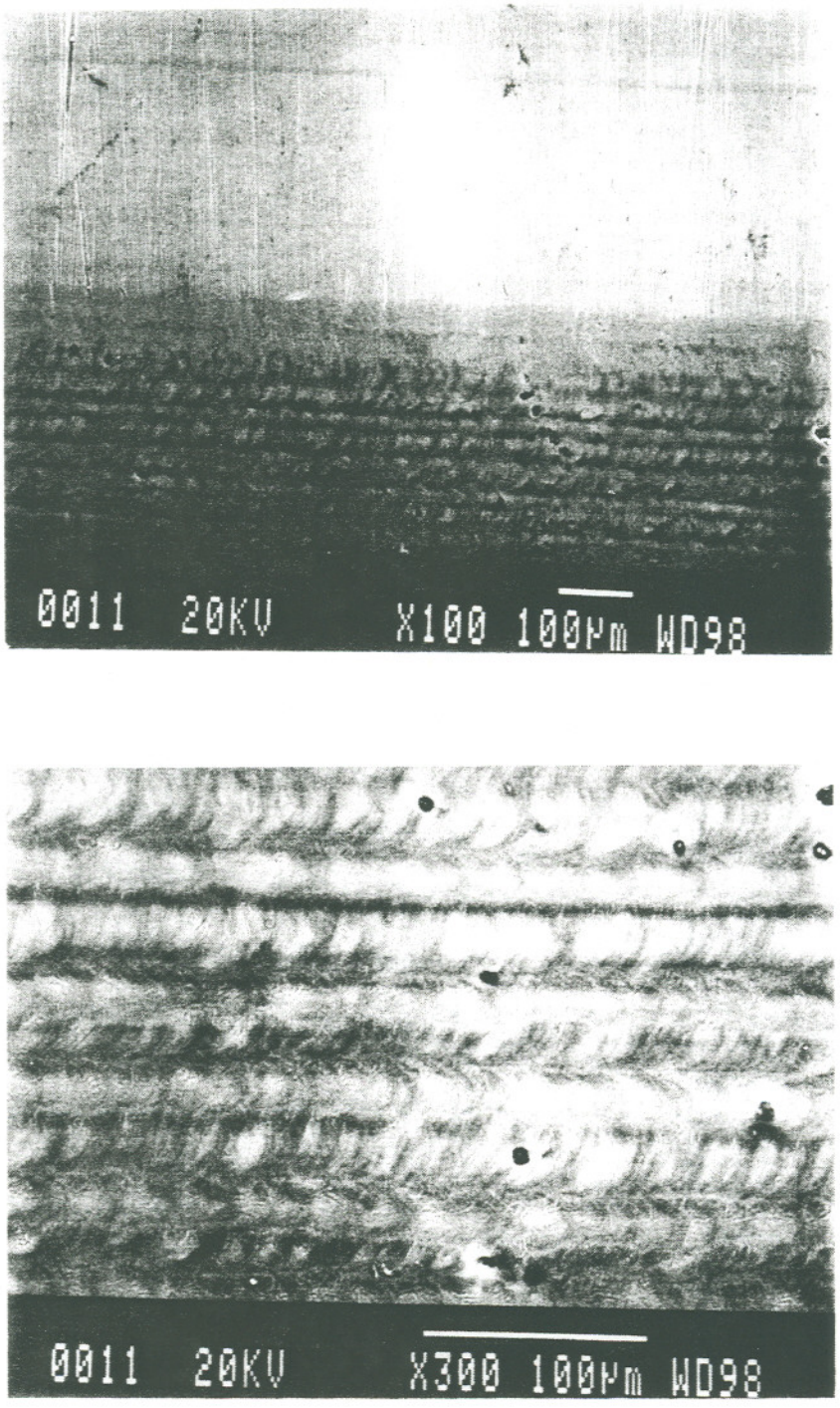


Figure 12. *A286 CRES* (100X & 300X)
The marked surface was readily apparent, although the depth of the re-cast layer appeared to be moderate to shallow. No cracking was noted.

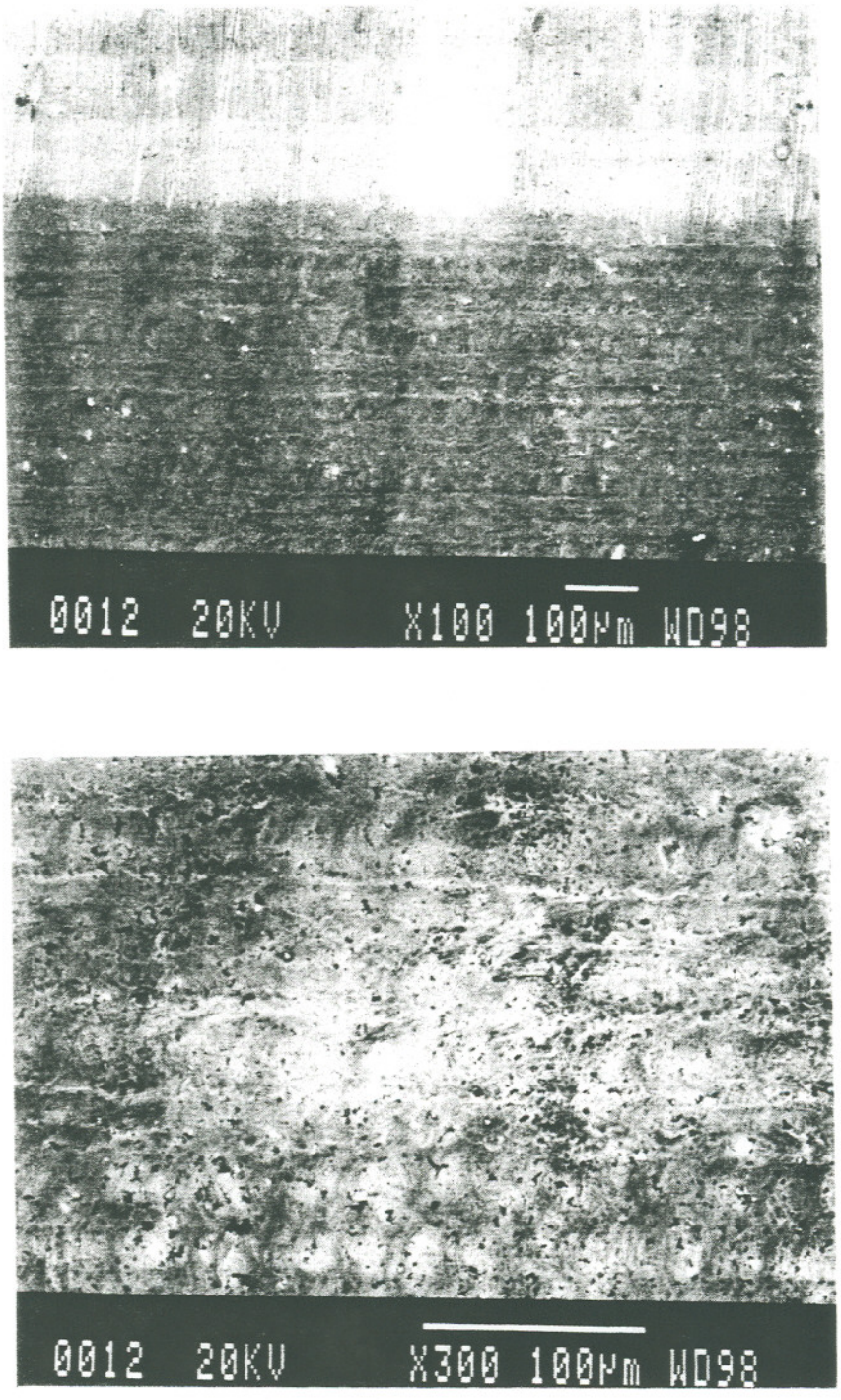
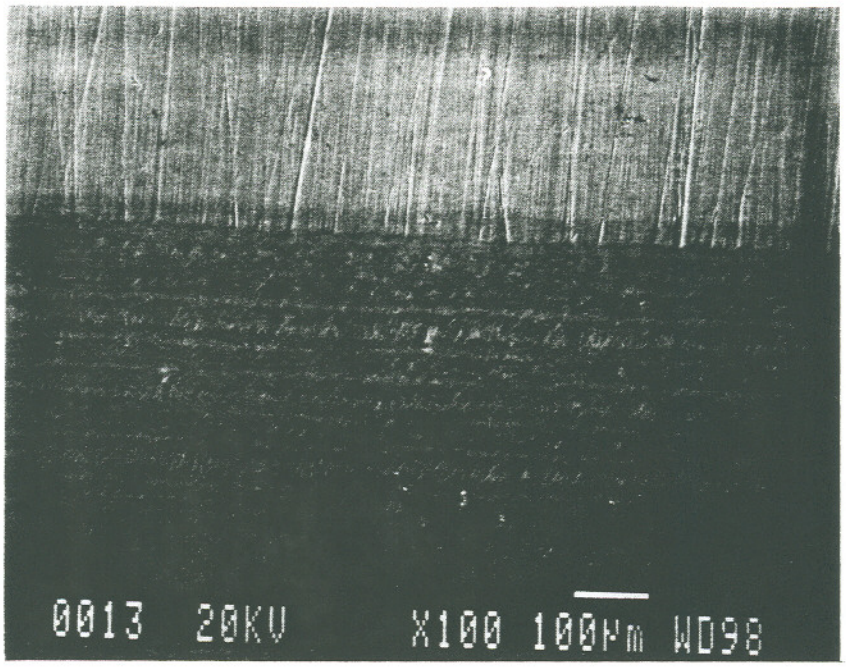


Figure 13. *Inconel 625* (100X & 300X)
The marked area was generally smooth in texture, with small 'pock-marks'. No cracking was observed.



