CSDL-C-6257

ANALYSIS of ITT SCAN BEARING PACKAGE

(Bearing Package S/N 7-1004)

December 1991

by

E. Gelotte
J. Kauppinen

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1. SUMMARY.

A GOES E-W scan bearing assembly having completed operation under accelerated in-orbit conditions equivalent to two and one-half years of service was examined at CSDL.

The conclusions reached as a result of the examination are:

1. Lubricant breakdown was found in both bearings.
2. Patchy wear-bands running only approximately half-way around the races indicating a load distribution in the ball groups consistent with very low preload.
3. Contact angles of 31.2° (S/N 1004) and 28.7° (S/N 1004A) in bearings whose contact angles are supposed to be 20 ±2°.
4. Contamination was present in the bearings.

2. INTRODUCTION.

The East-West scan axis is carried in two bearing sets, one fixed (set 7-1004) and one floating (set 7-1011). Each set consists of a DF pair of 1219 size bearings having 20° contact angles, 6 lbs preload, 440-C races, TiC coated 440-C balls and porous polyimide retainers. The lubricant is Krytox 143 AC grease.

The bearings were run in a life test motor assembly in the "imager-mode" at 50 deg/sec (5 X normal) over a ±4 degree range with the range extended to ±6.5 degrees every 75th cycle (24 seconds). After 6 months, or approximately 50% of the required 5-year mission life, the bearings were removed from the motor assembly and torque-tested at .01 r/min over approximately ±14 degrees. Successive torque traces showed a "torque build-up" from approx. 30 gm-cm. to approx. 120 gm-cm. This anomalous torque build-up, which was reported to be "released" to the 30 gm-cm. level with a "slight movement of the bearing by hand" has not been explained and was not detected in the weekly performance checks during the 6-month test-run.

After removal from the carrier the bearings were sent to CSDL for examination.

3. TEST PLAN.

Evaluation of the bearing set was based on a visual and dimensional examination of the bearing parts and chemical analysis in which GC/Mass Spec and FTIR were performed on successive extractions of the parts with Freon, hexane and methanol. Particulates removed from the bearing parts were examined using SEM/EDAX/WDX.

Race roundness, cross curvature and inner-race land finish were measured using Indi-Ron and Form Talysurf. Bearing contact angles were measured.

4. ANALYSIS EQUIPMENT.

4.1 GC/MS

Gas chromatography is a means of separating the components of a mixture for introduction into the mass spectrometer where they are ionized and identified on the basis of their atomic mass.

4.2 SEM/EDAX/WDX

In a scanning electron microscope (SEM), a means for identifying elements by atomic weight by X-ray energy analysis (EDAX) and their distribution in the sample by wavelength analysis of the X-rays emitted by the sample (WDX).

4.3 FTIR

A means of identifying functional groups of a sample based on its absorption of infrared energy.

Those materials which are not known to be constituents of the bearing package are considered to be contaminants.

Race roundness and cross-curvature are specified, respectively, at 100 micro-in. and 25 micro-in. maximum departure from true circularity.

5. RESULTS.

5.1 Chemical Analysis

5.1.1 Metal Parts S/N 7-1004 (Outer Race, Inner Race and Bearing Balls)

The metal parts from S/N 7-1004 were extracted together in Freon and the solvent was filtered in an attempt to obtain Krytox free particulates. The hardware was then extracted in hexane and methanol to collect any other materials not soluble in Freon. GC/Mass Spec and FTIR analyses were conducted on the three solvent extracts. Figure 1 displays the Mass Spectral evaluations of the Freon and hexane extractions. Phthalate ester, unsaturated hydrocarbon, and an acid were contaminants evident by this procedure. These materials are similar to those detected in the GOES Filter-Wheel life-test bearings (S/N 0032 and S/N 0032A). No extraneous compounds were detected in the methanol extraction. Figure 2 illustrates results obtained by FTIR analysis. Evidence of oxidation has been exhibited by this analysis with the presence of ester, acid and carboxylate absorptions at ~1735, 1698, and 1650 cm^{-1}, respectively. Although the origin of the hydrocarbon species is unknown at this time, materials used in the processing of the bearings is highly suspect.

SEM/EDAX/WDX analyses were conducted on the particulates from metal parts of S/N 7-1004. Extracted materials indicated the presence of lubricant (chlorine, fluorine and carbon), aluminum (most likely Al_2O_3), calcium carbonate (most likely from processing materials) and chromium, iron, and titanium (bearing hardware wear products). The presence of titanium may be attributed to wear debris. Also detected was one particle of a glass-like material (sodium, aluminum and silicon), most likely due to glass beads that are used in the processing of the hardware before being received by ITT. Figures 3-6 display these findings.

5.1.2 Metal Parts S/N 7-1004A (Outer Race, Inner Race and Bearing Balls)

The metal parts from S/N 7-1004A were extracted in the same manner as 7-1004. GC/Mass Spec revealed the presence of unsaturated hydrocarbon, phthalate ester and an unidentified acid (Figure 7). FTIR analyses revealed the same contaminants as in S/N 7-1004: hydrocarbon, ester, acid and carboxylate (Figure 8).

SEM/WDX/EDAX/analyses indicated the presence of lubricant (chlorine, fluorine and carbon), titanium whose source may be wear debris or from the stator housing, manganese, iron and chromium due to metal wear (Figures 9-12).

5.1.3 Polyimide Retainer From S/N 7-1004

The polyimide retainer was extracted in Freon, filtered and then consecutively extracted in hexane and methanol. GC/Mass Spec and FTIR analyses were conducted on these extractions.

GC/Mass Spec analysis revealed the presence of tetrachloroethylene (Figure 13). This solvent is not miscible with Krytox and may be corrosive to metal parts. One of the cleaning processes of the retainers involves rinsing in trichloroethylene and then vacuum bake. Trichloroethylene has a boiling point much lower than tetrachloroethylene. It is suspected that the wrong solvent was used in this case. No other extraneous contaminants were detected by Mass Spec.

FTIR analyses detected the presence of oxidation products - ester, acid and carboxylate as was seen with the metal parts. The presence of hydrocarbon is most likely due to processing materials (Figure 14).

