NCT Report No 3789/607

Advanced Tribological Coatings For High Specific Strength Alloys, R&D 5876-MS-01

Contract DAJ A45-87-C-004

5th Interim Report

National Centre of Tribology

Risley Nuclear Power Development Laboratories

NCT

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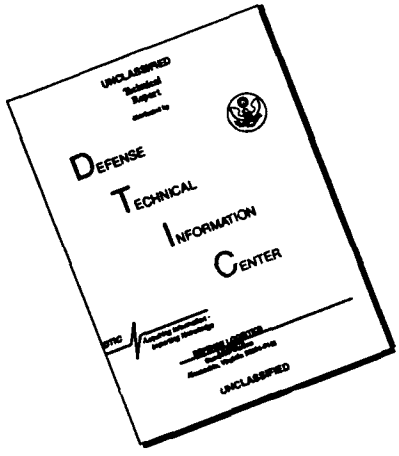

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5th Interim Report

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CONTENTS

1. INTRODUCTION

2. SURFACE TREATMENTS PERFORMED

3. SURFACE ROUGHNESS MEASUREMENTS

4. METALLOGRAPHIC EXAMINATION

   4.1 Coating Thickness
   4.2 Microhardness/Depth Profile

5. FRICTION AND WEAR MEASUREMENTS

   5.1 Test Conditions
   5.2 Results at 20N Load
   5.3 Results at 50N Load

6. DISCUSSION & FURTHER WORK PLANNED

Figures 1 - 10

APPENDIX 1: Scanning Electron Micrographs
APPENDIX 2: Optical Micrographs
APPENDIX 3: Microhardness Depth Profiles
APPENDIX 4: 20N Wear Profiles and SEM Micrographs of Wear Tracks
APPENDIX 5: 50N Wear Profiles and SEM Micrographs of Wear Tracks

1. INTRODUCTION

This 5th interim report summarises the work performed to date on the US Army contract 'Advanced Tribological Coatings for High Specific Strength Substrates'. The objective of this contract are to develop and test a surface treatment suitable for the hardening of a titanium alloy precision gear for use in a vacuum environment.

Attention has been primarily directed at surface hardening by the interstitial diffusion of the elements nitrogen, oxygen and carbon. Targets of a surface hardness of >500 HV and depth 50 microns, without the need of any post heat treatment operations have been identified.

2. SURFACE TREATMENTS

The surface treatments under study have been applied to specimens of IMI 318 (Ti6Al4V), cut from plate. The sample numbers and corresponding surface treatments which have been carried out and tested to date are listed in Table 1 below. 'SHT' indicates that the plates sample was in a solution heat treated condition before surface treatment. 'H&G' indicates that the sample was in a hardened and ground condition before surface treatment.

Table 1: Sample Number Allocated to Surface Treatments.

Sample Number	Surface Treatment
HSSA1	Solution Heat Treated
HSSA2	Hardened and Ground
HSSA3	(SHT) Plasma Nitrocarburized 1
HSSA4	(SHT) Beta Nitrocarburized
HSSA5	(SHT) Ion Implanted (N^+) 1
HSSA6	(H&G) Ion Implanted (N^+) 2
HSSA7	(SHT) Hard Anodised 1
HSSA8	(H&G) Hard Anodised 2
HSSA9	(SHT) Plasma Nitrocarburized 2
HSSA10	(SHT) Hard Anodised 3
HSSA11	(H&G) Hard Anodised 4
HSSA12	(SHT) Plasma Nitrided 1
HSSA13	(H&G) Plasma Nitrided 2
HSSA14	(SHT) High Temperature Nitrocarburized 1
HSSA15	(H&G) Nitrox 1
HSSA16	(SHT) Pack Aluminising 1
HSSA17	(SHT) Nitrox 2
HSSA18	(H&G) Nitrox 3
HSSA19	(SHT) Pack Aluminising 2
HSSA20	(SHT) Gas Carbonitriding 1
HSSA21	(SHT) Diamond-like Carbon (DLC) 1
HSSA22	(SHT) TiN Reactive Sputter
HSSA23	(SHT) TiN/HfN Multilayer
HSSA24	(SHT) Pack Aluminising 3

3. SURFACE ROUGHNESS MEASUREMENTS

For the application of dry lubricants (ie sputtered MoS_2) onto hardened titanium alloy gears, the surface roughness is an important parameter in determining film (and hence gear life). The surface roughness of all the sample plates were, therefore, measured using a Talysurf 6 profilometer, and the values of Ra, Delta-Q and R_{sk} recorded. These parameters are defined as:

Ra: The arithmetic mean of the departure of the roughness profile from the mean line (in micrometres).

Delta-Q: The RMS slope of the profile throughout the assessment length (in degrees).

R_{sk}: The measure of the symmetry of the profile about the mean line (in degrees). R_{sk} will distinguish between asymmetric profiles which have the same Ra value.

The surface roughness measurements for the samples are summarised in Figure 1. This figure has been arranged with the samples that were originally solution heat treated grouped first, followed by those which were originally hardened and ground. Essentially only pack aluminising (HSSA19) causes any detriment to the surface roughness, all other treatments either cause no change or a small improvement in the surface roughness.

4. METALLOGRAPHIC EXAMINATION

Optical metallographic specimens were prepared by nickel coating a small piece of each sample and embedding this in thermosetting resin. Each specimen was then ground and polished to produce a section through the sample at 90° to the hardened surface. From this section, coating structure and thickness could be ascertained, and a microhardness depth profile measured.

4.1 Coating Thickness

The micrographs from the metallographic examination of the samples, with the exception of HSSA10 are included in Appendix 2. From the micrographs the resulting coating thickness was determined and are given in table 2 below.

Table 2: Surface Treatment Coating Thickness & Hardness.

Sample	Surface Treatment	Coating Thickness	Hardness
HSSA1	Solution Heat Treated	not applicable	
HSSA2	Hardened and Ground	not applicable	
HSSA3	Plasma Nitrocarburized 1	<2 micrometres	Not measured
HSSA4	Beta Nitrocarburized	5-10 micrometres	550 Hv
HSSA5	Ion Implanted (N^+) 1	negligible	Not measured
HSSA6	Ion Implanted (N^+) 2	negligible	Not measured
HSSA7	Hard Anodised 1	negligible	Not measured
HSSA8	Hard Anodised 2	negligible	Not measured
HSSA9	Plasma Nitrocarburized 2	negligible	Not measured
HSSA10	Hard Anodised 3	negligible	Not measured
HSSA11	Hard Anodised 4	negligible	Not measured
HSSA12	Plasma Nitrided 1	<1 micrometre	Not measured
HSSA13	Plasma Nitrided 2	negligible	Not measured
HSSA14	High Temp Nitrocarburized	<2 micrometres	Not measured
HSSA15	Nitrox 1	~5 micrometres	~400 Hv
HSSA16	Pack Aluminising 1	25 micrometres	360 Hv
HSSA17	Nitrox 2	negligible	Not measured
HSSA18	Nitrox 3	low micrometres	~400 Hv
HSSA19	Pack Aluminising 2	25 micrometres	<400 Hv
HSSA20	Gas Carbonitriding 1	50 micrometres	700 Hv
HSSA21	Diamond-like Carbon 1	1 micrometre	Not measured
HSSA22	TiN Reactive Sputter	3 micrometres	Not measured
HSSA23	TiN/HfN Multilayer	5 micrometres	Not measured
HSSA24	Pack Aluminising 3	27 micrometres	560 Hv

4.2 Microhardness Depth Profile

Microhardness depth profiles were produced by measuring the Vickers microhardness at increasing depth into the sample on the metallographic specimens. The hardness was measured by applying a load of 50N for 15 seconds. The microhardness profiles are summarised in Appendix 3.

5. FRICTION AND WEAR MEASUREMENTS

To identify the most promising surface treatments from the large number of samples (for more detailed friction & wear evaluation in vacuum and for rolling contact surface fatigue assessment), the friction and wear of all samples was evaluated at two load conditions on a reciprocating tribometer at NCT. All these 'screening' tests were performed in air; any sample performing poorly in air would be very unlikely to perform well under vacuum conditions.

5.1 Test Conditions

The reciprocating tribometer was set to give a 20 mm stroke, with 500 cycles per test, giving a cumulative sliding distance of 20 metres. Tests were performed at two different loads (20 & 50N, equivalent to maximum Hertzian contact stresses of 1.30 & 1.76 Mpa respectively). The loads were applied using hardened En31 steel balls in contact with the treated titanium alloy plate. Both balls and plate samples were ultrasonically cleaned before test and no lubricant was added. Frictional forces were recorded continuously on a chart recorder.

Wear profiles and the volume of material removed from the specimens was measured using a 3D surface profilometer. All the wear scars were photographed at x50 in a SEM at 20kV using Secondary Electron Imaging (SEI), with additional photographs taken as needed at other magnifications and accelerating voltages, using both SEI and Back Scattered Imaging (BSI).

5.2 Results at 20N Load

Figures 2 and 3 summarise the friction (at various test intervals) and the measured wear rates. The wear profiles, with attached SEM micrographs of the central region of the scars, with the exception of HSSA16, are contained in Appendix 4.

Samples HSSA1 & HSSA2 can be regarded as the baseline performance, any coating exhibiting high friction or wear can be rejected from further study. At this load samples HSSA4, HSSA10, HSSA11, HSSA14, HSSA20 to HSSA 23 show 'good' performance. The extent of the wear on HSSA4, HSSA20 and HSSA24 is not readily apparent in the micrographs attached to the wear profiles. The scars show up more clearly when viewed in back

scattered image (Figure 4). The TiN/HfN multilayer coating of HSSA23 appears to have started to break up during this test (Figure 5).

5.3 Results at 50N Load

Figures 6 and 7 show the friction (at various test intervals) and the measured wear rates. The wear profiles, with attached SEM micrographs of the central region of the scars, with the exception of HSSA16, are contained in Appendix 5.

Samples HSSA4, HSSA14, HSSA20 & HSSA 22 give low wear rates and reasonable friction coefficients. SEM analysis revealed metal transfer from the En 31 ball to the plate occurred during the test on HSSA4 (Figure 8). A small hole can be seen in the coating of sample HSSA 22 which may indicate that the coating is starting to break up (Figure 9).

6. DISCUSSION & FURTHER WORK PLANNED

To date samples HSSA4, HSSA14, HSSA20 & HSSA22 show the most promising friction and wear performance. Sample HSSA20 also meets the targets for surface hardness and treatment depth

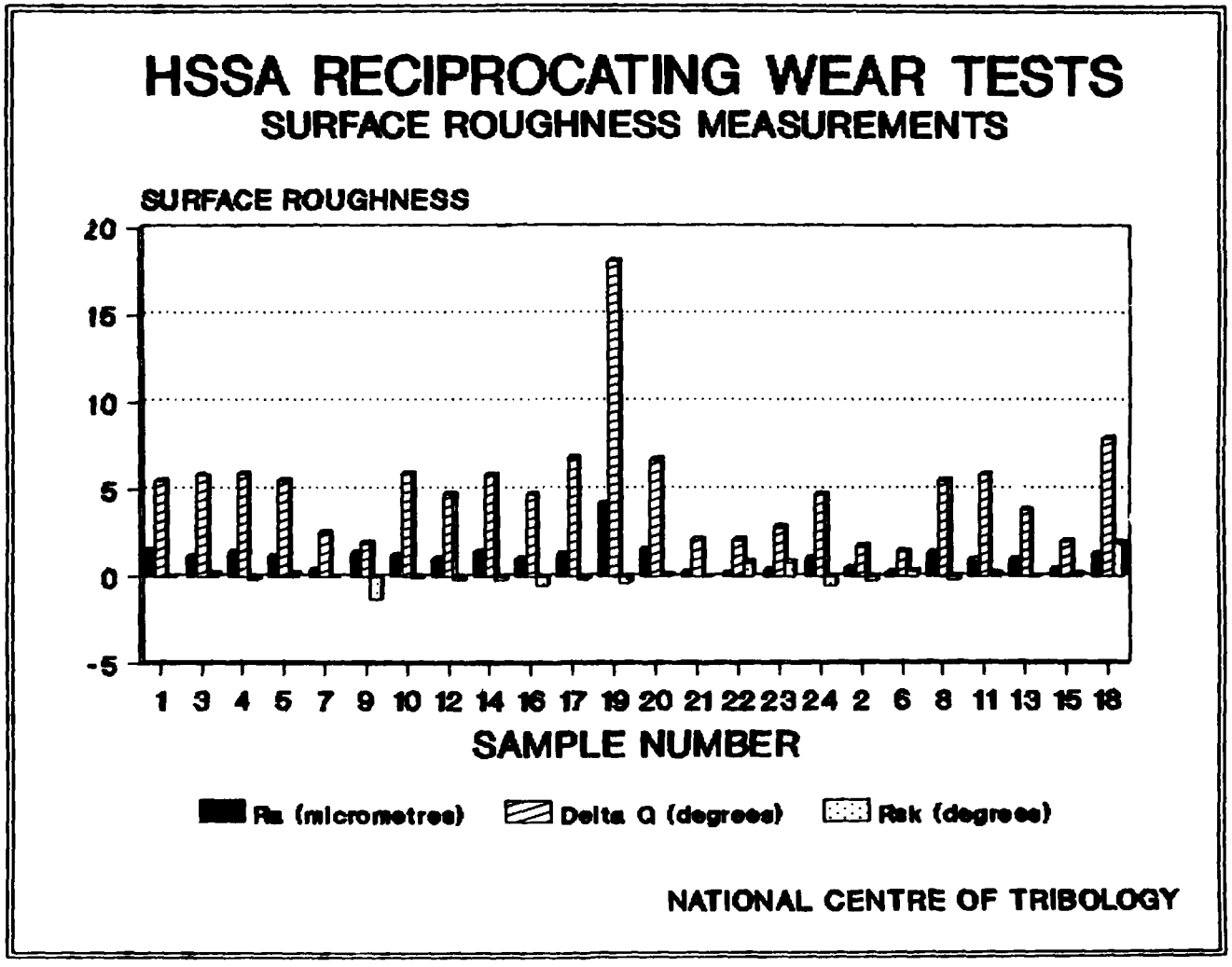
Analysis of the plasma nitrided samples (HSSA12 and HSSA13) has revealed poor processing, further samples are being prepared with a different supplier. The TiN/HfN multilayer (HSSA23) probably failed at 50N because substrate could not support the coating (cf ice on mud). The wear rate for this treatment is greater than that for uncoated titanium because of the presence of TiN and HfN particles in the wear debris. These are very hard and effectively improve the cutting properties of the En30 ball. Multi-treatment (e.g. Nitrocarburize then TiN/HfN multilayer) would result in support for the film and improved results. This approach is being evaluated.

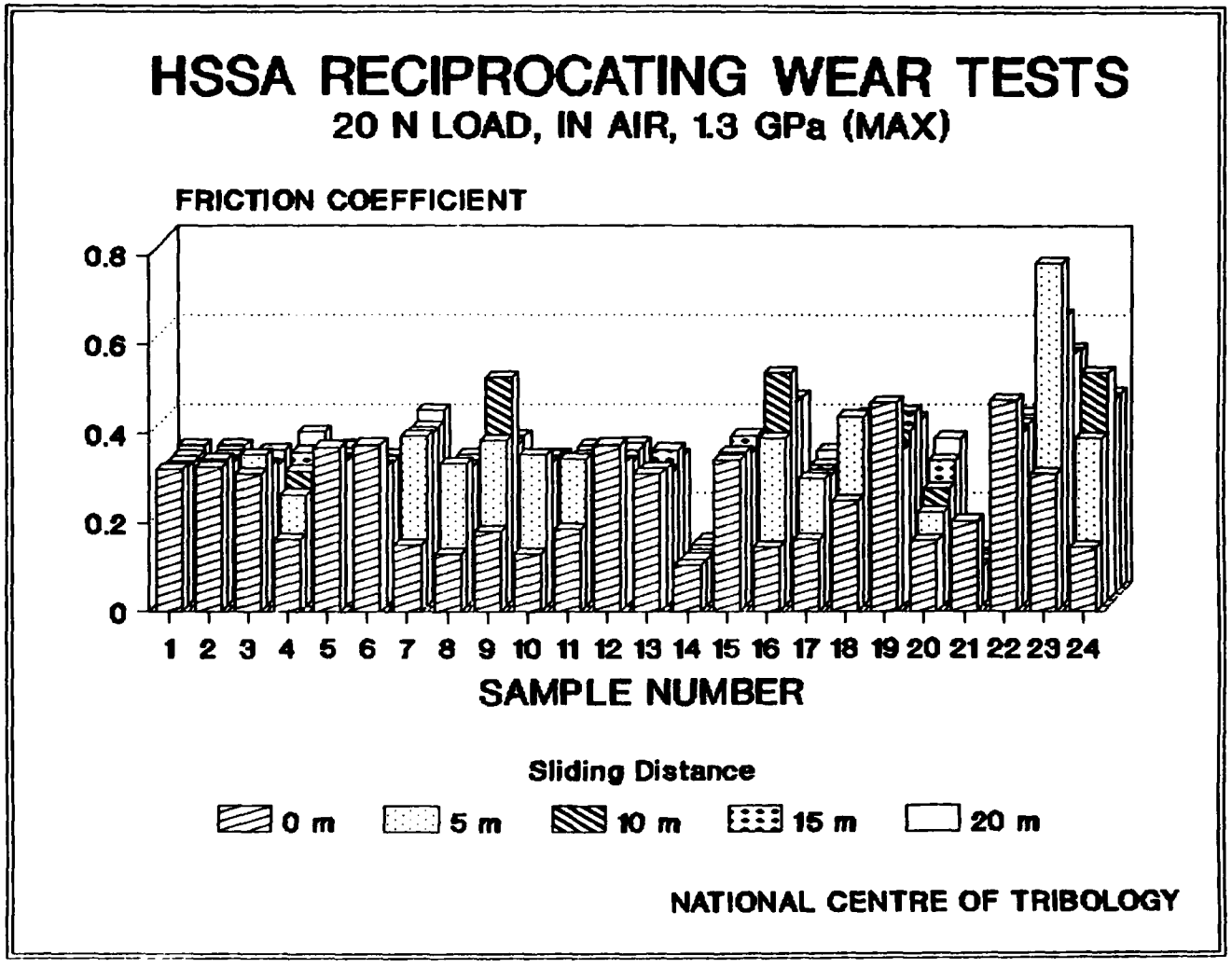
Further work is aimed at measuring the friction and wear performance of samples HSSA1, HSSA2, HSSA4, HSSA14, HSSA20 and HSSA22 at a load of 250N (3 GPa). This is the maximum achievable on the NCT reciprocating tribometer.

Sample HSSA26 (High Temperature Plasma Nitriding) has recently arrived, and is currently undergoing metallographic examination. The remaining samples are still with the

coating/surface treatment companies.

All test items for the NCT vacuum test rig and rolling contact fatigue specimens have been manufactured. After completion of the 250N tests, the fatigue specimens will be sent for treatment and then forwarded to AMTL for evaluation.


HSSA RECIPROCATING WEAR TESTS
SURFACE ROUGHNESS MEASUREMENTS
SURFACE ROUGHNESS
20
15
10
5
0
-5
1 3 4 5 7 9 10 12 14 16 17 19 20 21 22 23 24 2 6 8 11 13 15 18
SAMPLE NUMBER
Ra (micrometres)
Delta Q (degrees)
Rsk (degrees)
NATIONAL CENTRE OF TRIBOLOGY


HSSA RECIPROCATING WEAR TESTS
20 N LOAD, IN AIR, 1.3 GPa (MAX)
FRICTION COEFFICIENT
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
SAMPLE NUMBER
Sliding Distance
0 m
5 m
10 m
15 m
20 m
NATIONAL CENTRE OF TRIBOLOGY

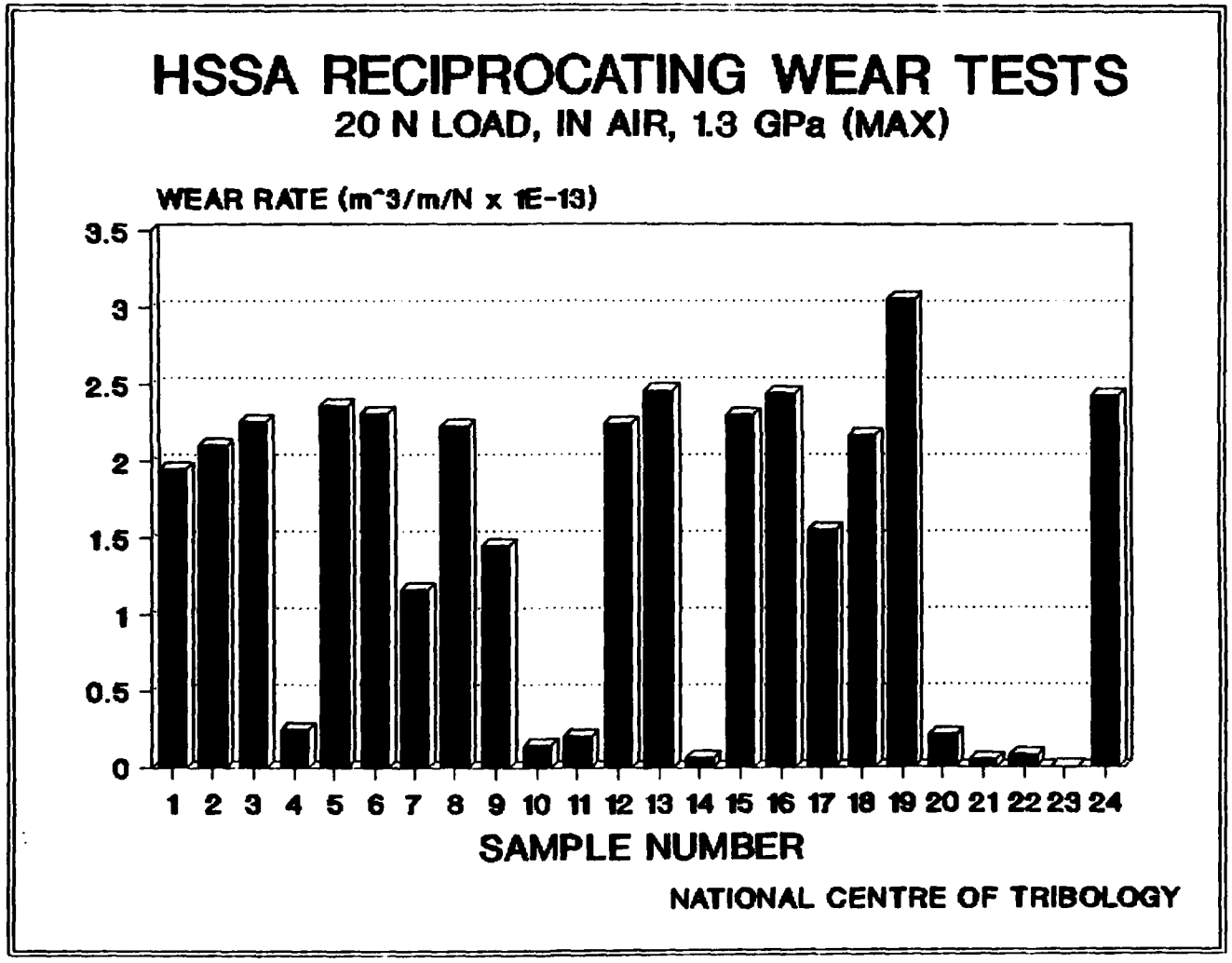

HSSA RECIPROCATING WEAR TESTS
20 N LOAD, IN AIR, 1.3 GPa (MAX)
WEAR RATE (m^3/m/N x 1E-13)
3.5
3
2.5
2
1.5
1
0.5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
SAMPLE NUMBER
NATIONAL CENTRE OF TRIBOLOGY