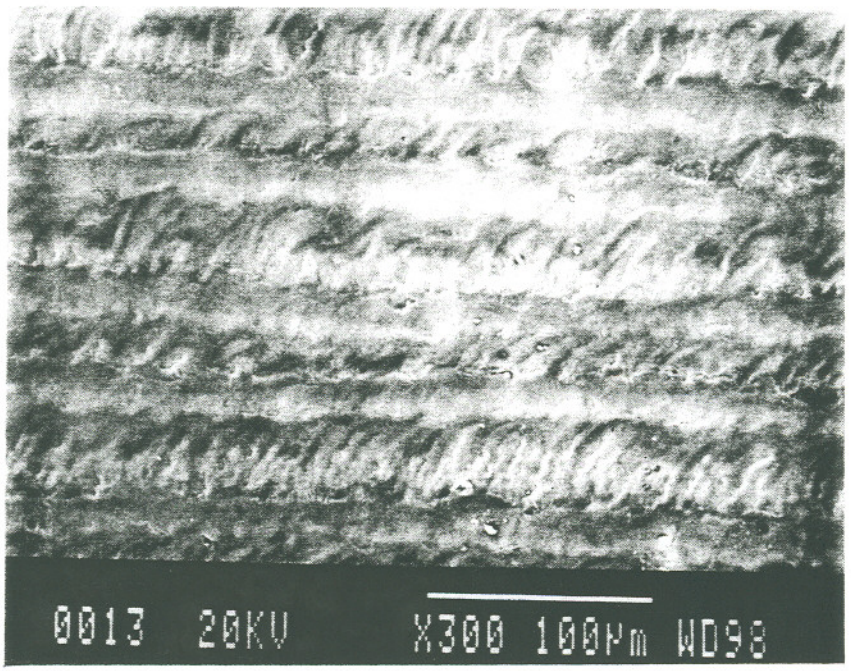


Figure 14. *Inconel 718* (100X & 300X)
The path of laser travel was readily apparent and the depth of the re-cast layer appeared to be moderate. Again, no cracking was discovered.

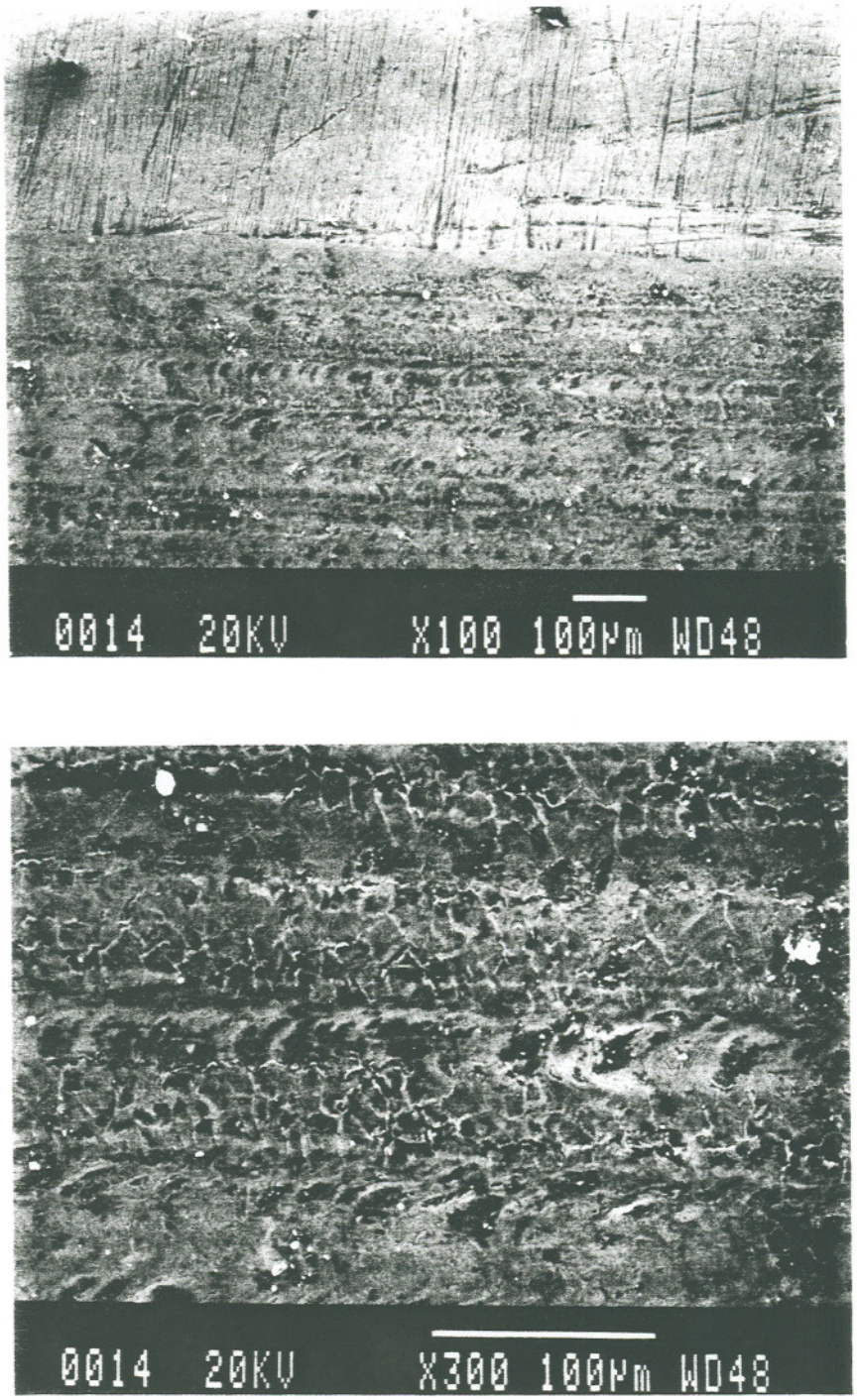


Figure 15. *MP35N* (100X & 300X)
This material marked well, exhibiting an apparent shallow re-cast layer with fine, but distinct surface texture. No cracking of the substrate was noted.

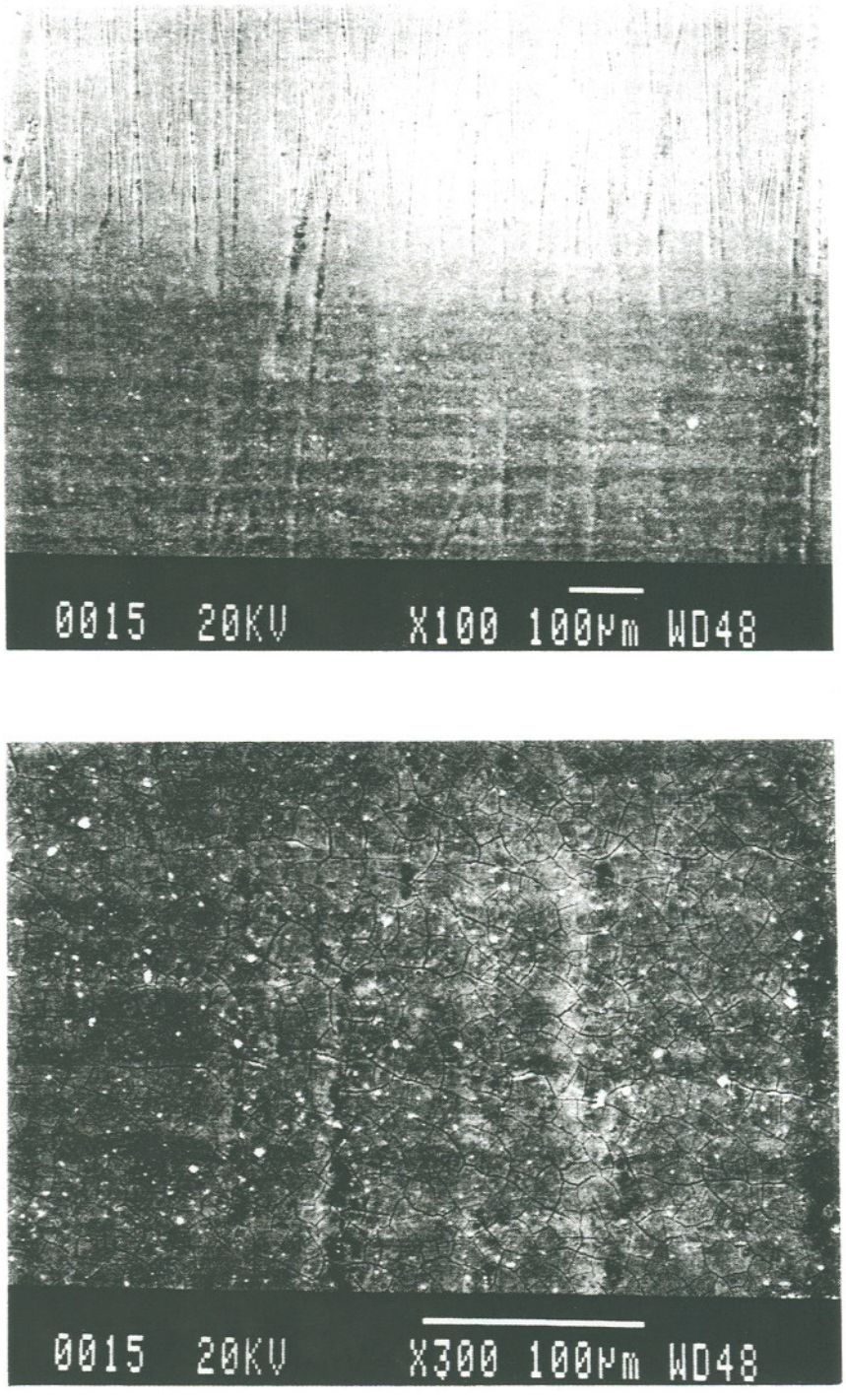


Figure 16. *Ti-6Al-4V* (100X & 300X)
Re-casting of the surface layer resulted in smoothing of the surface texture. At higher magnifications surface 'mud-flat' type cracking was observed, but it appeared to be shallow.