SEM/EDAX/WDX analyses were performed on the particles of debris on the filter from the Freon extraction of the retainer. Results indicate the presence of lubricant (fluorine, chlorine and carbon), wear products titanium, chromium, iron and a particle of glass-like material (Figures 15 and 16). Once again, this particle is most likely due to a chip from the glass beads used in the hardware processing. A metal particle was also removed from the retainer which is a suspected wear product of the race (Figure 17).

5.1.4 Polyimide Retainer From S/N 7-1004A

The retainer from S/N 7-1004A was prepared for analyses in the same manner as S/N 7-1004. GC/Mass Spec analyses revealed the presence of tetrachloroethylene, more significant than that of S/N 7-1004 (Figure 18). No other extraneous compounds were detected.

FTIR analyses revealed the same findings as in 7-1004 with evidence of oxidation with the presence of ester, acid and carboxylate (Figure 19).

6. VISUAL EXAMINATIONS.

The inner and outer races of both bearings show wear bands which extend only approx. half way around the race suggesting operation under very low preload (Figures 20-28). Balls from each bearing show the "dither-mode" of operation with which the test was run (Figures 29-32). The retainer shows the difference between the extent of lube degradation in the pockets containing heavily loaded balls (Figure 33) and lightly loaded balls (Figure 34). This retainer also shows signs of considerable "scrubbing" by the piloting (inner-race) levels (Figure 35). Higher magnification views of the race contact areas show clearly the differences between the heavily loaded (Figures 36-39) and lightly loaded (Figures 40-43) race contacts. All of the photos were taken after solvent extraction, showing clearly the lube degradation left behind.

Bearing contact angle measurements:

7-1004	31.2°
7-1004A	28.7°

Race roundnesses:

7-1004	outer race	.000045
	inner race	.000025
7-1004A	outer race	.000020
	inner race	.000020

Cross-race curvatures:

7-1004	outer race	.000016/.000025	(180° apart)
	inner race	.000024/.000035	(180° apart)
7-1004A	outer race	.000017/.000039	(180° apart)
	inner race	.000030/.000034	(180° apart)

Surface finish measurements made on inner race lands:

7-1004	1.18/1.42	μ-in. (R_a)
7-1004A	0.54/1.12	μ-in. (R_a)

7. CONCLUSIONS.

1. Although these bearings were said not to have shown any operational anomalies, CSDL considers these bearings failures in the sense that they would not have passed a CSDL screening test.

2. Considerable chemical contamination was found in these bearings:

   Tetrachloroethylene (retainers)

   Phthalate ester

   Hydrocarbon

   Acid

   Carboxylate

   These materials are foreign to this bearing system and should be eliminated.

3. CSDL does not consider Krytox a good lubricant for bearings operating in the boundary mode (even when fully flooded) and knows of no successful utilization of Krytox in such an application which has not included a boundary additive.

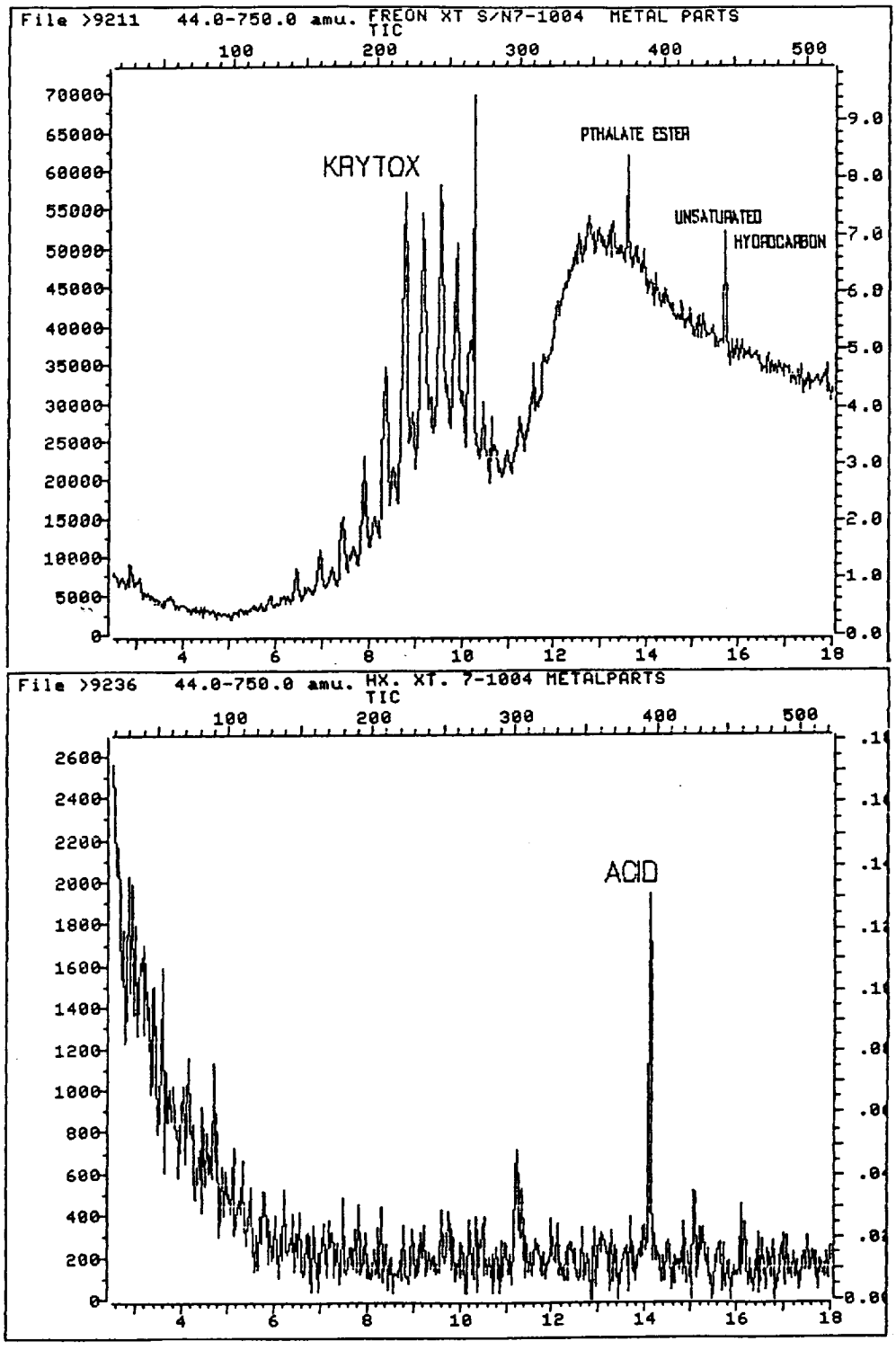


Figure 1. **Mass spectra of Freon (upper) and hexane (lower) extractions of 7-1004 races and balls.**