Figure 4: x50, 20kV Accelerating Voltage
Back Scattered Image

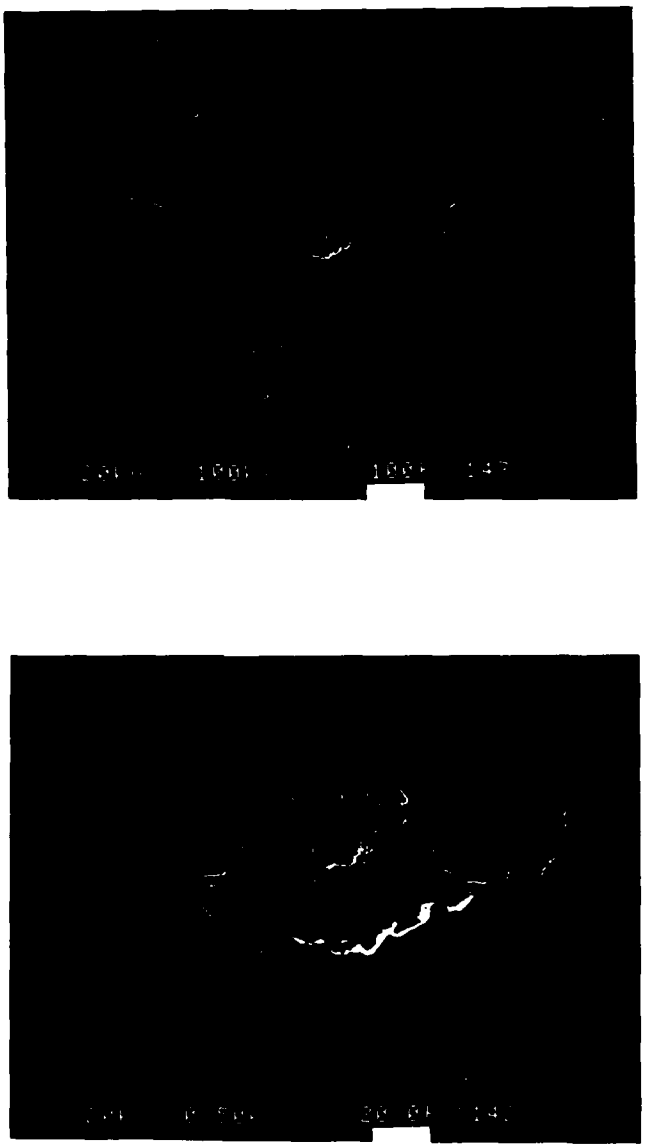
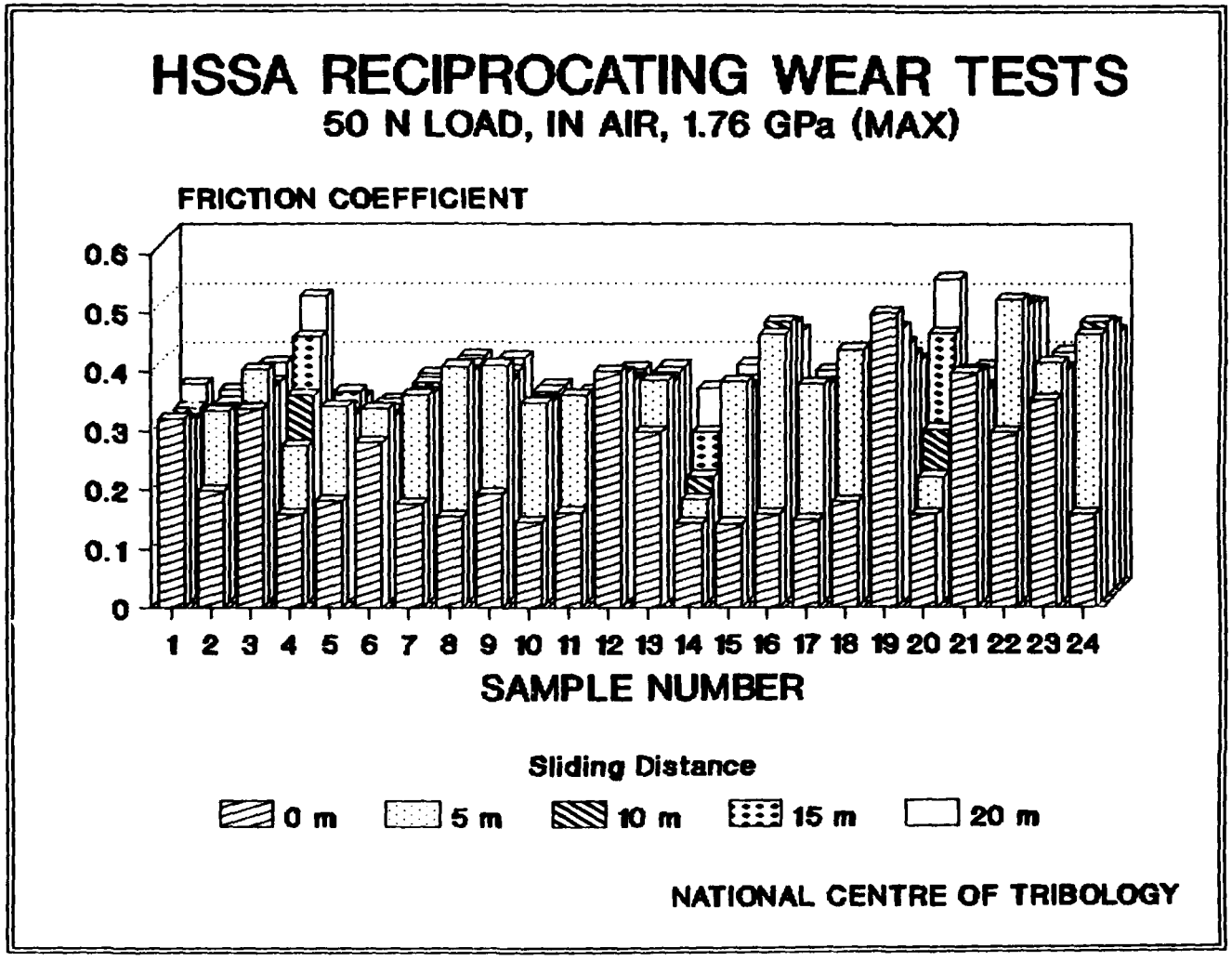
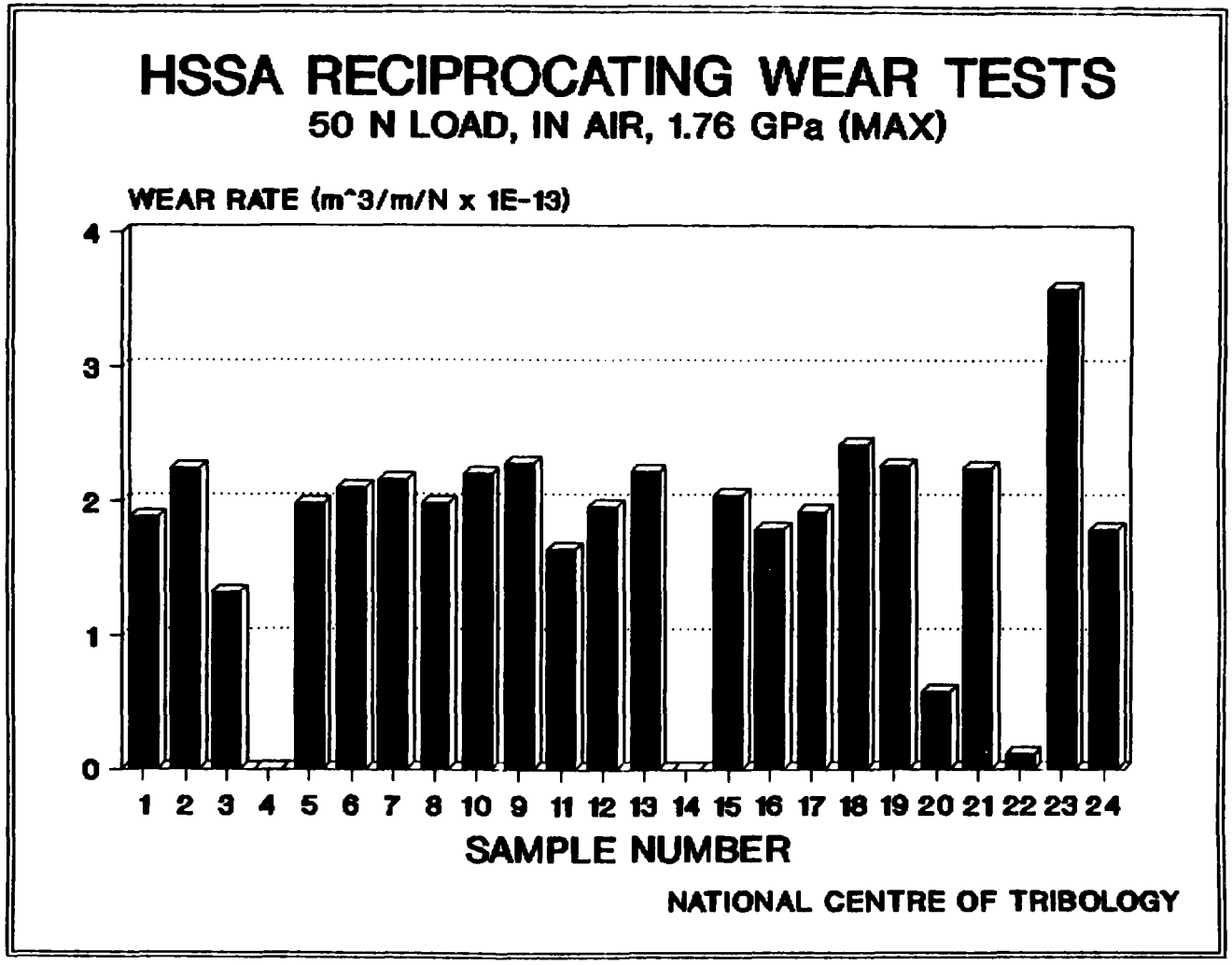
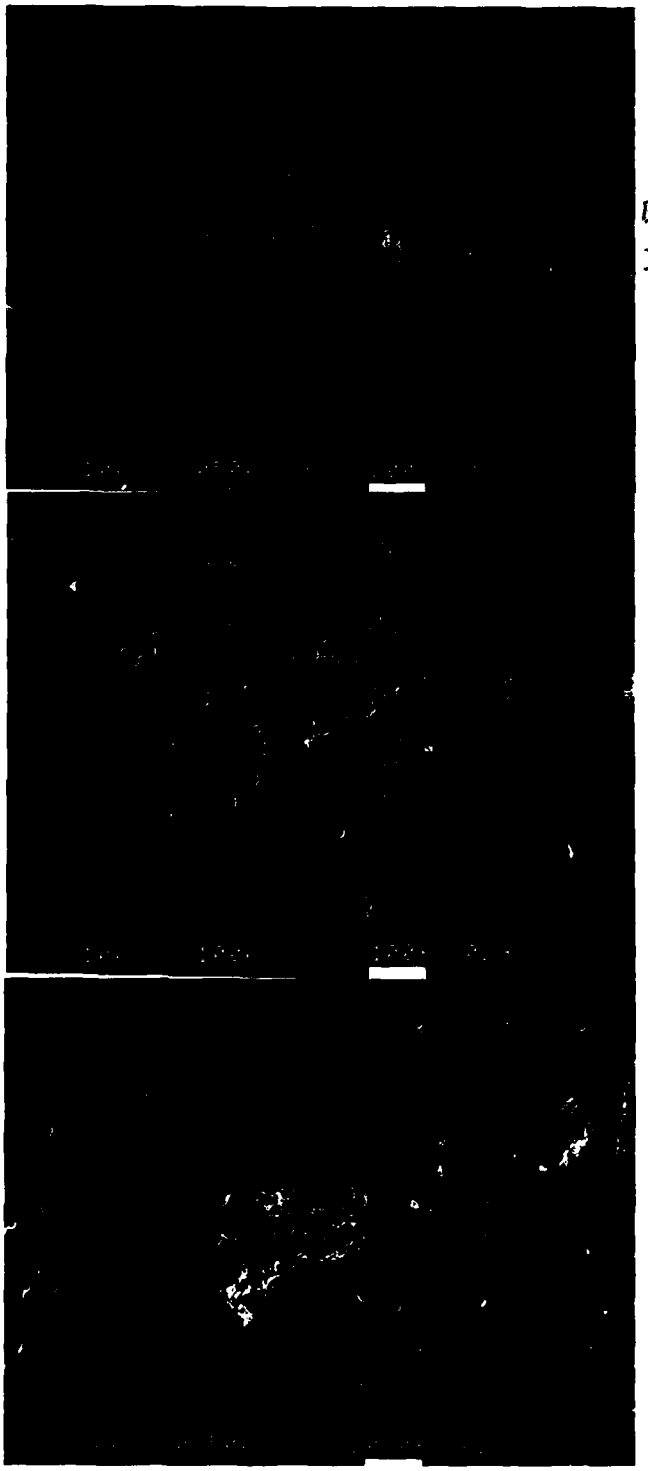


Figure 5: HSSA23: Coating damage at 20N load.


HSSA RECIPROCATING WEAR TESTS
50 N LOAD, IN AIR, 1.76 GPa (MAX)
FRICTION COEFFICIENT
0.6
0.5
0.4
0.3
0.2
0.1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
SAMPLE NUMBER
Sliding Distance
0 m
5 m
10 m
15 m
20 m
NATIONAL CENTRE OF TRIBOLOGY


HSSA RECIPROCATING WEAR TESTS
50 N LOAD, IN AIR, 1.76 GPa (MAX)
WEAR RATE (m^3/m/N x 1E-13)
4
3
2
1
0
1 2 3 4 5 6 7 8 10 9 11 12 13 14 15 16 17 18 19 20 21 22 23 24
SAMPLE NUMBER
NATIONAL CENTRE OF TRIBOLOGY



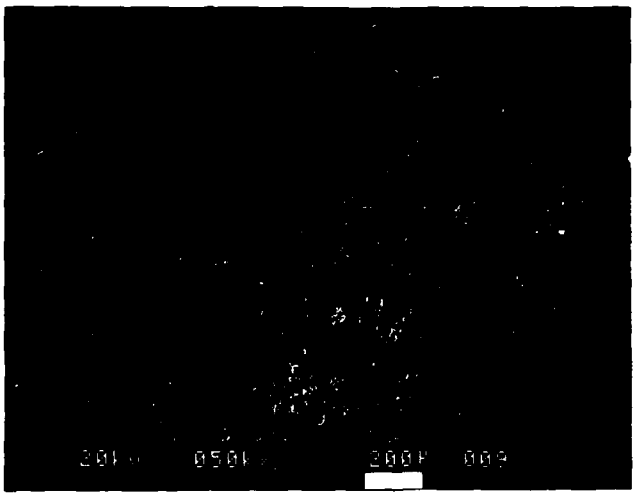
Back-scattered Image

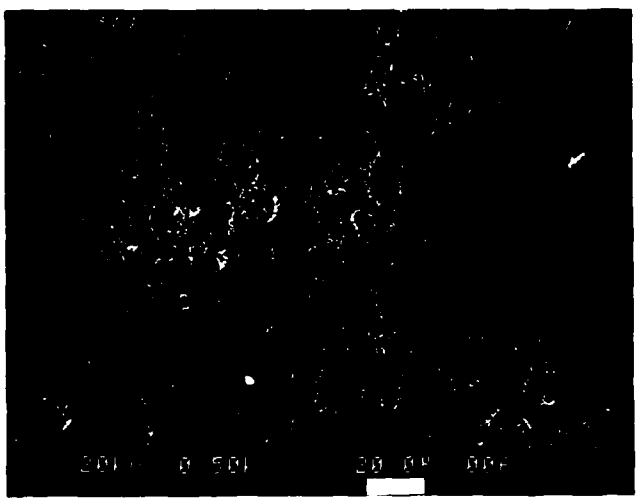
Figure 8: HSSA4, 10kV Accelerating Voltage, Showing Metal Transfer.

Back Scattered Image

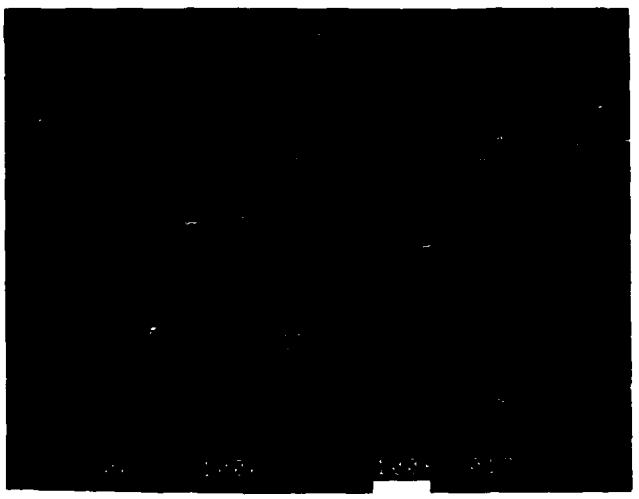
Figure 9:
HSSA 22, 50N. Hole in Coating in Scar.

APPENDIX 1: Scanning Electron Micrographs

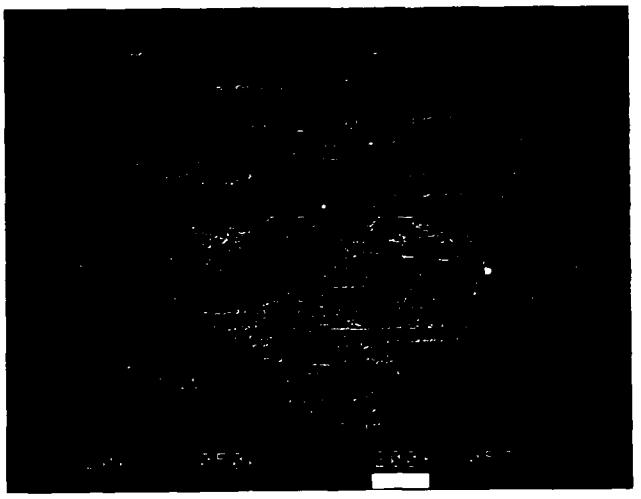


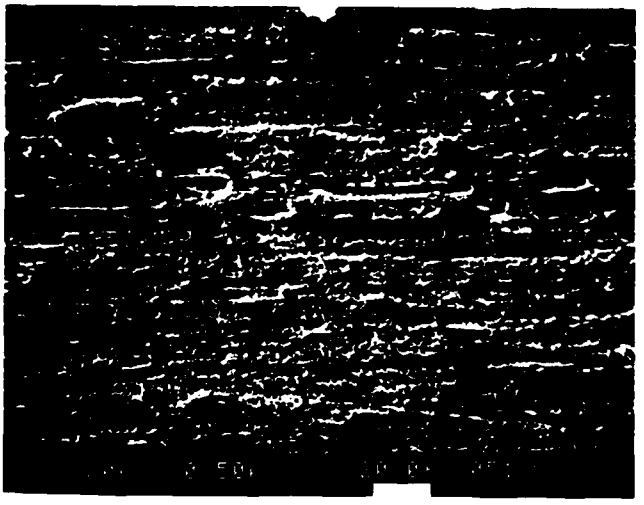


HSSA 1: Solution Heat Treated

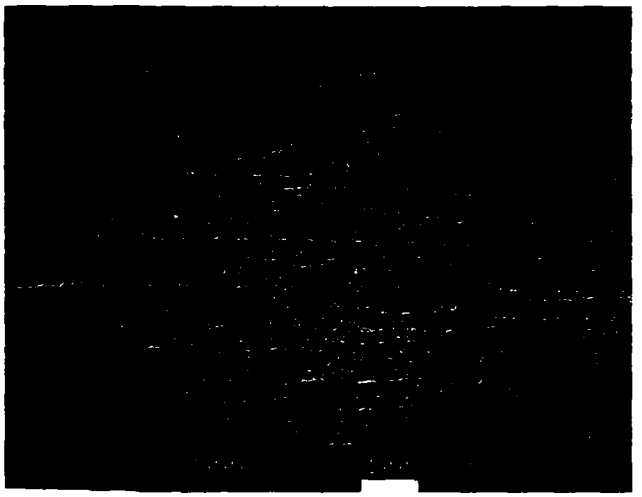


HSSA 2: Hardened and Ground

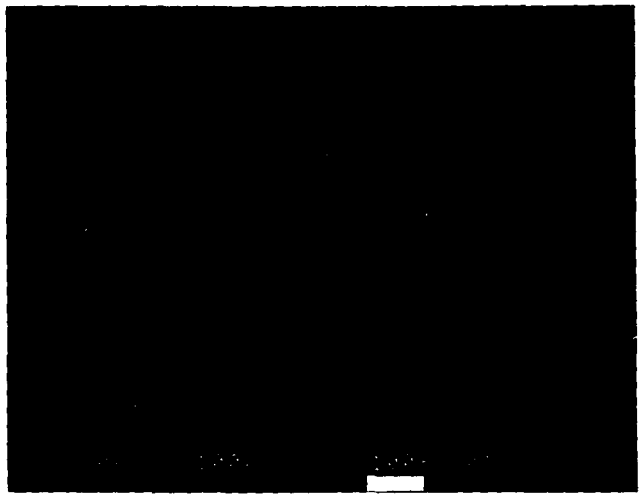


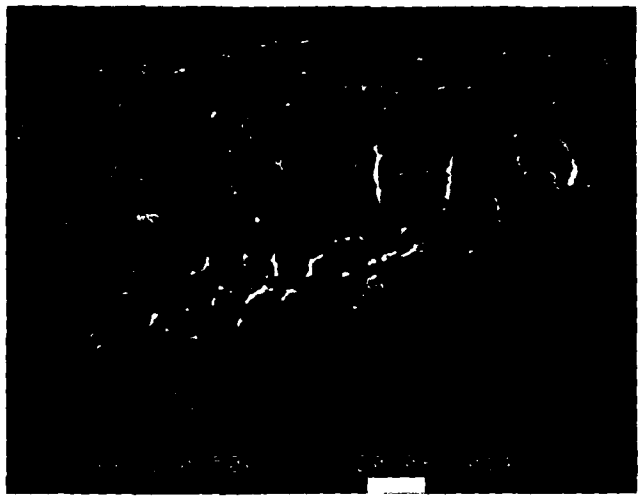


HSSA 7: Hard Anodised 1



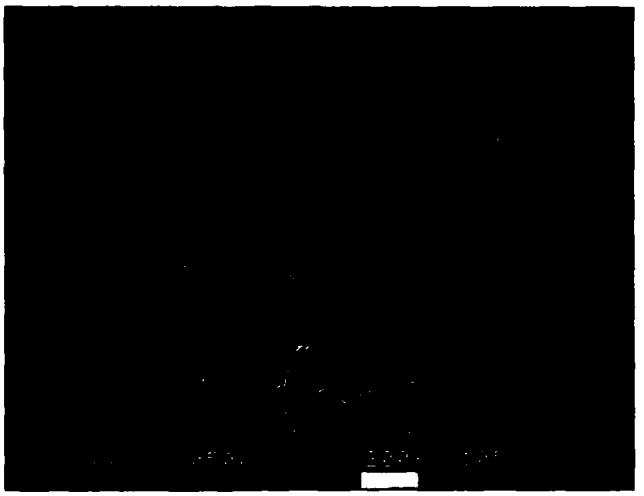
HSSA 11: Hard Anodised 4



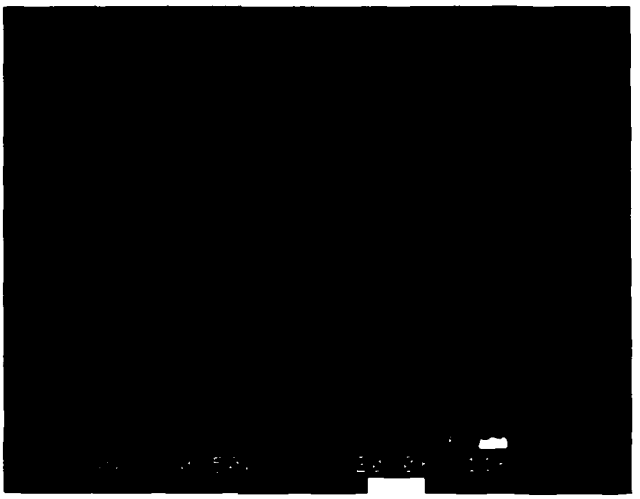


HSSA 13: Plasma Nitrided 2

HSSA 15: Nitrox 1



HSSA 19: Pack Aluminising 2



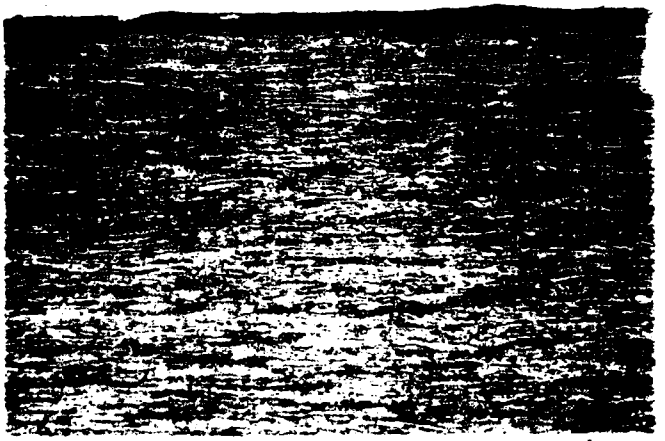
HSSA21: Diamond-like Carbon

HSSA23: TiN/HfN Multilayer

APPENDIX 2: Optical Micrographs

ISSA
samples
1,2 & 3

HSSA1 1200

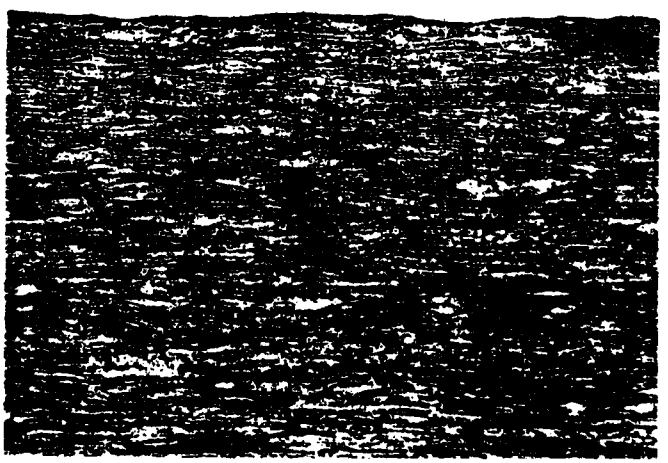


6362

HSSA2 1200

6363

HSSA3 1200



6364

SSA
miles
185

HSSA 4 X200

6365

HSSA 5 X200

HSSA 5 X200

6367

HSSA6

HSSA6 side(b) X200

5451

Hardened + Ion Implanted
HSSA6 side(a) X200

5450 bulk = 391 HV (50g)

HSSA7

HSSA7 Salt Treated Boeron Anodised X200

5449 bulk = 401 HV (50g)

HSSA7 X1000

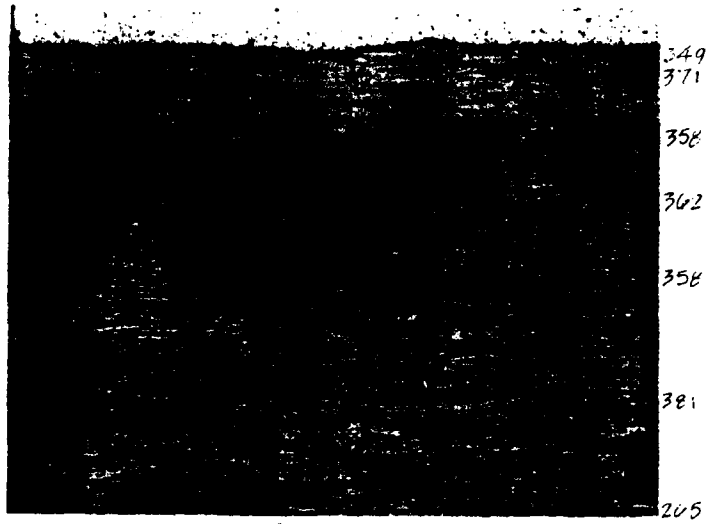
5448

HSSA7 S.T. Centre X1000

5447

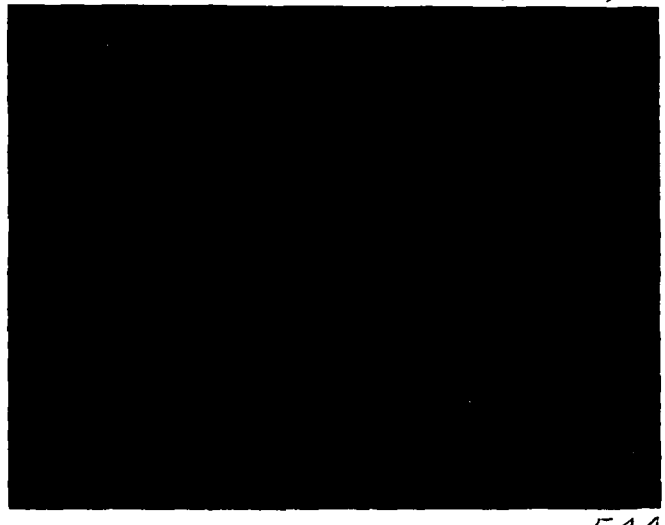
HSSA 8

HSSA 8 Hardened Ground Pocron Anodised x200



5446 bulk = 412 HV (50g)

HSSA 8 x1000



5445

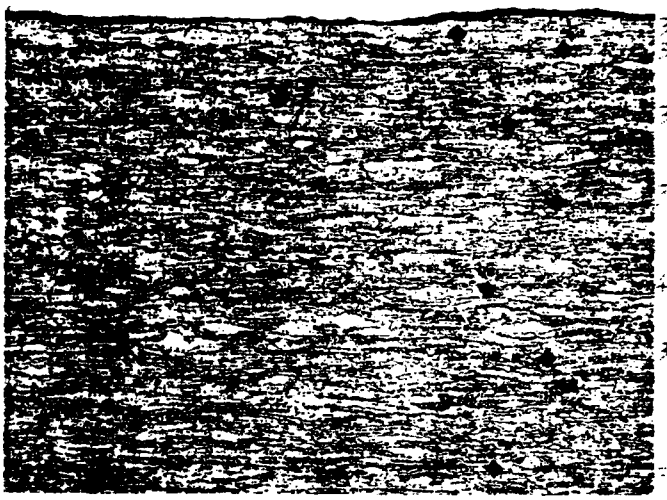
HSSA8 Centre x1000

5444

HSSA 9

HSSA 9

X200



bulk = 359 HV 5459

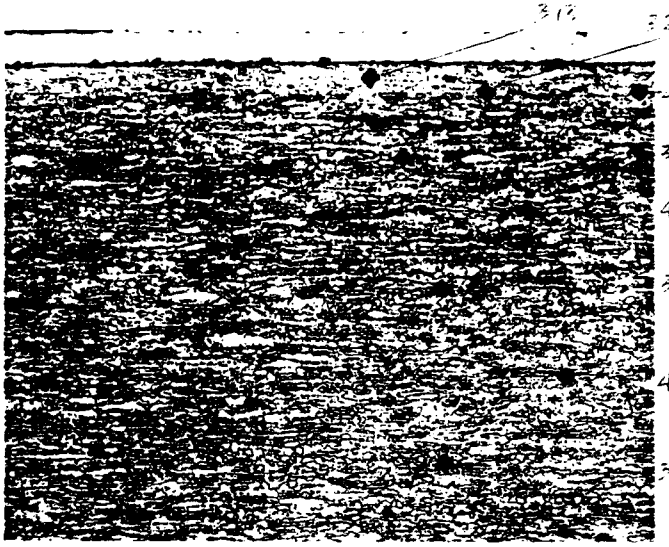
HSSA 9

X1000

5458

I 15SA11

H5SA11 X200



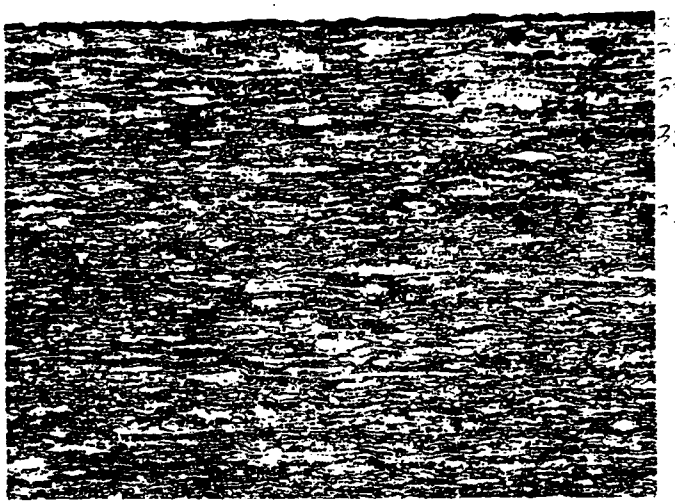
bulk = 40 THV 5453

H5SA11 X1000

5452

HSSA12

HSSA12 x200



5457

HSSA12 x1000

5456

H55A13

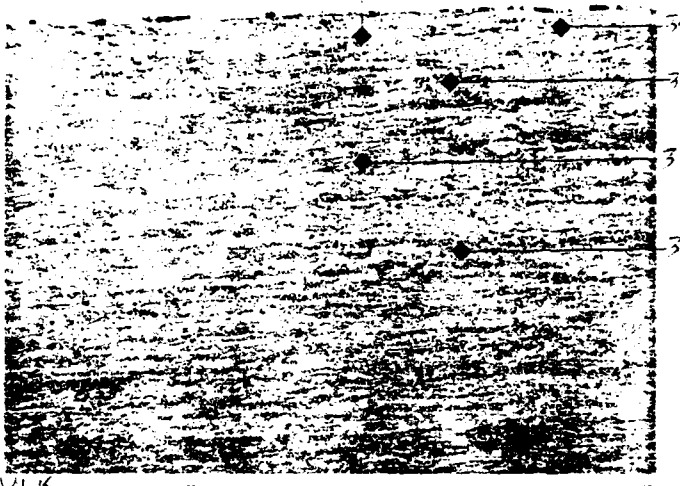
H55A13 ×200

5455

H55A13 Centre ×1000

5454

HSSA14

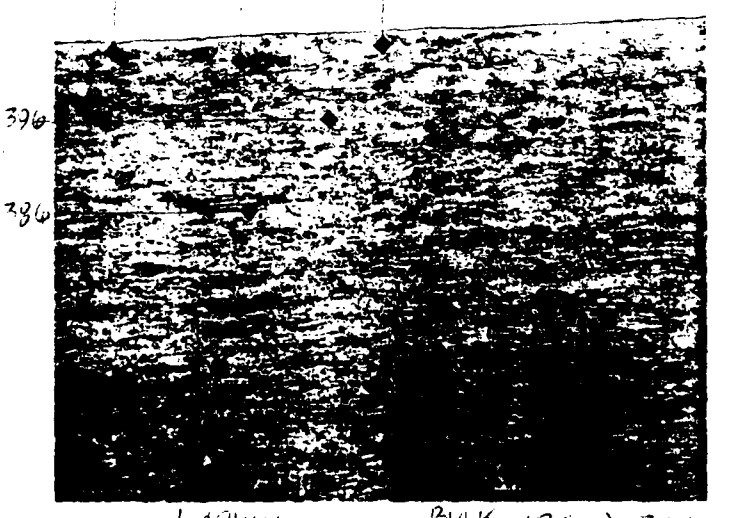


BULK MACRO (20kg) = 356HV mik ↓ 341HV 5700

x200

HSSA14

HSSA15



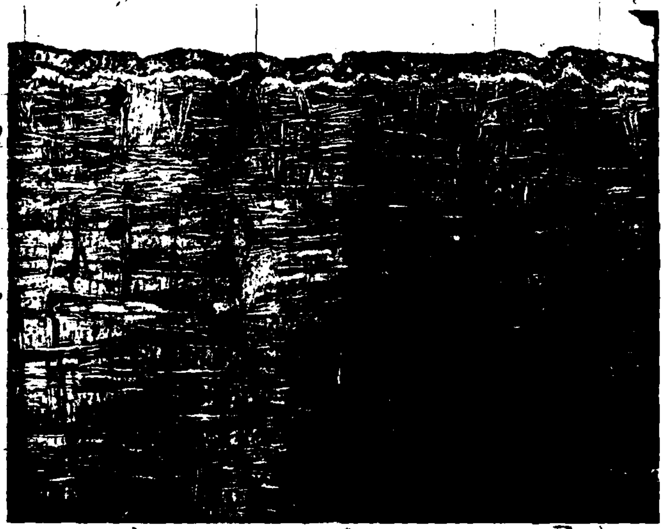
mik ↓ 401HV BULK MACRO (20kg) = 398HV

x200

HSSA15

HSSA 16

5705
x50
HSSA 16
260
243



321
50g/15sec
368
357
297 (25g/15sec)
X200
274
262
271
290
283
5701
HSSA 16
Bulk 280/293 HV
Bulk (20kg) = 313/321 HV