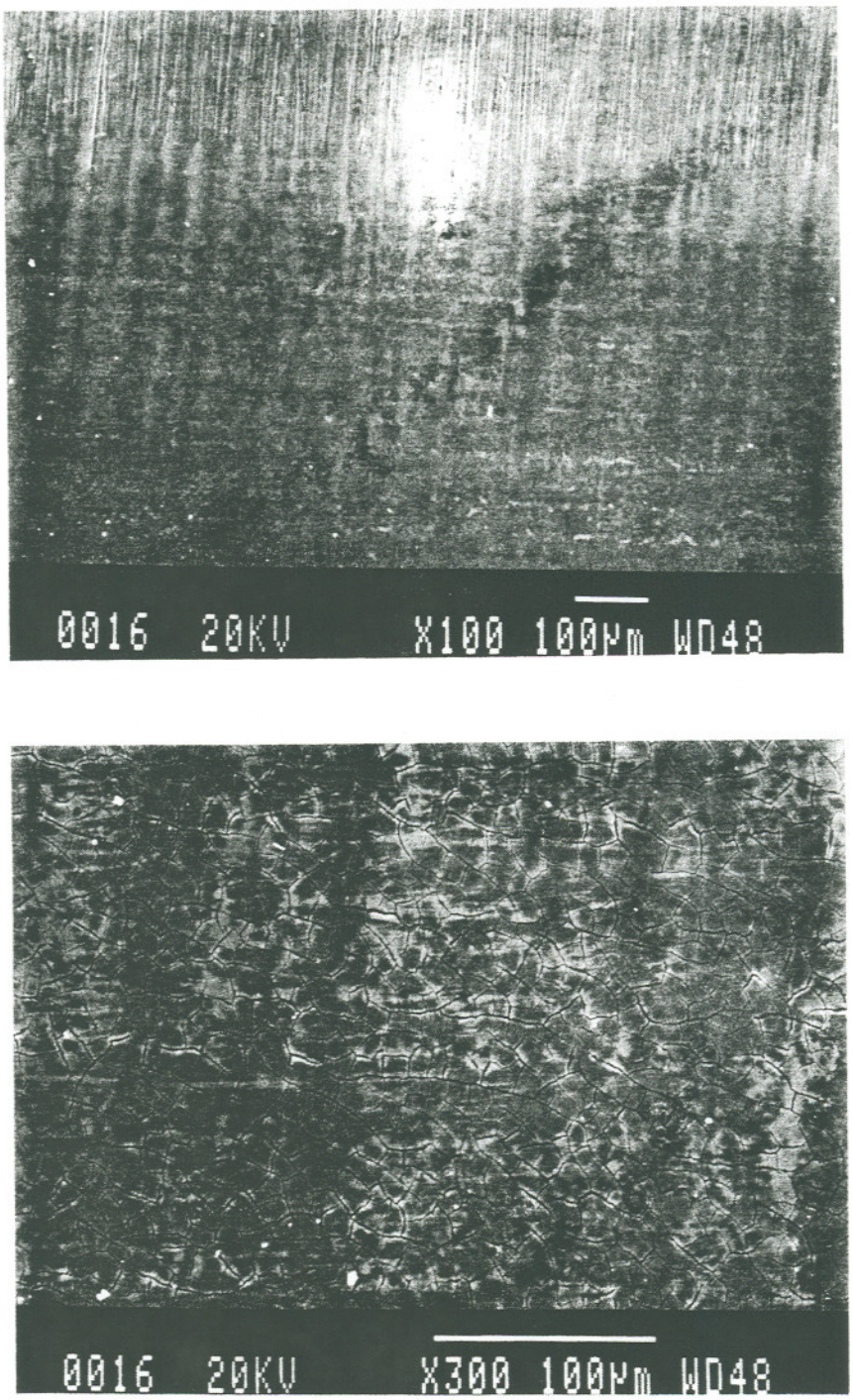


Figure 17. *Ti-3Al-2.5V* (100X & 300X)
Surface effects from laser marking were generally very similar to those found on the Ti-6Al-4V specimen.

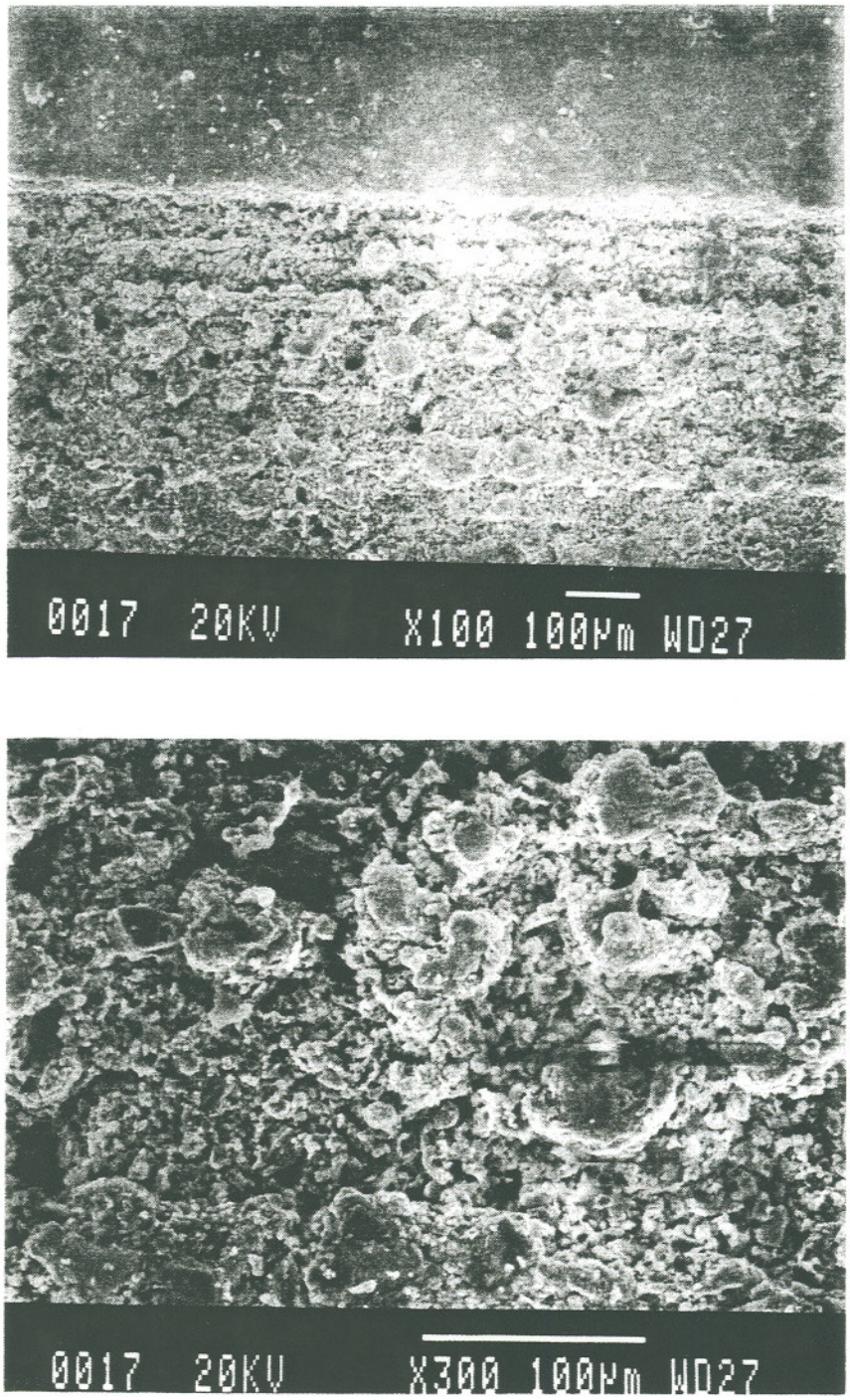


Figure 18. *Super Koropon over Aluminum* (100X & 300X) Surface texture in the marked area was very irregular, however no cracking was noted. While the aluminum substrate was not visible macroscopically, damage was present.

