Appendix A—Material Test Plan

Figure 4-2. Magneto-optic Markings Applied to Operational Aircraft in the Field and Being Flight Tested

5. Standards

Publications to be updated include NASA standards NASA-STD-6002, "Applying Data Matrix Identification Symbols on Aerospace Parts," and NASA handbook NASA-HDK-6003, "Application of Data Matrix Identification Symbols to Aerospace Parts Using Direct Part Marking methods/Techniques." These publications have been updated to include 2D technology and developments.

Request for general information concerning standards should be sent to the NASA Technical Standards Program Office, ED 41, MSFC, AL 35812. NASA will provide copies of their updated standard and handbook to the other Data Matrix Marking and Verification Standards organizations as part of their normal standard review process.

6. Summary and Conclusions

Three prototype portable marking carts with reading and verification capability have been delivered to military depots. Operators have been trained in their use, and depots are continuing to evaluate. All project objectives have been successfully met with the exception of environmental testing. Cherry Point Naval Aviation and Solar Turbine have yet to complete environmental testing on the parts they received. These Material Test Data Reports shall be completed and submitted to NCMS once completed.

Previous restrictions that hindered the implementation of UID have been removed by conducting the Parts ID project. New marking and reading methods have been introduced and current parts held by military depots can now be marked and tracked, thus eliminating the introduction of counterfeit parts detrimental to our armed forces.

6.1 Recommendations

It is recommended that pilot projects be immediately implemented in areas that require further development for nuclear, biological, and chemical weapons, ground-based vehicles, seaborne vehicles, and pilfered items such as small arms and tools to ensure the transition for identifying parts runs smoothly. Such projects would also aid in the implementation of new procedures and standards as potential problems are discovered and resolved.

The Parts ID goal was to evaluate retrofit and new direct part marking methods as well as physical testing to determine if the marking methods were invasive to substrates in any way and readable after typical overhaul exposures. This would allow the fastest implementation of safe retrofit marking methods. The Parts ID project met its goal. The project was limited to five material types all of which were selected not to exceed the capabilities of the UTSI test equipment. It is recommended that future projects expand the substrate selection to cover more materials typically used.

The Parts ID project was a good first effort, but with the rapid development of technology that can be seen today, there certainly needs to be an avenue for ongoing evaluations of additional direct part marking methods. All point-of-manufacturing marking methods evaluations are recommended. Already, newer methods exist that offer lower cost yet more durable marks, but may only be available to industry unless avenues for ongoing evaluations are established. With adequate funding, NCMS may consider establishing a technical board that directs those future marking evaluation activities and projects. This would ensure a continued evaluation effort of new marking methods based first on the engineering data and second, the implementation expenses so our military can reach their traceability goals in a realistic timeframe and with a realistic cost.

Direct part marking scanners or readers have come a long way since the start of the Parts ID project. Industry's largest scanner manufacturer now has 1,500 direct part marking readers in production. NCMS may consider establishing a direct part marking reader evaluation process to provide avenues for the competitive scanning or reading technology to reach customers in need. NCMS could provide the means to combine the needs of the services into one direct part marking problem-solving location furthering the continuity of the effort. NCMS may consider assisting industry by providing technical data for safely marking components directly.

Test	Profilometer
Number of marks	All
Purpose	Determine surface morphology
Test Standard	None
Equipment	WYKO Surface Profiler, VEECO
General Description	A non-contact optical profiler using phase-shifting interferometry Relative surface height is calculated from the phase shift
Sample Configuration	Flat plate preferred
Testing Conditions	N/A
Test Procedure	Samples are placed and leveled in the profilometer Automated scans are initiated Data is taken and parameters are calculated automatically
Test Data	R_q = root mean square roughness R_a = average roughness R_t = maximum height of the profile R_p = maximum profile peak height R_v = maximum profile valley depth
Pass/Fail Criteria	None

Test	Microhardness
Number of marks	One
Purpose	To evaluate resistance to indentation of applied load.
Test Standard	ASTM E3-84
Equipment	LECO AMH - 32
General Description	A small hard indenter is applied to polished sample surface at a specific load and duration. The resulting indentation size is evaluated and a hardness value is determined from it.
Sample Configuration	Flat, polished surface of sufficient size to accommodate hardness indentations.
Testing Conditions	Sample polished to ASTM E3-01 1200 grit and .3 micron alumina suspension. Knoop Hardness tester 100 g load (soft material) Load applied 15 seconds
Test Procedure	Samples surface is polished Hardness tester is calibrated using standard sample. Hardness indentations are taken in lines parallel to surface and perpendicular to surface Series of linear data points averaged
For conversion of Knoop hardness see	http://www.efunda.com/units/hardness/convert_hardness.cfm?Cat=Steel&HD=HK
Test Data	Kn_b = average hardness of base Kn_m = average hardness of mark Kn_z = average hardness of transition zone Measurements taken @ 100 micron intervals
Pass/Fail Criteria	None

Test	Chemical
Number of marks	Equal to number of chemicals
Purpose	Determine resistance to chemical attack
Test Standard	None
Equipment	
General Description	Immerse marked and baseline samples in test solutions
Sample Configuration	Flat plate desired
Testing Conditions	Dye Penetrant Hydraulic Fluid JP5 Fuel Oil (SAE 30 Non-detergent) Mineral Spirits Grease [Mobilegrease Special (premium lubricating grease with Moly)] Acetone MEK
Test Procedure	Immerse samples in test solutions for 1 hour, 6 hours and 12 hours Remove at intervals, wipe and monitor readability. The Dye Penetrant Tests were done according to manufacturers instructions.
Test Data	C = Nominal cell size C_{tr} = % Contrast U_A = Axial Uniformity G_P = Print Growth E_C = Error Correction G = Overall Grade
Pass/Fail Criteria	Readability

Test	Temperature Cycling
Number of marks	Two
Purpose	Evaluate effect of temperature cycling on mark readability
Test Standard	
Equipment	
General Description	Marked and baseline samples are heated in a furnace. Marked and baseline samples are placed in freezer.
Sample Configuration	Flat plates preferred
Testing Conditions	Maximum – see table for 10 minutes Minimum – 25°F for 1 hour
Test Procedure	Sample is placed in furnace for allocated time (10 minutes) Sample is removed from furnace. Monitor readability Sample is placed in freezer Sample is removed Monitor readability
Test Data	C = Nominal cell size C_{tr} = % Contrast U_A = Axial Uniformity G_P = Print Growth E_C = Error Correction G = Overall Grade
Pass/Fail Criteria	Readability

Table

Alloy	Temperature
4130	900° C
4340	900° C
H13	850° C
316	1040° C
2024	495° C
6061	530° C
7075	480° C
Ti 64	955° C

Test	Dry Wear - Block on disk
Number of marks	Two
Purpose	To evaluate resistance to contact wear
Test Standard	
Equipment	
General Description	Marked and baseline samples are pressed with a specific load against a rotating disk of hardened steel to determine weight loss as a function of contact time with the rotating surface.
Sample Configuration	Varies – Flat plate preferred
Testing Conditions	Disk – 3.25" diameter, steel, Rc 27. Disk Surface – Polished to 400 grit Sample surface – As processed surface Load applied – 5585 g weight for steel, plus sample – 4794 g weight for aluminum, plus sample Disc rotation – 1000 rpm Test duration – 10 min Measurement Intervals – 2 minutes
Test Procedure	Samples are weighed and read Testing is initiated Weight and readability are monitored during testing Wear rate is calculated from data
Test Data	R_W = Wear rate C = Nominal cell size C_{tr} = % Contrast U_A = Axial Uniformity G_P = Print Growth E_C = Error Correction G = Overall Grade
Pass/Fail Criteria	Readability

Test	Erosion
Number of marks	Two
Purpose	To evaluate resistance to abrasive wear
Test Standard	ASTM G76-95
Equipment	Plint TE 68 Gas Jet Erosion Rig
General Description	Marked and baseline samples are impinged with a hard medium at specific velocities, concentrations and incidence angle and the rate at which the surface is eroded is measured.
Sample Configuration	Varies – Flat plate preferred.
Testing Conditions	Erosive medium Velocity of particles: 90m/sec Particle incidence angle: 60 degrees Testing duration: 10 minutes Particle feed rate: 2 g minute Measurement intervals: 1 minute
Test Procedure	Samples are weighed and read Testing is initiated Weight and readability are monitored during testing Abrasion rate is calculated from data
Test Data	R_W = Wear rate C = Nominal cell size C_{tr} = % Contrast U_A = Axial Uniformity G_P = Print Growth E_C = Error Correction G = Overall Grade
Pass/Fail Criteria	Readability

Impact Testing Procedures TP-IX

Test	Impact
Number of marks	Two
Purpose	Investigate the initiation of brittle fractures
Test Standard	ASTM E-208-95a (Reapproved 2000)
Equipment	
General Description	Marked and baseline samples are impacted by a free-falling weight.
Sample Configuration	2" x 6" x 1/8" flat plate
Testing Conditions	Air, Room Temperature
Test Procedure	Samples are placed in apparatus A guided free-falling weight is released from a selected height Visual examination of sample
Test Data	
Pass/Fail Criteria	The occurrence of a fracture