HSSA16

5703

1.5 mm

HSSA16 X1000

5704

HSSA16 X200

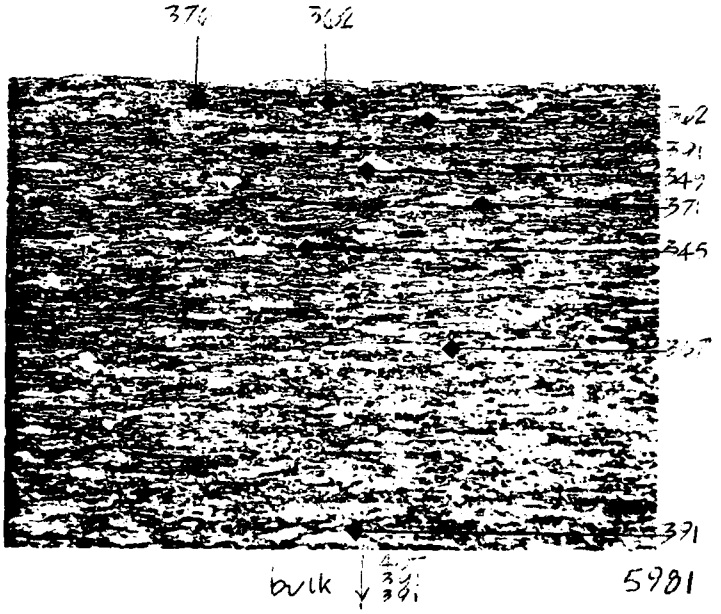
5702

HSSA16 X1000

HSSA17

HSSA17

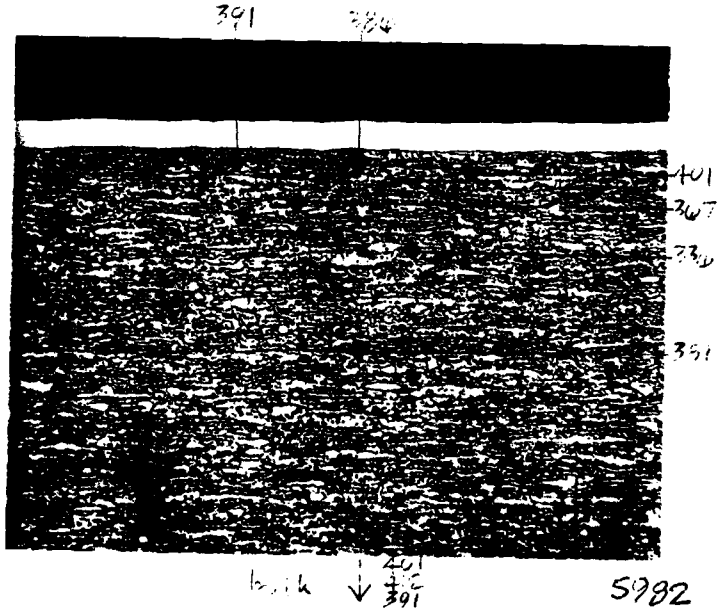
X200



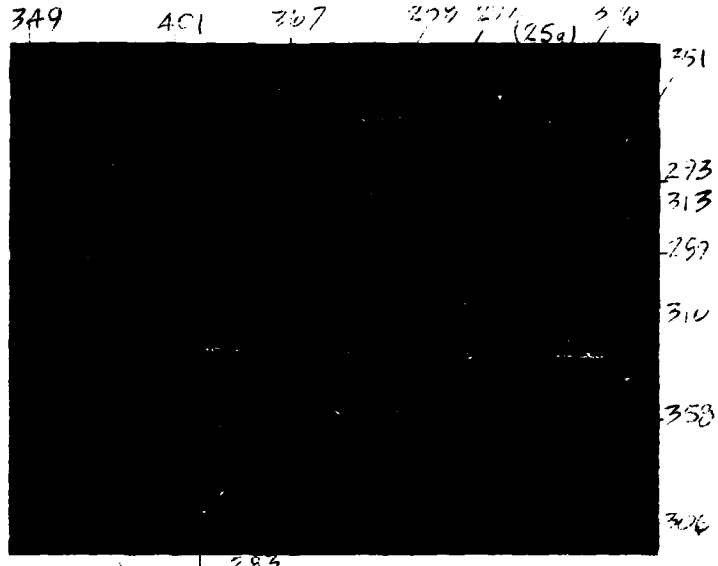
HSSA18

HSSA18

X200



HSSA 19



HSSA19 X200

HSSA19 X200

HSSA 19

HSSA19 X1000

5985

HSSA19 X1000

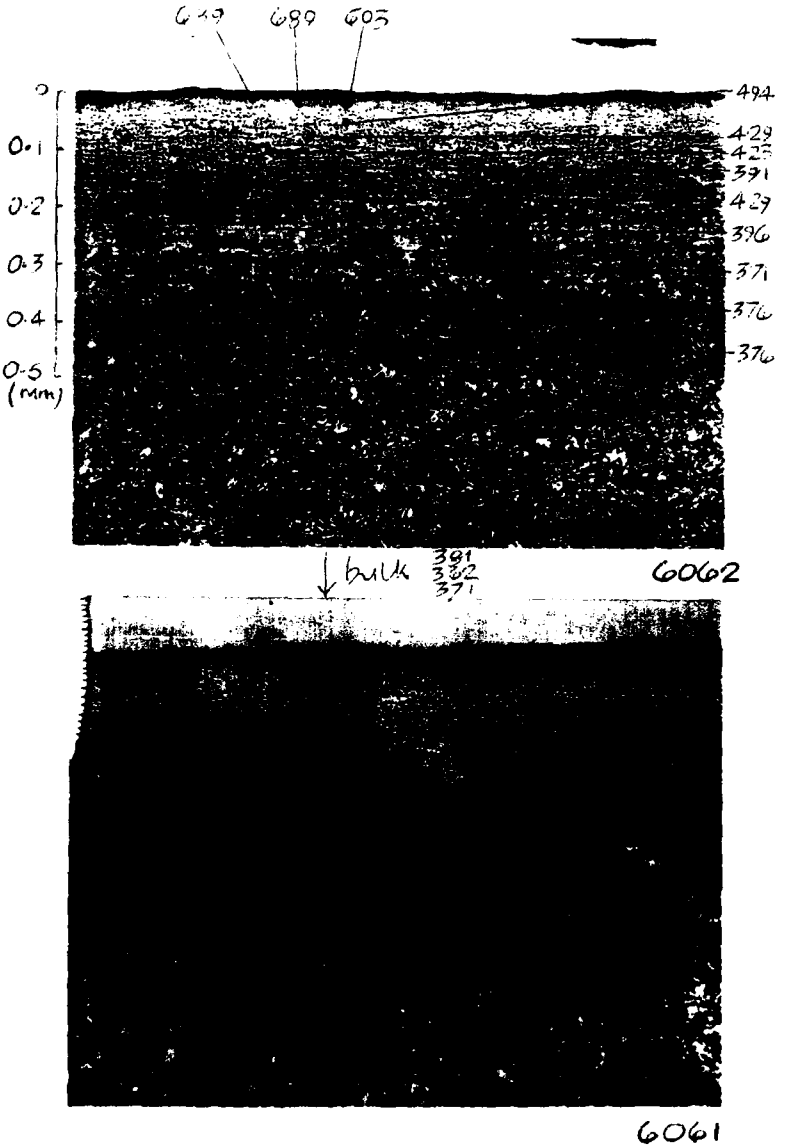
5986

BULK X1000

5987

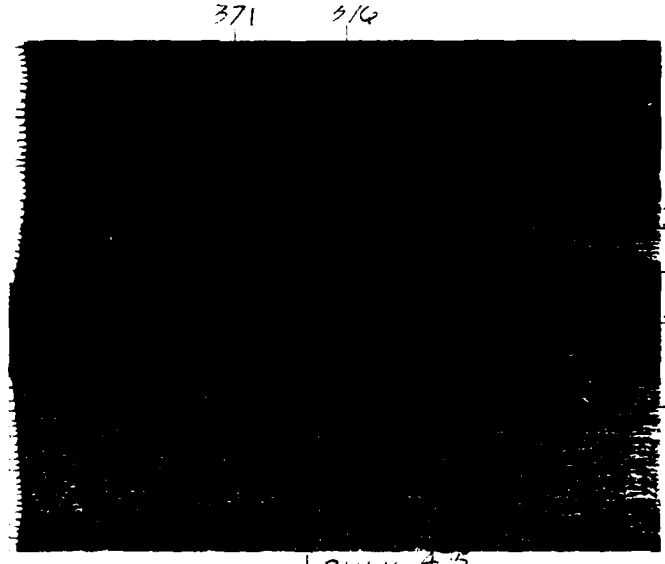
SSA 20

Carb/Carbo Nitrided (Luyton)



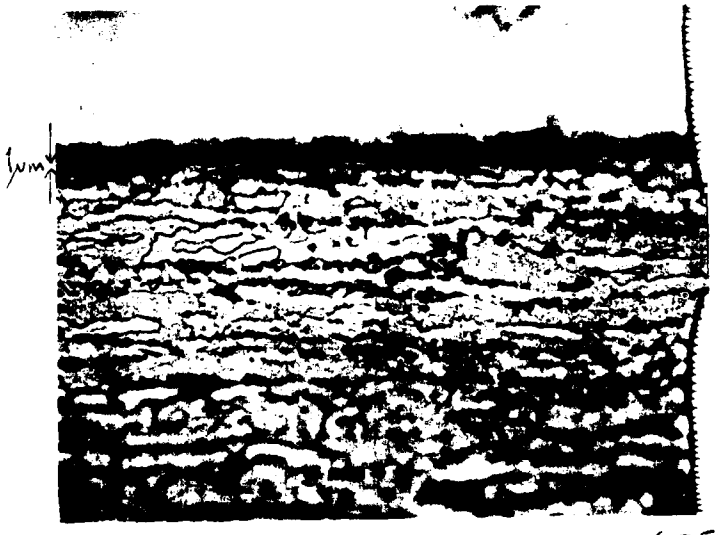
HSSA 21

Hard Carbon



HSSA 21 X200

6060

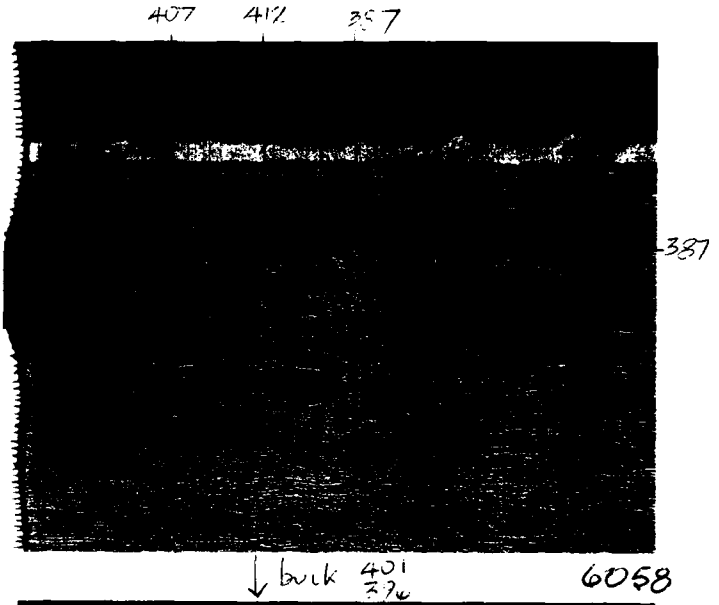


X1000 1135A21

6059

HSSA22
Special
TiN

HSSA22 X200



6058

↓ bulk 401 ± 2%

HSSA22 X1000

6057

ISSA 23
.iN/HfN
x 1µm
'layers'

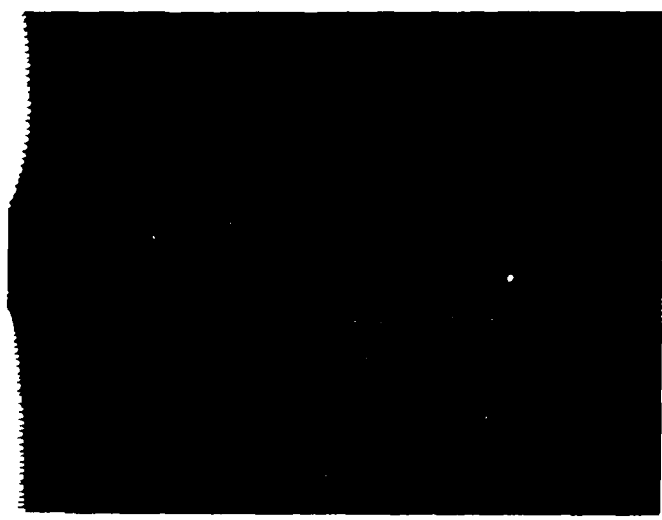
HSSA23
X200

6054

HSSA23
X1000

6055

HSSA23
X1000



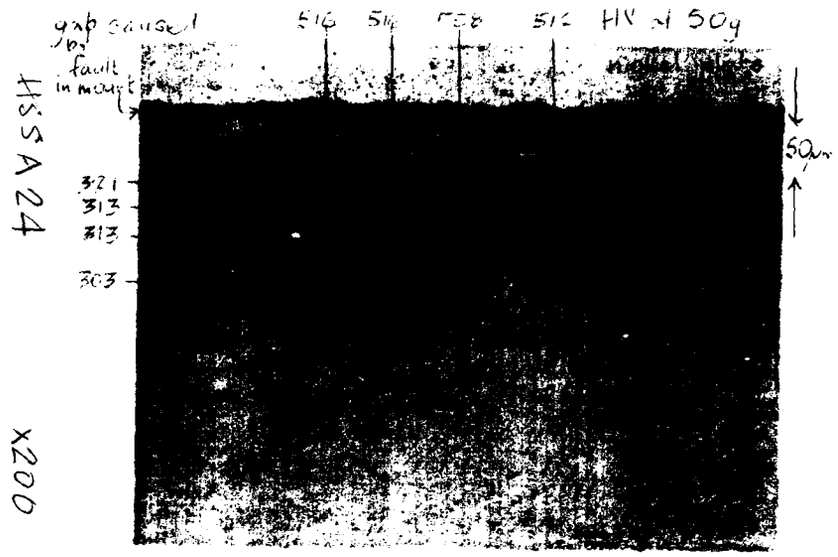
between the 2 sides of the sample

6056

ISSA 24

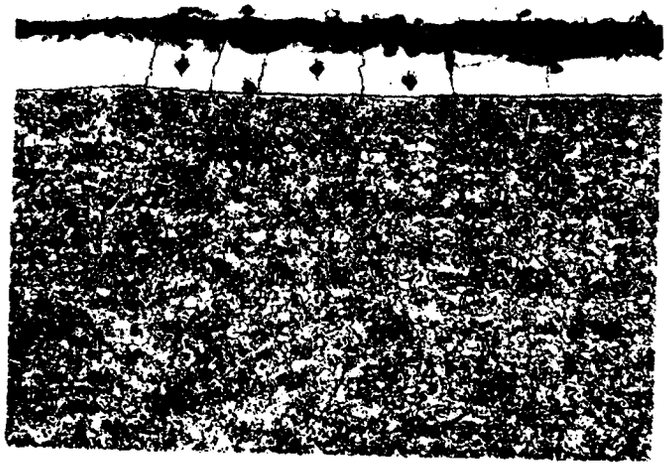
luminised

)AL 85



HSSA 24 x200

G1200



HSSA 24 x200

G179

HSSA 24 x200

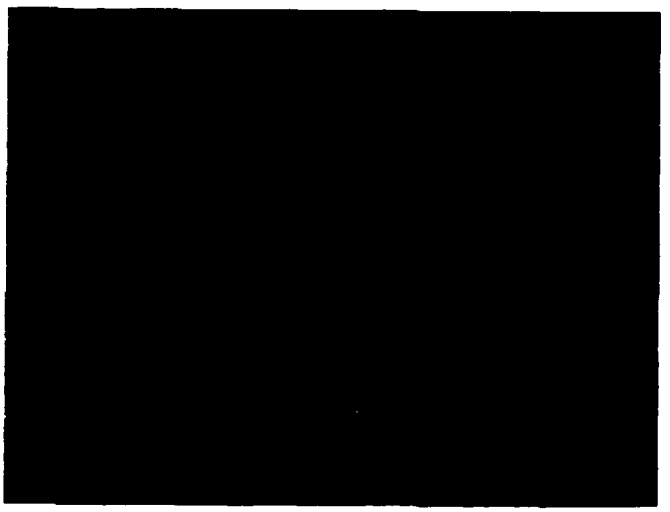
G178

HSSA 24
Luminised
PAL 85

HSSA 24 X1000

6201

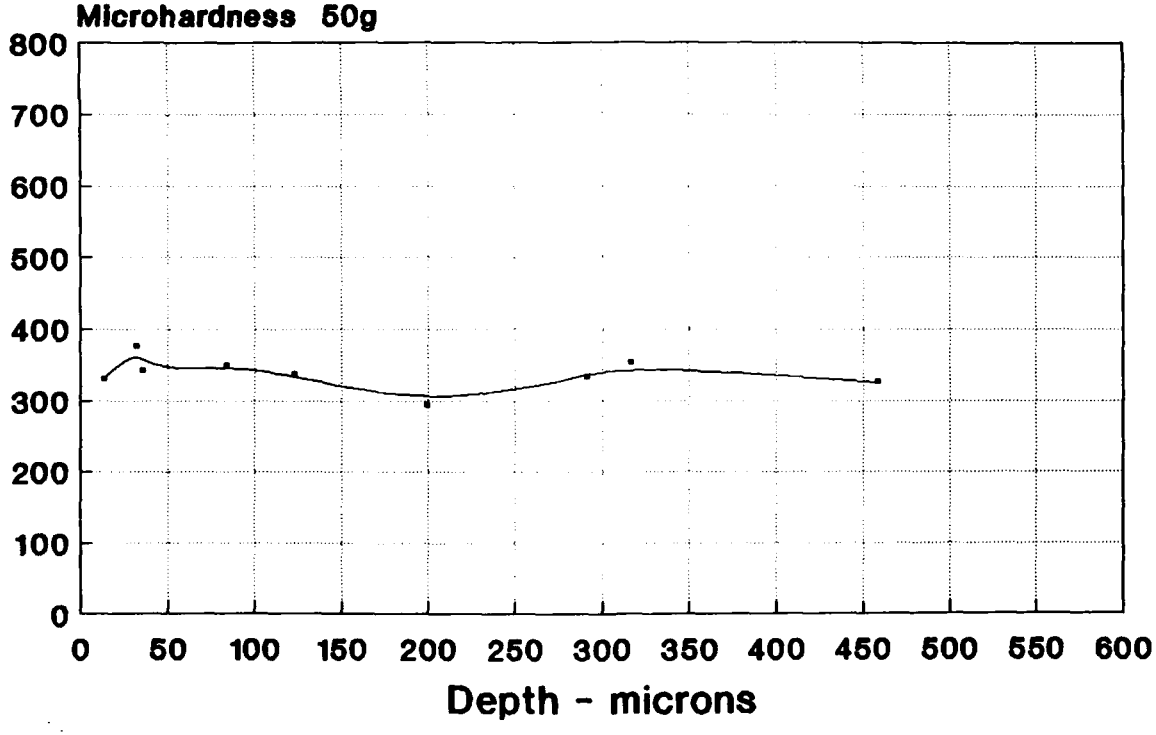
HSSA24 X1000



6197

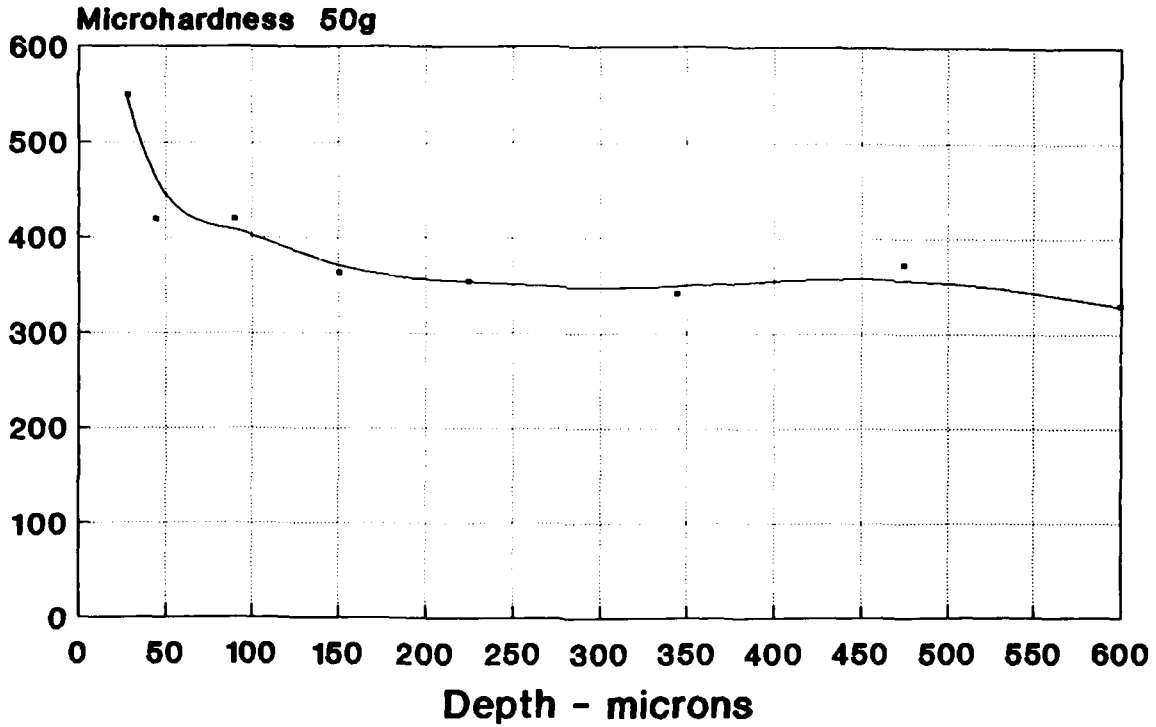
APPENDIX 3: Microhardness Depth Profiles

MICROHARDNESS DEPTH PROFILE
HSSA 3/ PLASMA NITROCARBURIZED #1



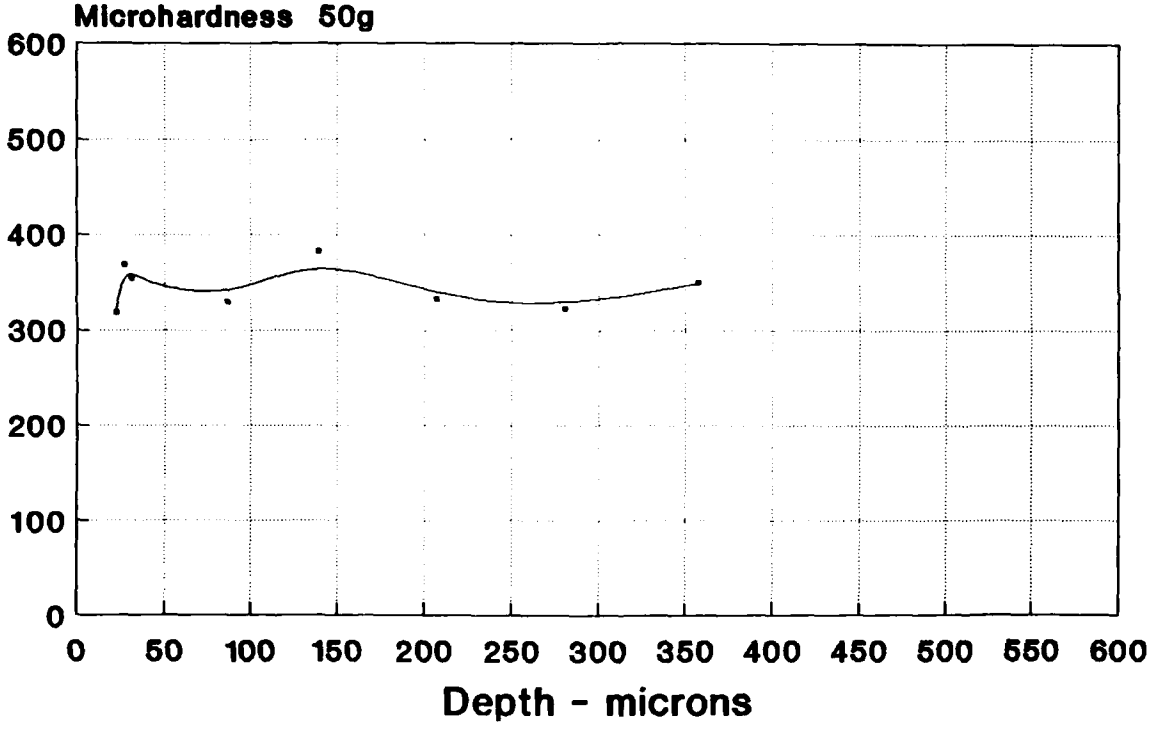
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 4/ BETA NITROCARBURIZED #1



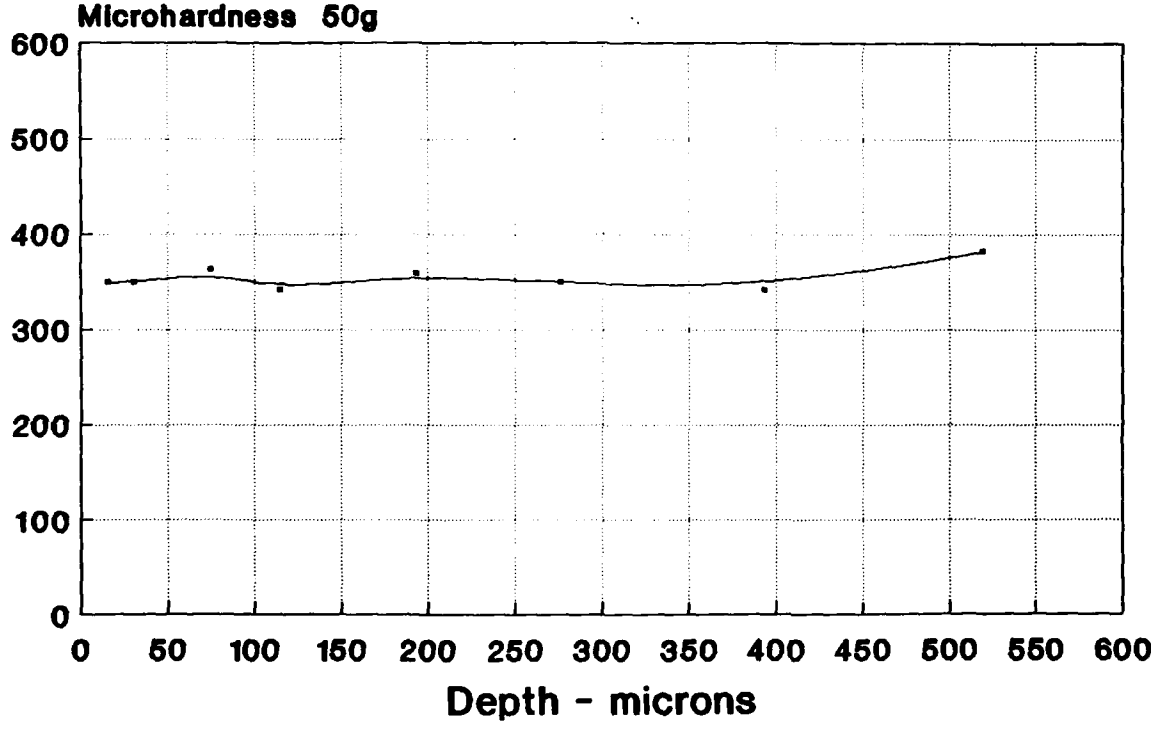
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 5/ ION IMPLANTATION #1