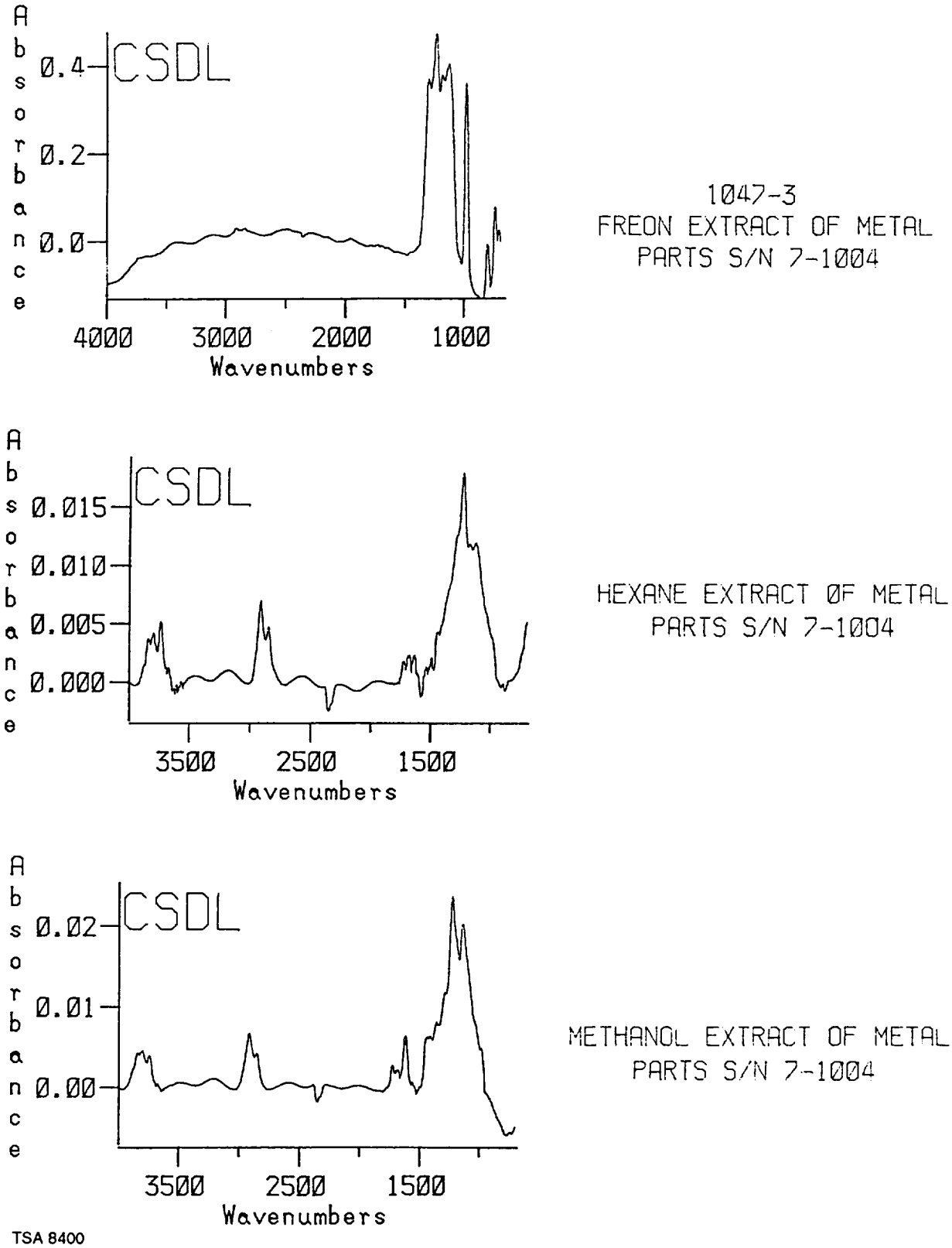
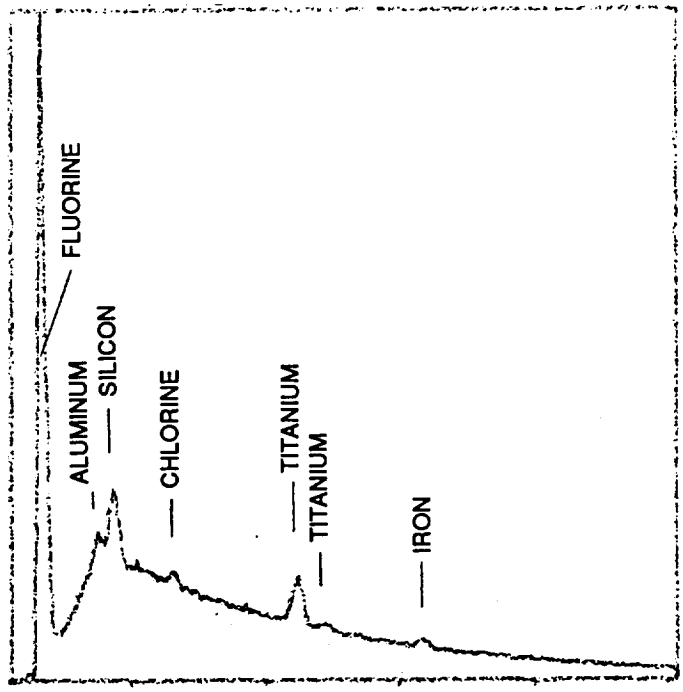
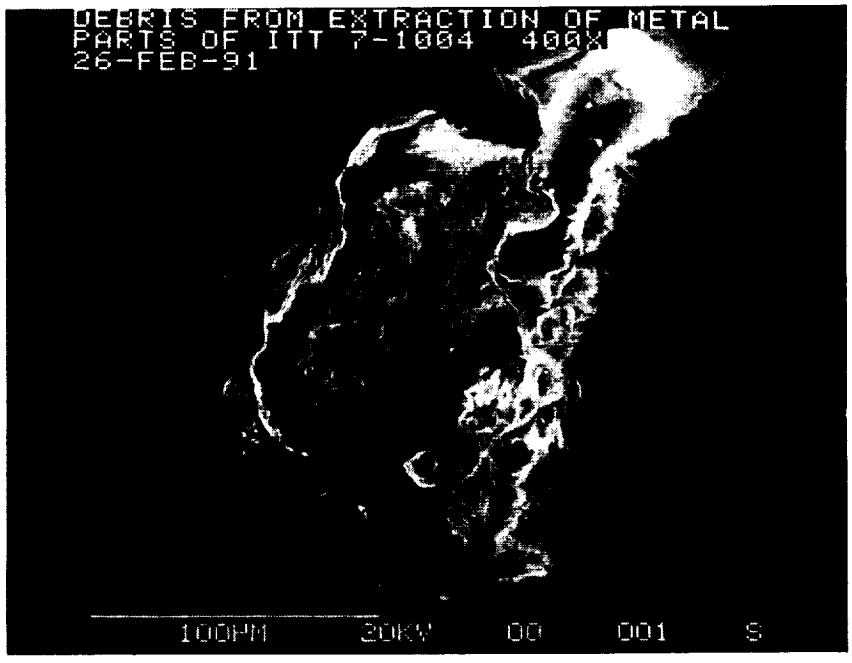