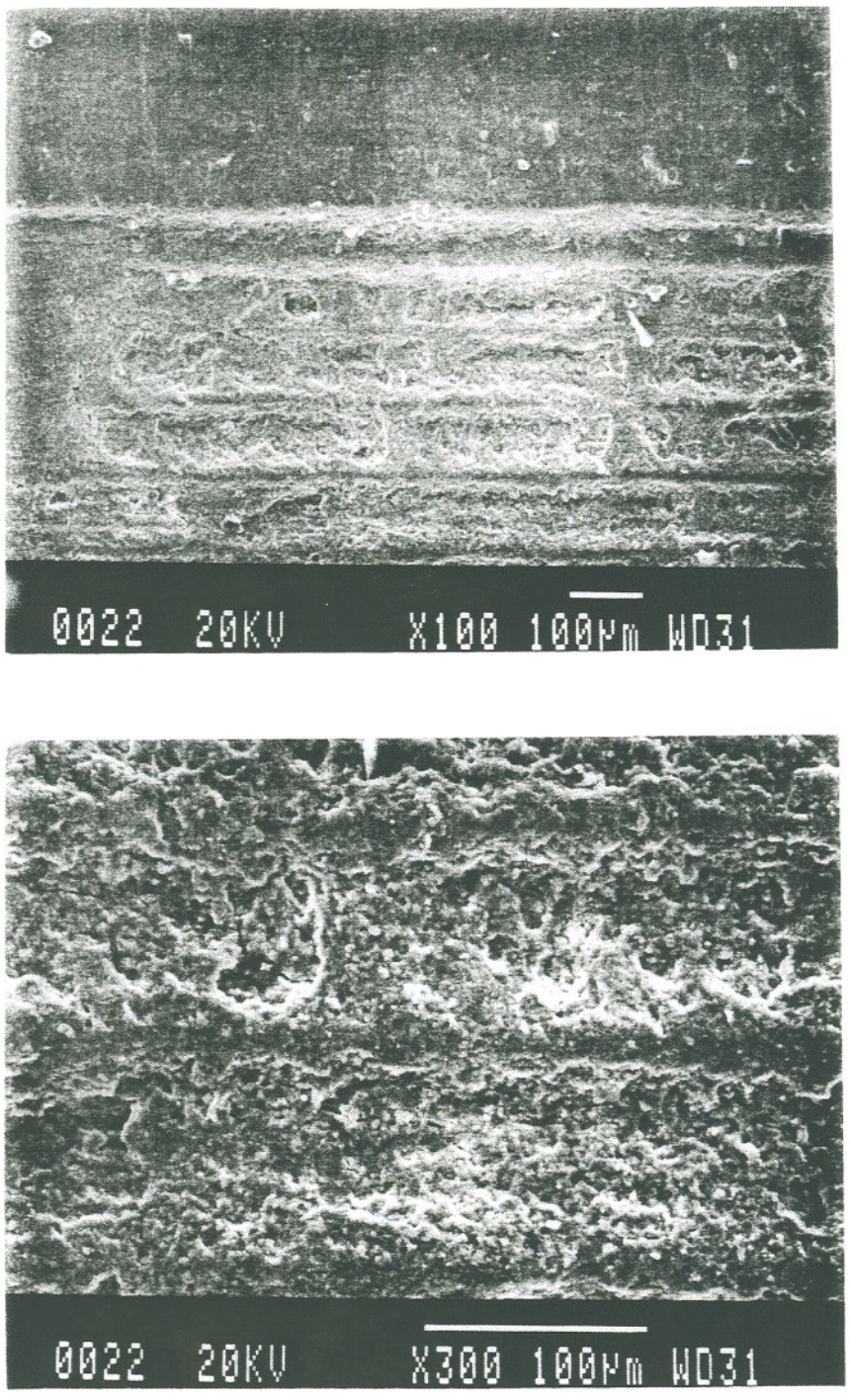


Figure 19. *Neoprene Rubber* (100X & 300X)
The marked region exhibited fine surface roughness, but no evidence of any substrate cracking.

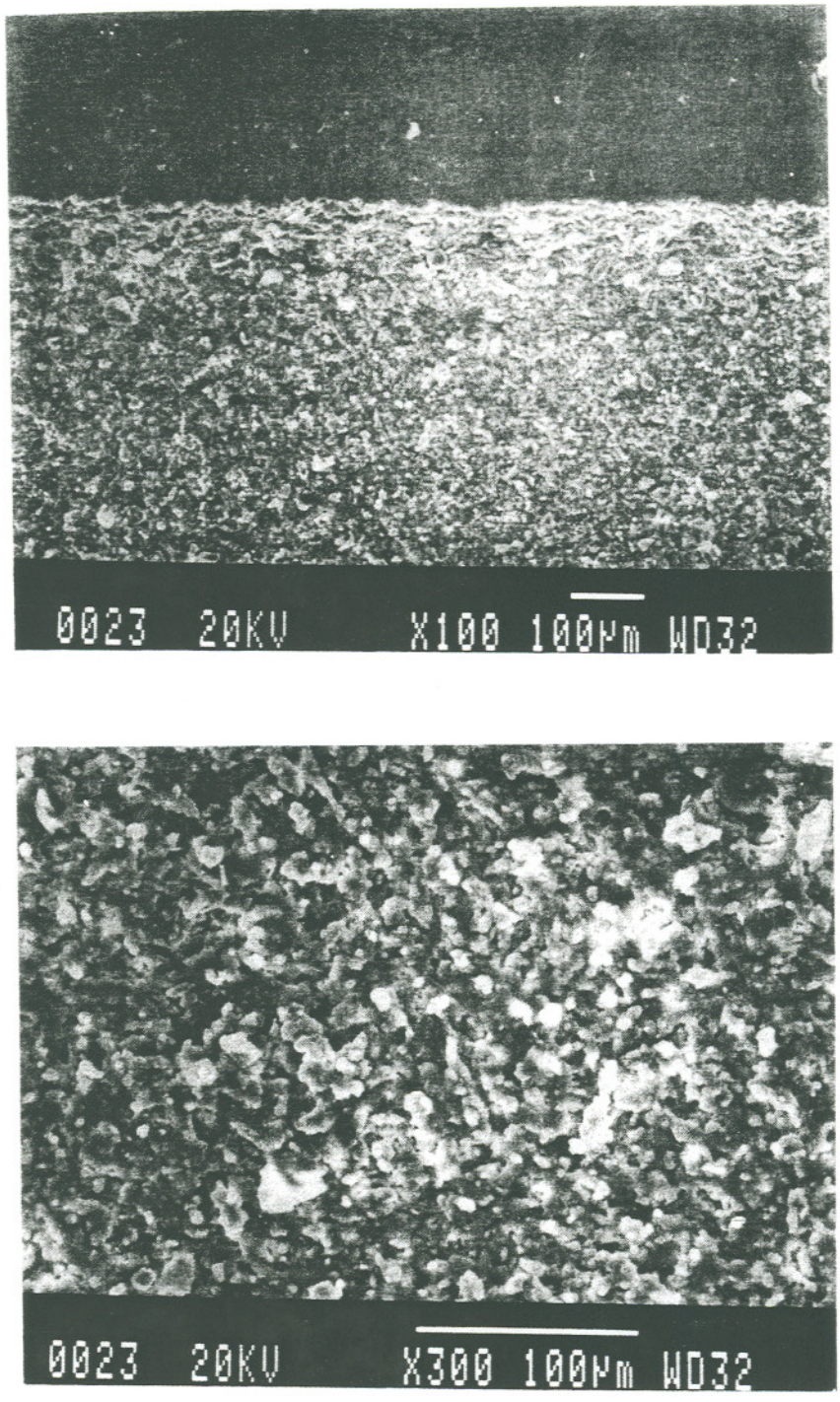


Figure 20. *Silicone Rubber* (100X & 300X)
The marked area was uniform in texture, exhibiting moderate surface roughness. No indication of substrate cracking was discovered.