Salt Spray Testing Procedures TP-X

Test	Salt Spray
Number of marks	Two
Purpose	To evaluate corrosion resistance of materials.
Test Standard	ASTM B117
Equipment	Q-Fog Cyclic Corrosion Tester
General Description	Marked and baseline samples are placed in a sealed chamber that maintains specific environmental conditions to surround samples with a fog of 5% salt solution. This simulates the (accelerated) performance of materials in similar real-world exposures.
Sample Configuration	Varies – flat plates preferred.
Testing Conditions	Electrolyte solution – 5% NaCl Solution pH: 6.5 to 7.2 Fog Temperature: 35°C Fog deposition: 1-2 ml/hr (100 mm funnel) Spray pressure: 8 psi Flow Rate: 0.5 l/hr
Test Procedure	Photograph is taken prior to exposure Sample is placed in chamber Remove sample after 1, 4, 8, 100 and 410 hours exposure for photography and readability, Samples are rinsed, then air dryed before readings are taken
Test Data	Photographs C = Nominal cell size C_{tr} = % Contrast U_A = Axial Uniformity G_P = Print Growth E_C = Error Correction G = Overall Grade
Pass/Fail Criteria	Readability

Test	Constant Amplitude Axial Fatigue
Number of marks	Eight
Purpose	To determine the effect of surface marks on fatigue properties
Test Standard	ASTM E466-96
Equipment	MTS System with Test Star IIS Automation Package
General Description	Marked and baseline samples are subjected to a constant amplitude, periodic forcing function.
Sample Configuration	Flat specimen with reduced test cross section in one dimension
Testing Conditions	Air at room temperature
Test Procedure	Visually inspect sample. Mount and align sample in test fixture. Subject to a load with a selected +/- amplitude load applied. Continue test until the sample fails or a predetermined number of cycles. Repeat test sequence at different loads for statistical data. Repeat entire test sequence for baseline samples.
Test Data	S-N curve
Pass/Fail Criteria	To be determined

Test	X-Ray Phase Identification
Number of marks	One
Purpose	To determine the compositional phases present
Test Standard	None
Equipment	Phillips Norelco X-ray diffraction Unit Jade XRD Pattern Processing Software
General Description	Marked and baseline samples are struck with x-rays. The diffracted x-rays are collected at specific angles and used to identify the phases present
Sample Configuration	Flat plate preferred
Testing Conditions	N/A
Test Procedure	Sample is placed in chamber. Goniometer is activated to scan the range of 2 θ degree angles. X-rays are collected versus angle spectrums are displayed.
Test Data	Ph_b = phases of base Ph_m = phases of mark
Pass/Fail Criteria	None

Test	X-ray Residual Stress Analysis
Number of marks	One
Purpose	To evaluate if residual stress occurs due to marking
Test Standard	ASTM E 1426-98
Equipment	Philips X'Pert PC
General Description	Marked and baseline samples are struck with x-rays. The diffracted x-rays are collected at specific angles and the peak shifts are used to calculate residual stress
Sample Configuration	Flat surface
Testing Conditions	N/A
Test Procedure	Sample is placed in chamber Goniometer is activated to scan the range of 2 θ angles X-rays are collected versus angle Spectrums are displayed For calibration sample, the strain sis changed and the test repeated 0-20 micro in./in.
Test Data	σ_{Φ} = residual stress
Pass/Fail Criteria	None

Data Matrix Direct Part Marking (DPM) Testing Program
(Relationships and Status)

USAF Phase I Environmental Tests (Aircraft Landing Gear Parts)

USAF Phase I Environmental Tests (Aircraft Landing Gear Parts)	Results	Approved For FSCAP Marking
Laser Bonding (Field Marking)	Failed	No
Laser Etching	Failed	No
Gas Assisted Laser Etch (GALE)	Failed	No
Laser Induced Surface Improvement (LISI)	Failed	No
LaserShot Peening	Failed	Yes
Deep Dot Peening (Field Marking)	Passed	Yes
Laser Engraving	Passed	Yes
Micro-Milling (Field Marking)	Passed	Yes

UTSI Materials & Environmental Testing

UTSI Materials & Environmental Testing	Results
Laser Bonding (Field Marking)	Passed
Gas Assisted Laser Etch (GALE)	Passed
Laser Induced Surface Improvement (LISI)	Passed
Laser Etching	Failed

Solar & US Navy Environmental Tests (Internal Aircraft Engine Parts)

Solar & US Navy Environmental Tests (Internal Aircraft Engine Parts)	Results
Laser Bonding (Field Marking)	In work
Gas Assisted Laser Etch (GALE)	In work
Laser Induced Surface Improvement (LISI)	In work

NCMS/DoD Environmental Tests

NCMS/DoD Environmental Tests	Results
Dot Peening (Deeper)	Passed
Micro-Milling (Ball Mill)	Passed
Laser Engraving	Passed

USCG Flight Testing (Safety Critical Parts Other Than Engines)

USCG Flight Testing (Safety Critical Parts Other Than Engines)	Results
Dot Peening	In work
Micro-Milling	Planned
Laser Bonding	In work

- Forging
- Laser Engineered Net Shaping (LENS)
- Investment Casting
- Sand Casting
- Thermal Spray (HVOF)

→ Good candidates for future testing. Processes being modified to produce Data Matrix symbols.

Appendix B—Material Test Reports

NCMS

Material Testing Report

The University of Tennessee Space Institute

May 12, 2003

Kit 200

Laser Engraving on 2024 Aluminum

Marking Parameters:

FOBA 94S 100Wlamp-pumped, Q-switched, Nd:YAG laser

Laser has a 6x beam expander, f163 mm lens, and 1.8 mm aperture.

Speed	= 300 mm/s
Aperture	= 2.4
Frequency	= 8k
Power	= 29 amps (30 max)
Line spacing	= 0.074 mm
2D code cell size	= 0.75 mm
Passes	= 0.28

Initial Reading Trials

Table 1

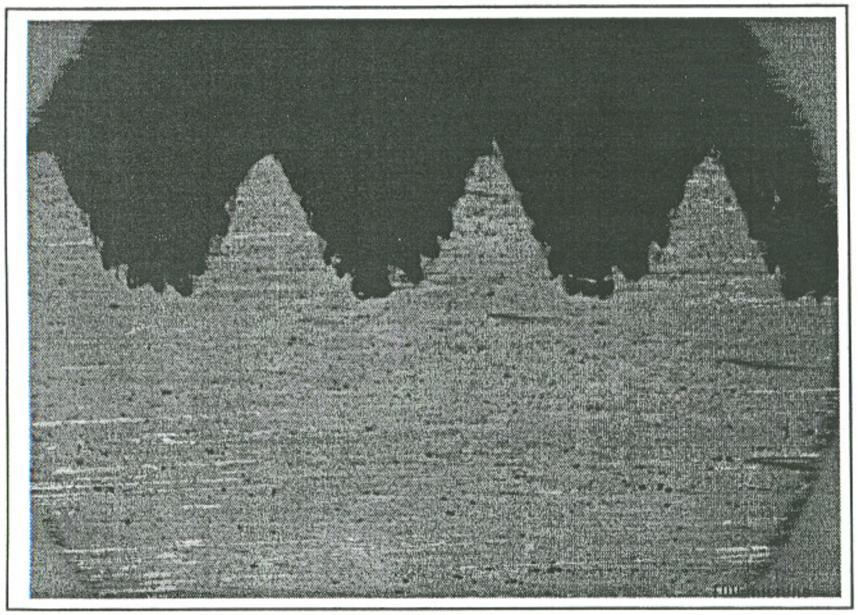
Table 1

		TP-V Chemical								TP-VI Temperature		TP-VII Dry Wear	TP-VIII Erosion	TP-IX Impact	TP-X Salt Spray
Mark	Initial Reading	Dye Penetrant	Hydraulic Fluid	JP5 Fuel	SAE 30 Oil	Mineral Spirits	Mobile-grease	Acetone	MEK	Low	High				
			Hours 1/6/12	Hours 1/6/12	Hours 1/6/12	Hours 1/6/12	Hours 1/6/12	Hours 1/6/12	Hours 1/6/12	(1hr)	(10Min)		Minutes 2/4/6/8/10		Hours 1/4/8
A	D														
B	C														
C	A														(A/B/C)
D	B	B													(A/F/D)
E	A		(C/A/B)												
F	B			(B/B/B)											
G	A				(C/A/A)										
H	A					(A/A/B)									
I	B						(B/A/A)								
J	D							(B/B/B)							
K	B								(B/B/B)						
L	A									B					
M	A										B				
N	A														
O	B											F			
P	A											F			
Q	B												(B/B/B/B/B)		
R	A												(A/B/B/B/B)		
S	C														
T	A														
U	A													A	
V	A													A	
AA	C														
BB	B														
CC	C														
DD	C														
EE	B														
FF	B														
GG	B														
HH	B														

The results of all of the reading trials are given in Table 1 for all of the marks.