Figure 2. FTIR on extractions 7-1004 races and balls.

```
LIST-%-ZAF:
LABEL = ITT 7-1004 1
26-FEB-91    10:46:42
  200.003  LIVE SECONDS
KV= 20.    TILT=45.    TKOFF=45.
           ZAF CORRECTION

 ELEM    K       Z       A       F

 ALK  0.1190  1.028   0.732   1.013
 SIK  0.2447  1.058   0.721   1.004
 CLK  0.0568  1.005   0.820   1.011
 TIK  0.3269  0.942   0.965   1.009
 FEK  0.0903  0.940   0.963   1.000
```

ELEM	CPS	WT % ELEM
AL K	36.9495	15.62
SI K	86.0689	31.97
CL K	17.6548	6.81
TI K	66.3241	35.62
FE K	11.7898	9.98
		100.00

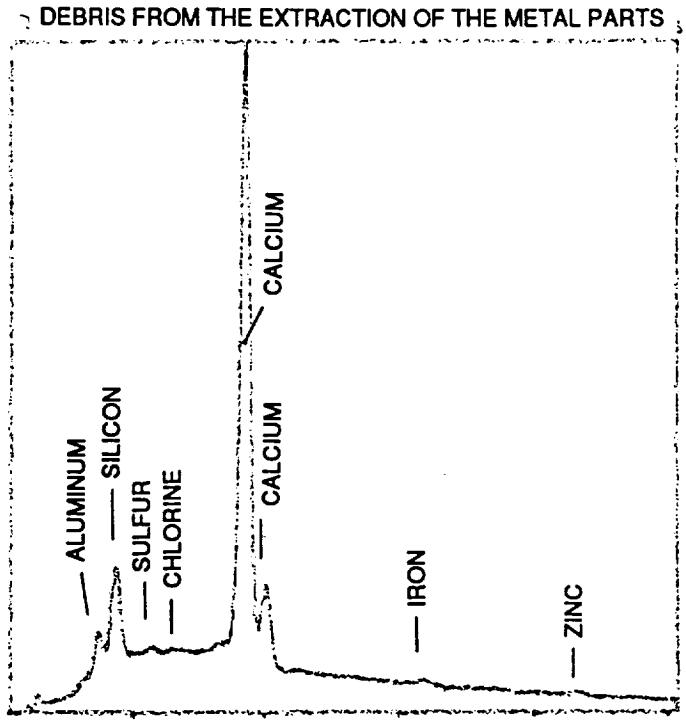


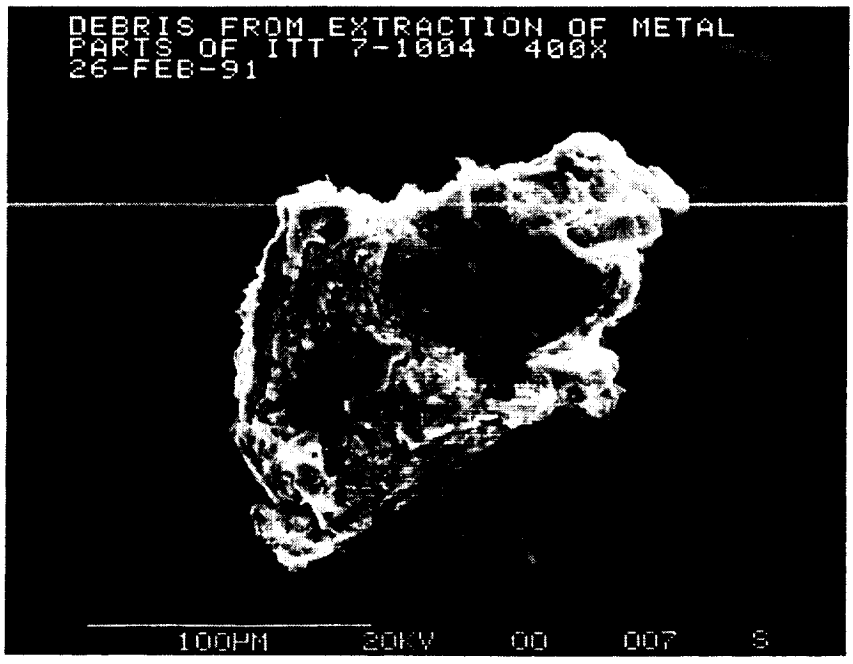


TSA 8401

Figure 3. SEM/EDAX of particulate from 7-1004 races and balls.

```
LIST-%-ZAF:
LABEL = ITT 7-1004 2
26-FEB-91    11:08:19
  200.002  LIVE SECONDS
KV= 20.    TILT=45.    TKOFF=45.
           ZAF CORRECTION


 ELEM    K       Z       A       F

 ALK 0.0210 0.995 0.715 1.010
 SIK 0.0727 1.024 0.793 1.013
 S K 0.0059 1.020 0.877 1.041
 CLK 0.0016 0.974 0.919 1.075
 CAK 0.8396 0.999 0.984 1.001
 FEK 0.0183 0.911 0.946 1.000



                                  WT %
ELEM          CPS                 ELEM
AL K        30.4397               2.93
SI K       119.1837               8.83
S  K         9.2149               0.64
CL K         2.3350               0.17
CA K       996.6541              85.32
FE K        11.1349               2.12
                                 ------
                                 100.00
```