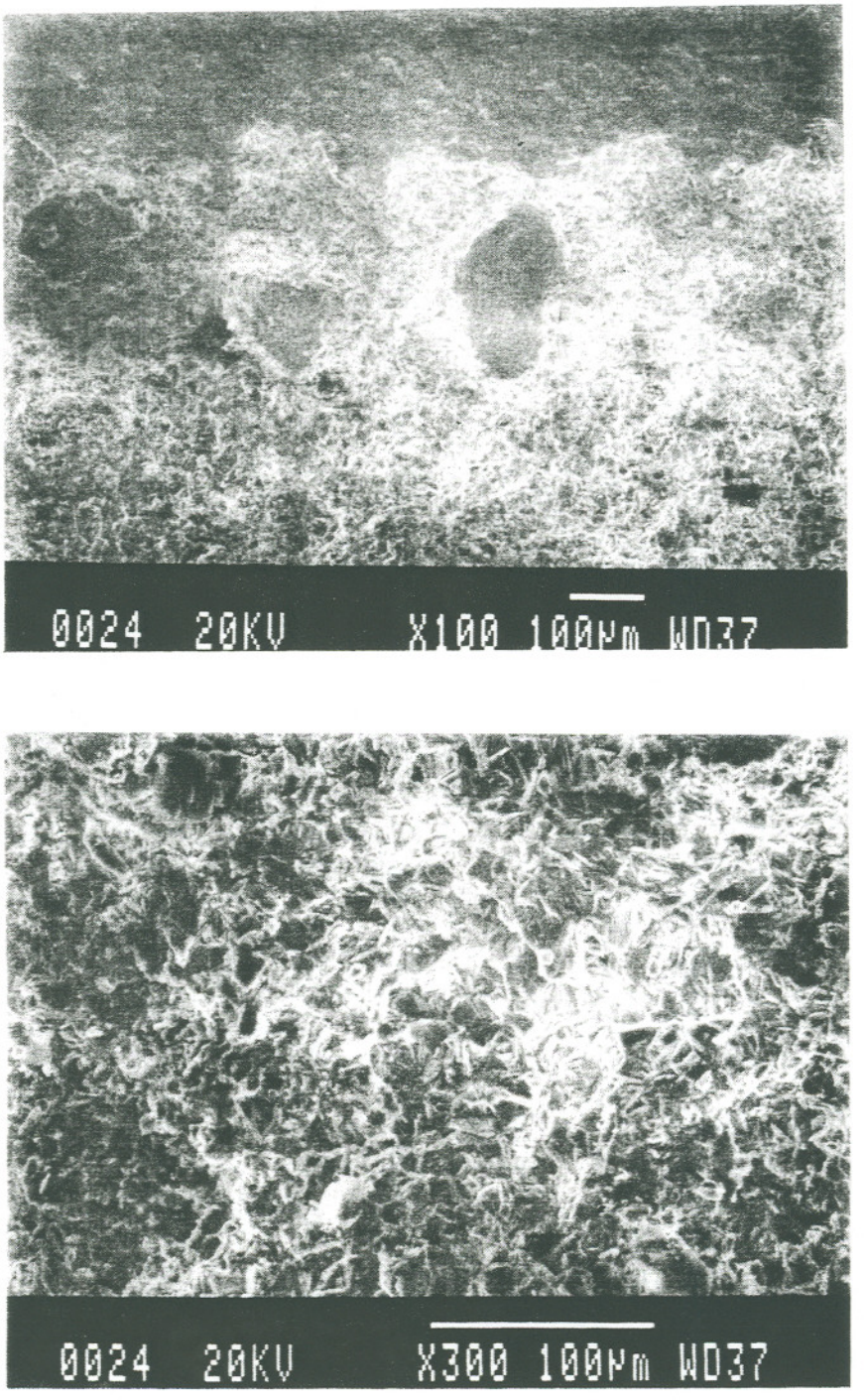


Figure 21. *Macor* (100X & 300X)
The marked region was readily distinguishable, however there appears to have been substantial substrate damage, mostly in the form of material erosion.

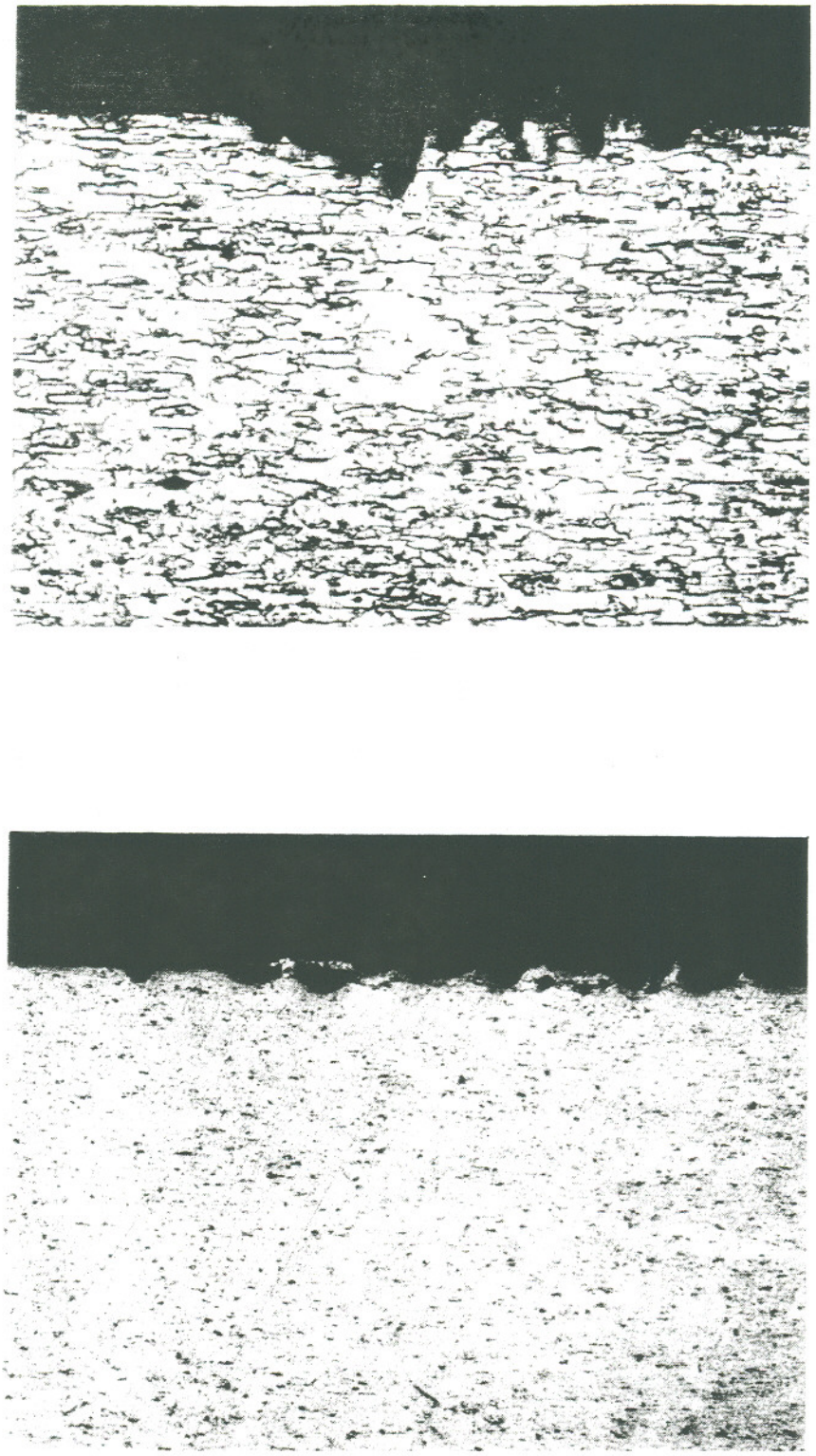


Figure 23. Metallography of 6061-T6 Aluminum showing moderate and irregular material erosion. Depth of penetration is about 0.001" (100X)

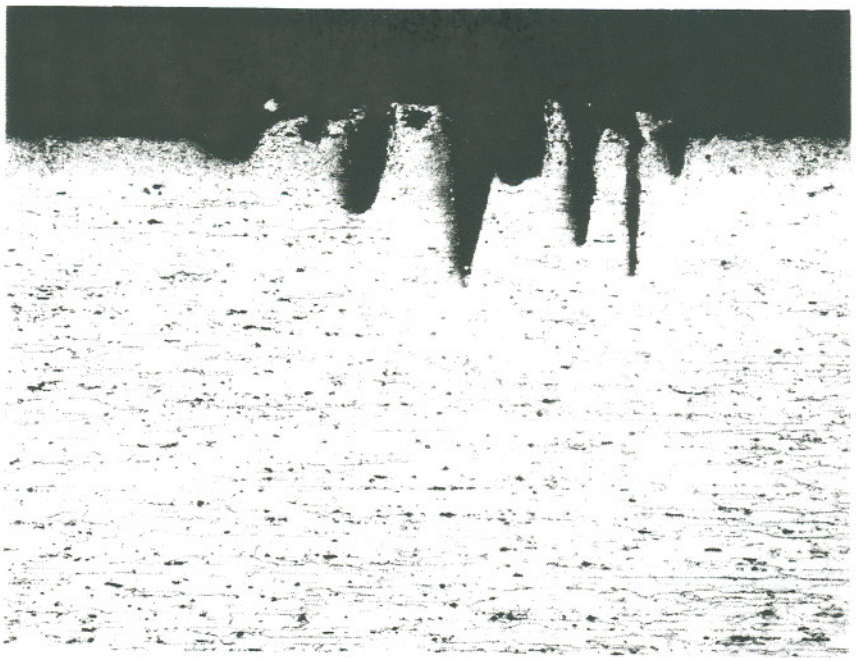


Figure 24. Metallography of 7075 Aluminum showing sharp, deep penetration (0.008") into the substrate. No cracking is apparent at any of the sites. (100X)

Figure 25. Metallography of 356.2 Aluminum showing irregular, smooth bottomed erosion of the substrate. No cracking is evident. (100X)

Figure 26. Metallography of CDA 101 Copper. The affected depth was less than 0.001" with no evidence of substrate cracking. (100X)

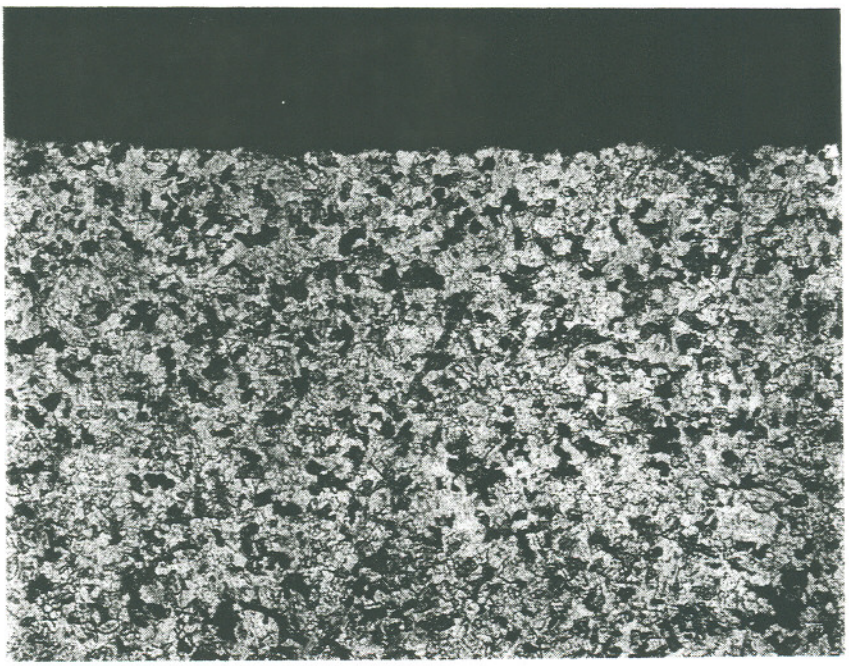


Figure 27. Metallography of C1020 Steel showing only minor surface roughness and an affected depth of less than 0.001". No cracking is evident. (100X)