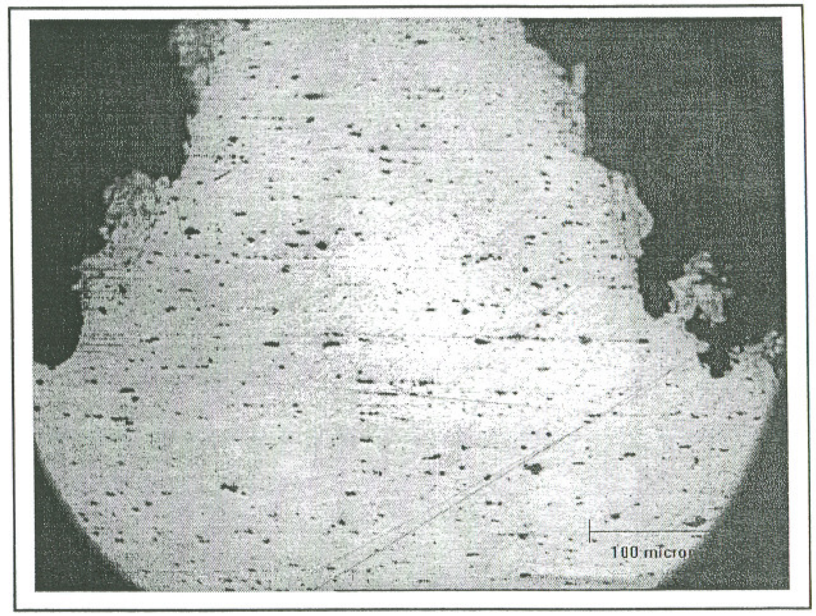
TP – I Metallography

Figure F-1



(a) 200-A-TP1

Figure F-2



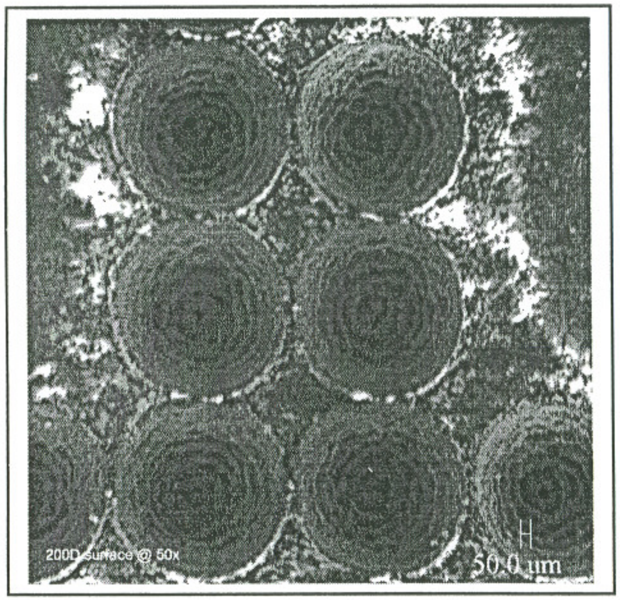
(b) 200-A-TP1

Examination of cross-sections of the laser engraved mark shows a small region of affected area.

TP – II Scanning Electron Microscopy

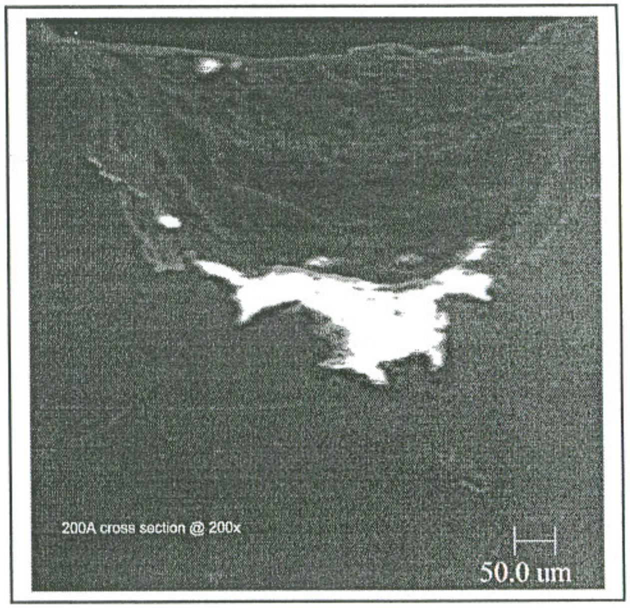
SEM Views of Mark

Figure F-3



(a) 50X Surface

Figure F-4

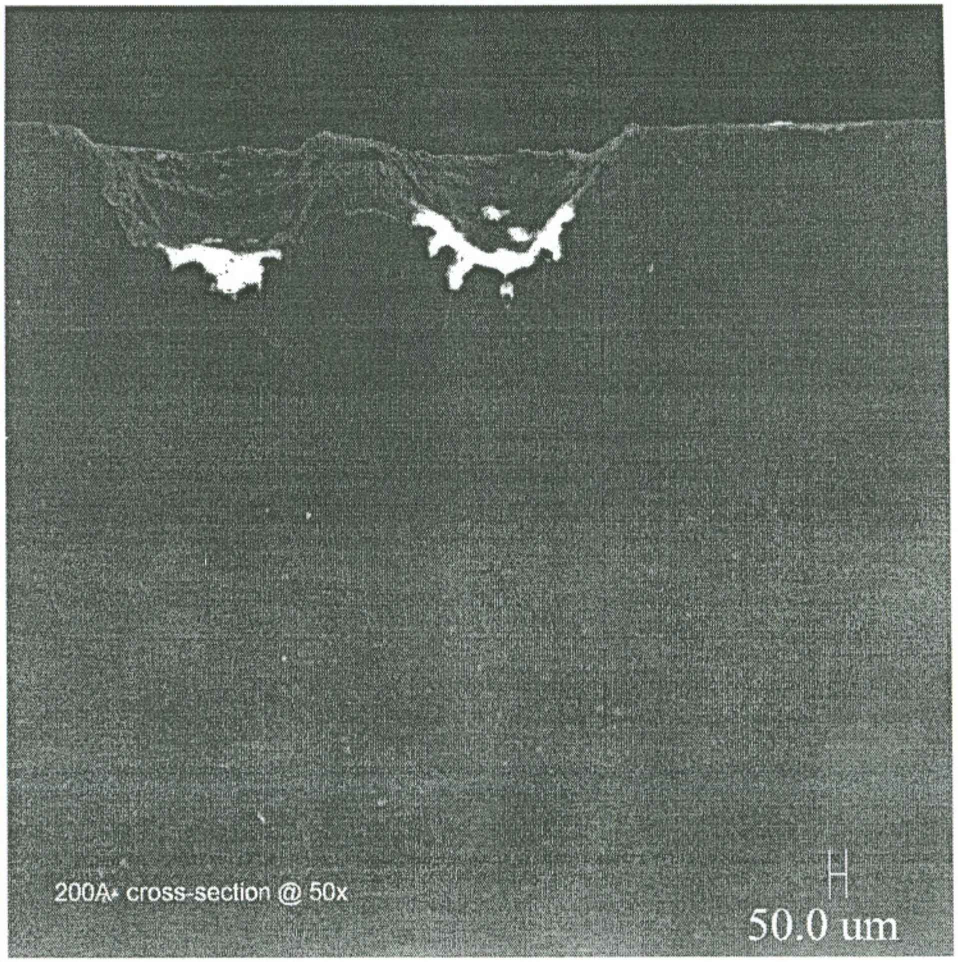


(b) 200X Cross -Section

TP – II Scanning Electron Microscopy (continued)

Figure F-5

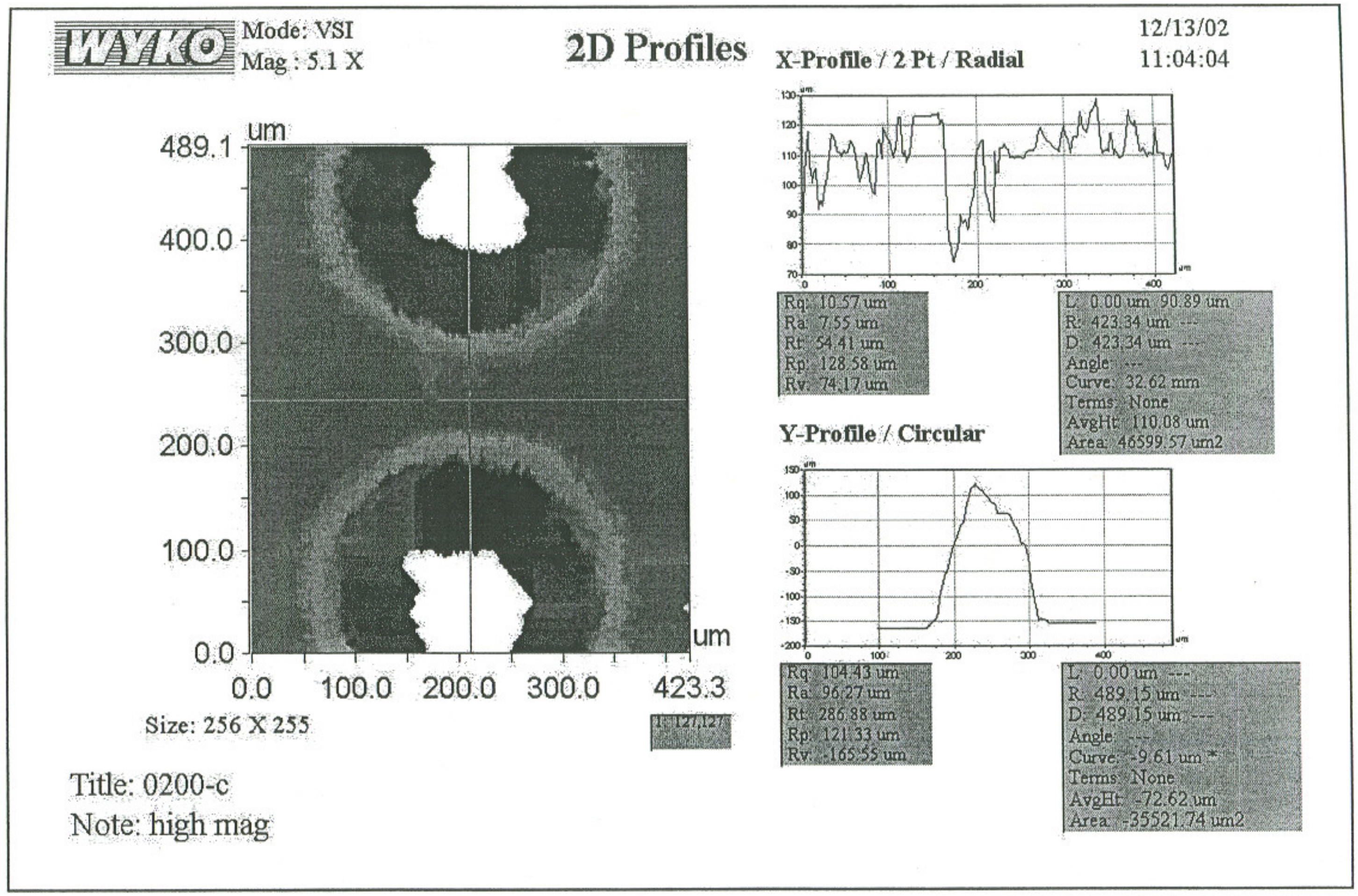
SEM Views of Mark Surface



SEM View of Mark cross-section (50X)

TP – III Profilometer

Figure F-6



Profilometry indicates that the marking process has created a conical hole in the base material.