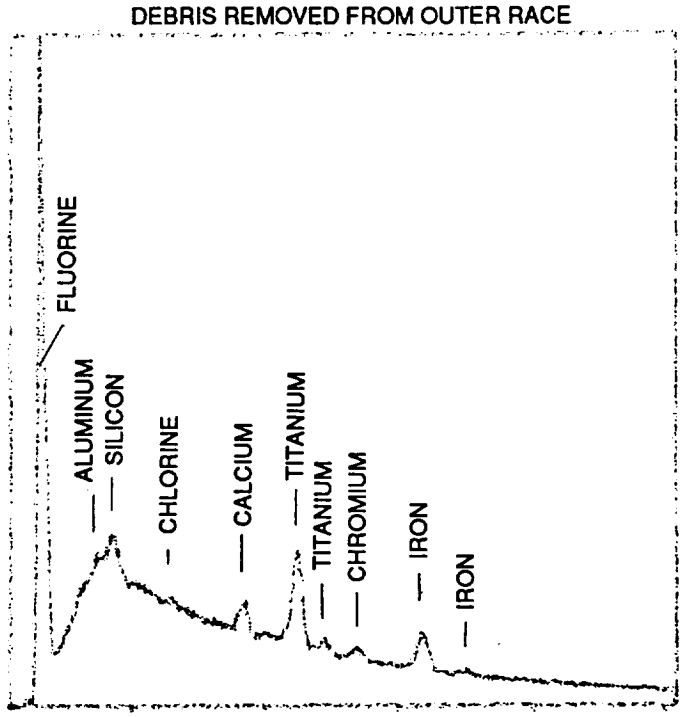




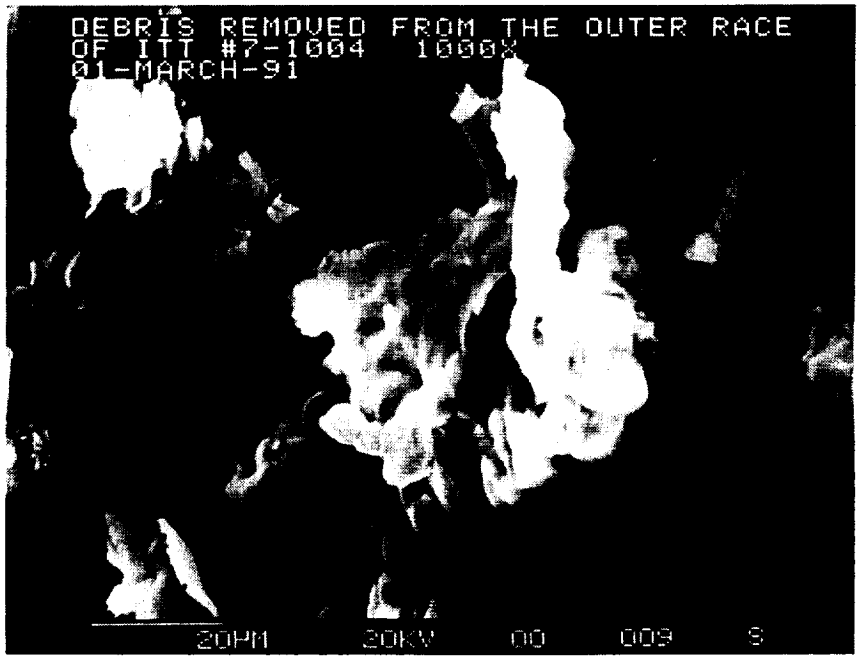
TSA 8402

Figure 4. SEM/EDAX of particulate from 7-1004 races and balls.

```
LIST-%-ZAF:
LABEL = ITT 7-1004 4
28-FEB-91    16:13:23
  200.000  LIVE SECONDS
KV= 20.    TILT=45.    TKOFF=45.
           ZAF CORRECTION

 ELEM    K      Z      A      F

 ALK 0.0406 1.056 0.593 1.006
 SIK 0.0866 1.087 0.676 1.004
 CLK 0.0272 1.037 0.861 1.020
 CAK 0.0753 1.062 0.952 1.066
 TIK 0.3817 0.970 0.967 1.028
 CRK 0.0556 0.968 0.928 1.037
 FEK 0.2427 0.969 0.953 1.000
```



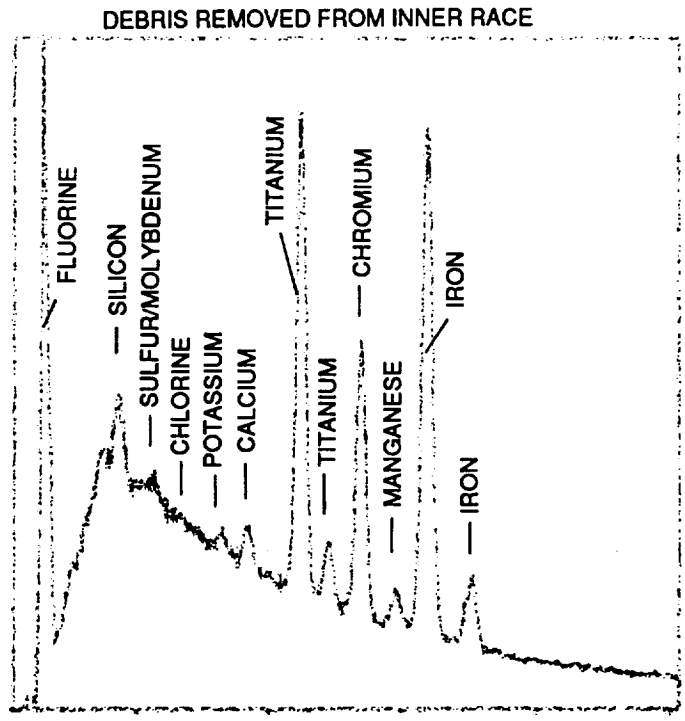
ELEM	CPS	WT % ELEM
AL K	15.2200	6.45
SI K	36.7749	11.75
CL K	10.2000	2.99
CA K	23.1500	6.99
TI K	93.4998	39.58
CR K	11.3000	5.96
FE K	38.2649	26.29
		100.00