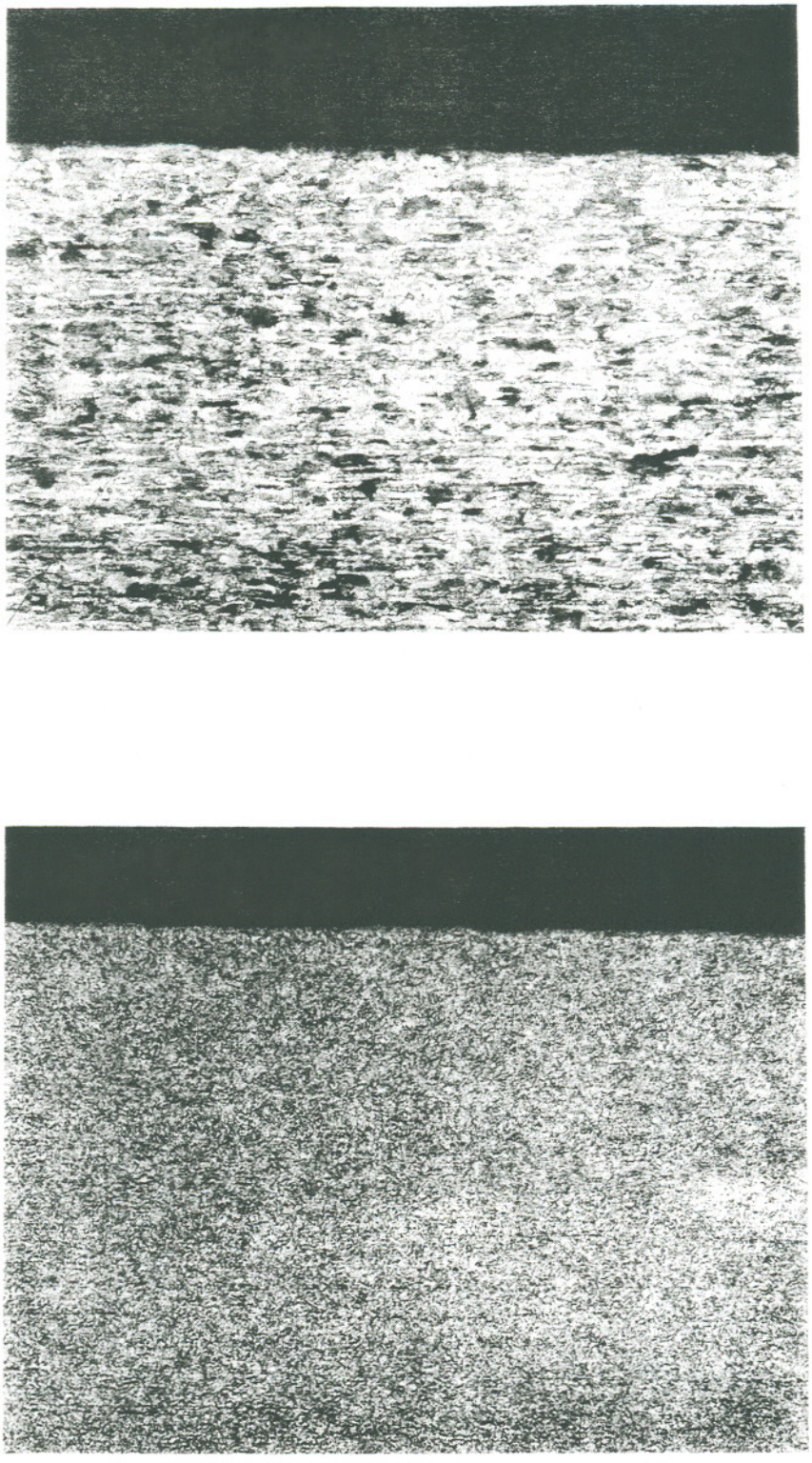


Figure 29. Metallography of 17-4PH Steel showing virtually no substrate damage. Only a slight surface irregularity is apparent. (100X)

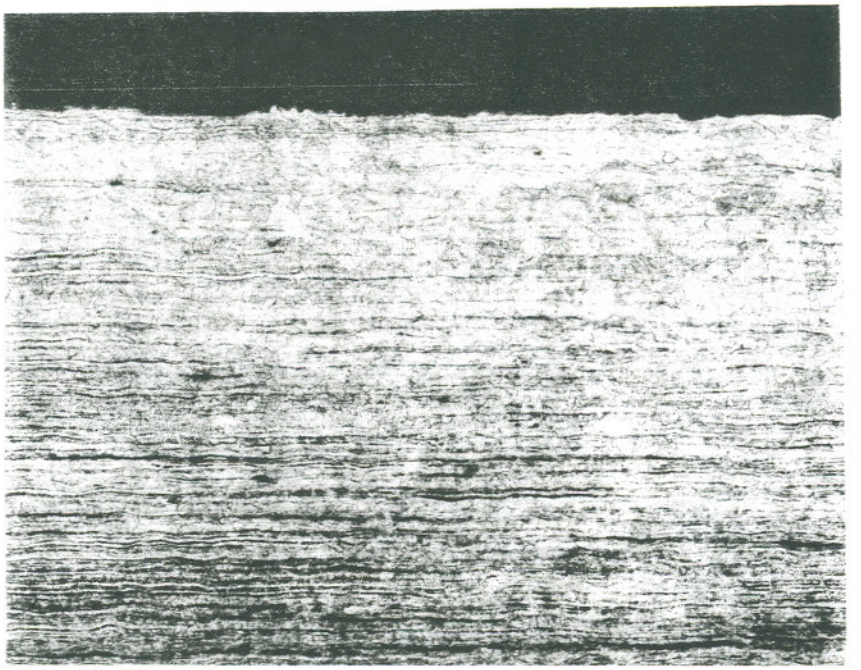


Figure 30. Metallography of 316 CRES showing slight surface irregularity to a depth of about 0.001". No cracking is evident. (100X)

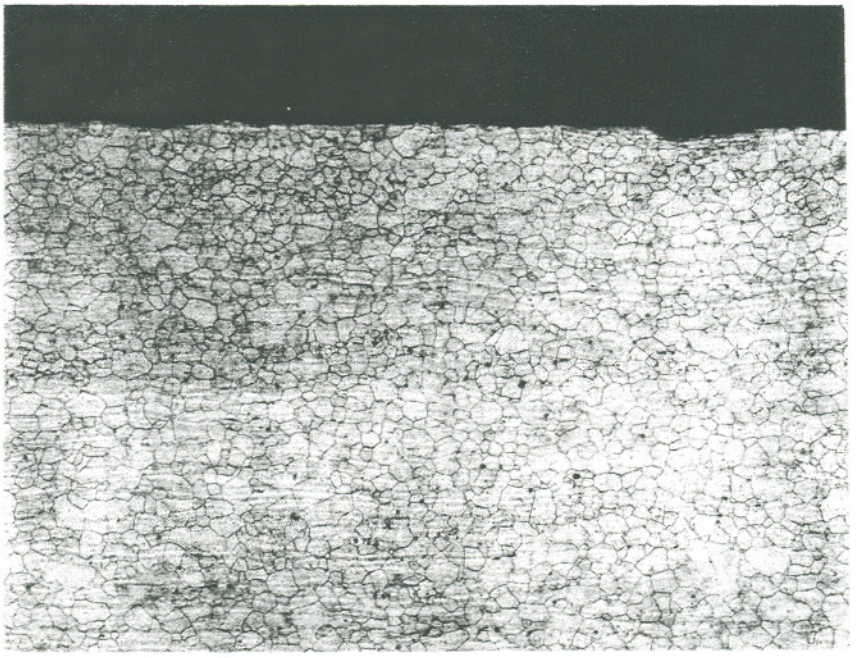


Figure 31. Metallography of 446 CRES showing shallow, rounded effect of laser marking. No substrate cracking was observed. (100X)