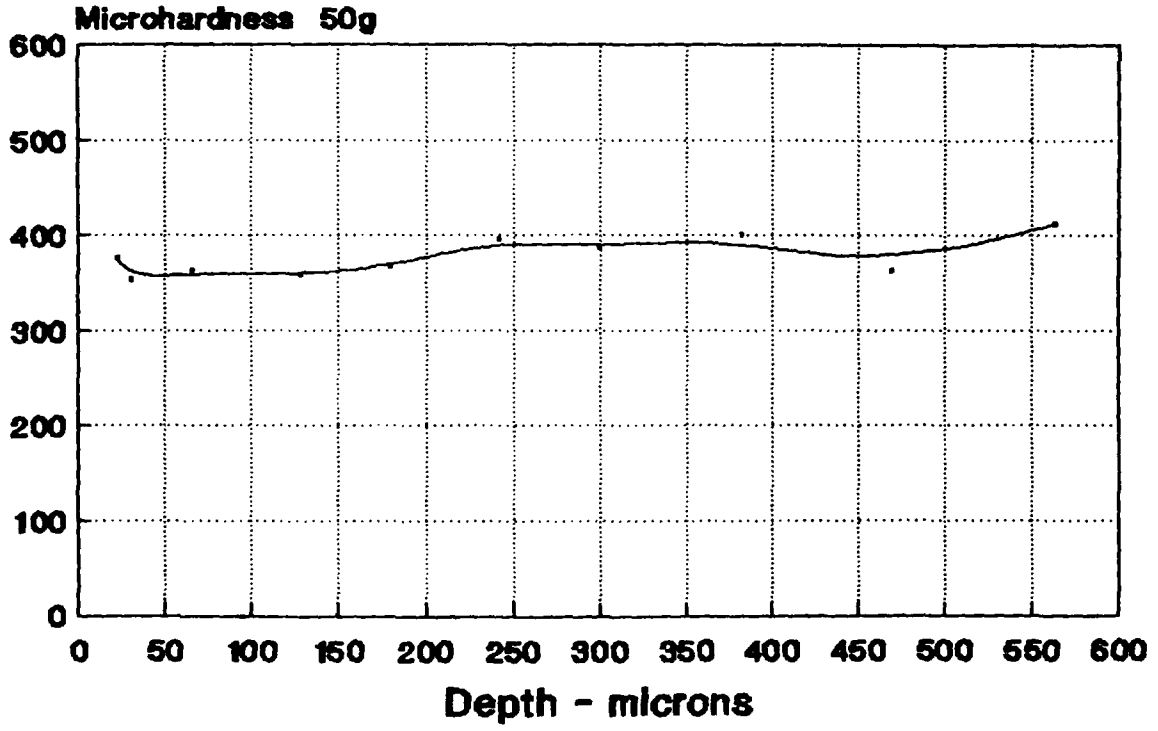
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 6/ ION IMPLANTATION #2



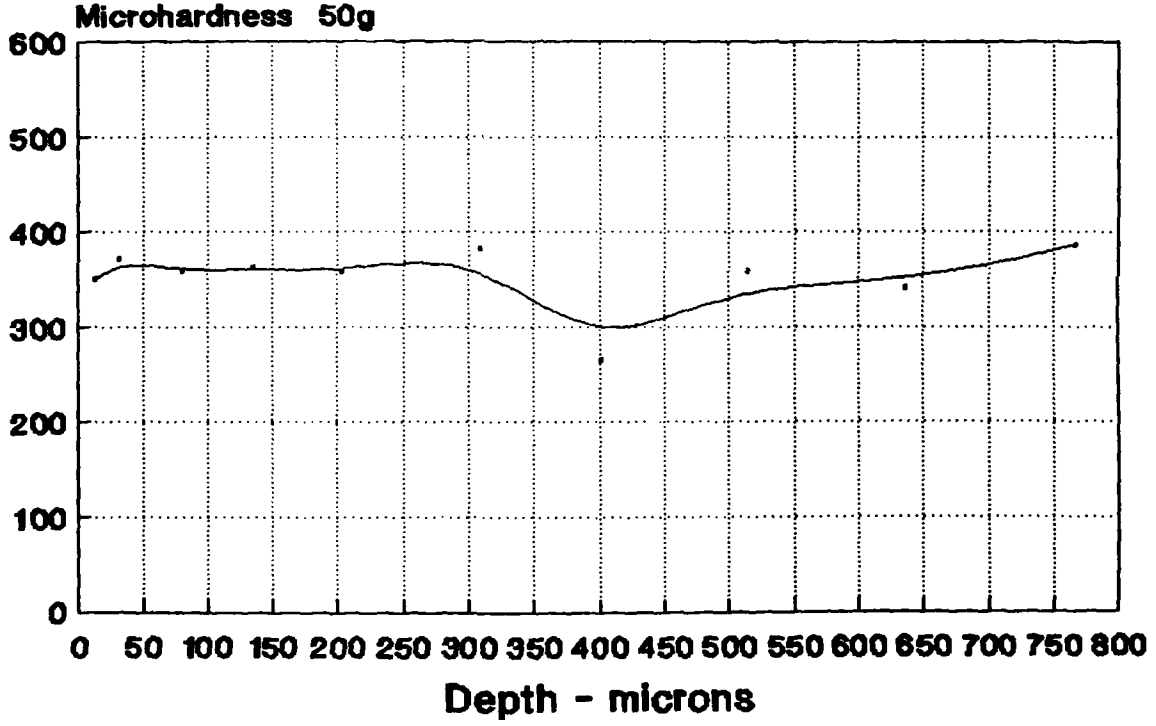
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 7/ HARD ANODISED #1



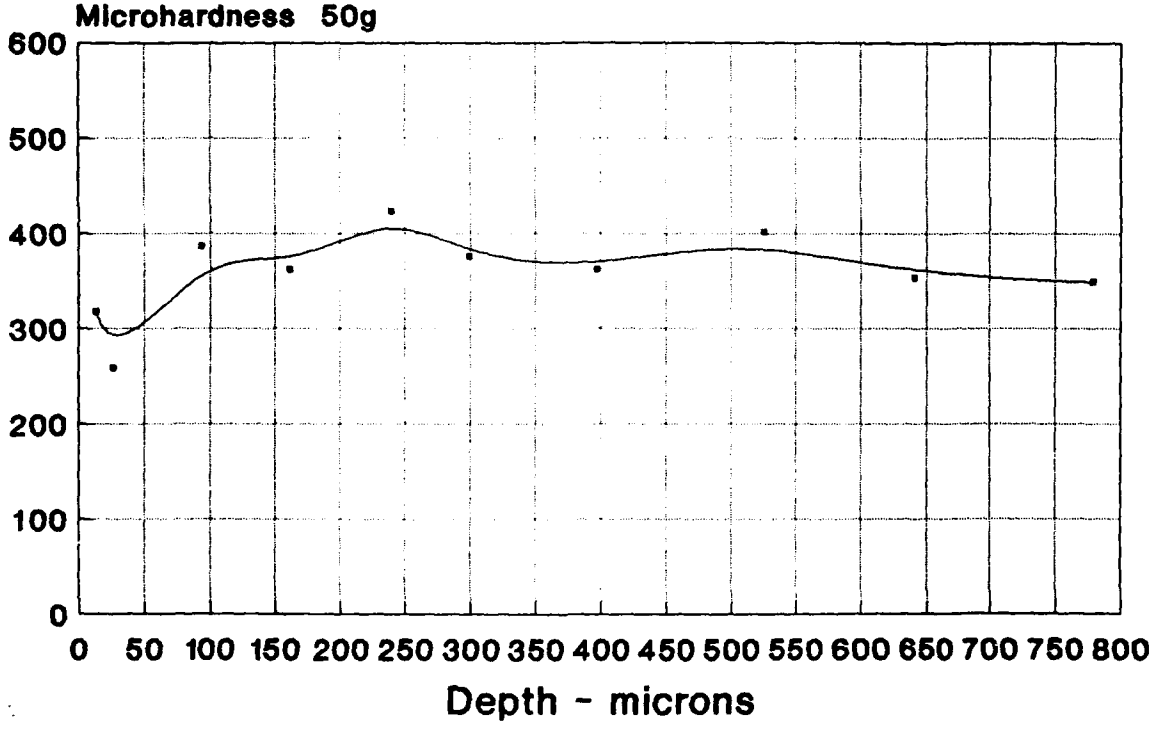
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 8/ HARD ANODISED #2



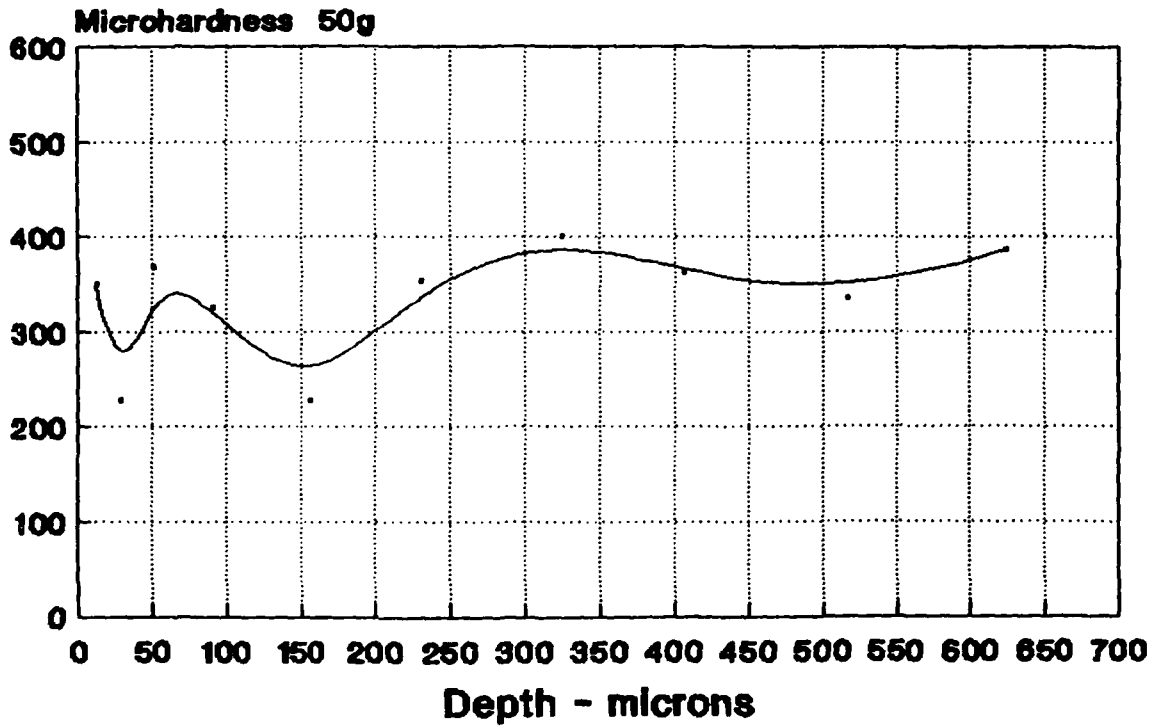
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 9/ PLASMA NITROCARBURIZED #1



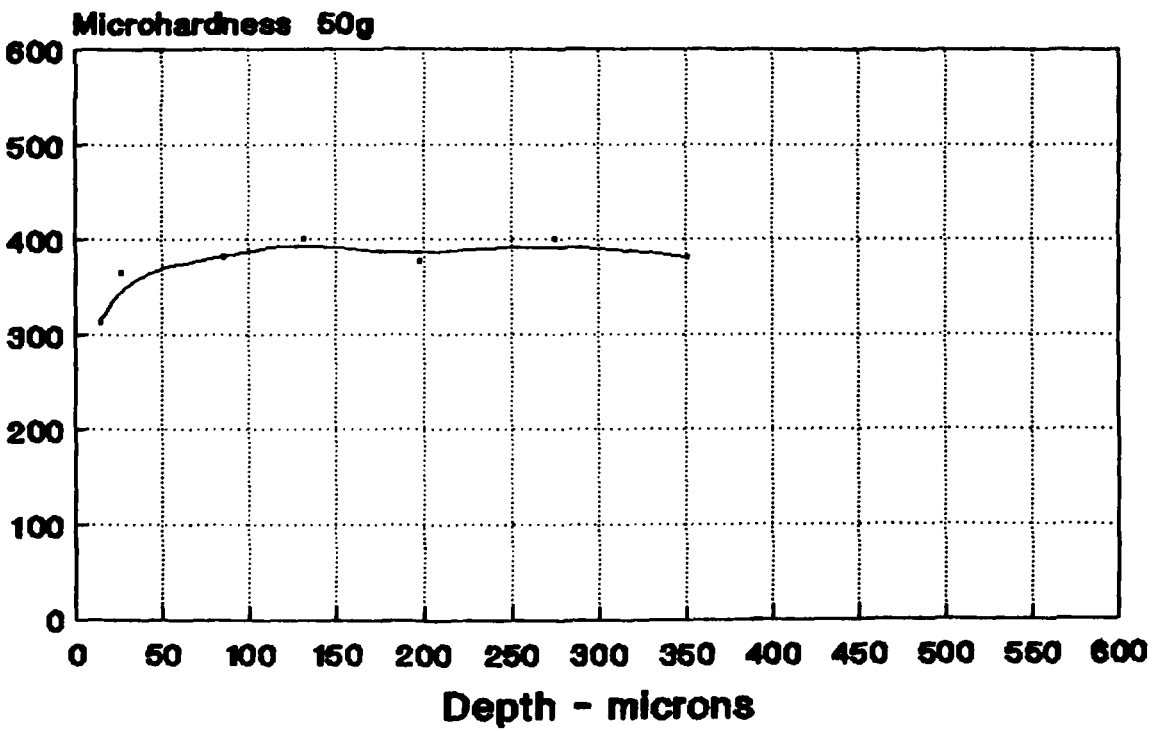
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 10/ HARD ANODISED #3



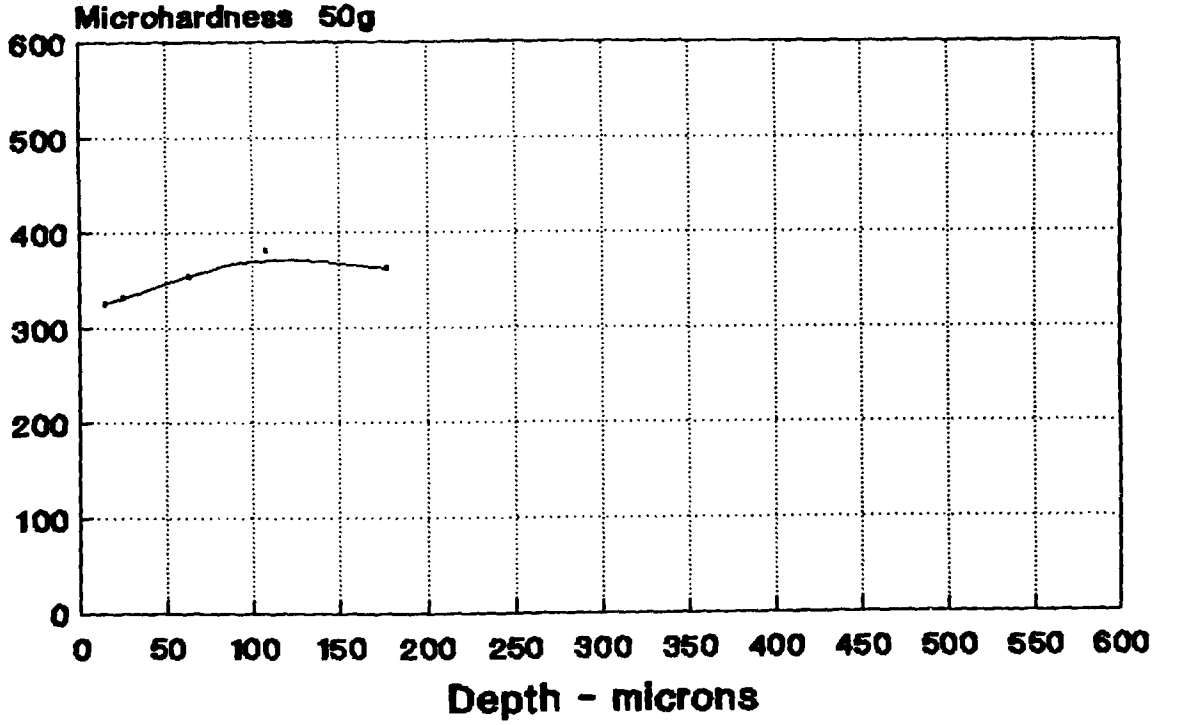
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 11/ HARD ANODISED #4



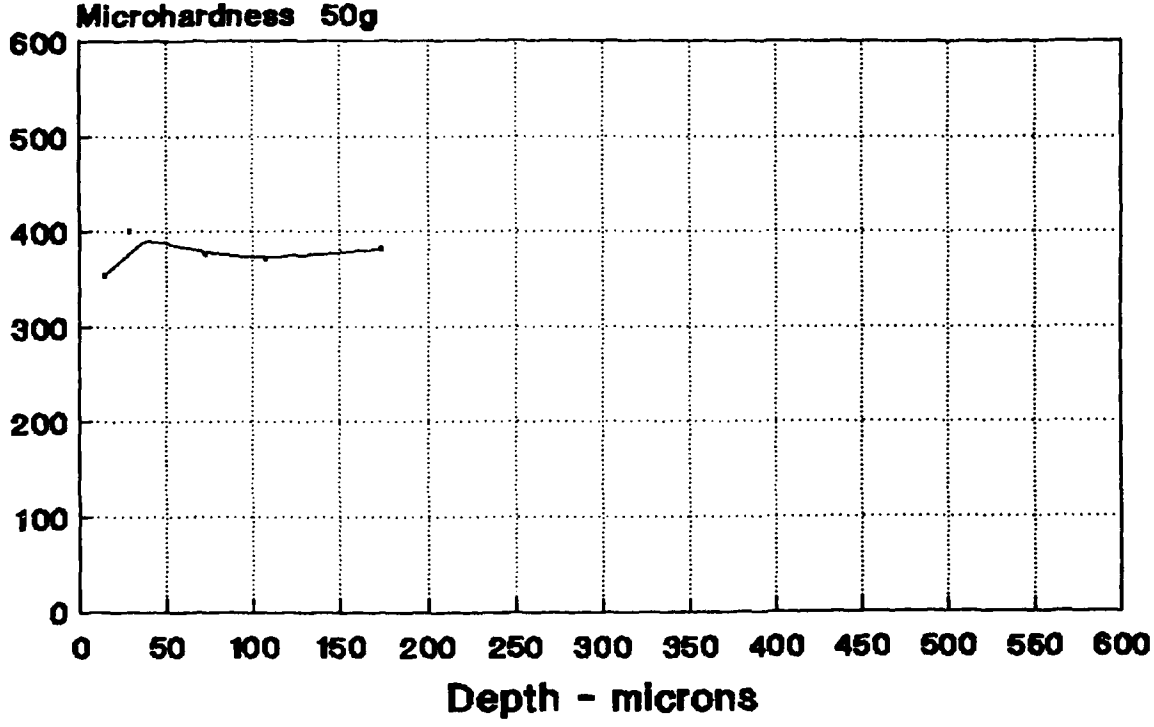
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 12/ PLASMA NITRIDED #1



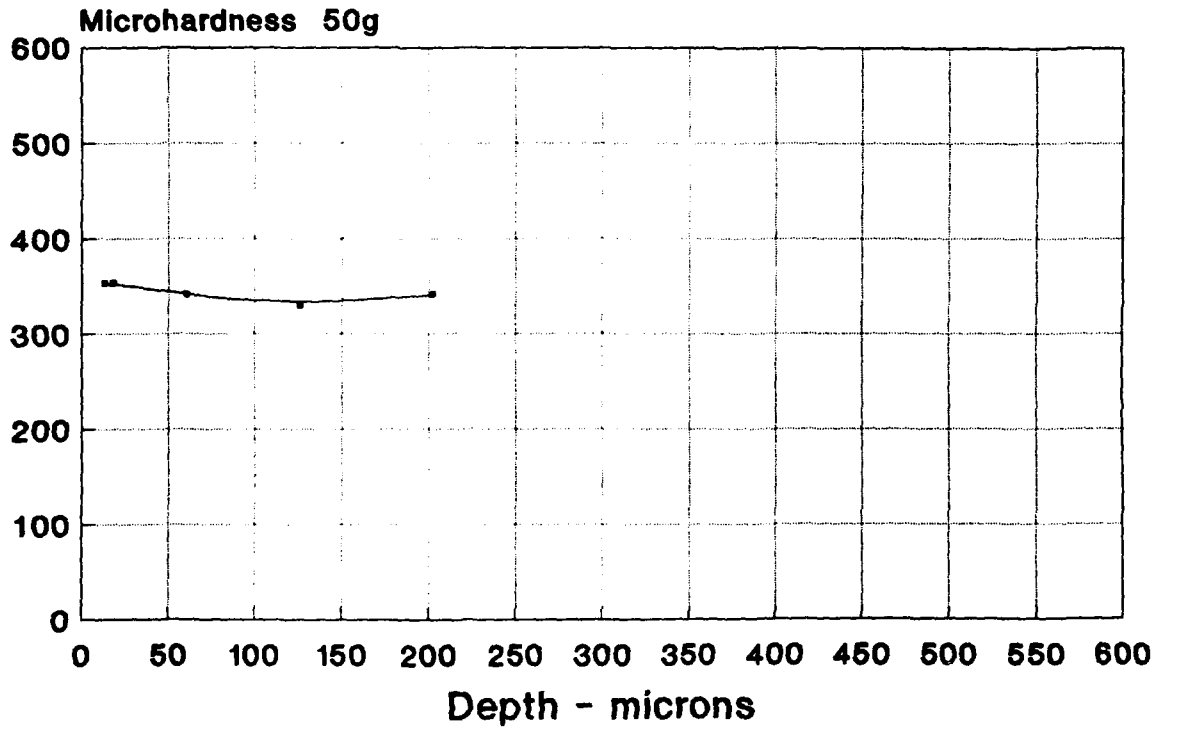
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 13/ PLASMA NITRIDED #2



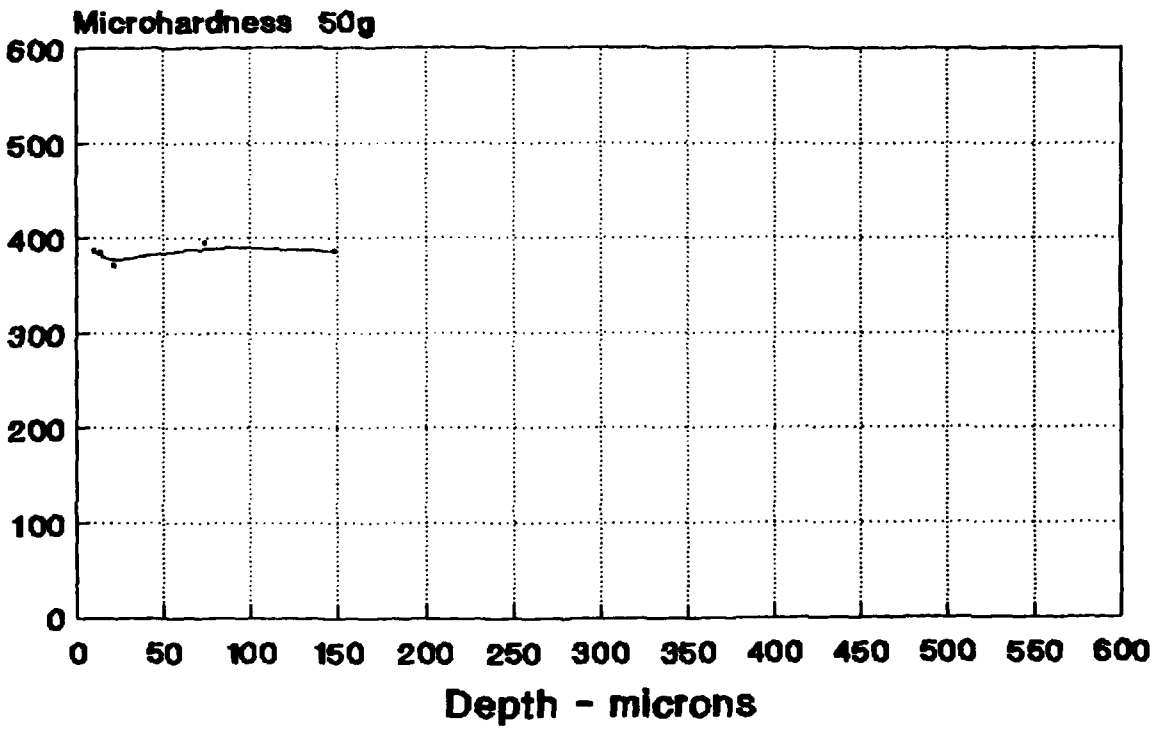
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 14/ HT NITROCARBURIZING #1



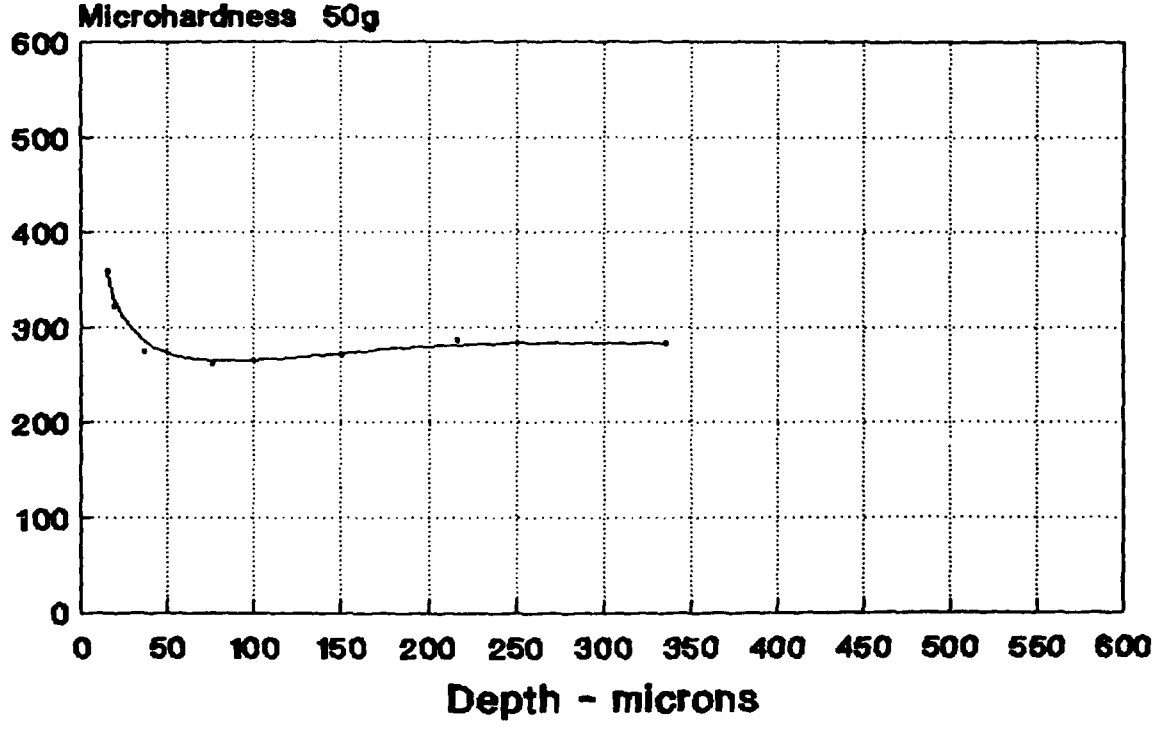
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 15/ NITROX #1



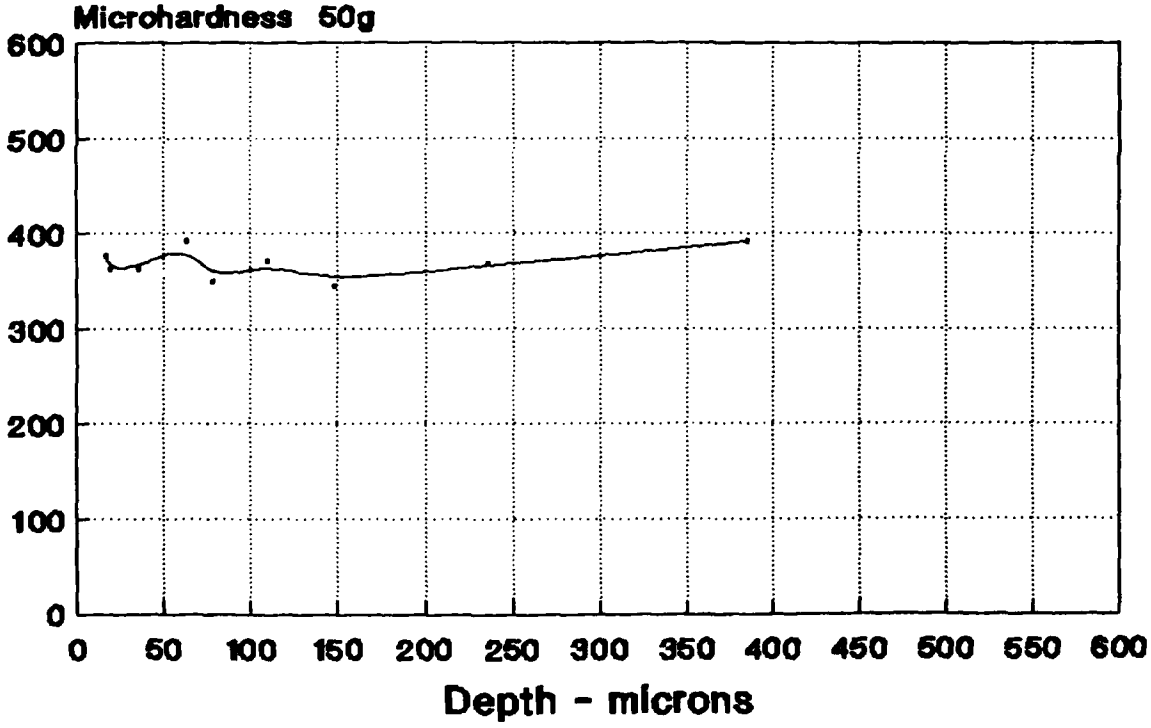
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 16/ PACK ALUMINISING #1