TSA 8403

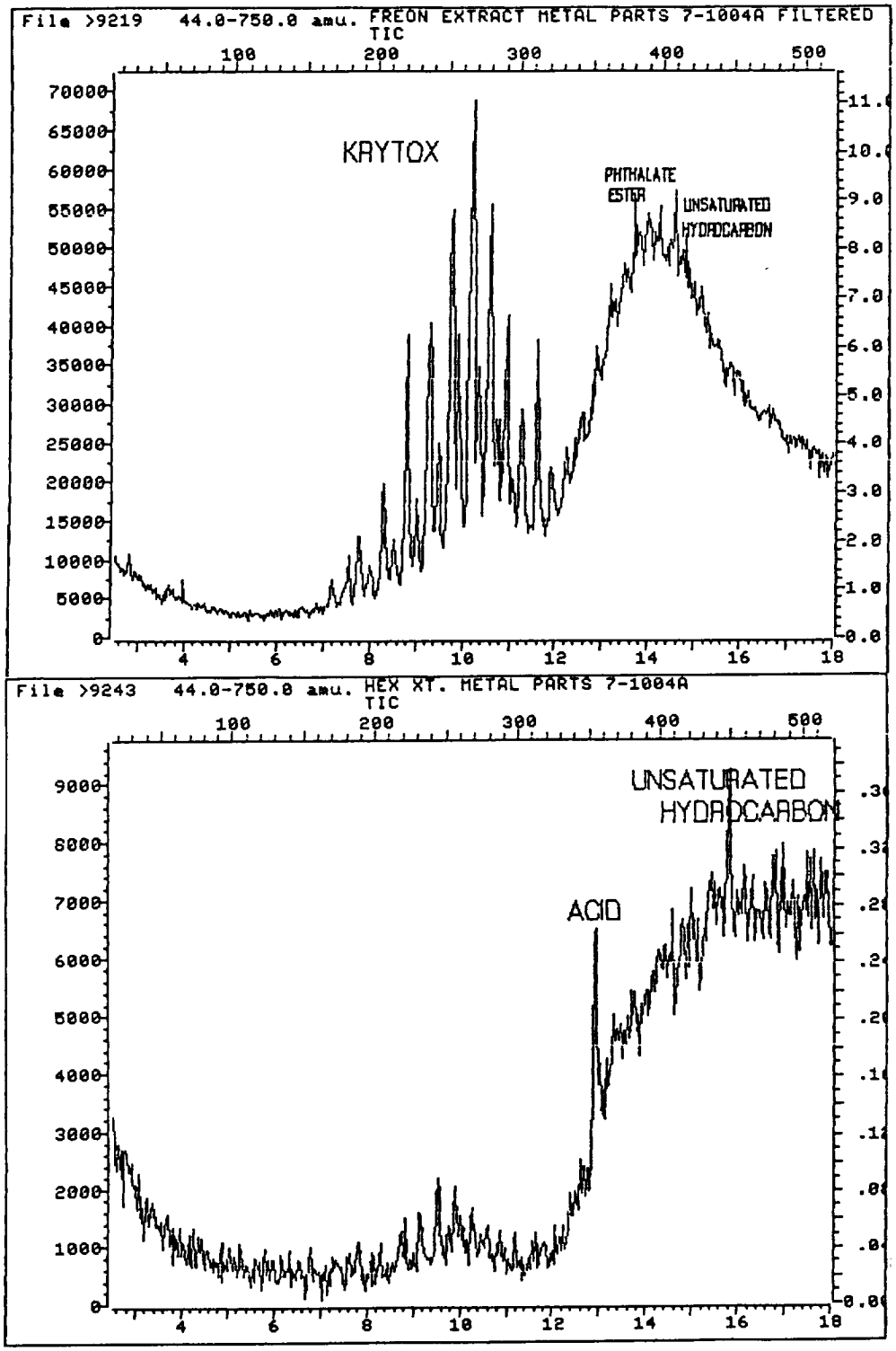
Figure 5. SEM/EDAX of particulate from 7-1004 races and balls.

```
LIST-%-ZAF:
LABEL = ITT 7-1004 5
01-MAR-91    08:50:17
  200.002  LIVE SECONDS
KV= 20.    TILT=45.    TKOFF=45.
            ZAF CORRECTION
 ELEM    K       Z       A       F

 NAK  0.0027  1.081   0.222   1.001
 ALK  0.0094  1.075   0.502   1.002
 SIK  0.0227  1.106   0.623   1.003
 S K  0.0084  1.109   0.799   1.009
 CLK  0.0046  1.058   0.857   1.016
 K K  0.0096  1.059   0.933   1.044
 CAK  0.0181  1.082   0.953   1.064
 TIK  0.2461  0.989   0.978   1.071
 CRK  0.1780  0.987   0.957   1.080
 FEK  0.4604  0.989   0.958   1.000

                                WT %
ELEM          CPS              ELEM
NA K        2.0238             1.13
AL K       14.1398             1.75
SI K       38.5046             3.28
S  K       13.5698             0.95
CL K        6.9449             0.50
K  K       12.6549             0.93
CA K       22.2047             1.65
TI K      240.9722            23.76
CR K      144.6983            17.45
FE K      290.0717            48.61
                              ------
                              100.00
```



TSA 8404

Figure 6. SEM/EDAX of particulate from 7-1004 races and balls.



TSA 8405

Figure 7. **Mass spectra of Freon (upper) and hexane (lower) extractions of 7-1004A races and balls.**