TP – IV Microhardness

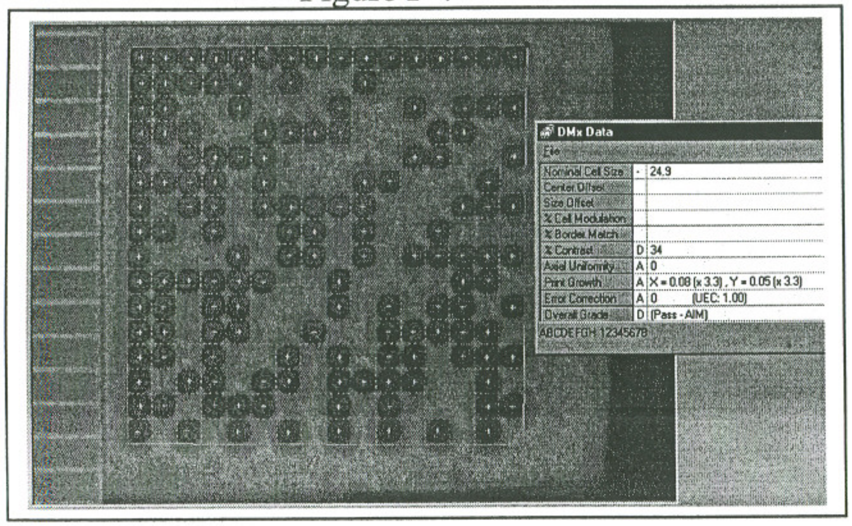
The microhardness did not appear to be affected by the marking process.

TP – V Chemical

Chemical testing did not affect the readability of the marks.

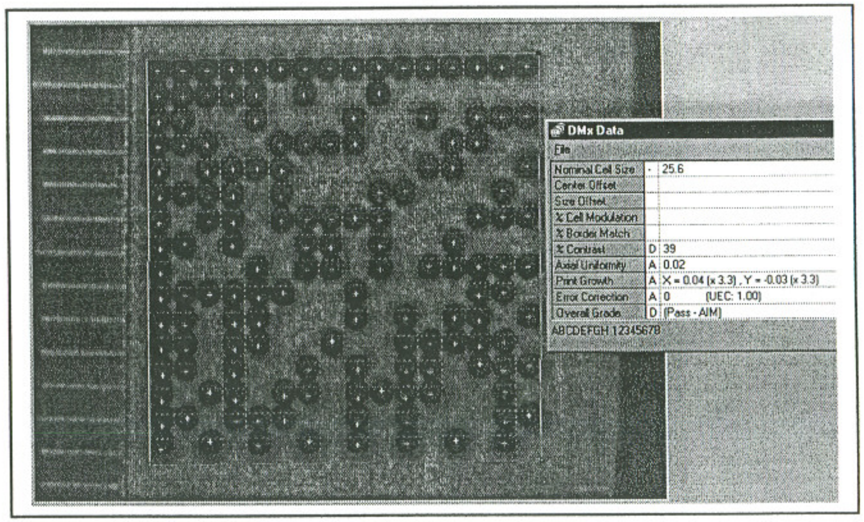
TP-VI Temperature

Figure F-7



200-L-TP6 1 hr
Low Temperature

Figure F-8

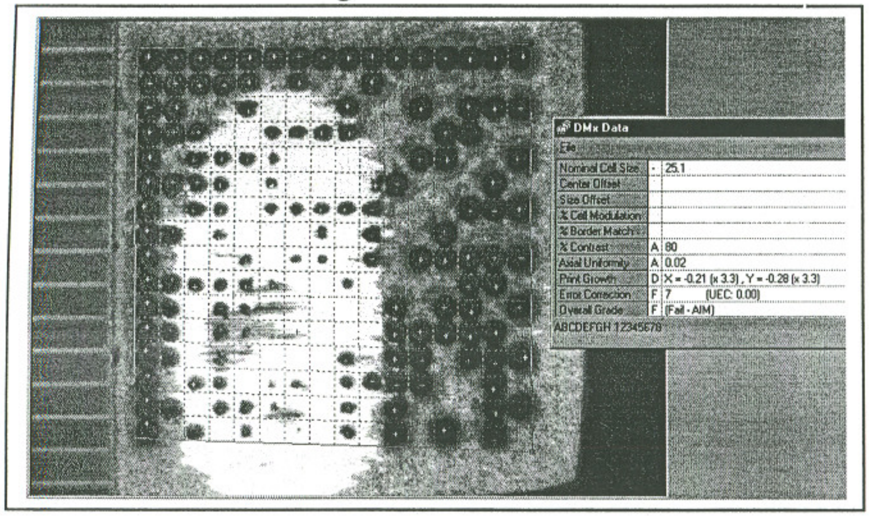


200-M-TP6 1 hr.
High Temperature

Cold and hot temperatures did not affect the readability of the marks.

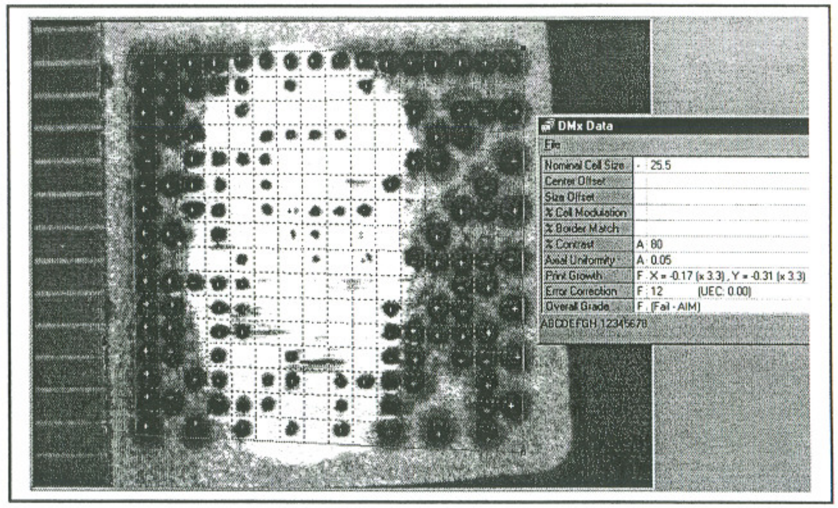
TP – VII Dry Wear

Figure F-9



200 O – TP7 2 min.

Figure F-10

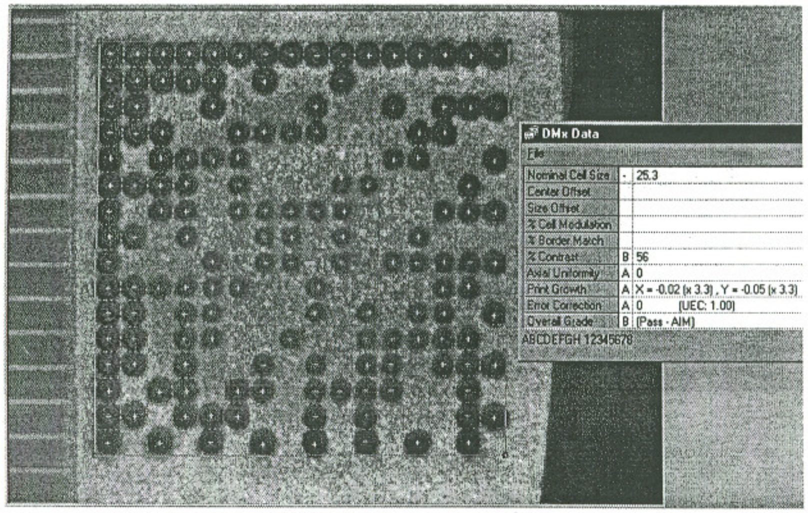


200 P – TP7 2 min.

Dry wear negatively affected the readability of the marks.