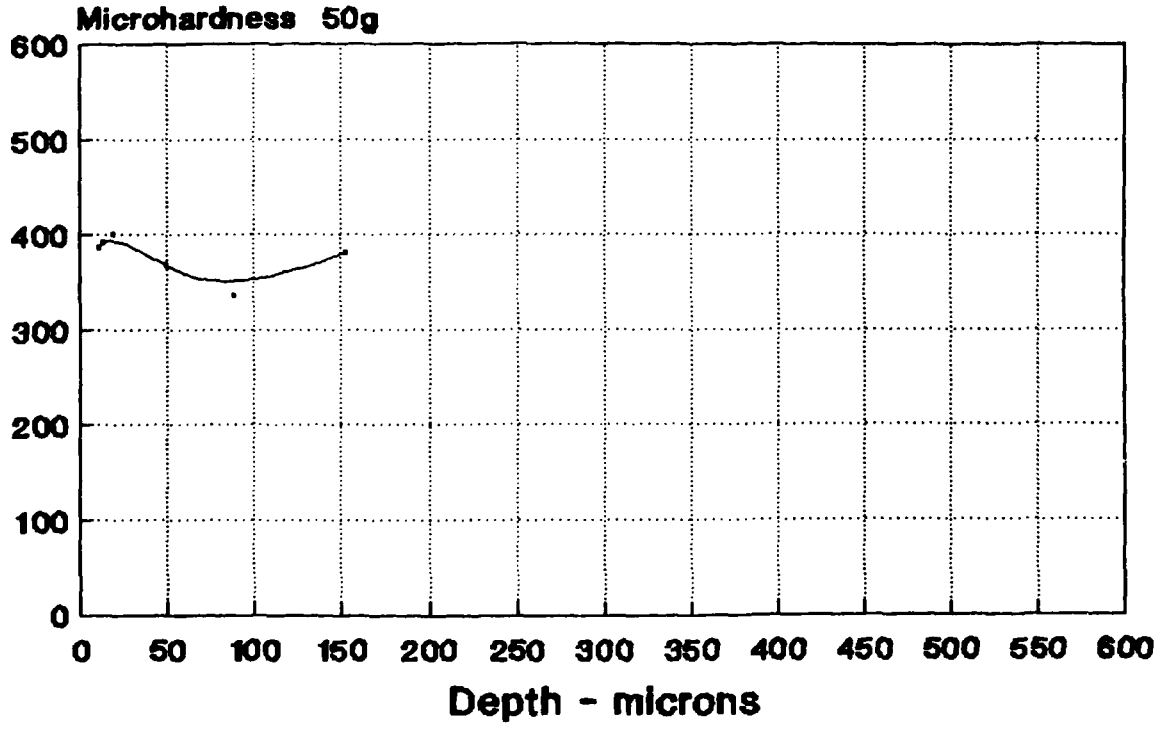
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 17/ NITROX #2



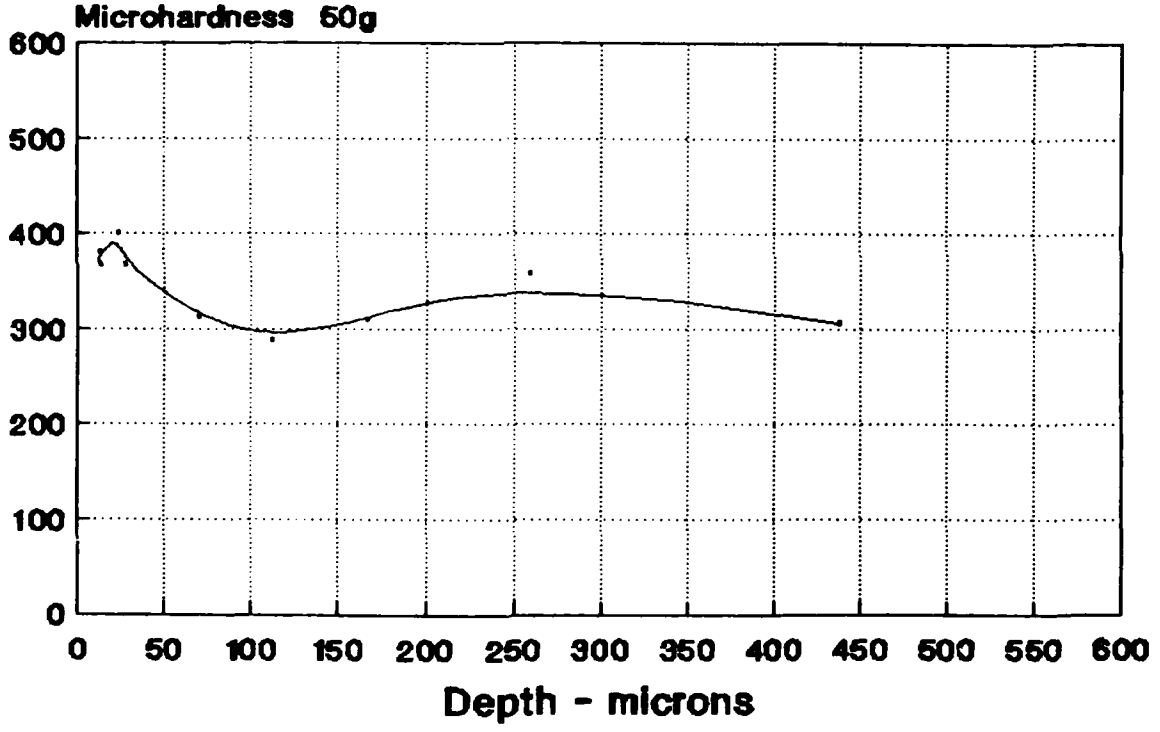
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 18/ NITROX #3



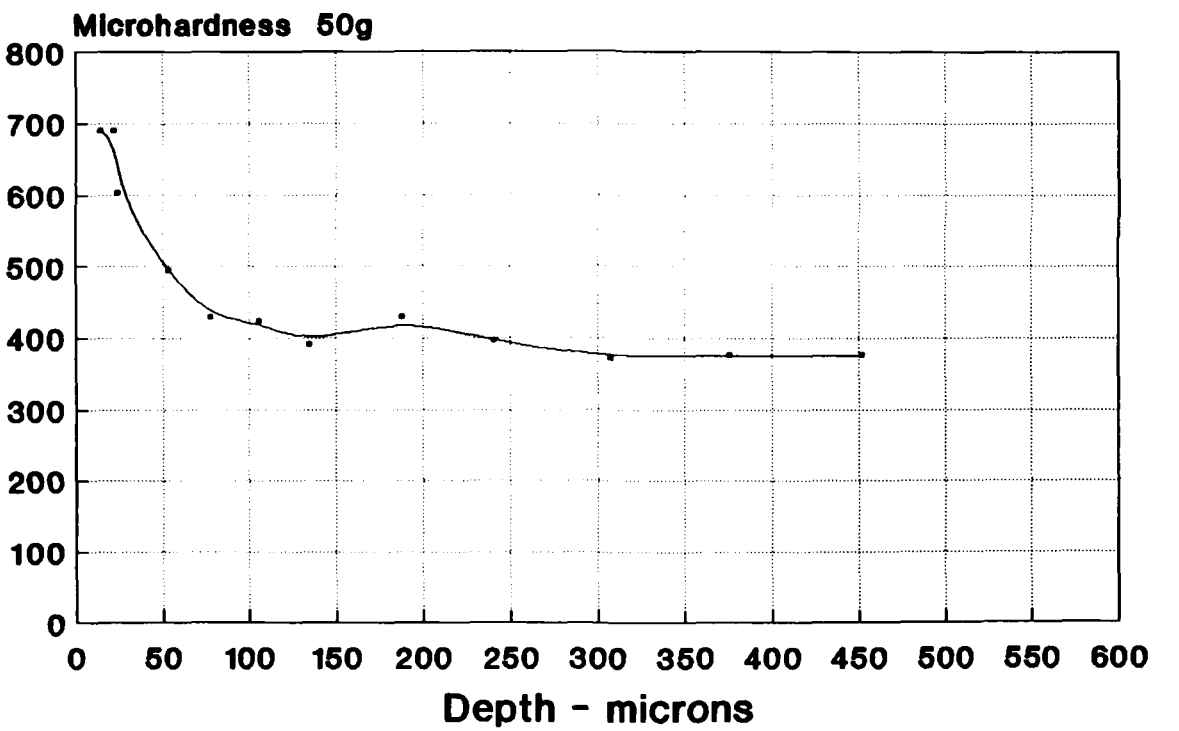
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 19/PACK ALUMINISING #2



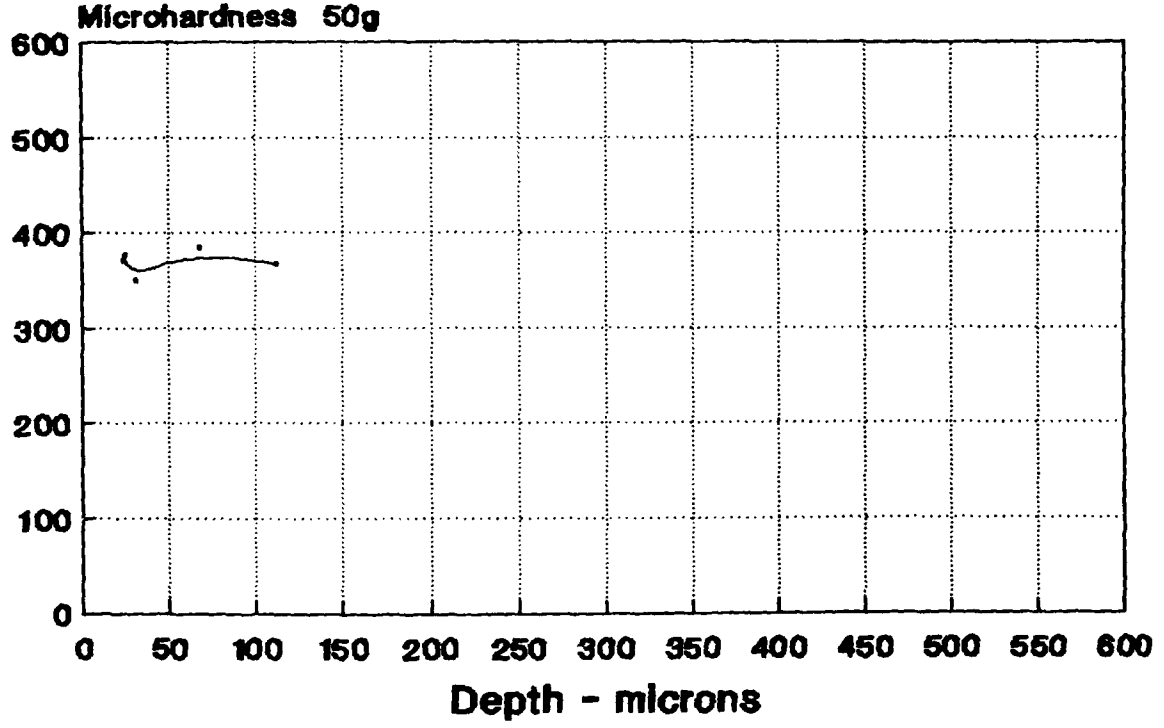
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 20/ CARBONITRIDED #1



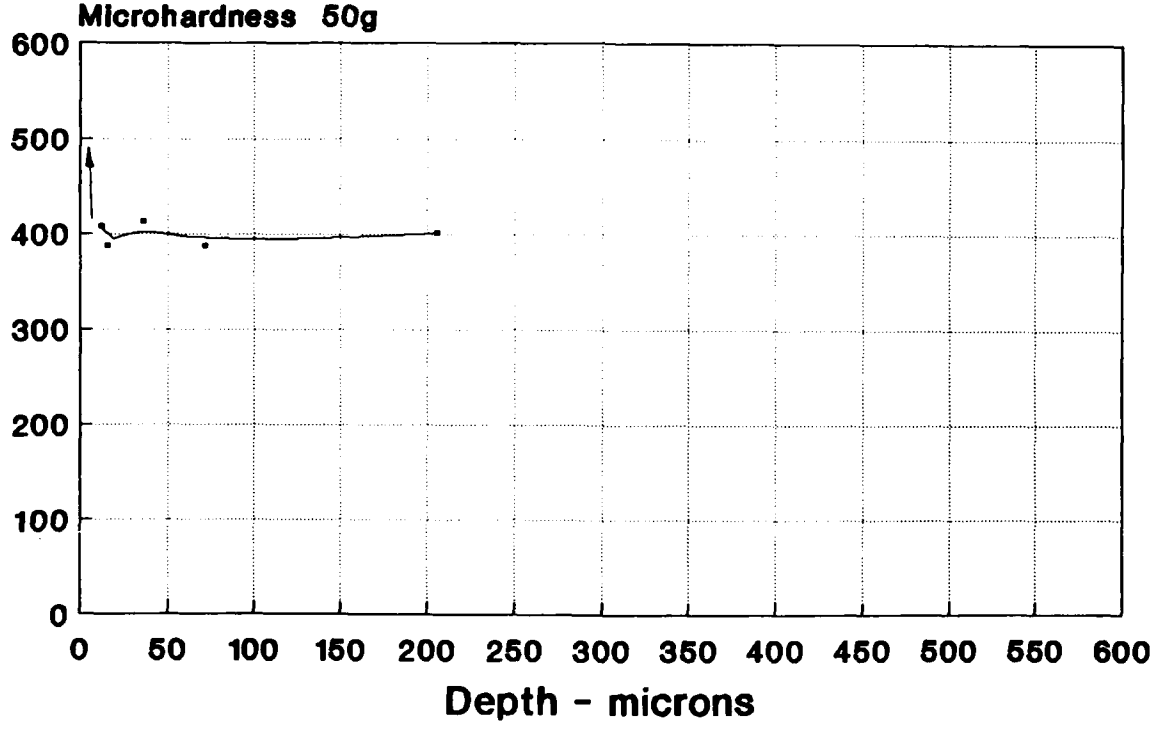
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 21/ DLC #1



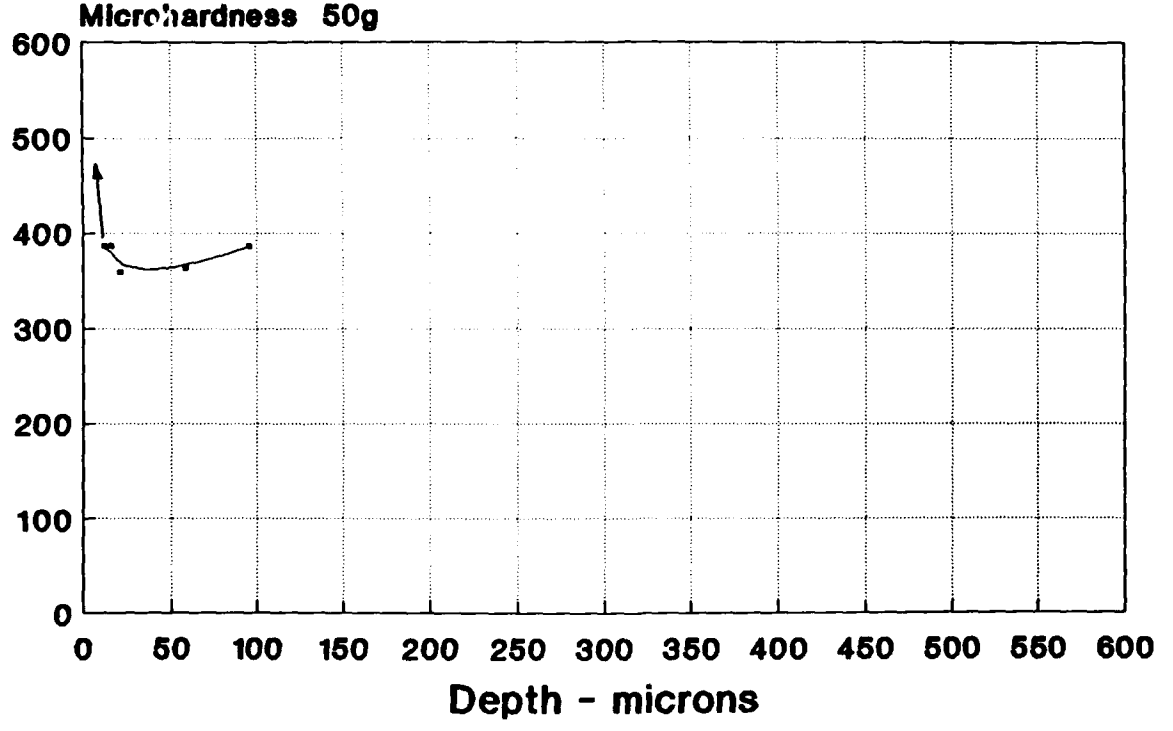
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 22/TiN #3



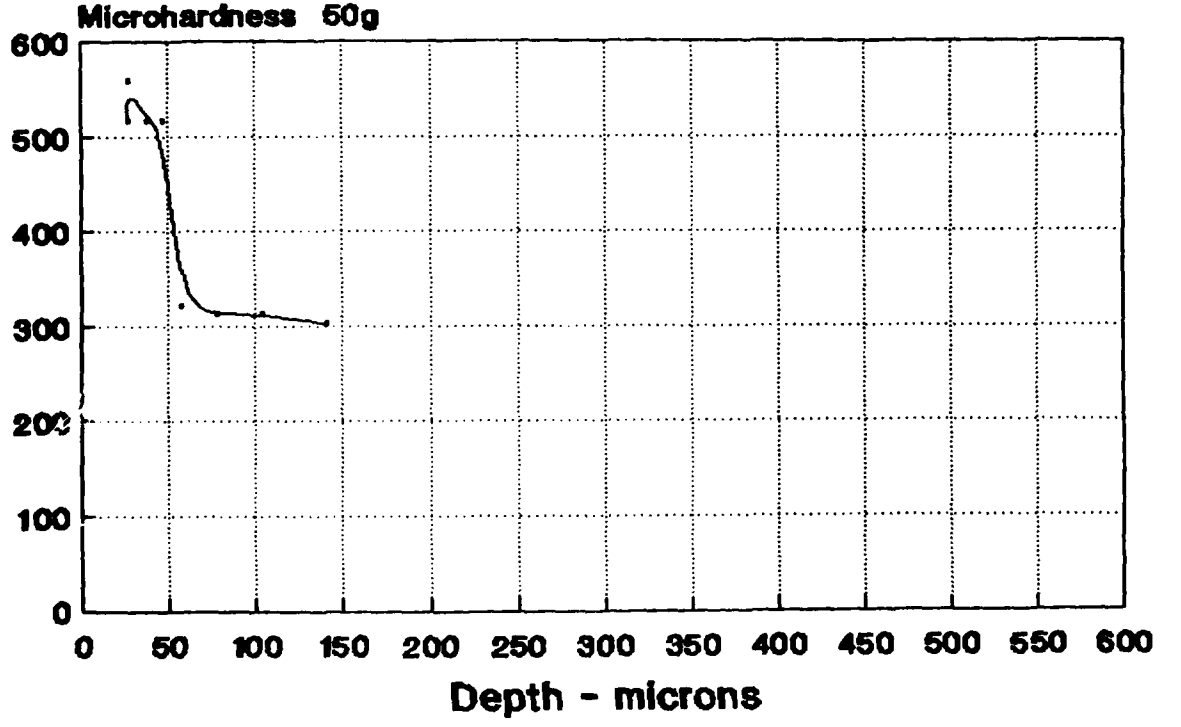
NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 23/ TiN/HfN MULTILAYER #1