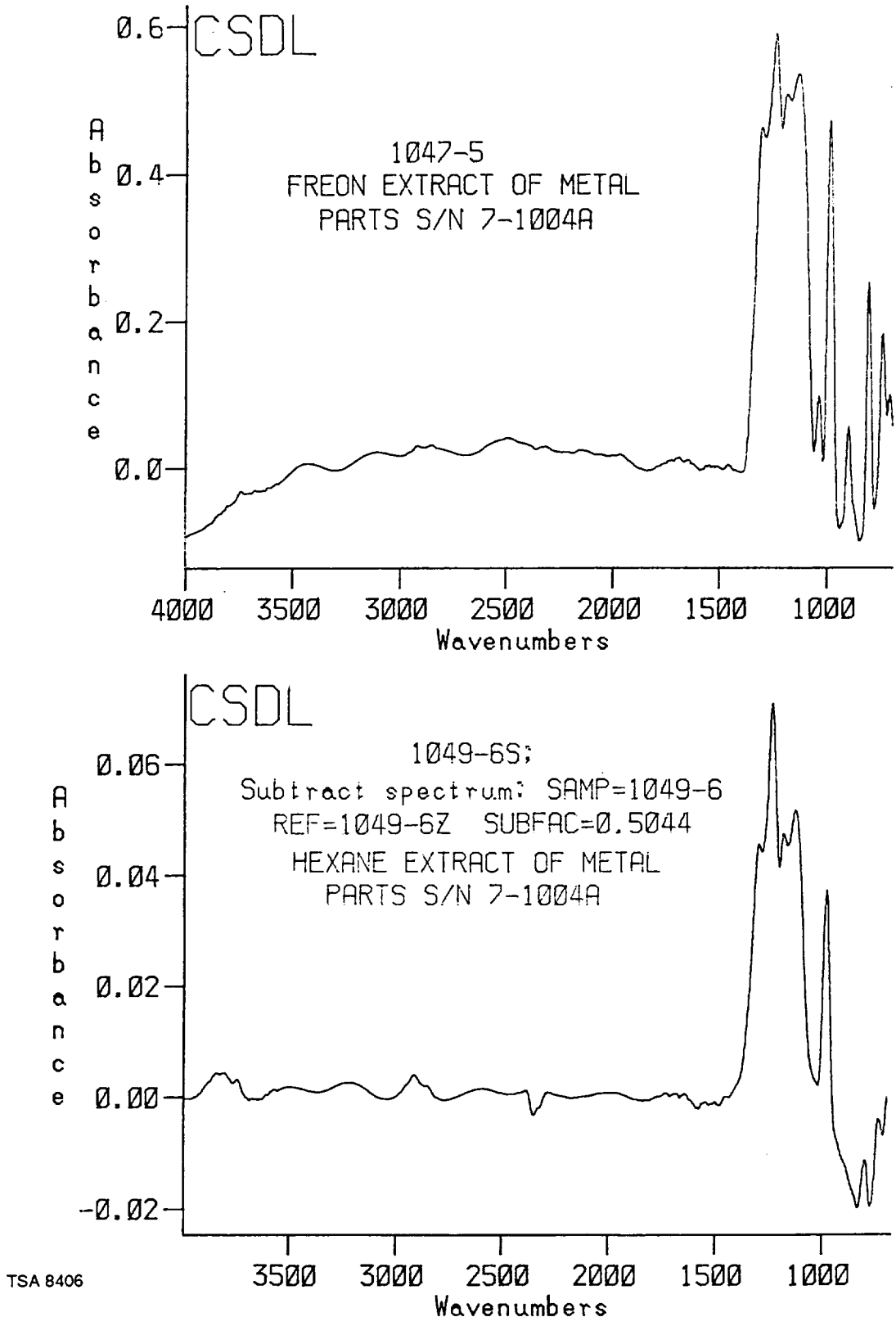
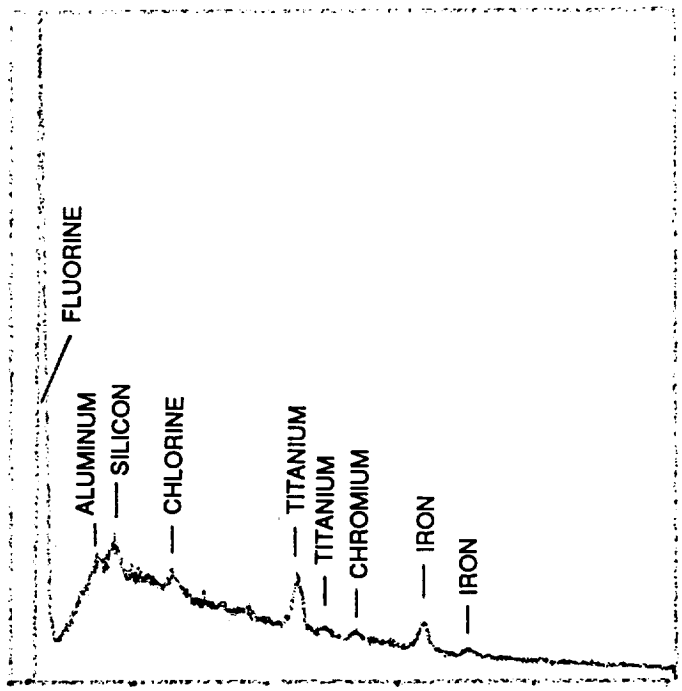


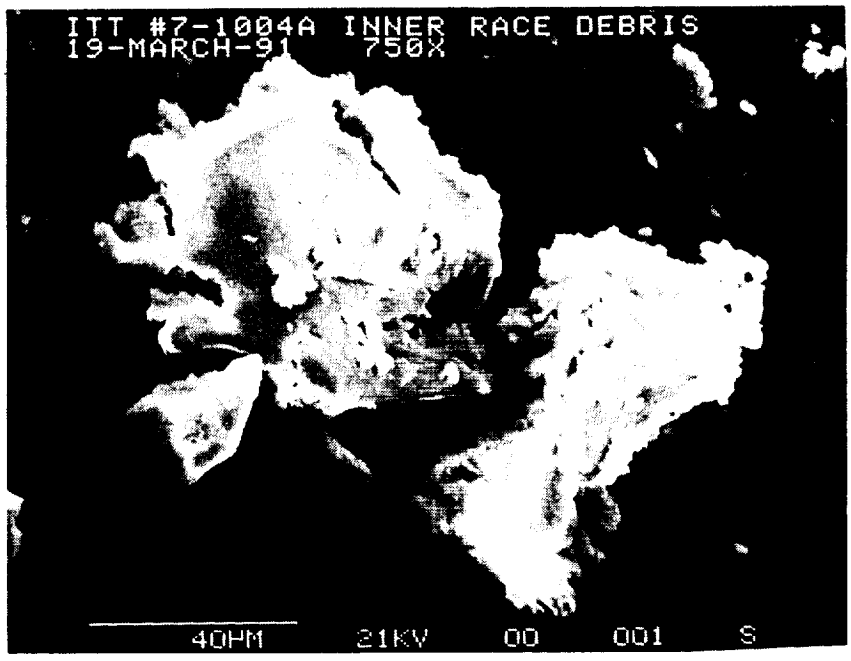
Figure 8. FTIR on extractions of 7-1004A races and balls.

```
LIST-%-ZAF:
LABEL = 1004A IR DBRS
15-MAR-91    13:23:57
  120.000  LIVE SECONDS
KV= 20.    TILT=45.    TKOFF=45.
           ZAF CORRECTION

 ELEM    K       Z       A       F

 ALK  0.0561  1.055   0.595   1.006
 SIK  0.0985  1.086   0.664   1.004
 CLK  0.0663  1.035   0.850   1.014
 TIK  0.3189  0.969   0.972   1.036
 CRK  0.0615  0.967   0.941   1.048
 FEK  0.2849  0.968   0.960   1.000
```