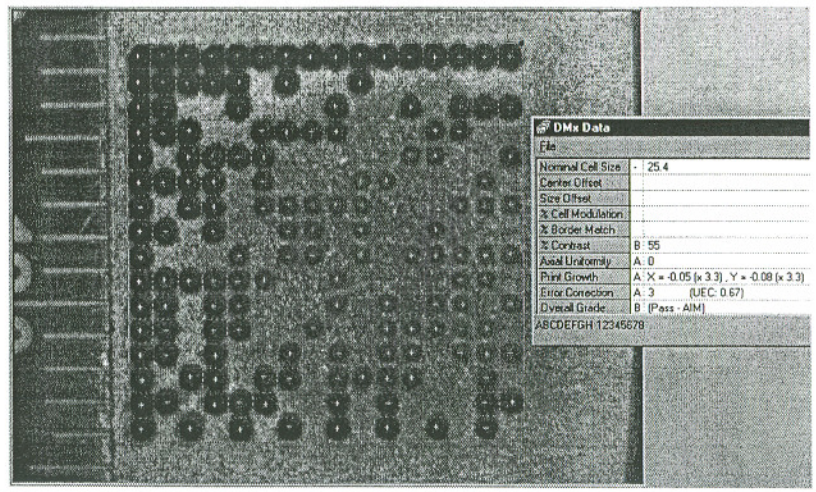
TP – VIII Erosion

Figure F-11



200 Q – TP8, 10 minutes

Figure F-12

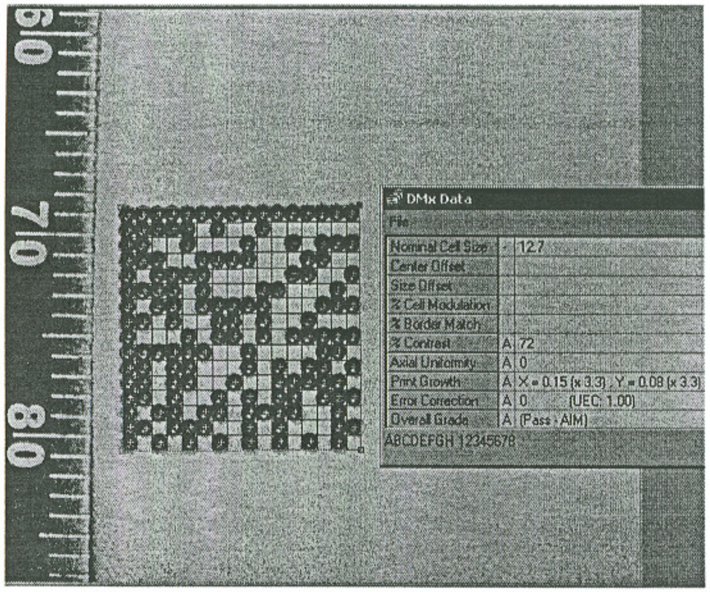


200 R – TP8, 10 minutes

Erosion did not seriously affect the readability of the marks.

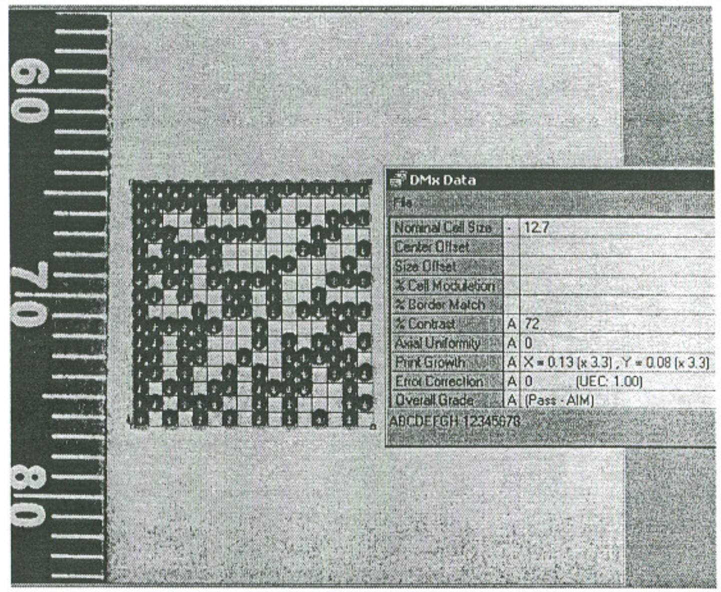
TP – IX Impact

Figure F-13



200 U-TP9

Figure F-14

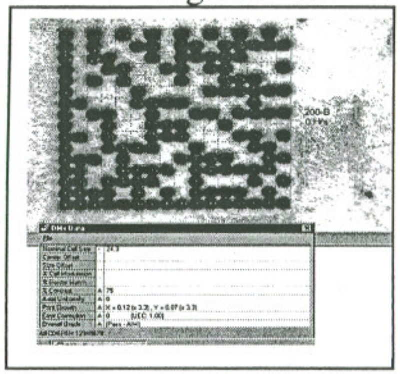


200 V- TP9

Impact testing did not affect the readability of the marks.

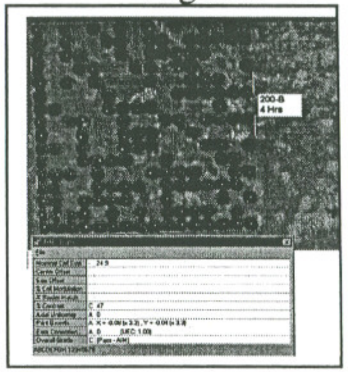
TP –X Salt Spray

Figure F-15



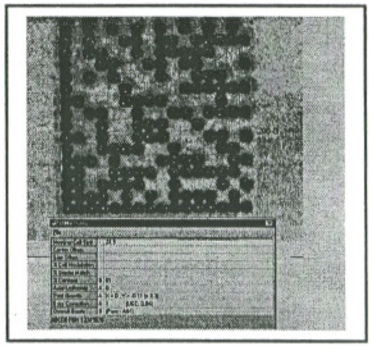
(a) 0 Hrs-Q-fog

Figure F-16



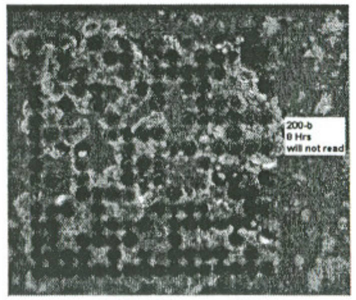
(c) 4 Hrs-Q-fog

Figure F-17



(b) 1 Hrs-Q-fog

Figure F-18

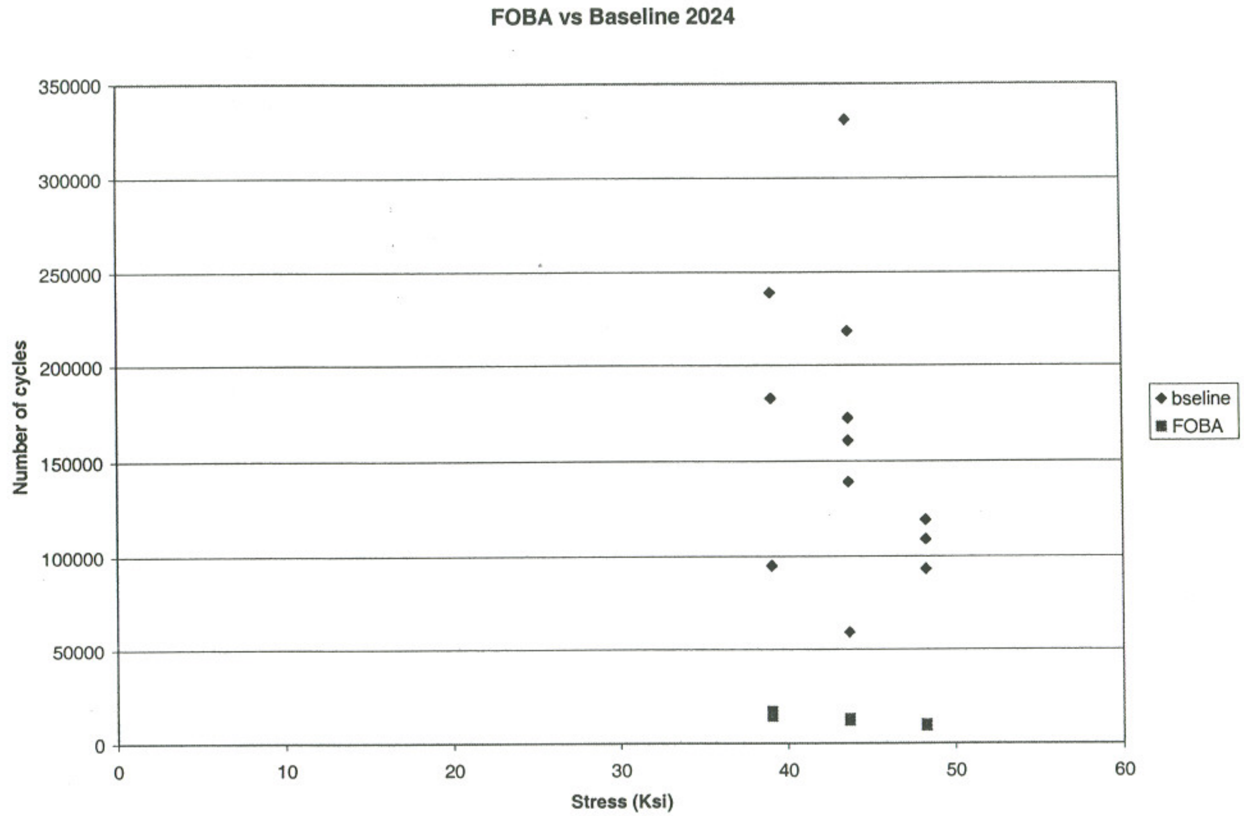


(d) 8 Hrs-Q-fog

The marks were readable after 1 hour and 4 hours. The readability was reduced after 8 hours of salt spray testing.