NATIONAL CENTRE OF TRIBOLOGY

MICROHARDNESS DEPTH PROFILE
HSSA 24/ PACK ALUMINISING #3

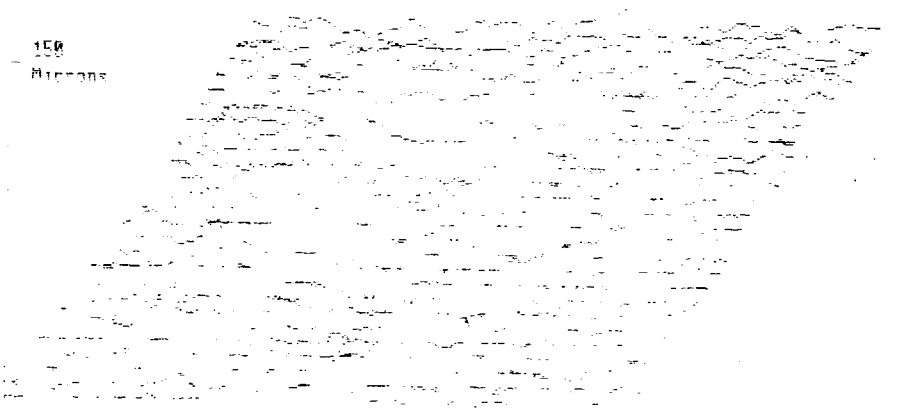


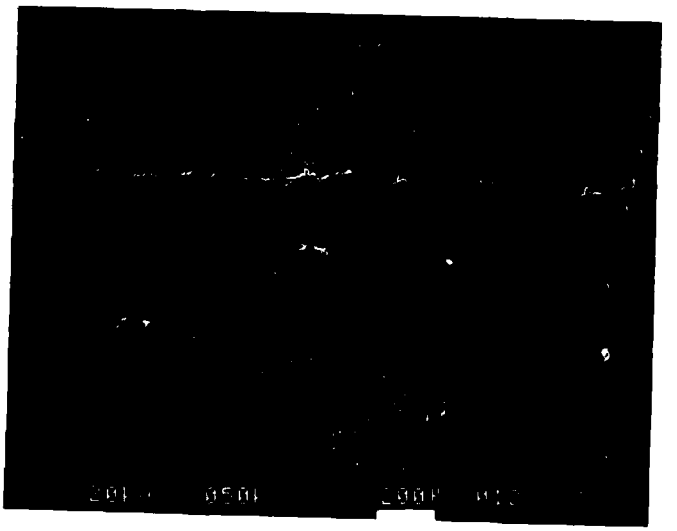
NATIONAL CENTRE OF TRIBOLOGY

APPENDIX 4: 20N Wear Profiles and SEM Micrographs of Wear Tracks

HSSA 1: Solution Heat Treated

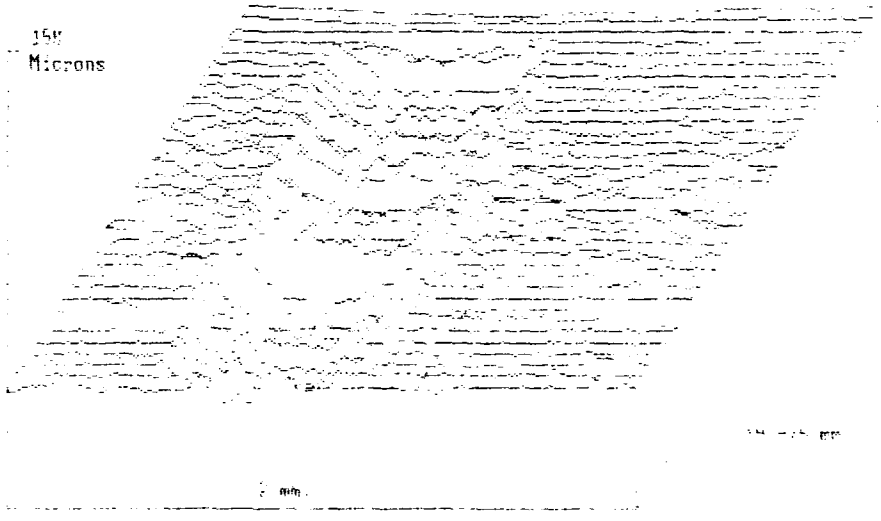
Data from b:hssa-1a.dat
Detrended





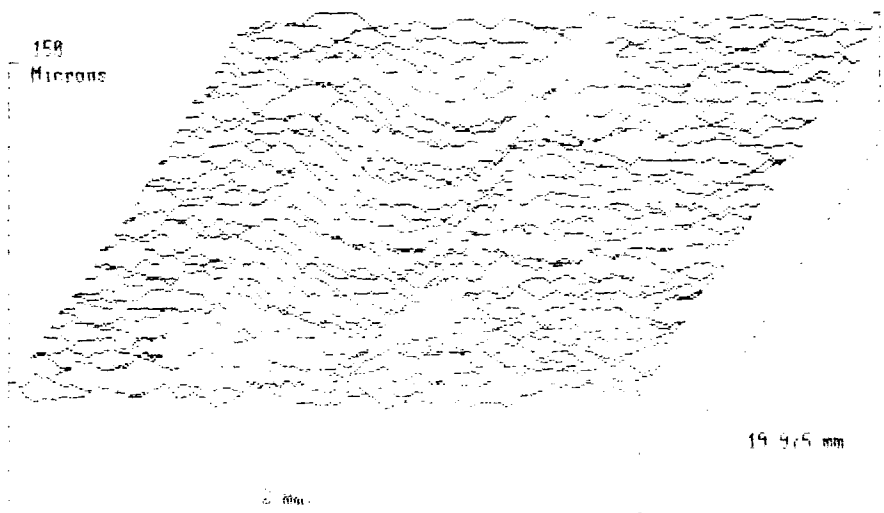
HSSA 2: Hardened and Ground

Data from Brasia Detroit
Detroit



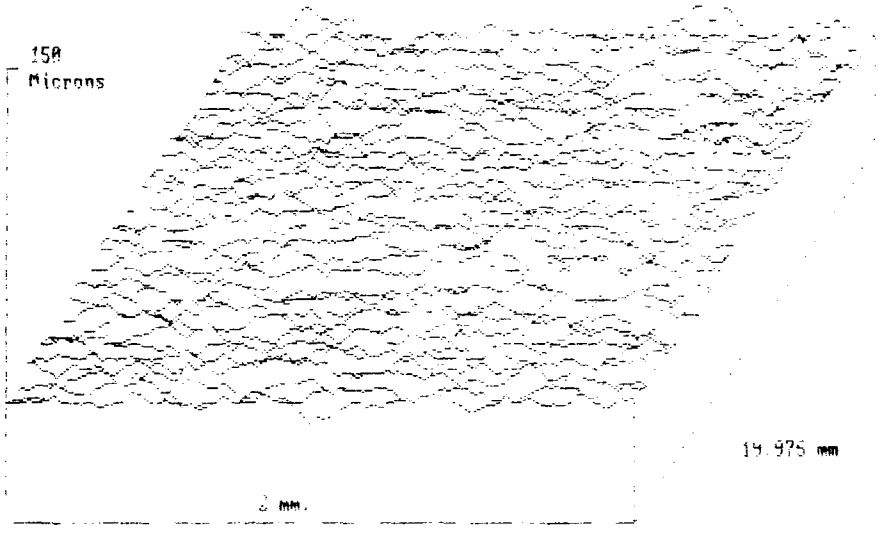
HSSA3: Plasma Nitrocarburized 1

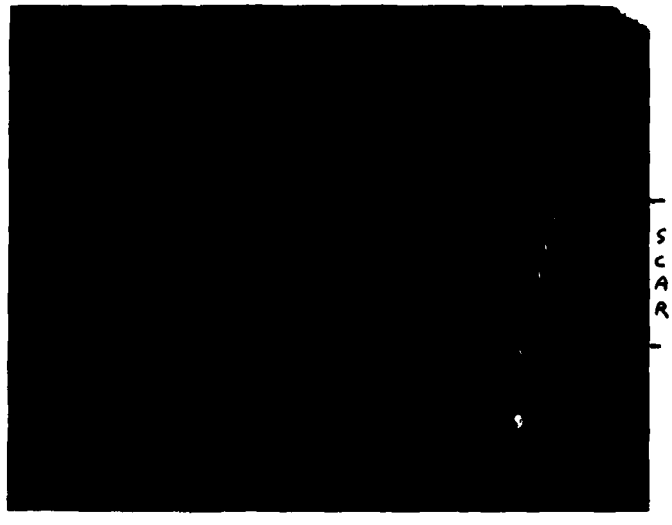
Data from b:hssa-3.dat
Detrended



HSSA4: Beta Nitrocarburized 1

Data from B:hssa-4.dat
Detrended

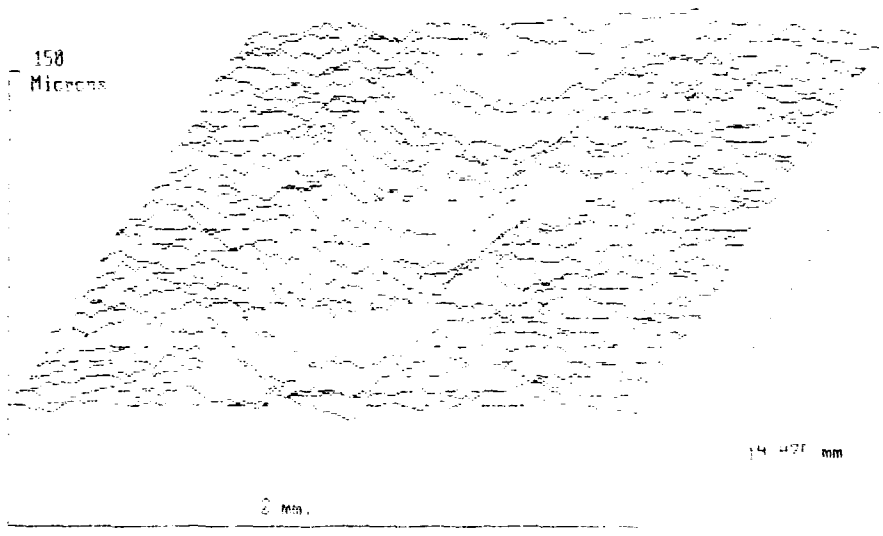




SCAR

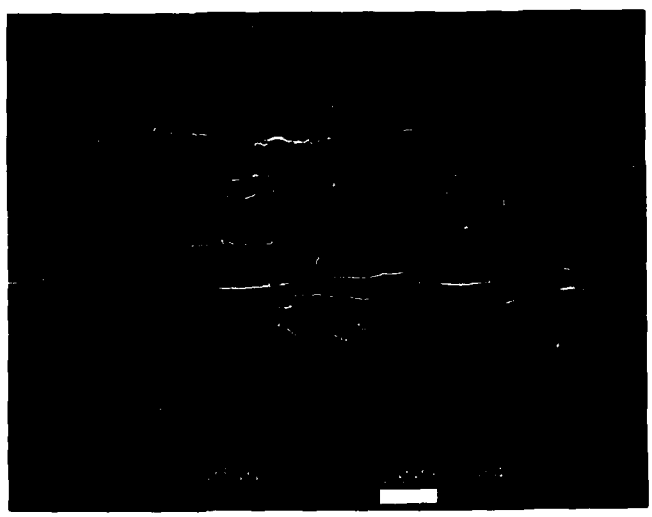
HSSA 5: Ion Implanted 1

Data from b:hssa-5.dat
Detrended



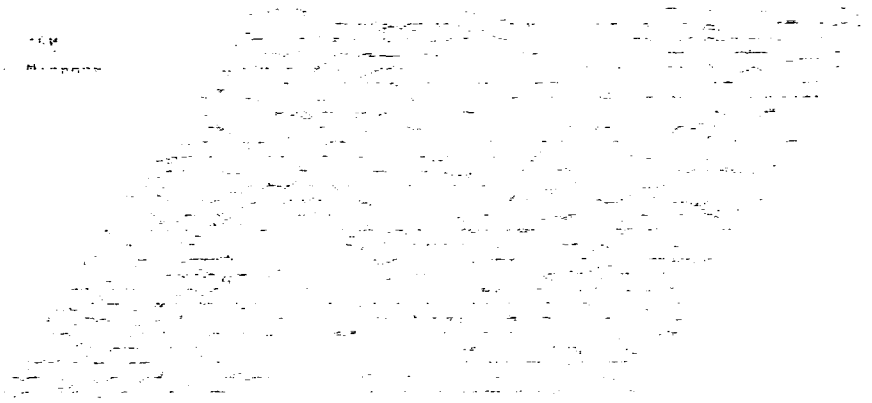
HSSA 6: Ion Implanted 2

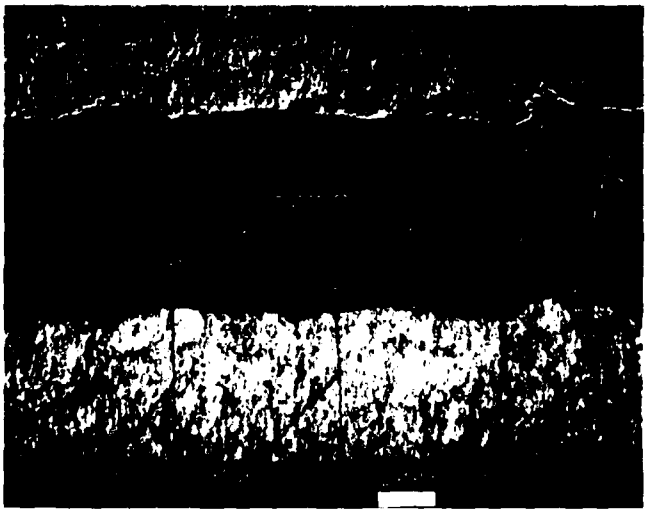
Data from b:hssa-6.dat
Detrended



HSSA7: Hard Anodised 1

HSSA8: Hard Anodised 2

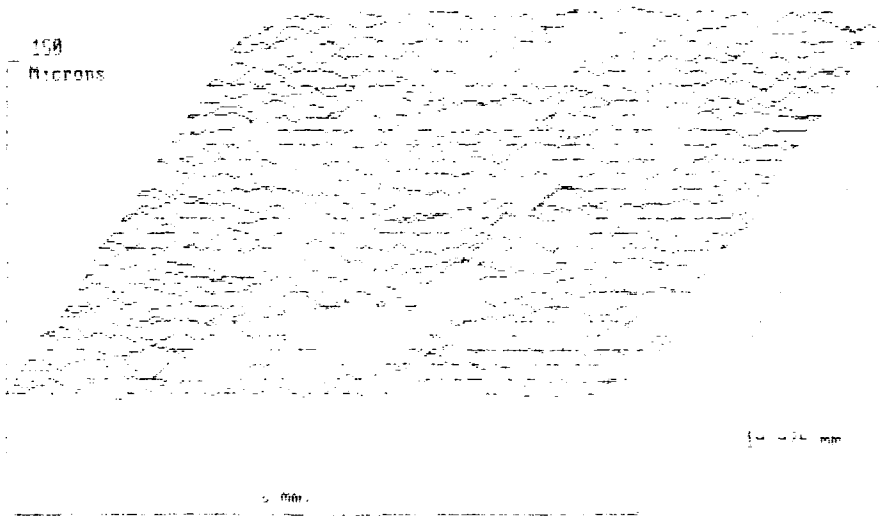


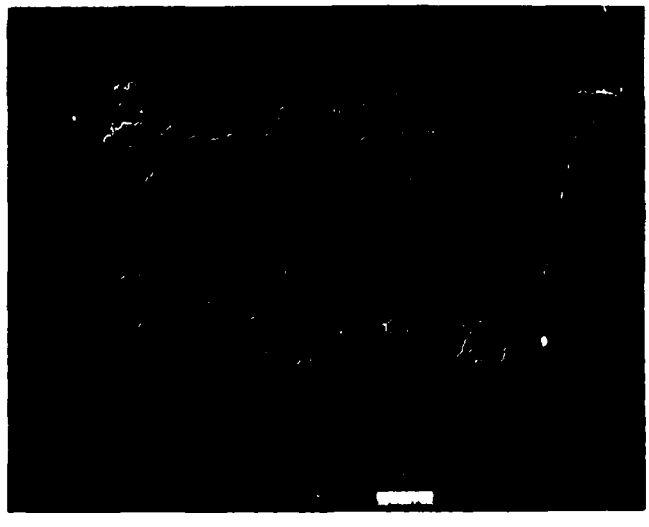


HSSA9: Plasma Nitrocarburized 2

HSSA 10: Hard Anodised 3

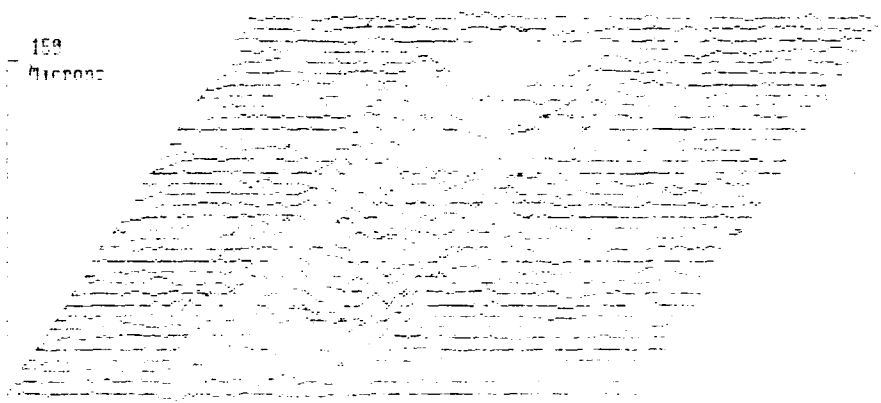
Data from Ulhsa 10.dat
Detrended

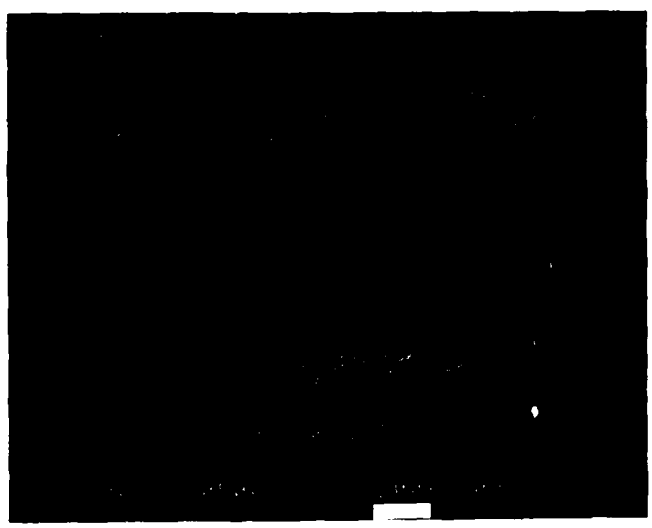




HSSA 11: Hard Anodised 4

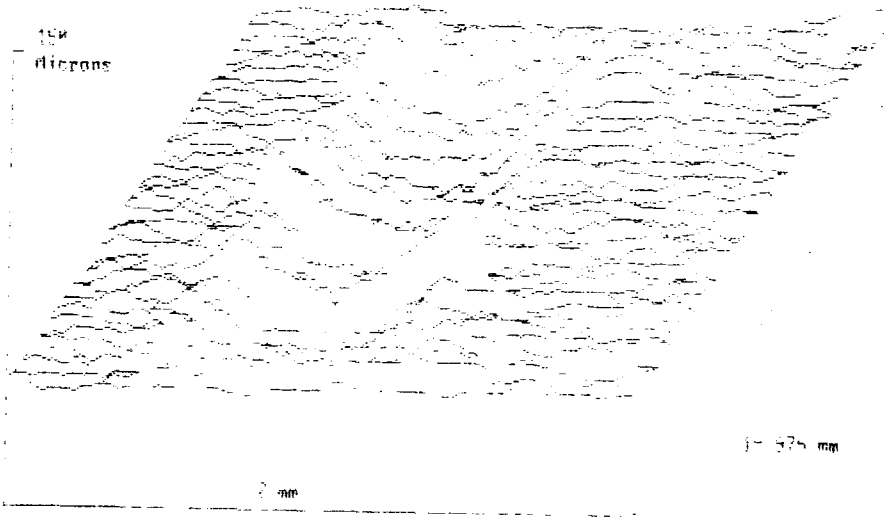
Data from b:hssa-11.dat
Detrended





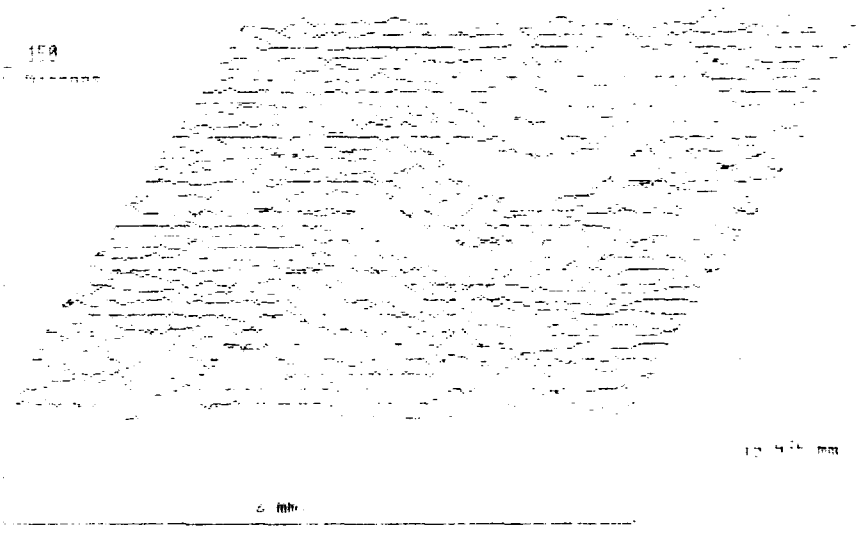
HSSA 12: Plasma Nitrided 1

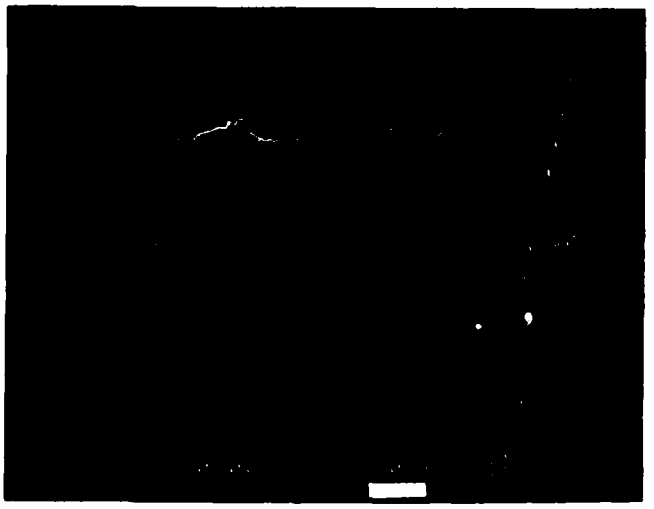
Data from b:hssa-12.dat
Detrended



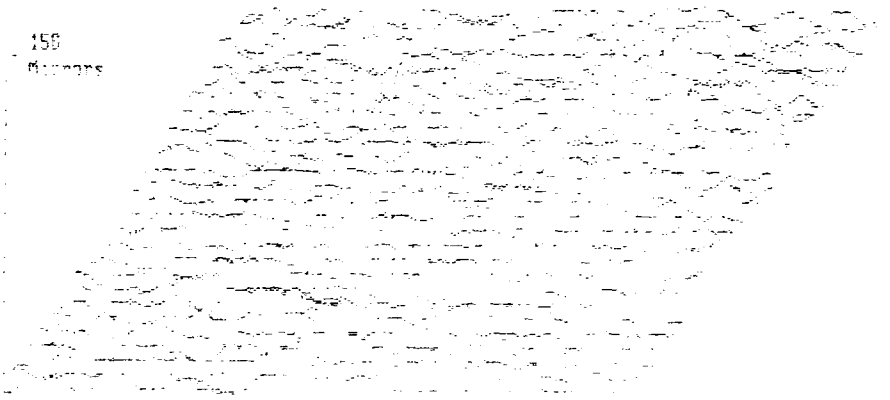
HSSA 13: Plasma Nitrided 2

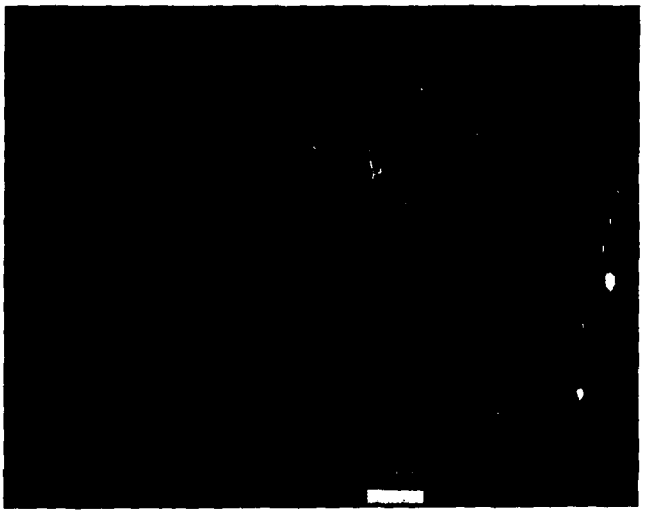
Data from D:\hssa 13.dat
Detrended





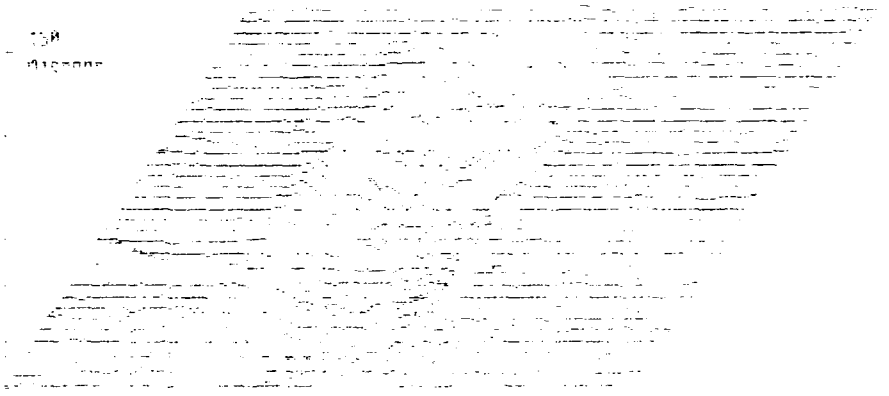
HSSA 14: High Temperature Nitrocarburized I

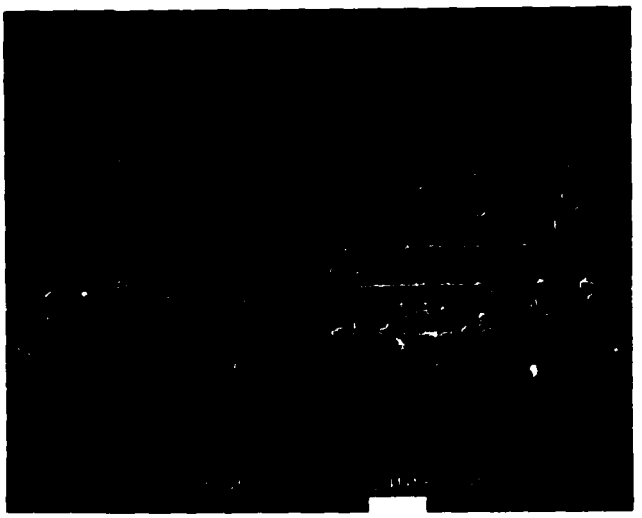




HSSA15: Nitrosc 1

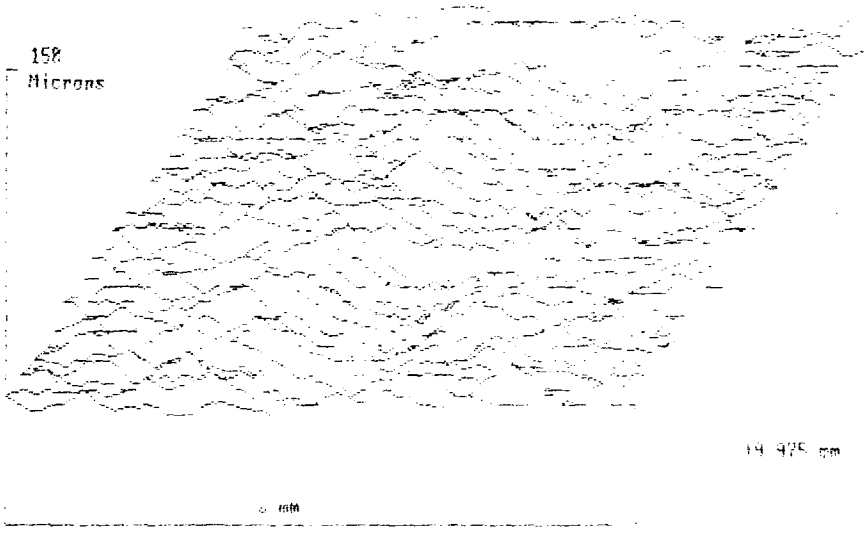
Data from [illegible]
[illegible]