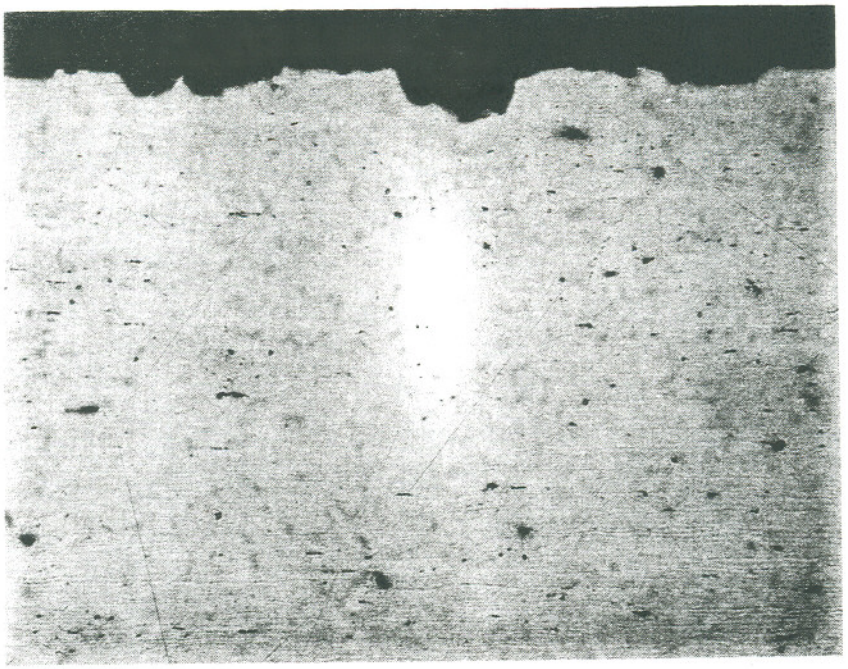


Figure 32. Metallography of A286 CRES. The material erosion was moderately deep (0.003") and irregularly shaped, however no substrate cracking was detected. (100X)

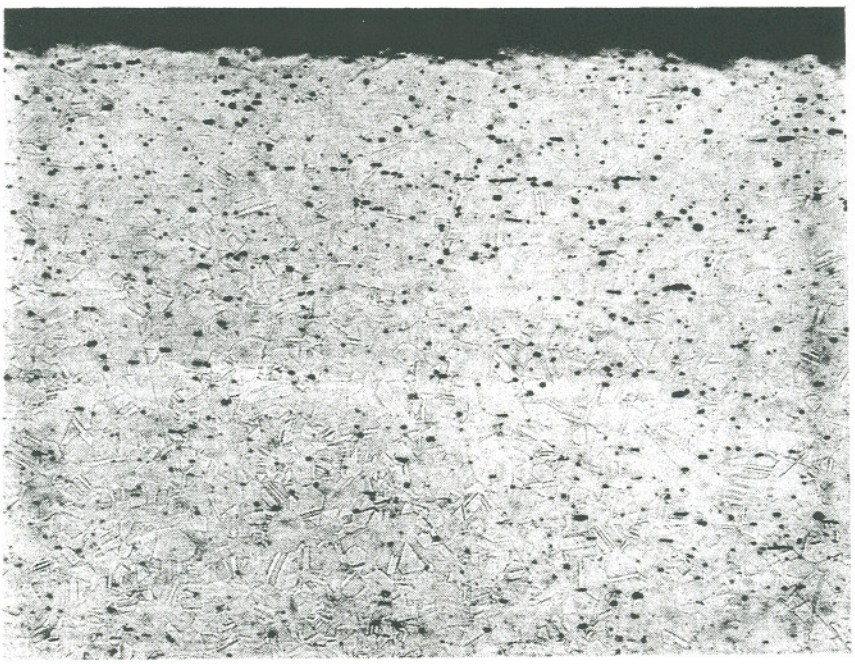


Figure 33. Metallography of Inconel 625 showing shallow, irregularly affected region. No substrate cracking is evident. (100X)

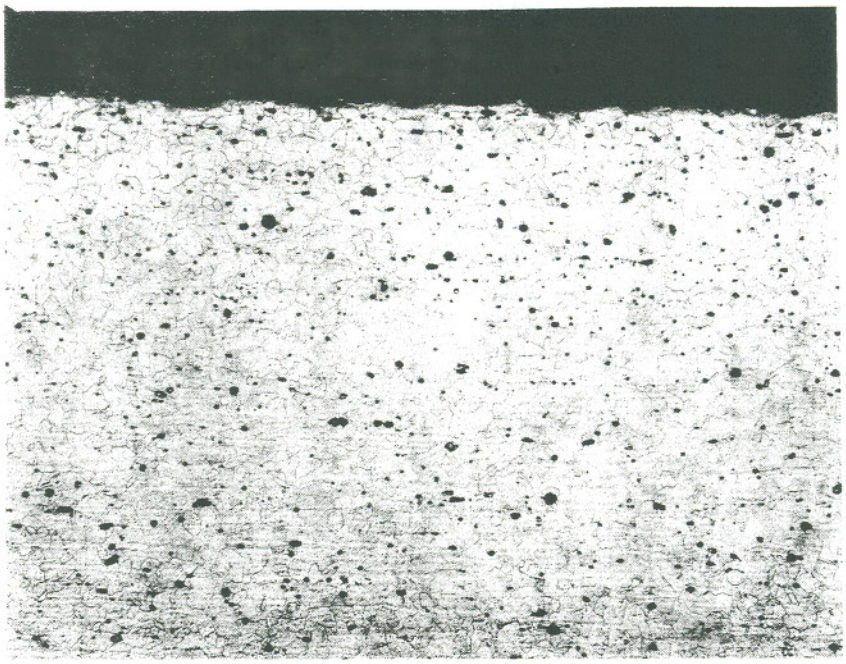


Figure 34. Metallography of Inconel 718 showing similar condition to that observed on the Inconel 625 specimen. (100X)

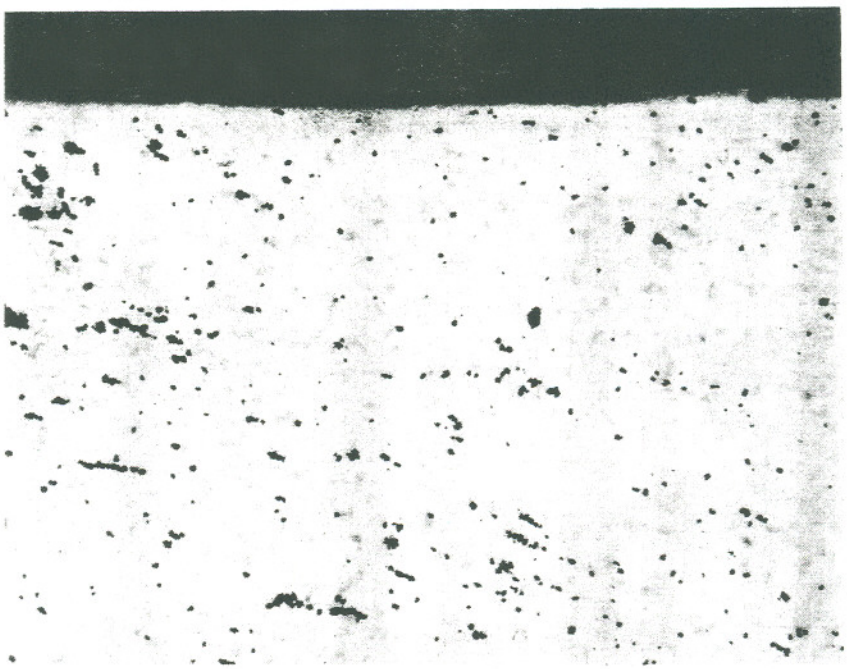


Figure 35. Metallography of MP35N. No substrate effect is apparent. (100X)