TP –XI Fatigue

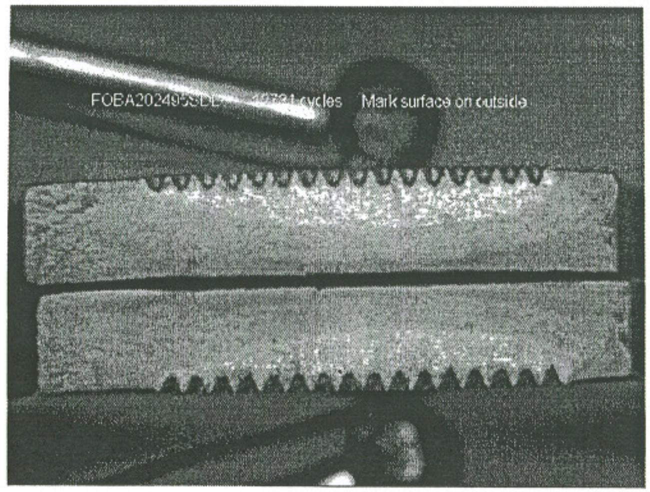
Figure F-19



The fatigue properties were noticeably reduced by the marking process.

TP –XI Fatigue – (continued)

Figure F-20



Cross Section View of Fatigue Fracture Surface

The cross-section shows that the failure occurred in the mark. Note however that the specimen shape encourages failure in this region.

TP –XII X-ray Phase

This test showed no interesting information.

TP –XIII X-ray Stress

These tests have not been analyzed.

NCMS
Material Testing Report
The University of Tennessee Space Institute
March 12, 2003

Kit 202
Laser Bonding on 2024 Aluminum

Marking Parameters:

Nd:YAG laser
Images/Ferro.plo marking file
Images/tools/mtbond1.idm data matrix marking file

Speed	= 10
Aperture	= 2.4
Frequency (QS)	= continuous mode
Current	= 13 for unpolished aluminum
	= 15 for polished aluminum (fatigue samples)
Power	= 12.2 watts
Marking Time	= 125 seconds
Laser Width	= 0.10
Beam Overlap	= 0.32
Lines per cell	= 9

Initial Reading Trials

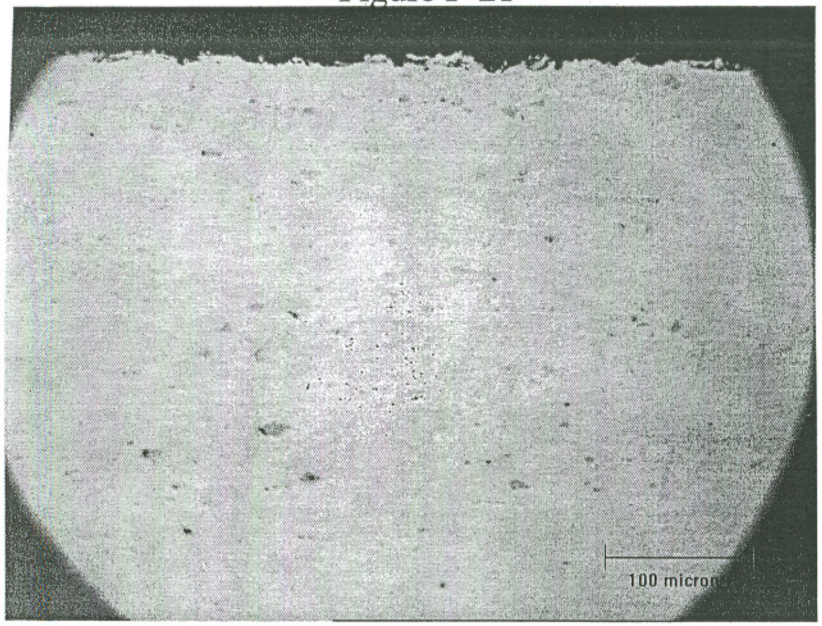
Table 1

		TP-V								TP-VI		TP-VII	TP-VIII	TP-IX	TP-X
	Initial	Chemical								Temperature		Dry Wear	Erosion	Impact	Salt Spray
Mark	Reading	Dye Penetrant	Hydraulic Fluid (1hr/6hr/12hr)	JP5 Fuel (1hr/6hr/12hr)	SAE 30 Oil (1hr/6hr/12hr)	Mineral Spirits (1hr/6hr/12hr)	Mobilegrease (1hr/6hr/12hr)	Acetone (1hr/6hr/12hr)	MEK (1hr/6hr/12hr)	Low (1hr)	High (10Min)				1hr/4hr/8hr
A	A														
B	B														
C	A														(B/A/F)
D	A	A													(A/A/D)
E	A		(B/A/A)												
F	A			(A/A/A)											
G	F				(B/A/B)										
H	A					(A/A/A)									
I	B						(B/B/B)								
J	A							(A/A/A)							
K	A								(A/A/A)						
L	A									(D)					
M	B										(F)				
N	B														
O	A											F			
P	A											F			
Q	B												F		
R	A												F		
S	D														
T	A														
U	A													A	
V	B													B	
AA	A														
BB	B														
CC	A														
DD	A														
EE	A														
FF	A														
GG	A														
HH	A														

The results of all of the reading trials are given in Table 1 for all of the marks.

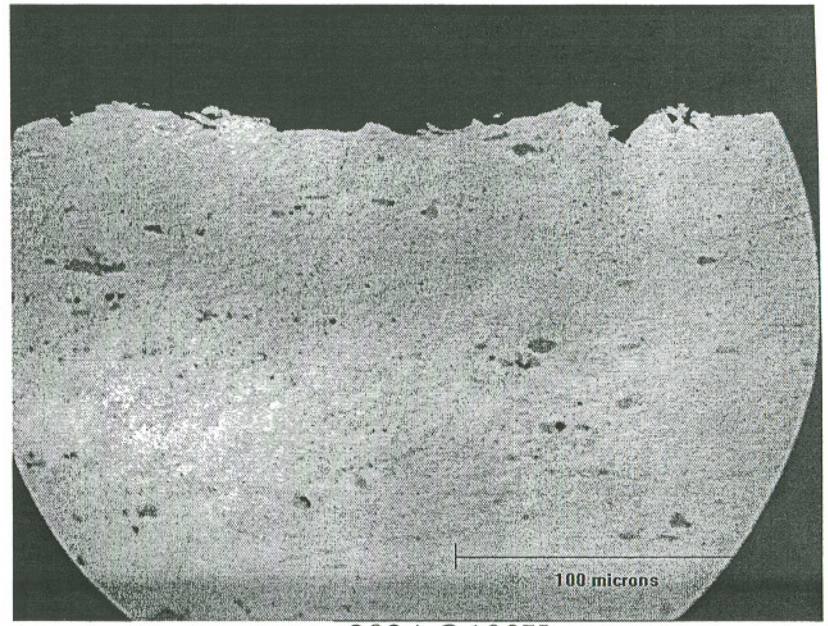
TP – I Metallography

Figure F-21



202A@50X

Figure F-22



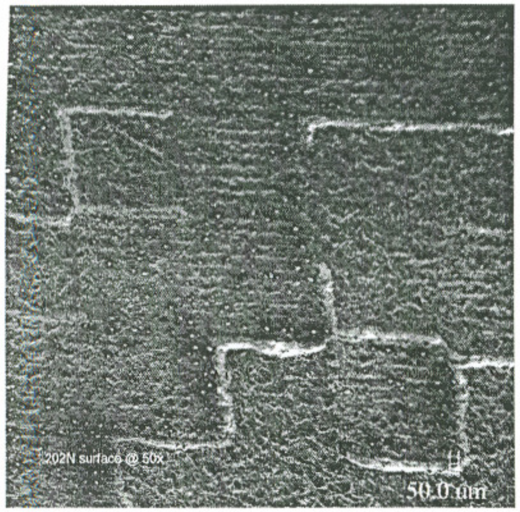
202A@100X

Examination of cross-sections of the laser bonded mark gave no indication that the marking process had affected the base material.