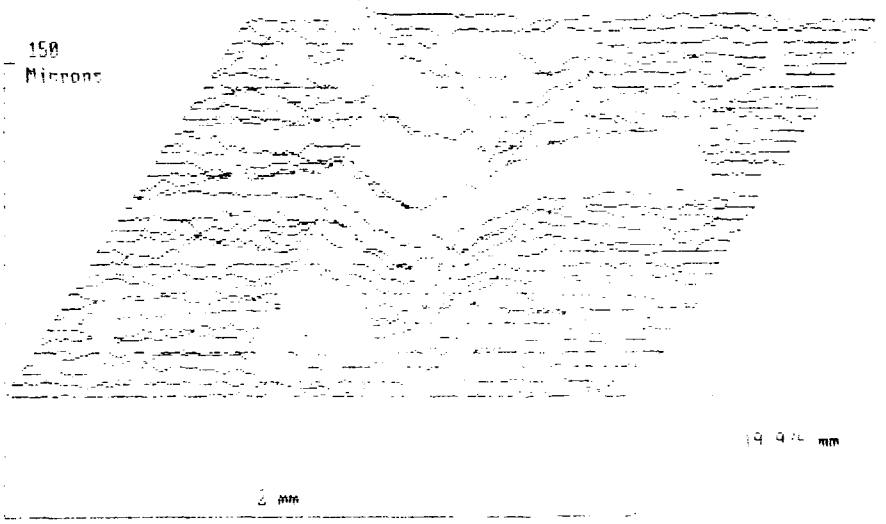
HSSA 17: Nitrox 2

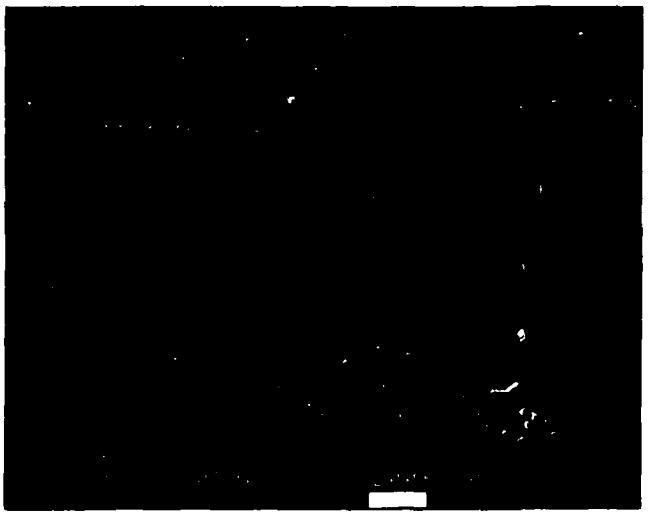
Data from hihssa-17.dat
Detrended



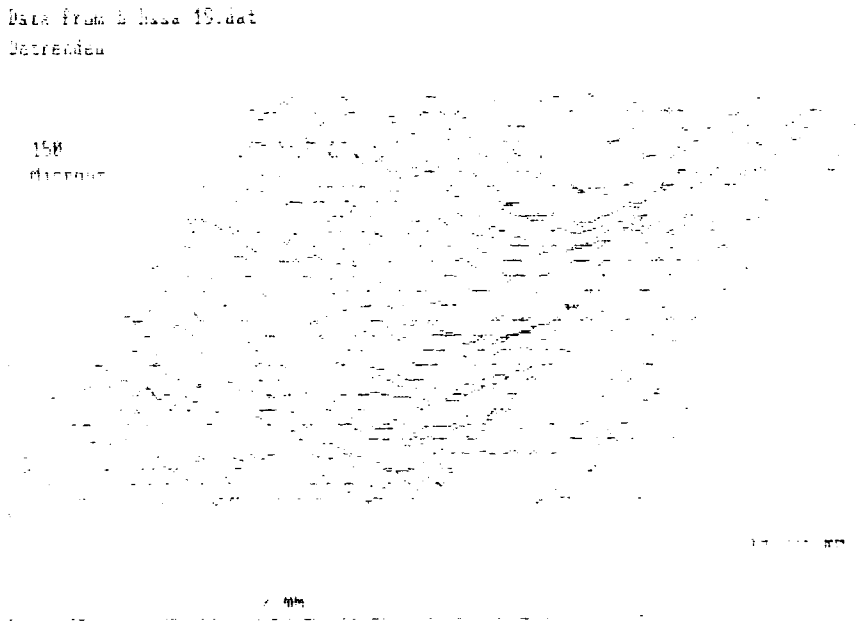
HSSA 18: Nitrox 3

Data from b:hssa-18.dat
Detrended



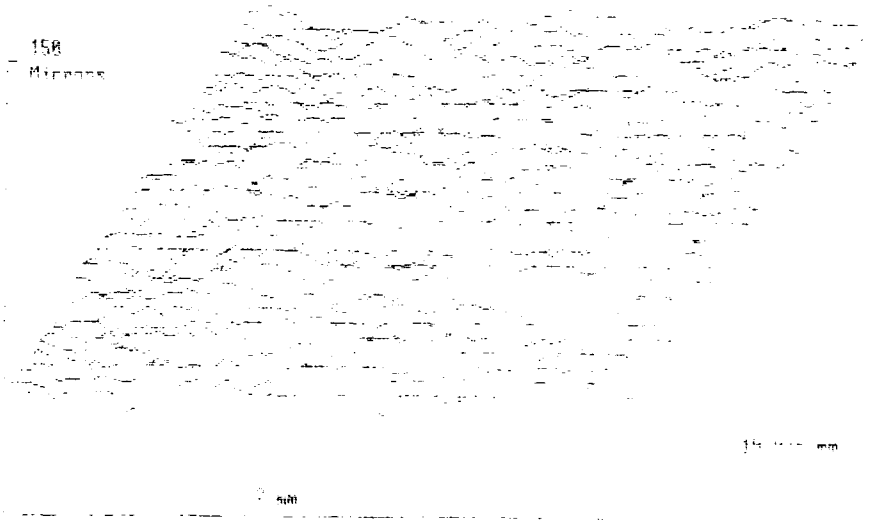


HSSA 19: Pack Aluminising 2



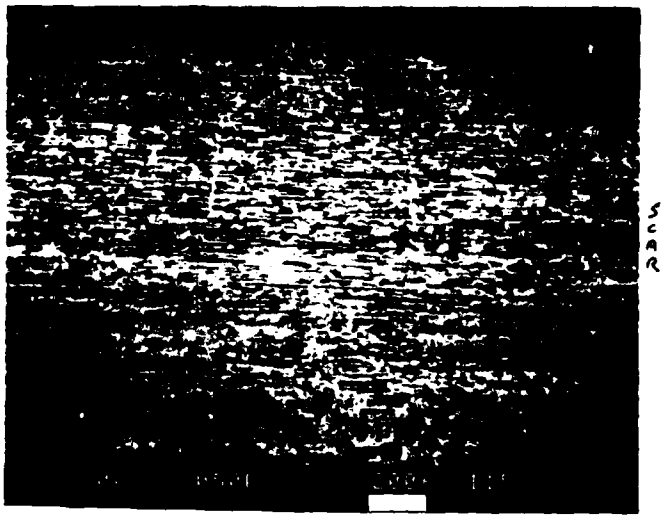
HSSA 20: Gas Carbonitriding 1

Data from S:\hssa 20.dat
Datamended

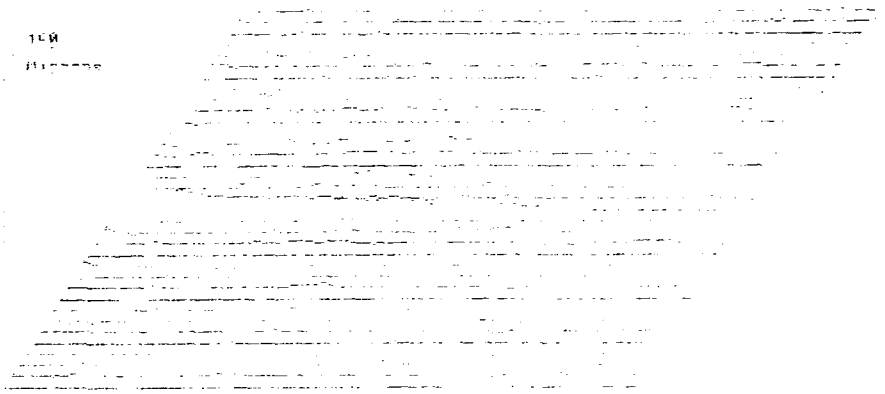


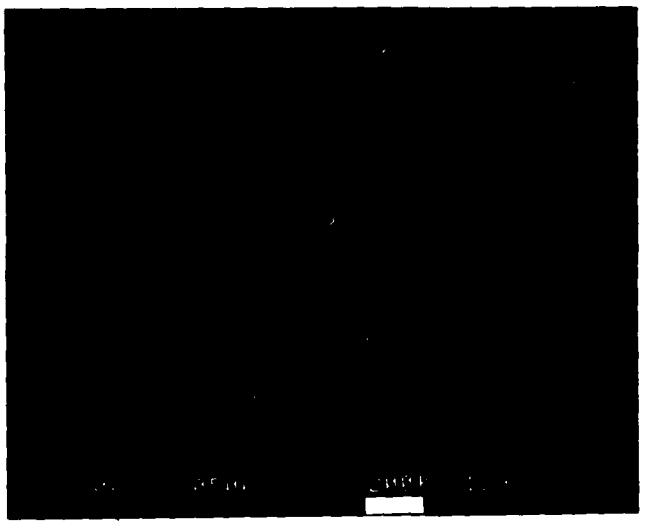
HSSA 21: Diamond-like Carbon 1

Data from Ethos-21.dat
Unloaded



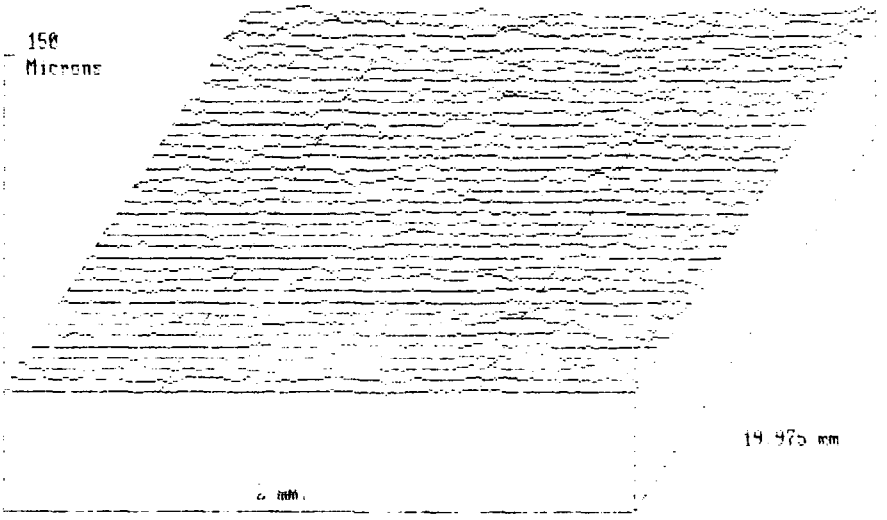
HSSA 22: TiN Reactive Sputter

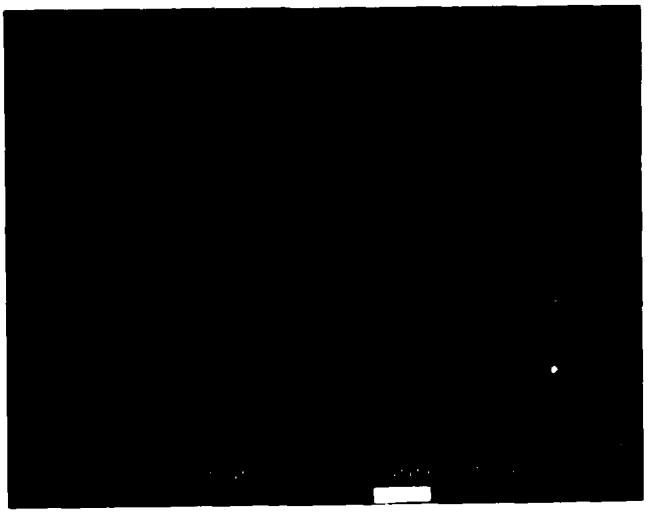




HSSA23: TiN/HfN Multilayer

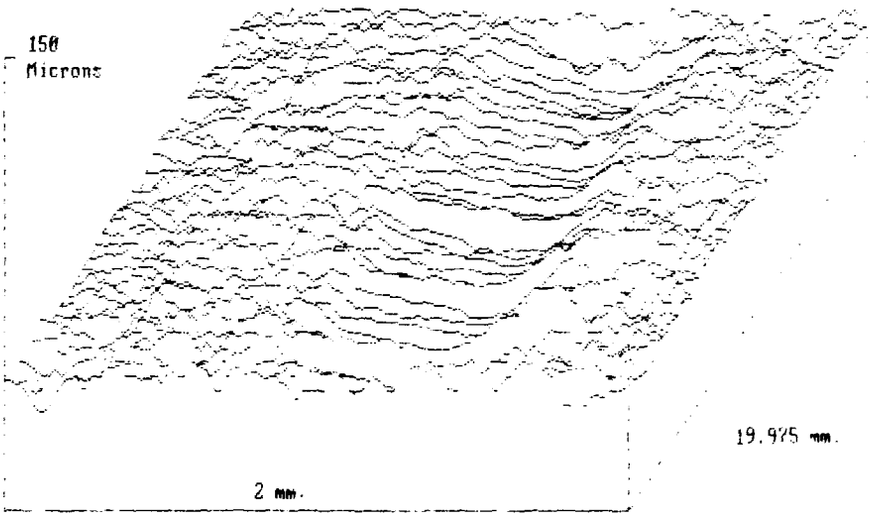
Data from b:hssa-23.dat
Detrended





HSSA 24: Pack Aluminising 3

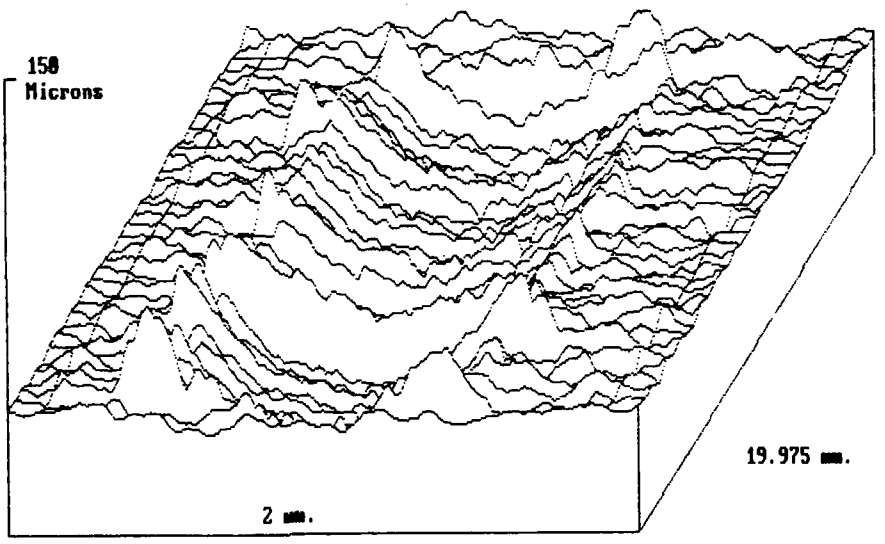
Data from b:hssa-24.dat
Detrended



APPENDIX 5: 50N Wear Profiles and SEM Micrographs of Wear Tracks

HSSA1: Solution Heat Treated

Data from b:hssa1.dat
Detrended

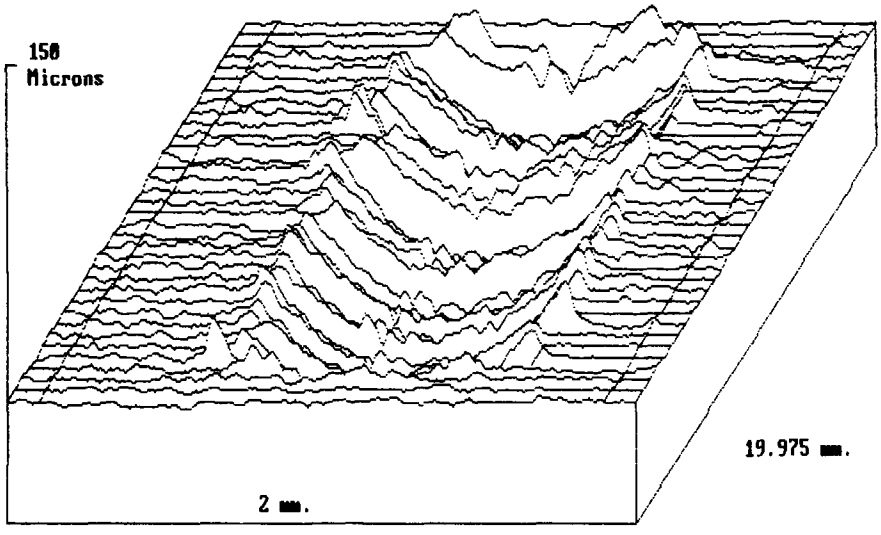


Wear volume in cubic millimetres

Above datum	Below datum	Net loss
.0456357	.2335793	.1879436

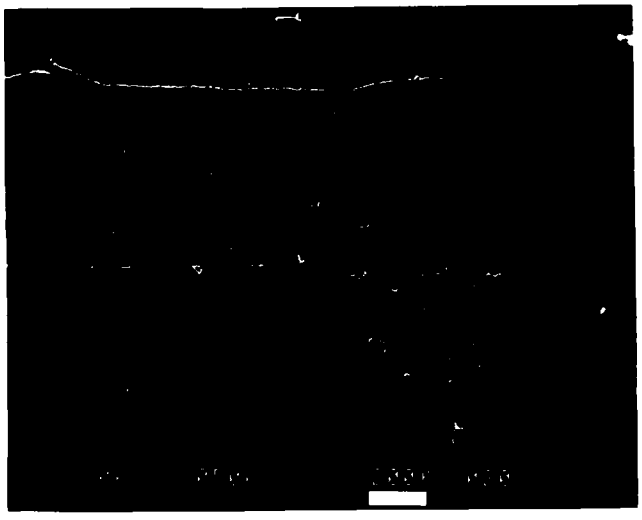
HSSA2: Hardened and Ground

Data from b:hssa2.dat
Detrended



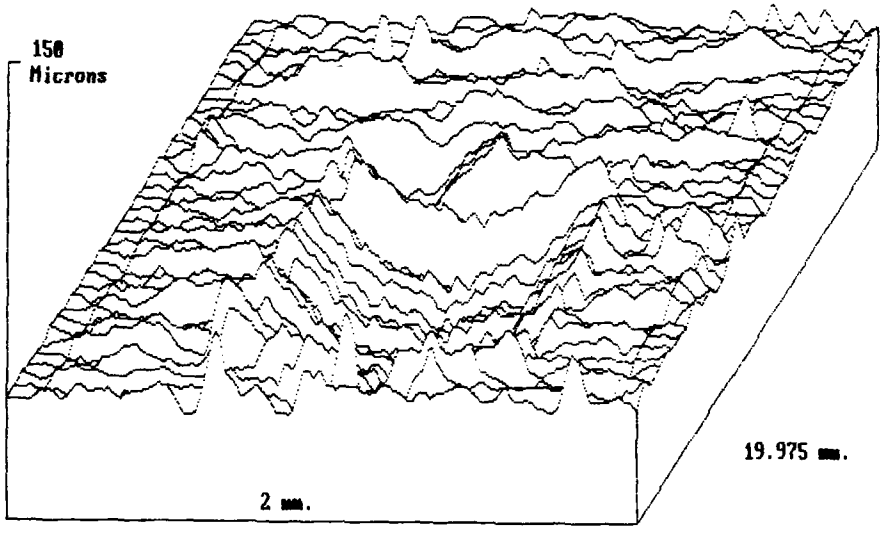
Wear volume in cubic millimetres

Above datum	Below datum	Net loss
1.857176E-02	.2437241	.2251523



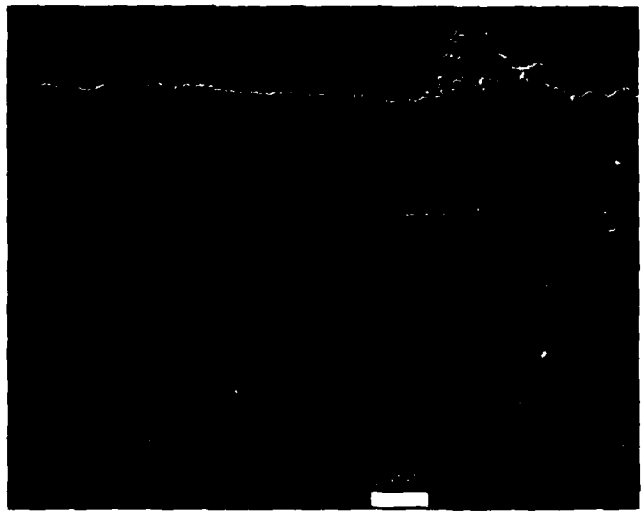
HSSA3: Plasma Nitrocarburized 1

Data from b:hssa3.dat
Detrended



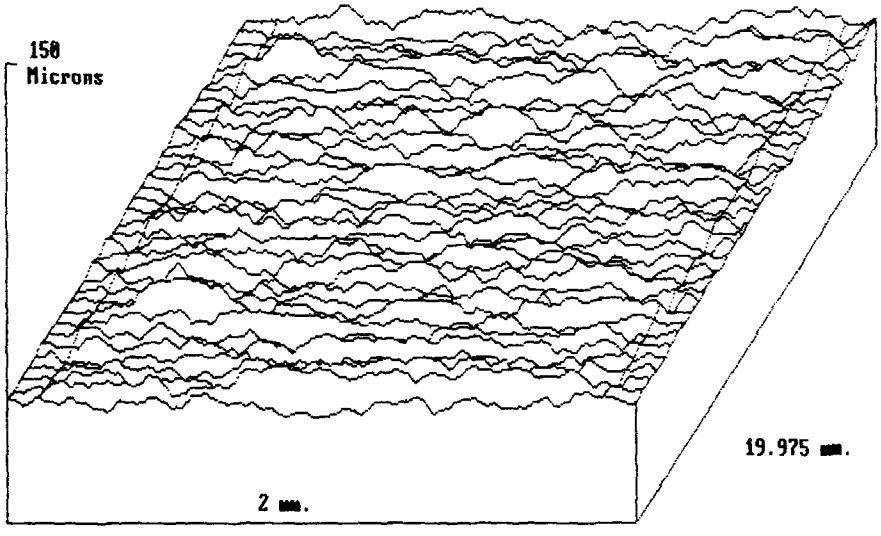
Wear volume in cubic millimetres

Above datum	Below datum	Net loss
5.616054E-02	.1875458	.1313852



HSSA4: Beta Nitrocarburized 1

Data from b:hssa4.dat
Detrended

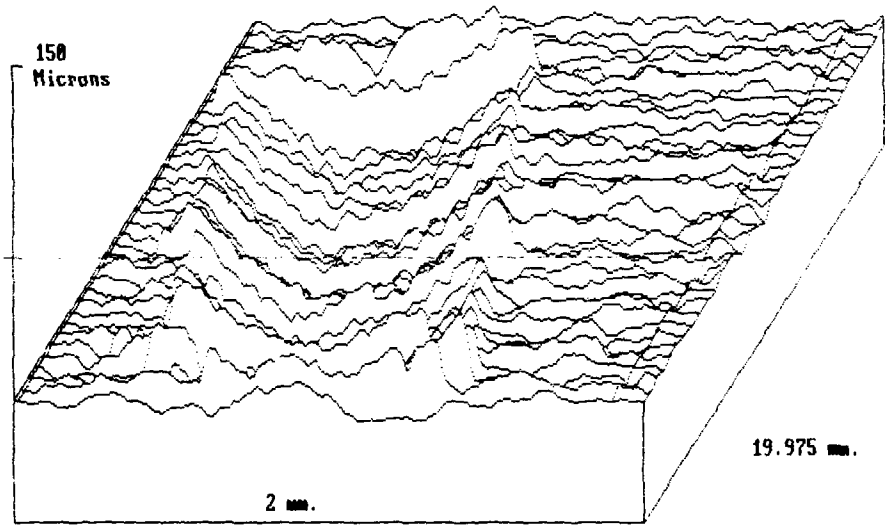


Wear volume in cubic millimetres

Above datum	Below datum	Net loss
3.921508E-02	3.531782E-02	-3.897257E-03

HSSA 5: Ion Implanted 1

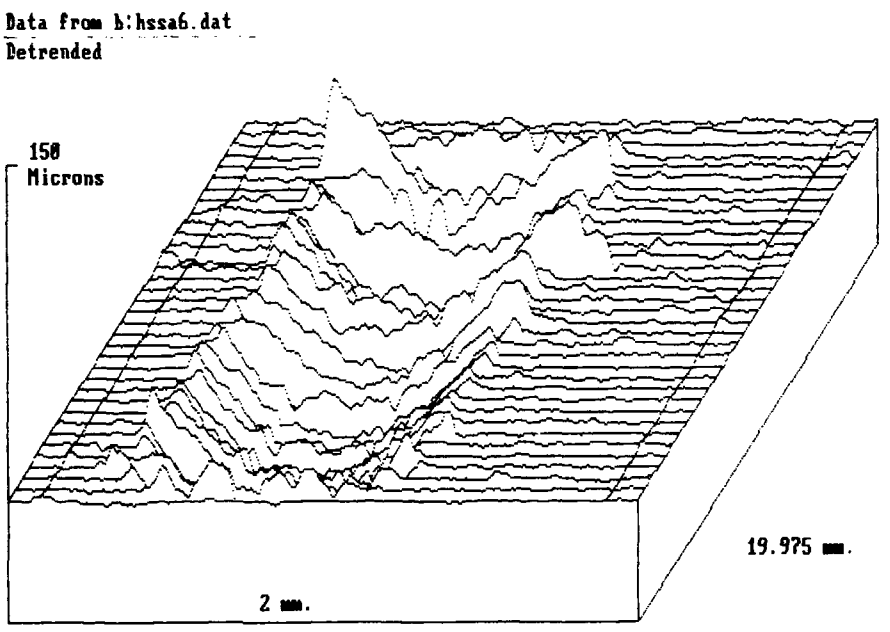
Data from b:hssa5.dat
Detrended



Wear volume in cubic millimetres

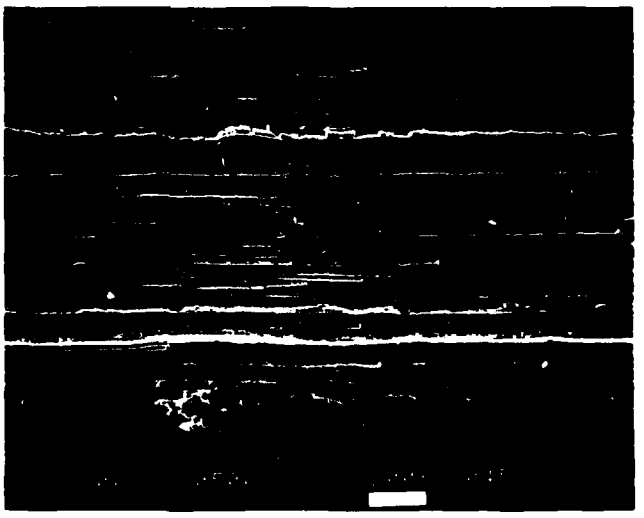
Above datum	Below datum	Net loss
4.209065E-02	.2399547	.1978641