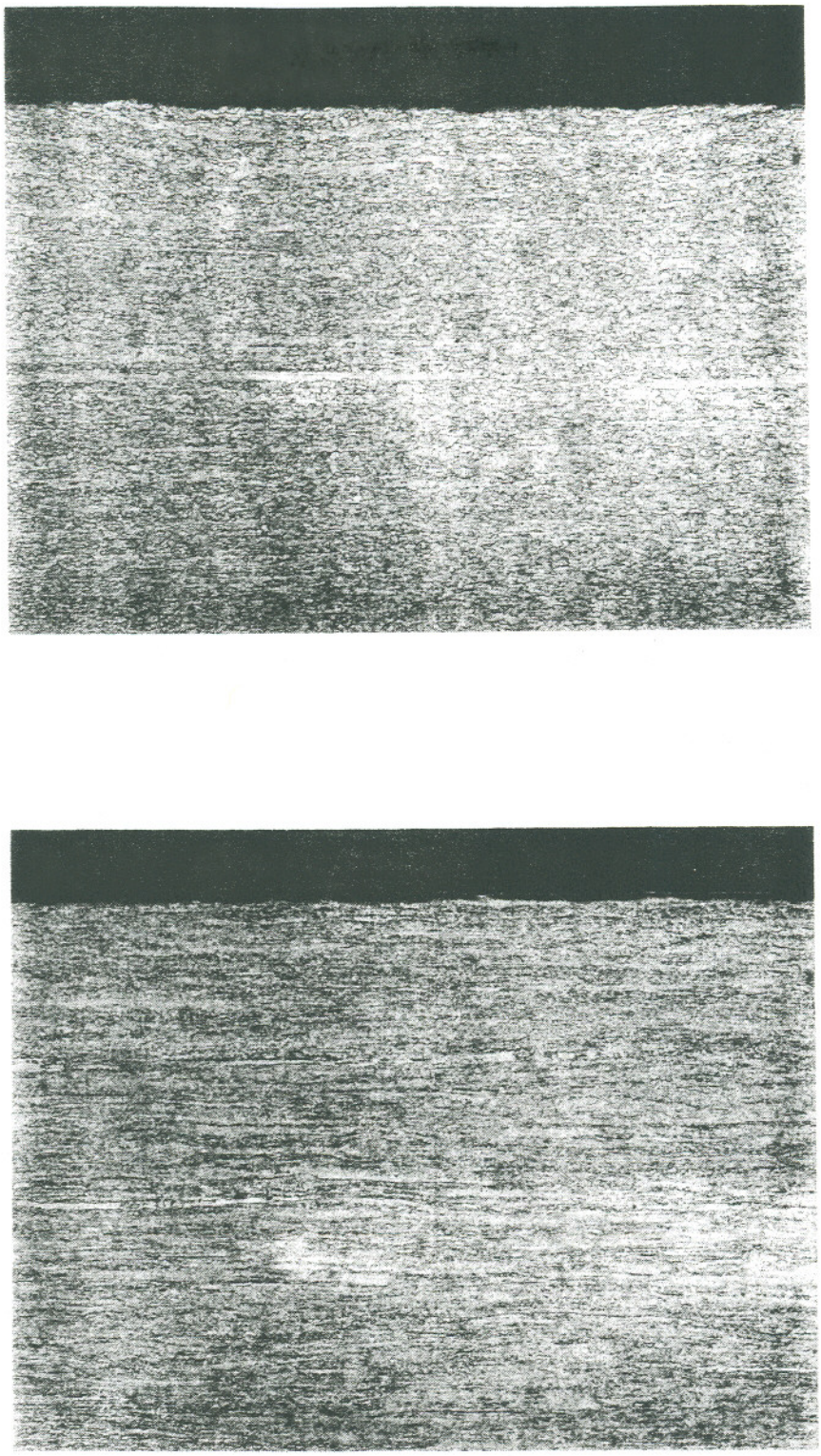


Figure 37. Metallography of Ti-3Al-2.5V showing conditions identical to that of the figure above. (100X)

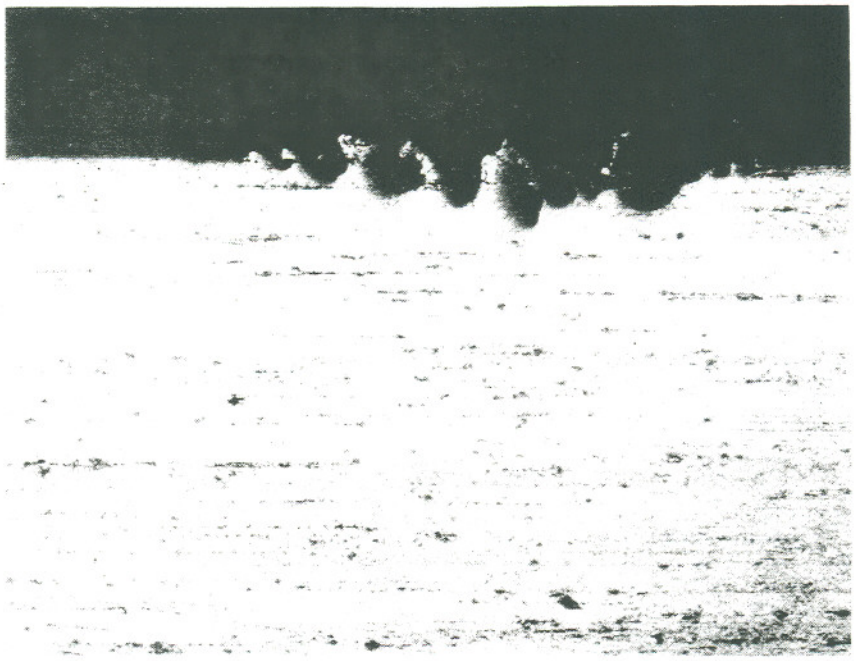


Figure 38. Metallography of Koropon painted aluminum showing damage to the substrate consistent with that observed on the other aluminum specimens. (100X)

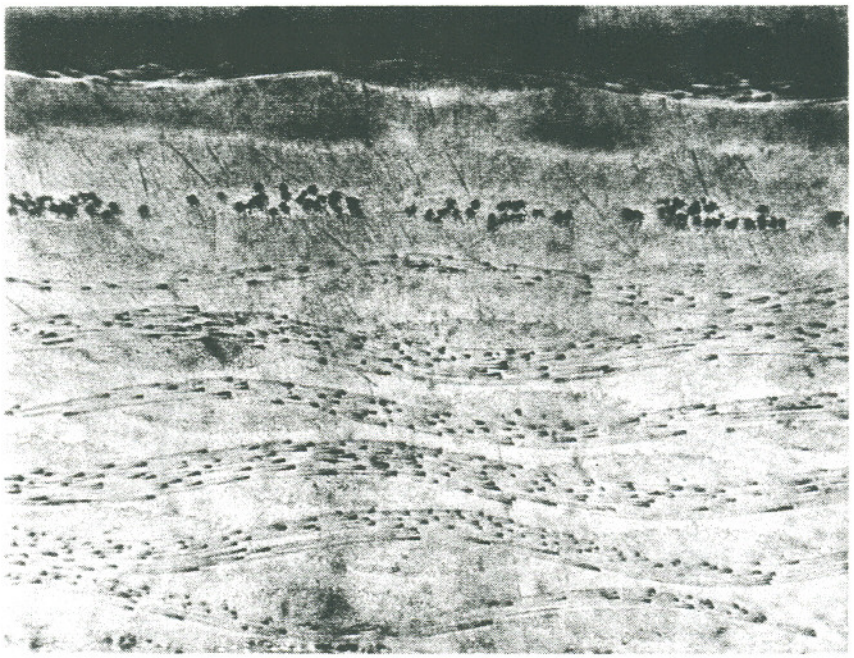


Figure 39. Metallography of Gr/Ep composite showing no visible effect of the laser marking on the substrate. (100X)

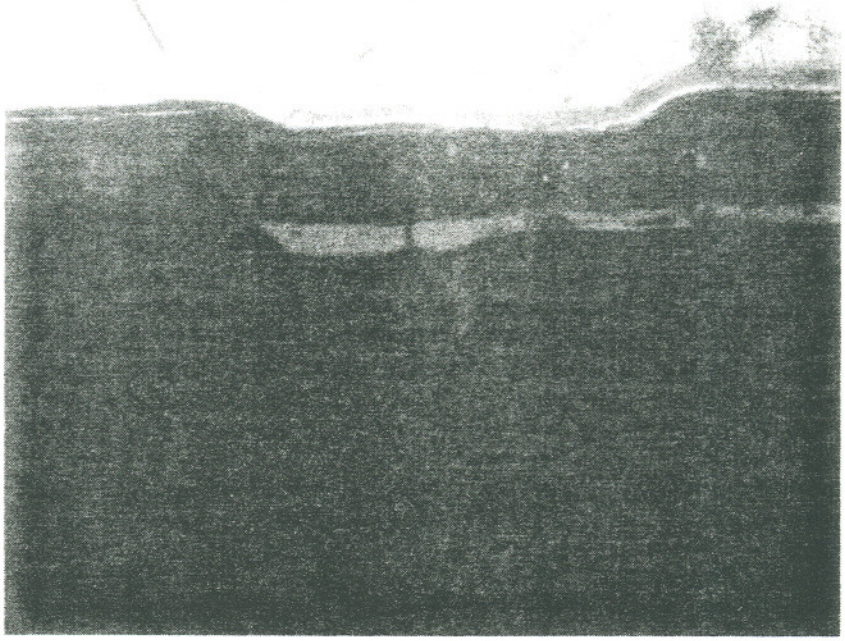


Figure 40. Metallography of Neoprene Rubber, showing the substrate to be smooth and rounded in the affected area. (100X)

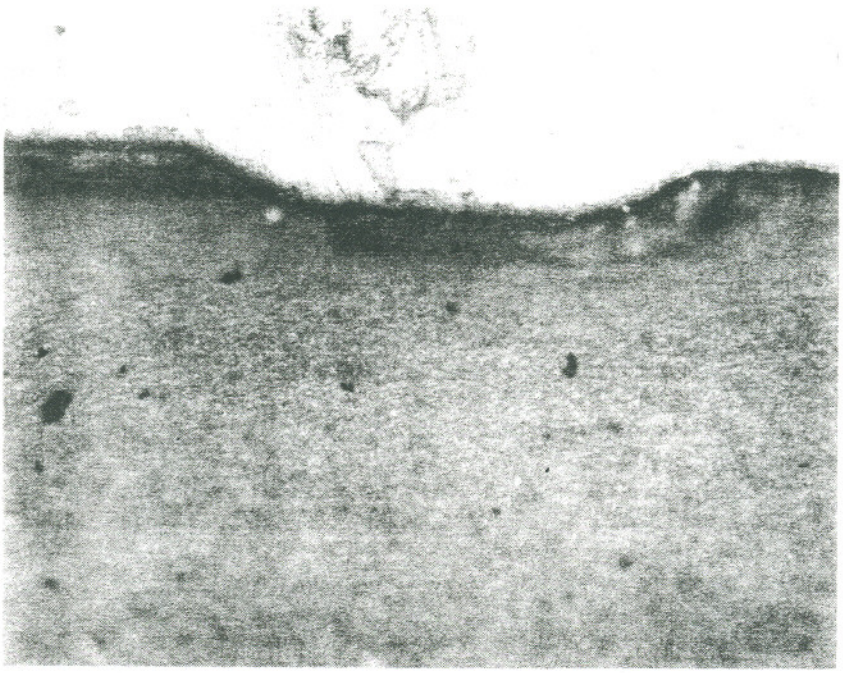


Figure 41. Metallography of Silicone Rubber, showing a smooth, rounded effect from laser marking. (100X)

APPENDIX A

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D. Roxby to L. Burgess