TP – II Scanning Electron Microscopy

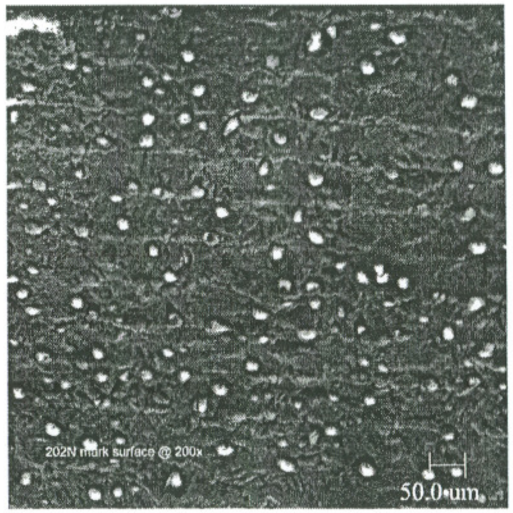
SEM Views of Mark Surface

Figure F-23



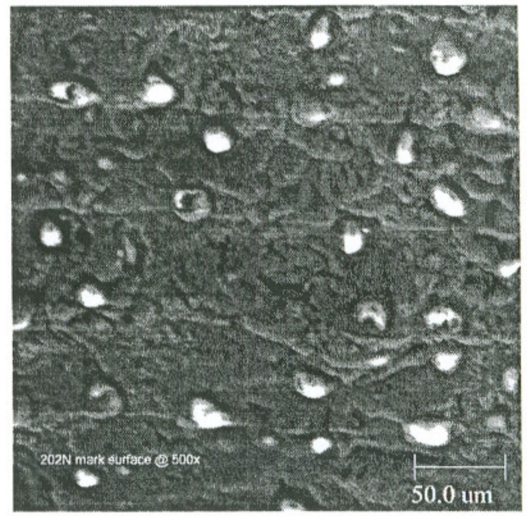
(a) 50X

Figure F-24



(b) 200X

Figure F-25



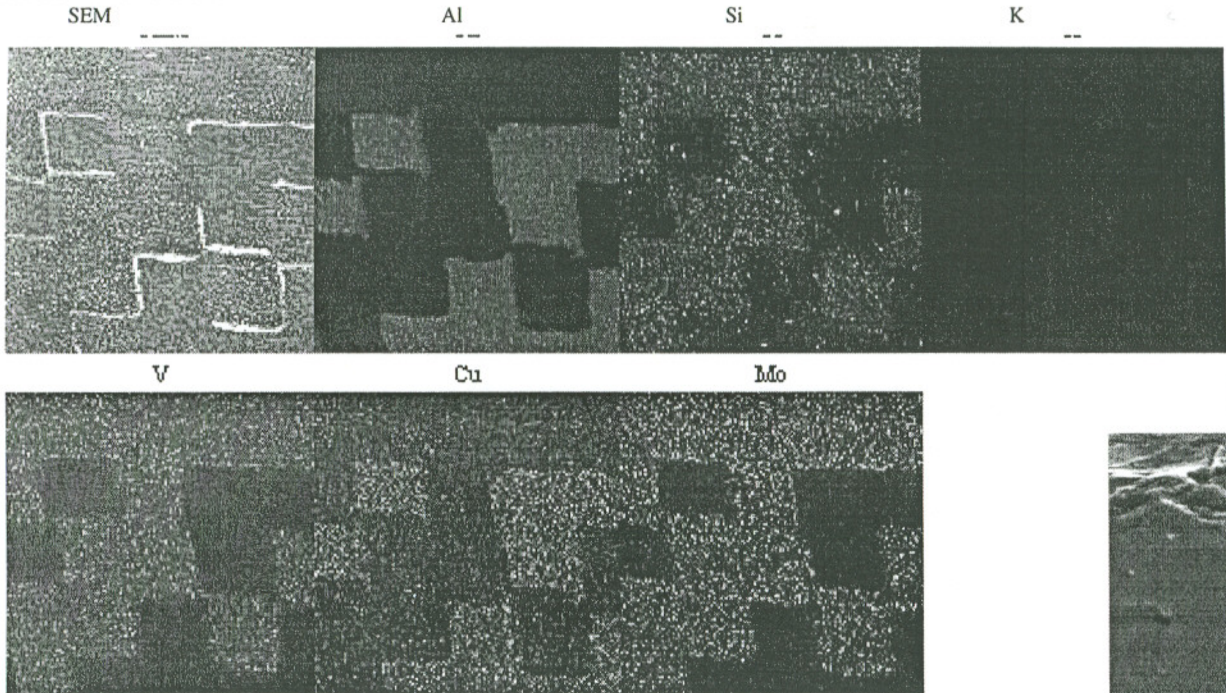
(c) 500X

TP – II Scanning Electron Microscopy

SEM Views of Mark Surface

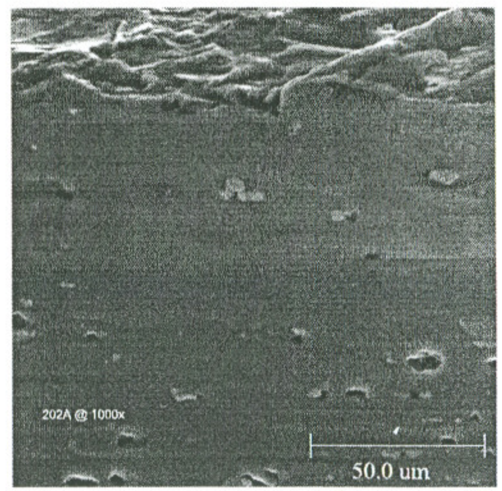
Figure F-26

202N surface @50x



(d) X-ray map

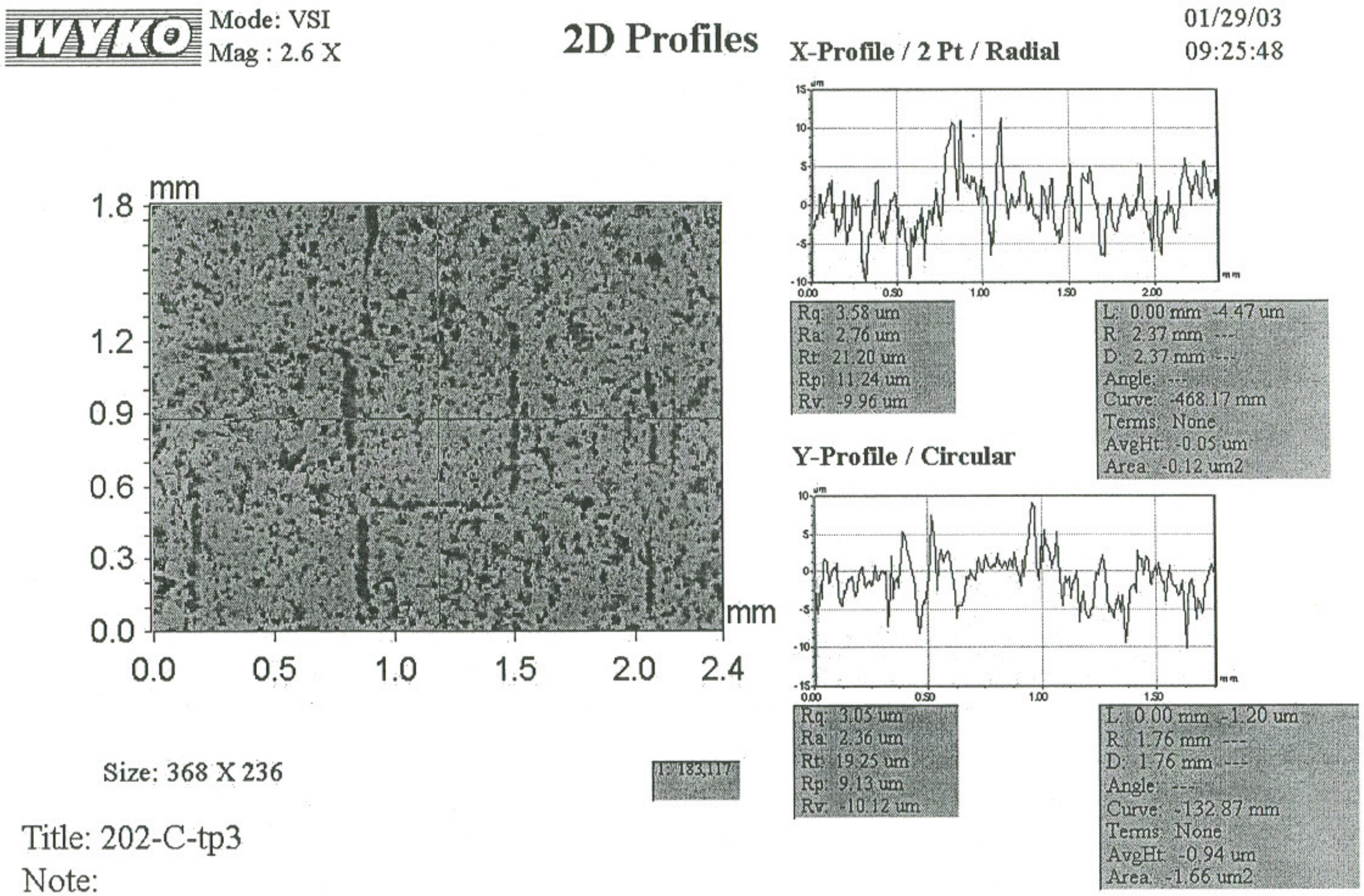
Figure F-27



SEM View of sample cross-section (1000X)

TP – III Profilometer

Figure F-28



Profilometry indicates that the mark process has not changed the surface roughness of the base material.

TP – IV Microhardness

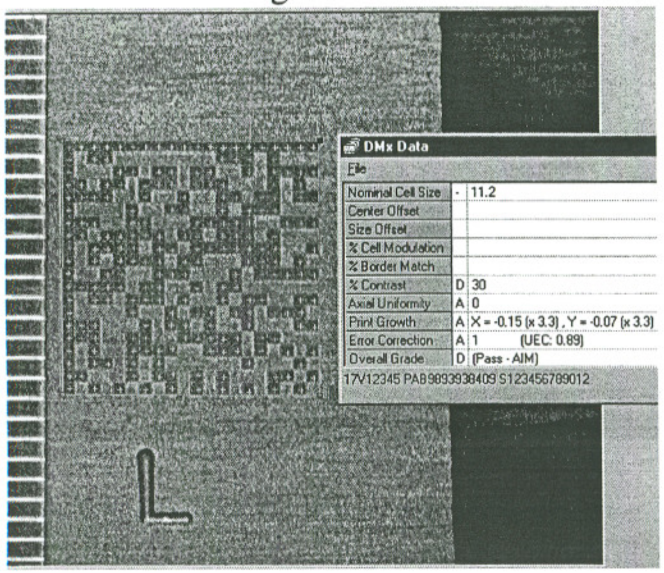
The microhardness was not affected by the marking process.

TP – V Chemical

Chemical testing did not affect the readability of the marks.