HSSA 6: Ion Implanted 2



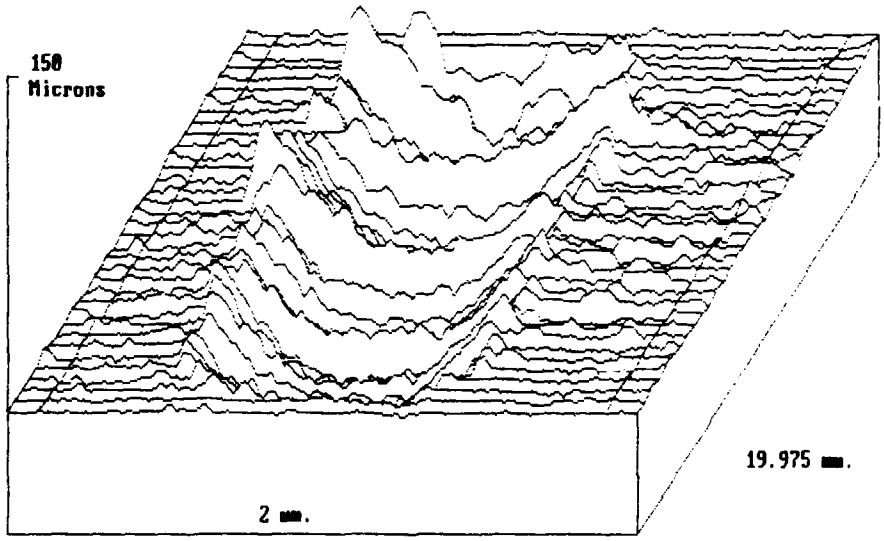
Wear volume in cubic millimetres

Above datum	Below datum	Net loss
2.041939E-02	.2303723	.2099529



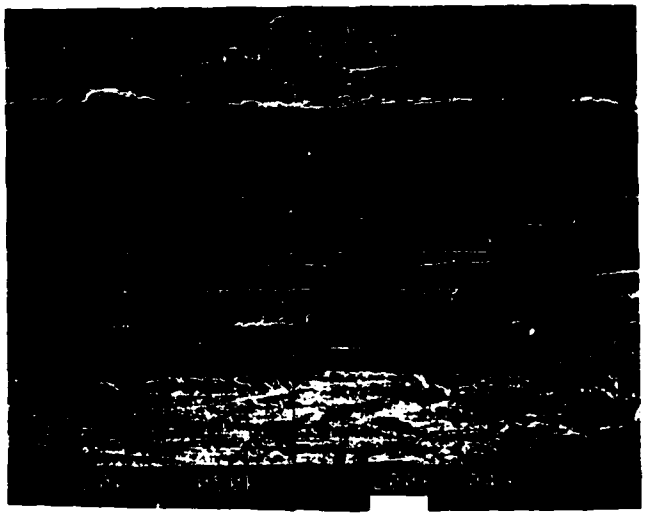
HSSA7: Hard Anodised 1

Data from b:hssa7.dat
Detrended



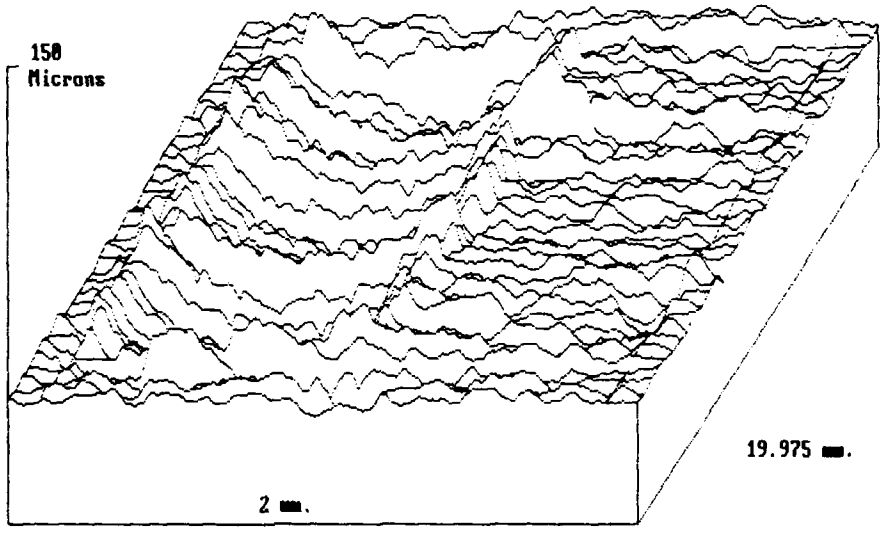
Wear volume in cubic millimetres

Above datum	Below datum	Net loss
2.642487E-02	.2412461	.2148212



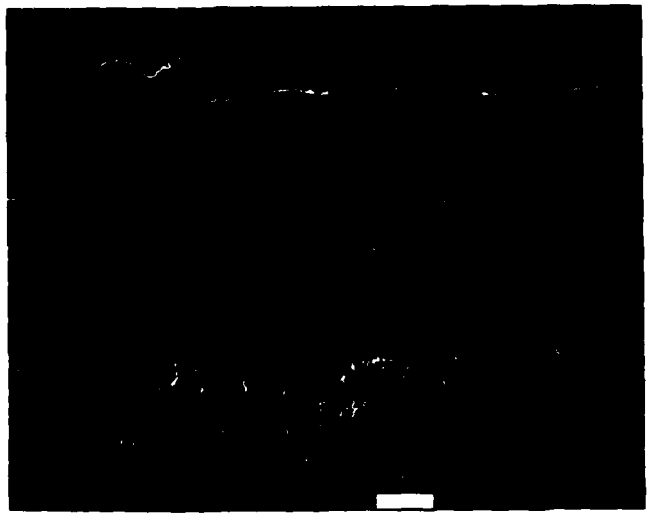
HSSA8: Hard Anodised 2

Data from b:hssa8.dat
Detrended



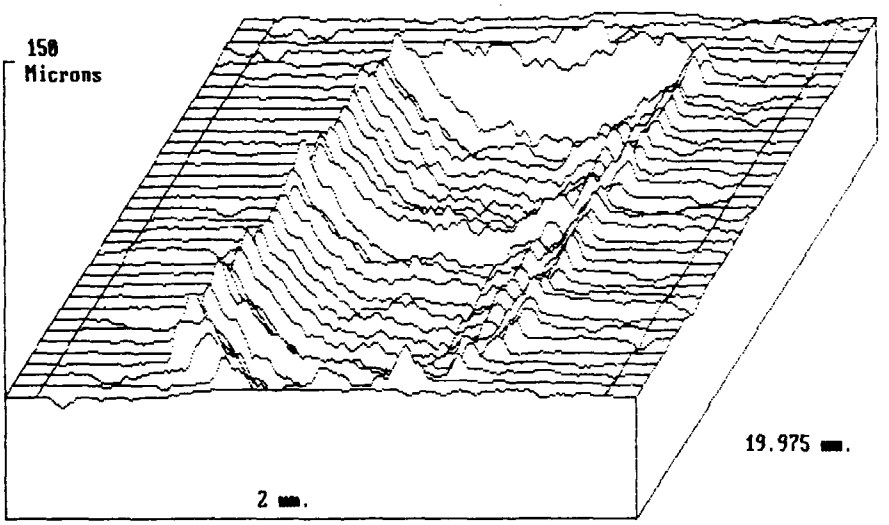
Wear volume in cubic millimetres

Above datum	Below datum	Net loss
4.153366E-02	.2389727	.197439



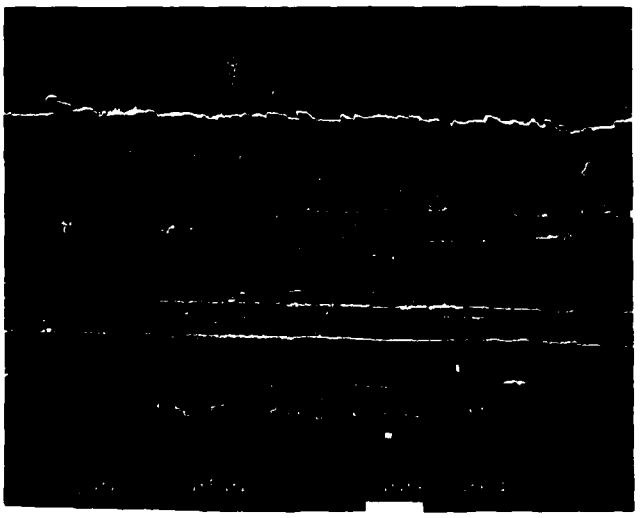
HSSA9: Plasma Nitrocarburized 2

Data from b:hssa9.dat
Detrended



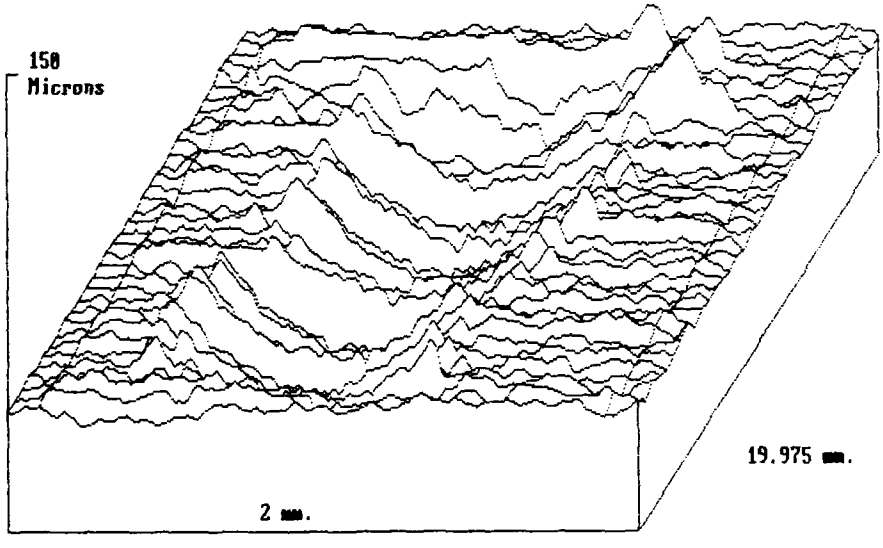
Wear volume in cubic millimetres

Above datum	Below datum	Net loss
2.866068E-02	.255984	.2273234



HSSA 10: Hard Anodised 3

Data from b:hssa10.dat
Detrended

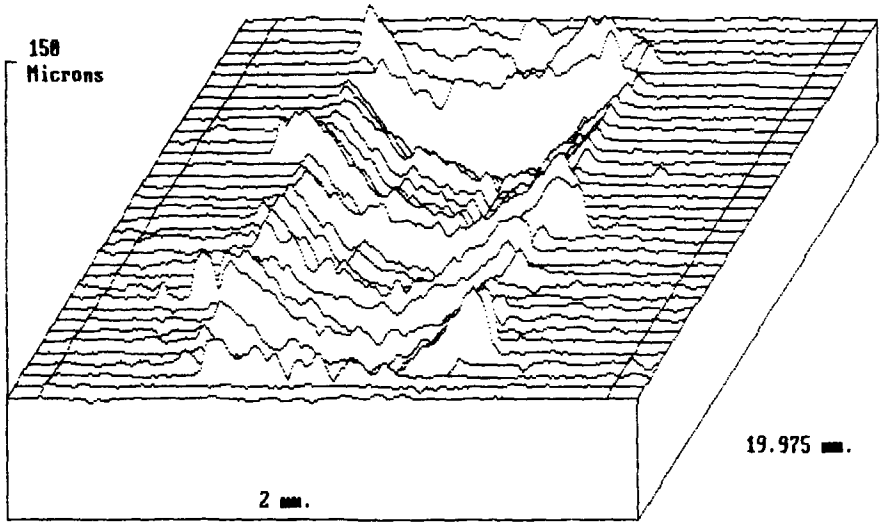


Wear volume in cubic millimetres

Above datum	Below datum	Net loss
3.6697301E-02	.2553586	.2186656

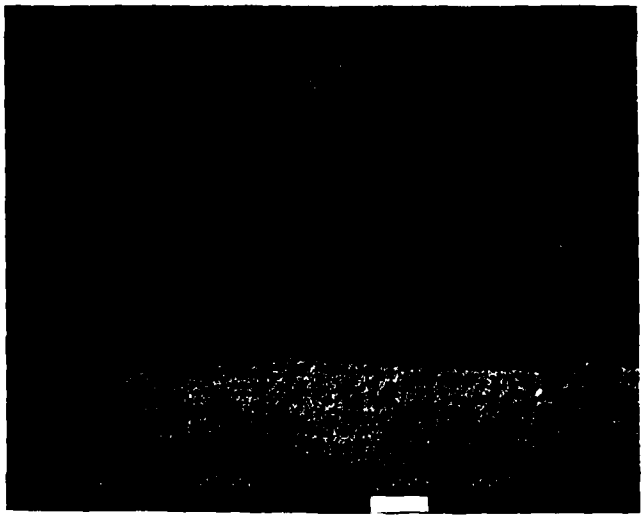
HSSA 11: Hard Anodised 4

Data from b:hssa11.dat
Detrended



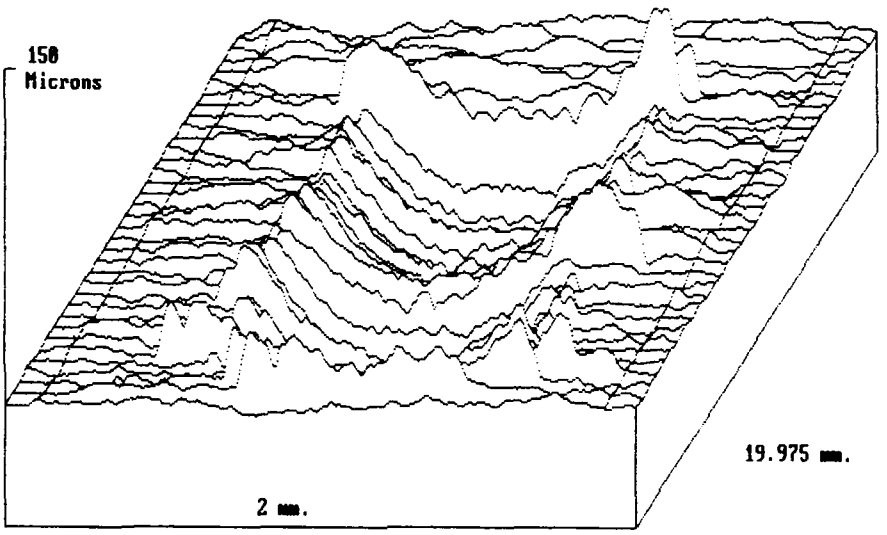
Wear volume in cubic millimetres

Above datum	Below datum	Net loss
2.775977E-02	.1922235	.1644637



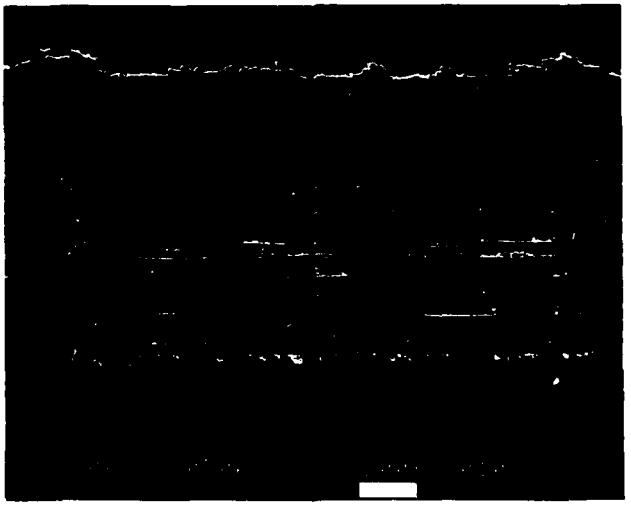
HSSA 12: Plasma Nitrided 1

Data from b:hssa12.dat
Detrended



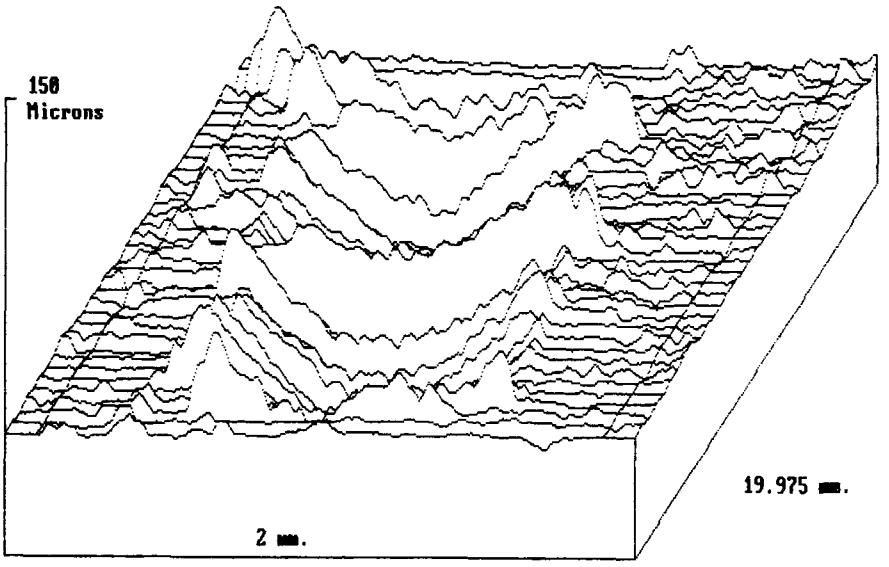
Wear volume in cubic millimetres

Above datum	Below datum	Net loss
5.554843E-02	.2511673	.1956188



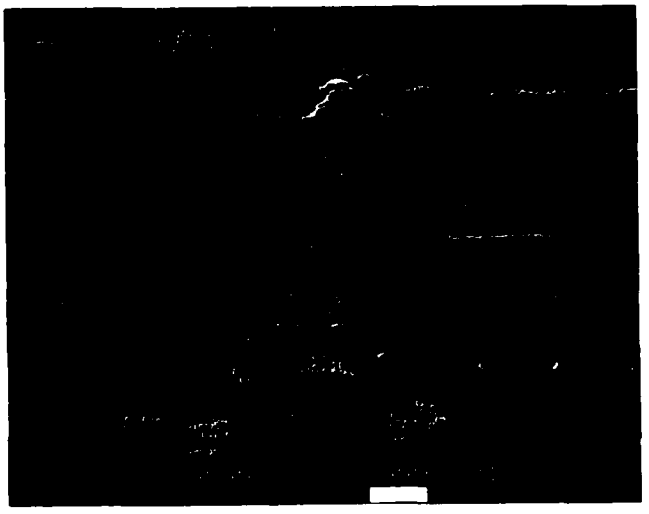
HSSA13: Plasma Nitrided 2

Data from b:hssa13.dat
Detrended



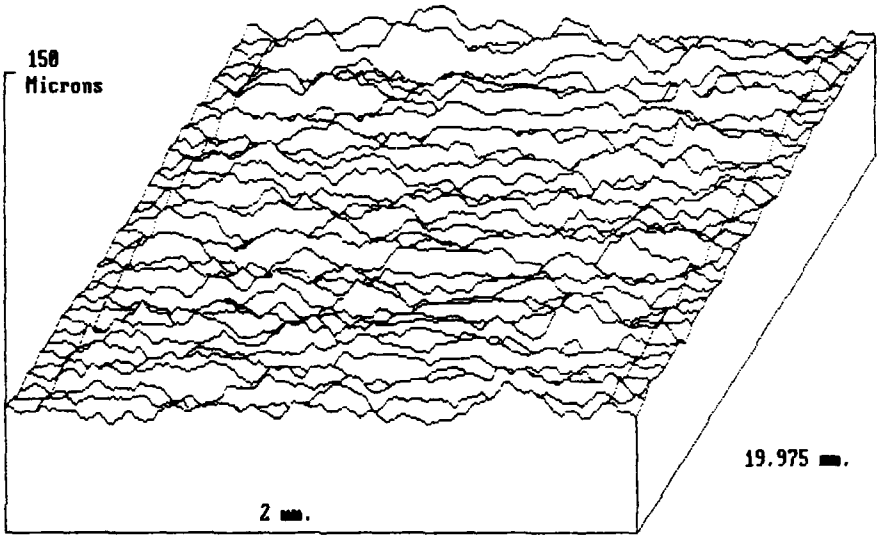
Wear volume in cubic millimetres

Above datum	Below datum	Net loss
4.008345E-02	.2619238	.2218404



HSSA14: High Temperature Nitrocarburized 1

Data from b:hssa14.dat
Detrended

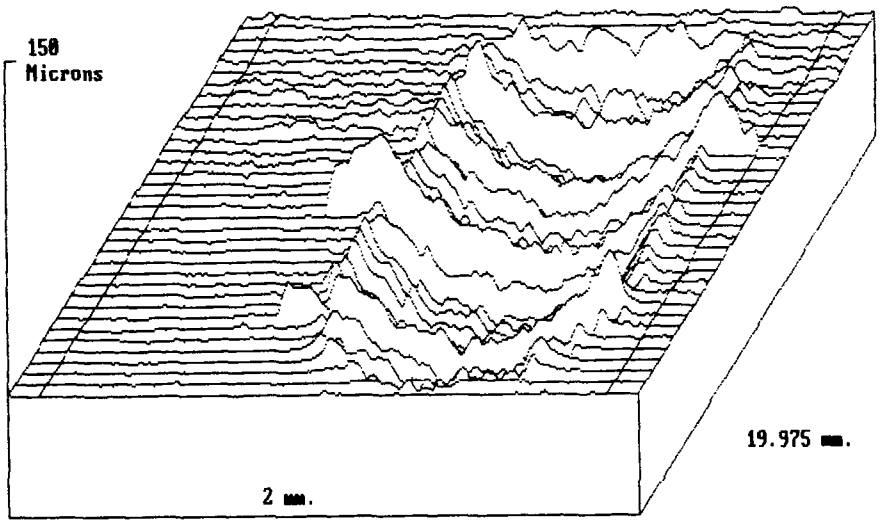


Wear volume in cubic millimetres

Above datum	Below datum	Net loss
4.902035E-02	4.254118E-02	-6.47917E-03

HSSA 15: Nitrox 1

Data from b:hssa15.dat
Detrended

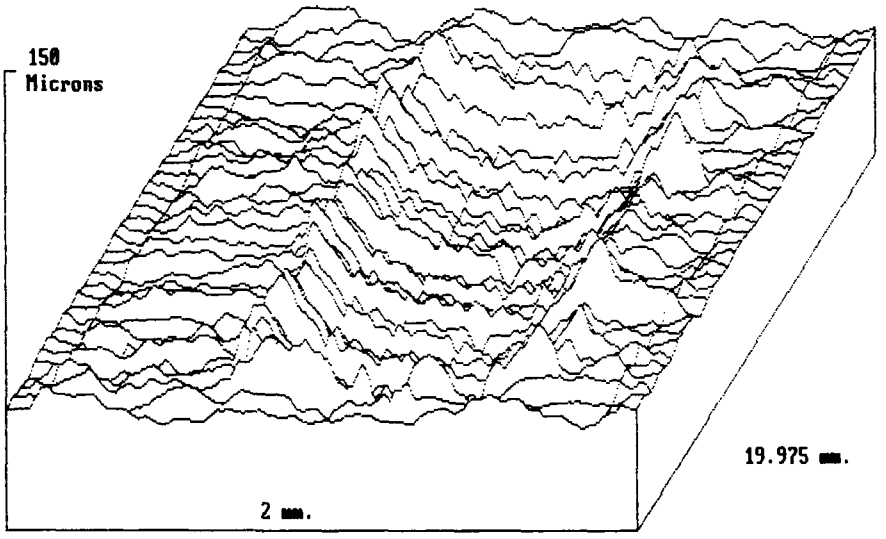


Wear volume in cubic millimetres

Above datum	Below datum	Net loss
1.879978E-02	.2240438	.205244

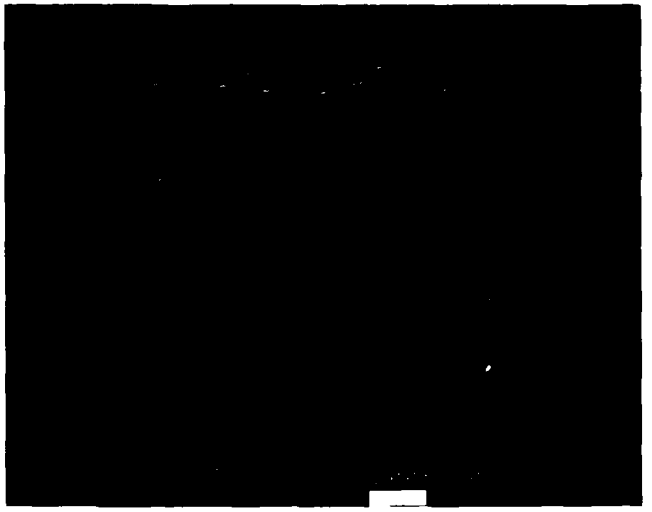
HSSA17: Nitrox 2

Data from b:hssa17.dat
Detrended



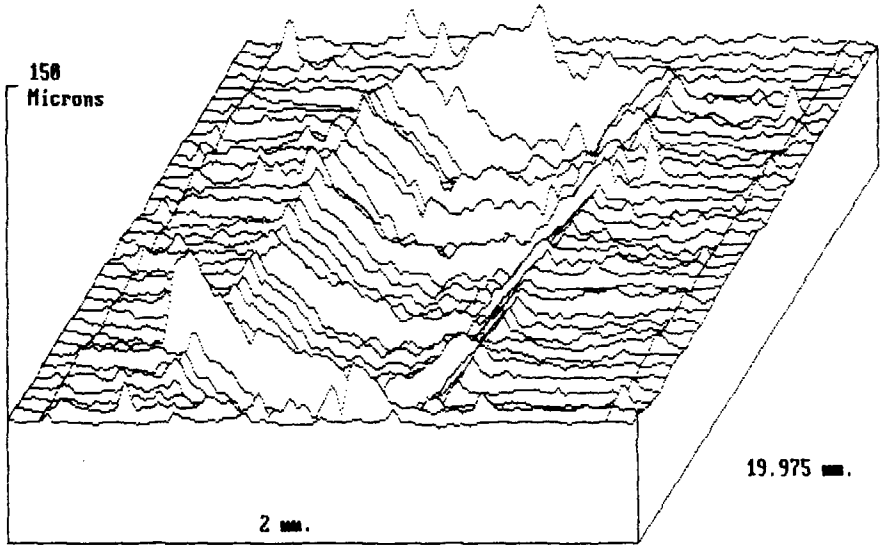
Wear volume in cubic millimetres

Above datum	Below datum	Net loss
4.378364E-02	.2352955	.1915119



HSSA 18: Nitrox 3

Data from b:hssa18.dat
Detrended

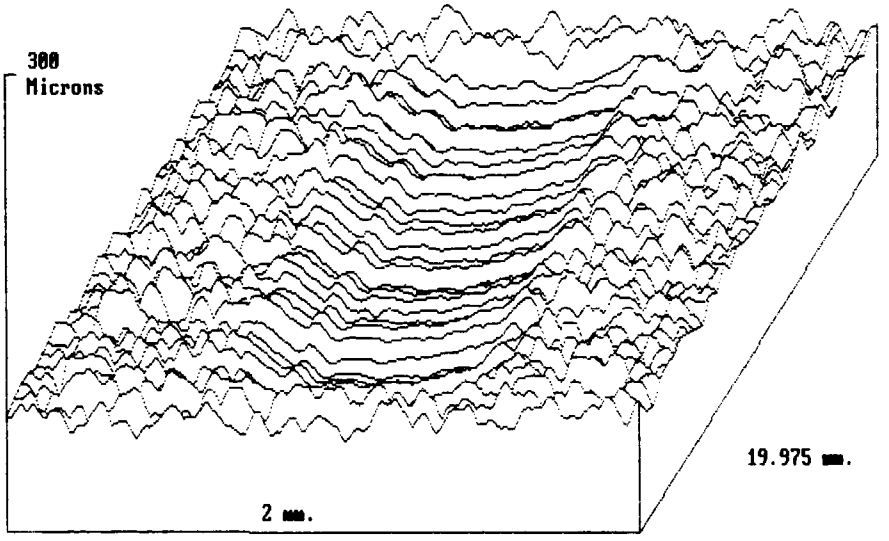


Wear volume in cubic millimetres

Above datum	Below datum	Net loss
2.324379E-02	.2662985	.2430547

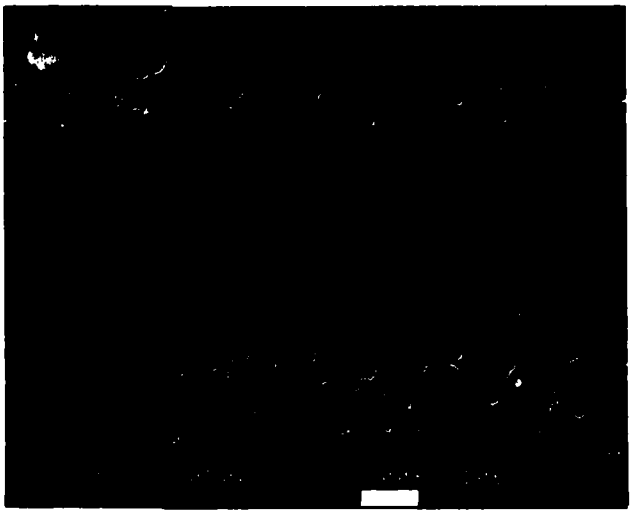
HSSA19: Pack Aluminising 2

Data from b:hssa19.dat
Detrended



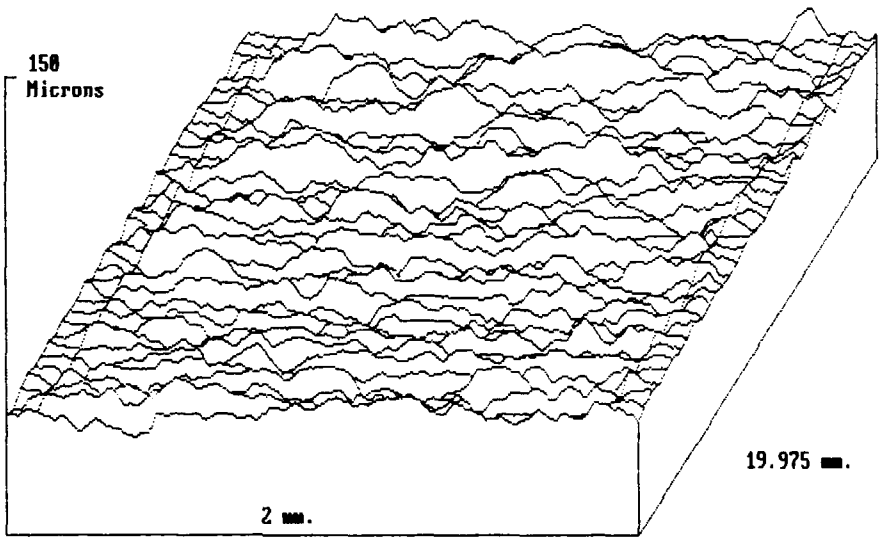
Wear volume in cubic millimetres

Above datum	Below datum	Net loss
7.481752E-02	.3003084	.2254909



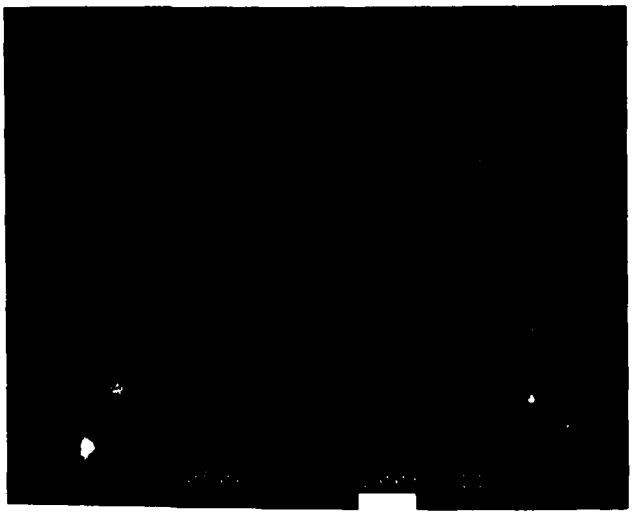
HSSA 20: Gas Carbonitriding 1

Data from b:hssa20.dat
Detrended



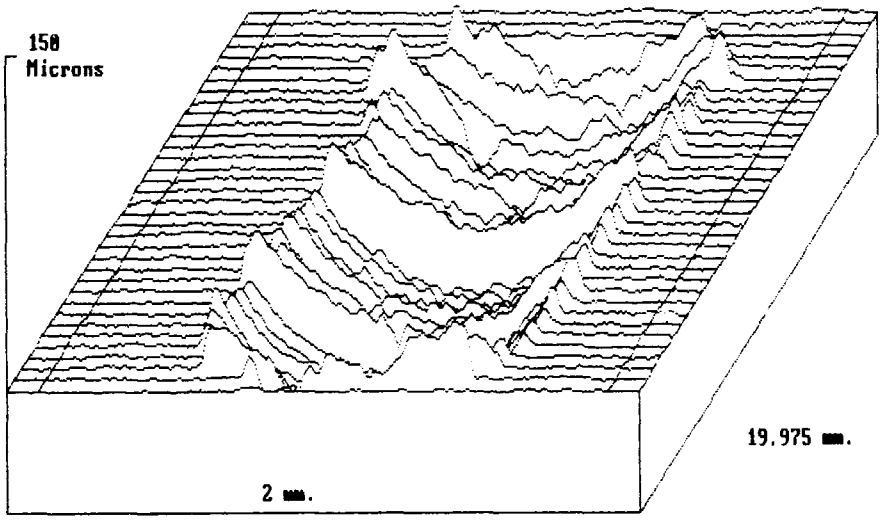
Wear volume in cubic millimetres

Above datum	Below datum	Net loss
4.566613E-02	5.848346E-02	1.281733E-02



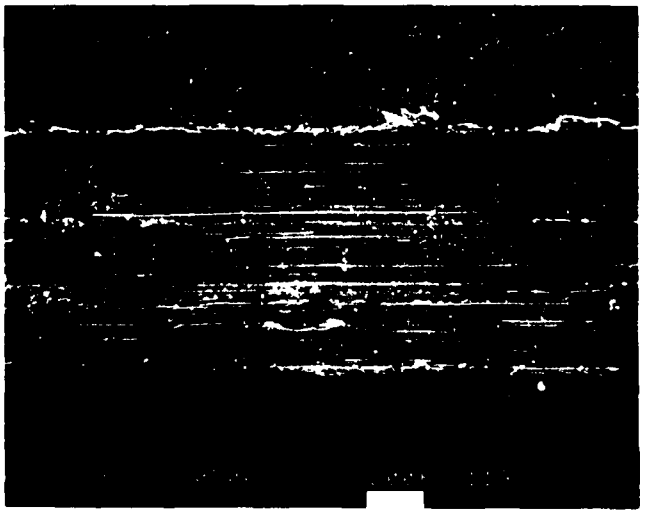
HSSA 21: Diamond-like Carbon 1

Data from h:hssa21.dat
Detrended



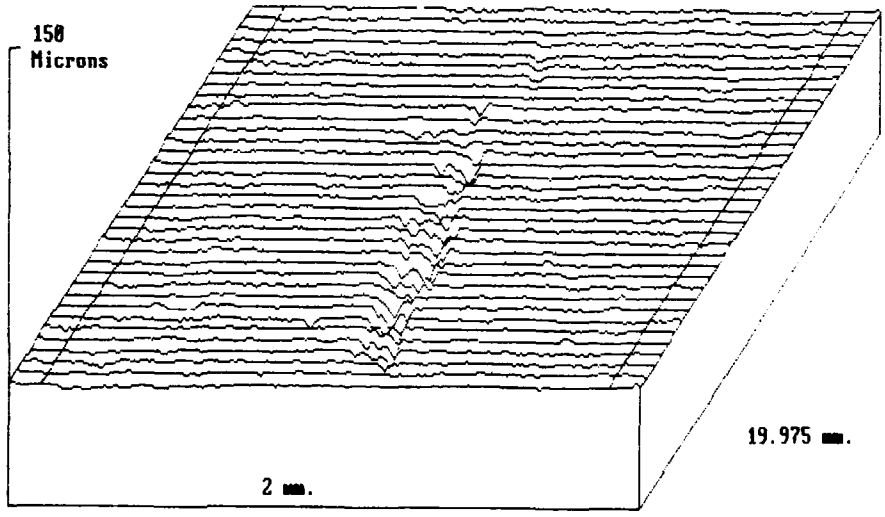
Wear volume in cubic millimetres

Above datum	Below datum	Net loss
2.667136E-02	.2495293	.222858



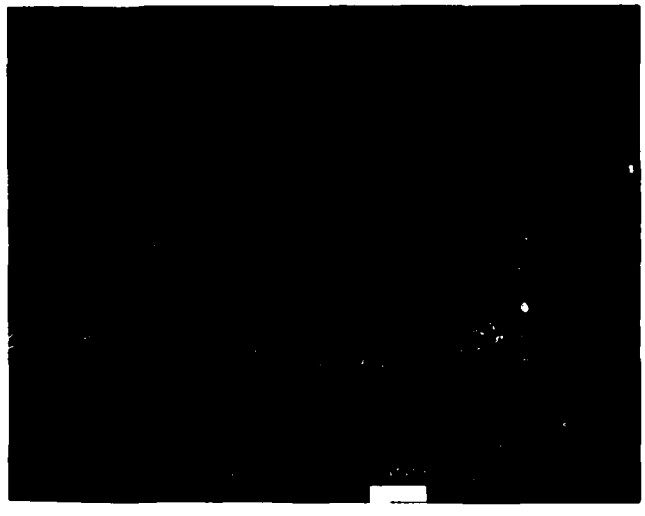
HSSA 22 : TiN Reactive Sputter

Data from b:hssa22.dat
Detrended



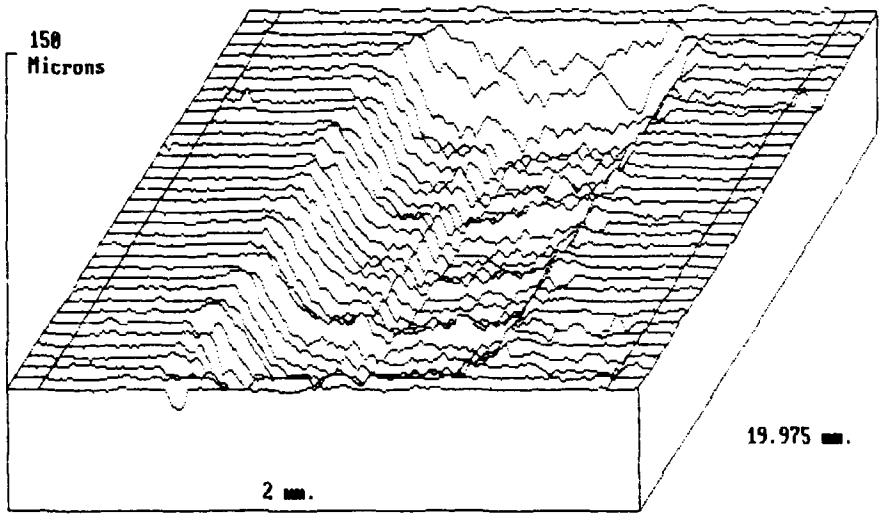
Wear volume in cubic millimetres

Above datum	Below datum	Net loss
3.728391E-03	1.470531E-02	1.097691E-02



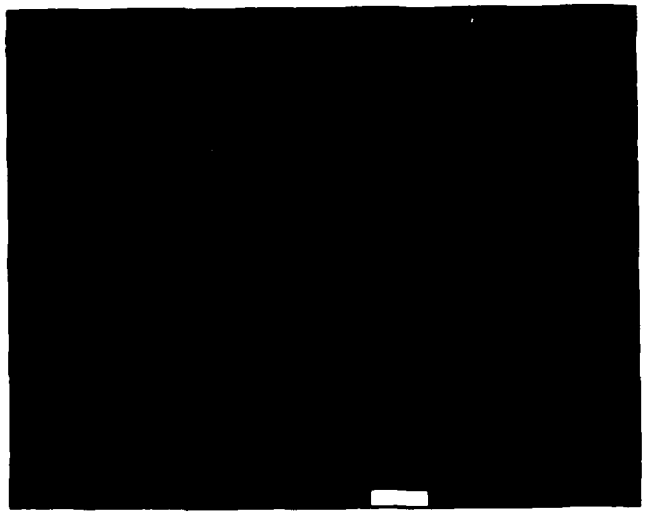
HSSA 23: TiN/HfN Multilayer

Data from b:hssa23.dat
Detrended



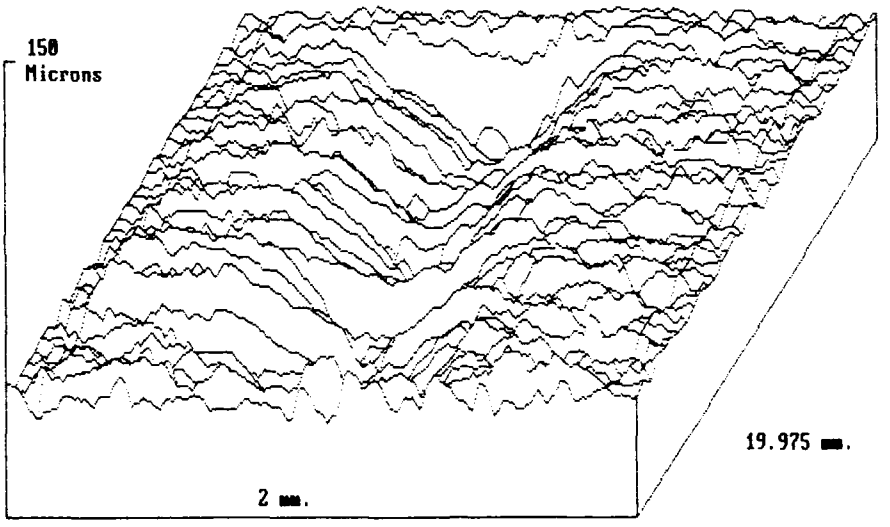
Wear volume in cubic millimetres

Above datum	Below datum	Net loss
4.79215E-03	.3629499	.3581578



HSSA 24: Pack Aluminising 3

Data from b:hssa24.dat
Detrended



Wear volume in cubic millimetres

Above datum	Below datum	Net loss
5.017138E-02	.2289717	.1788003