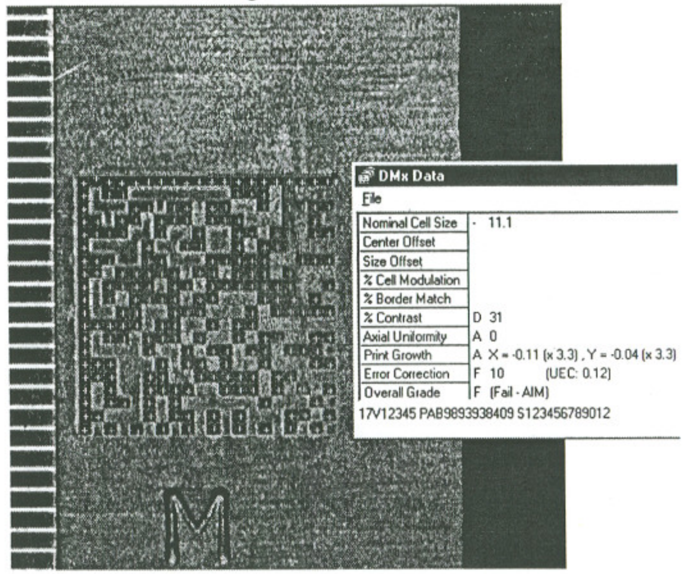
TP-VI Temperature

Figure F-29



202-L-TP6 1 hr

Figure F-30



202-M-TP6 1 hr.

Both cold and hot temperatures negatively affected the readability of the marks.

TP – VII Dry Wear

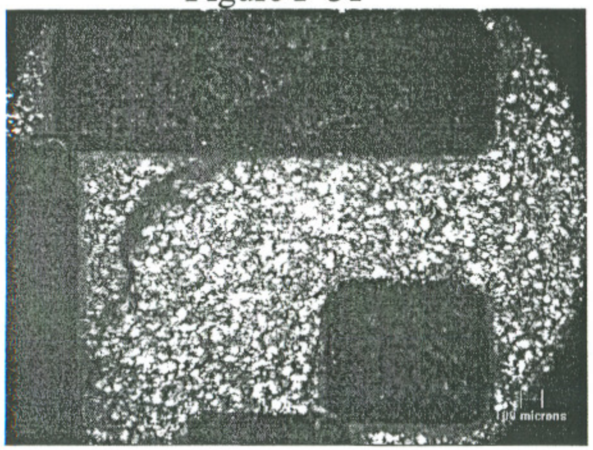
Dry wear negatively affected the readability of the marks.

TP – VIII Erosion

Erosion negatively affected the readability of the marks.

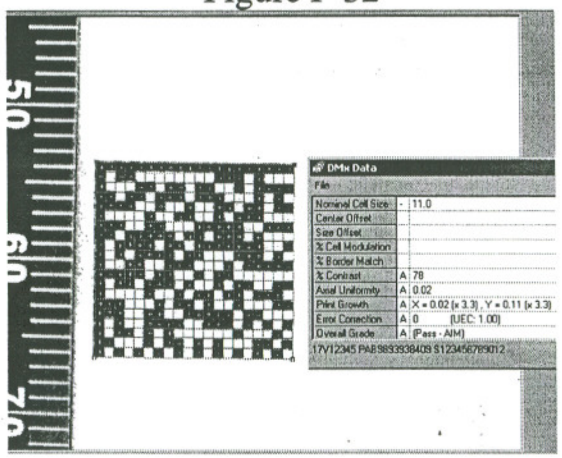
TP – IX Impact

Figure F-31



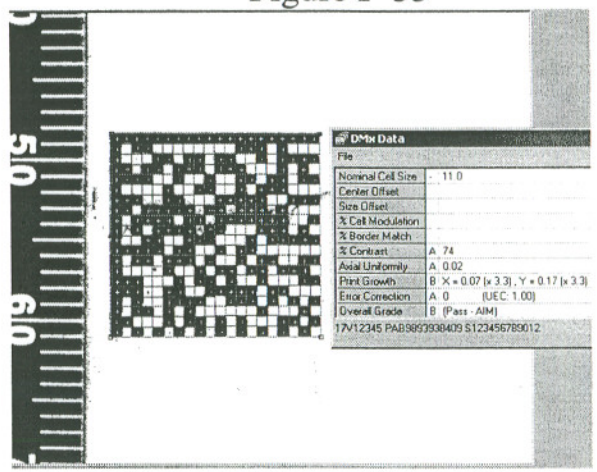
(a) Fracture

Figure F-32



(b)

Figure F-33

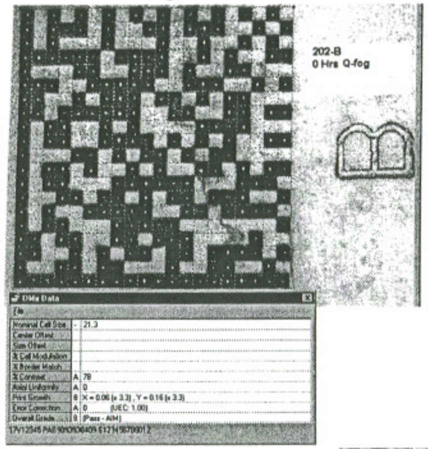


(c)

Impact testing did not affect the readability of the marks, although a crack did occur in one of the marks.

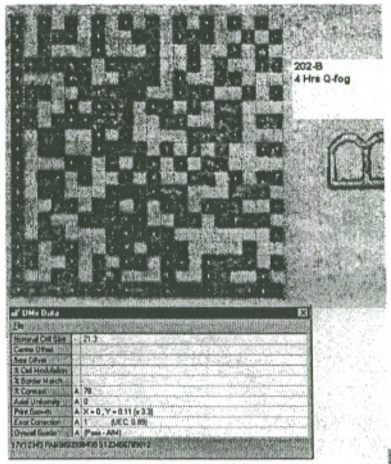
TP –X Salt Spray

Figure F-34



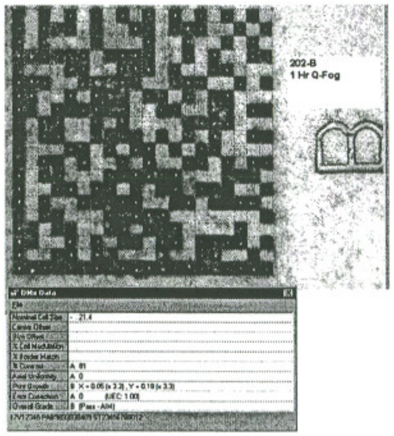
(a) 0 Hrs-Q-fog

Figure F-35



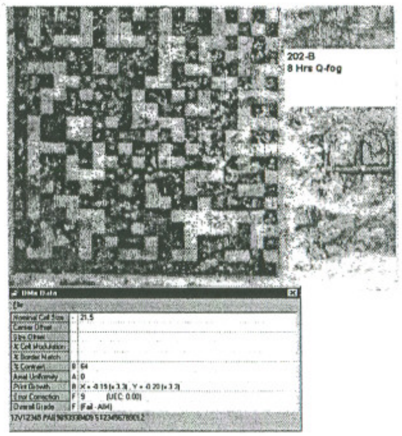
(c) 4 Hrs-Q-fog

Figure F-36



(b) 1 Hrs-Q-fog

Figure F-37

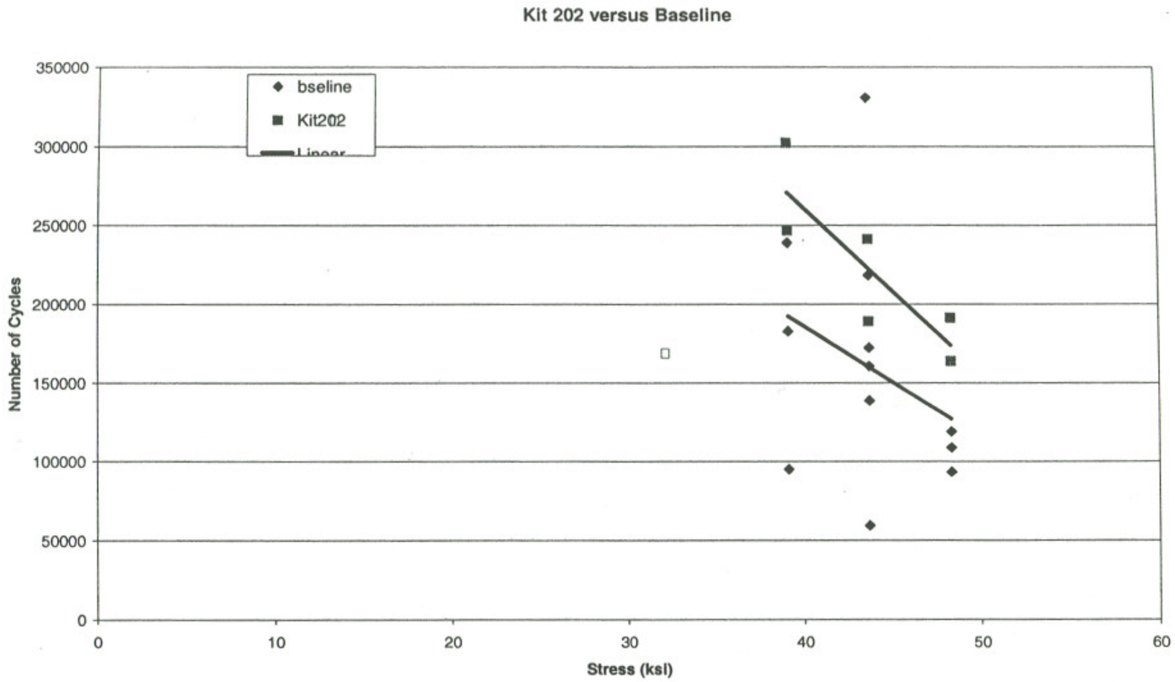


(d) 8 Hrs-Q-fog

The marks were readable after 1 hour and 4 hours. They were not readable after 8 hours of salt spray testing.

TP –XI Fatigue

Figure F-38



The fatigue properties were not affected negatively by the marking process.

TP –XII X-ray Phase

This test showed no interesting information.

TP –XIII X-ray Stress

These tests were not run.