DEBRIS REMOVED FROM INNER RACE



ELEM	CPS	WT % ELEM
AL K	9.7833	8.87
SI K	19.4833	13.60
CL K	11.6000	7.43
TI K	36.3833	32.67
CR K	6.1083	6.76
FE K	20.9167	30.66
		100.00



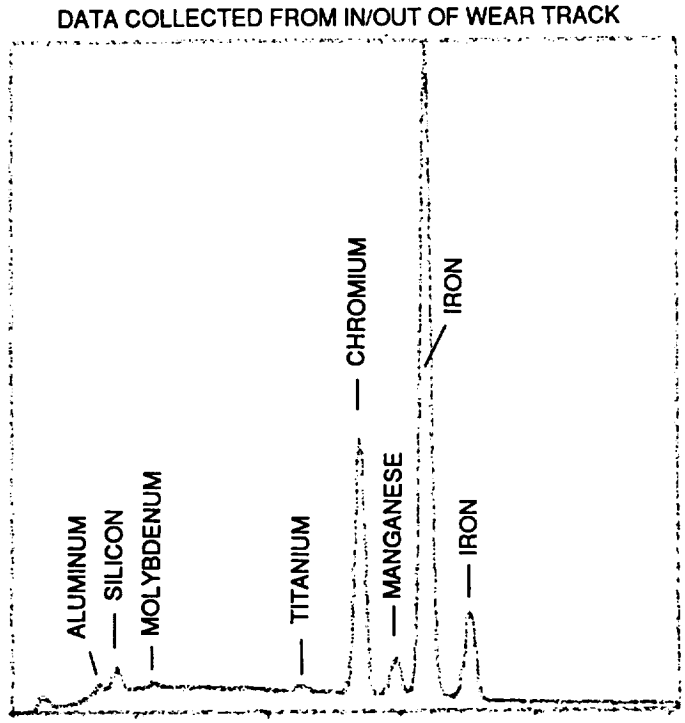
TSA 8407

Figure 9. SEM/EDAX of particulate from 7-1004A races and balls.

LIST-%-ZAF:
LABEL = 1004A IR I/OWT
19-MAR-91 10:01:54
120.000 LIVE SECONDS
KV= 20. TILT=45. TKOFF=45.
ZAF CORRECTION

ELEM	K	Z	A	F
ALK	0.0028	1.084	0.445	1.001
SIK	0.0072	1.115	0.575	1.002
MOL	0.0046	0.899	0.891	1.002
TIK	0.0050	0.998	0.978	1.134
CRK	0.2194	0.997	0.993	1.195
MNK	0.0049	0.979	0.997	1.000
FEK	0.7641	0.999	0.978	1.000

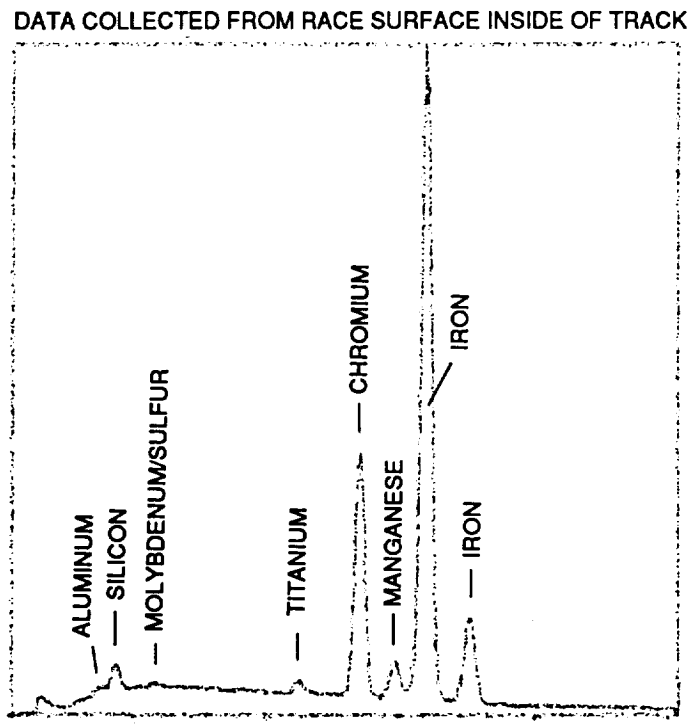
ELEM	CPS	WT % ELEM
AL K	15.0750	0.59
SI K	43.0166	1.12
MO L	10.2250	0.57
TI K	17.1417	0.45
CR K	630.6328	18.56
MN K	12.4167	0.50
FE K	1702.5653	78.21
		100.00



TSA 8408

Figure 10. SEM/EDAX of particulate from 7-1004A races and balls.

```
LIST-%-ZAF:
LABEL = 1004A IR IWT
19-MAR-91    10:26:10
  120.003  LIVE SECONDS
KV= 20.    TILT=45.    TKOFF=45.
            ZAF CORRECTION


 ELEM    K       Z       A       F

 ALK 0.0029 1.083 0.445 1.001
 SIK 0.0086 1.114 0.576 1.002
 MOL 0.0043 0.899 0.891 1.002
 TIK 0.0092 0.998 0.978 1.133
 CRK 0.2122 0.996 0.992 1.195
 MNK 0.0054 0.979 0.996 1.000
 FEK 0.7637 0.998 0.978 1.000



                                 WT %
ELEM          CPS               ELEM
AL K        15.1580             0.61
SI K        50.4322             1.34
MO L         9.2248             0.53
TI K        31.0827             0.83
CR K       595.9704            17.96
MN K        13.2997             0.55
FE K      1662.8556            78.18
                               ------
                               100.00
```



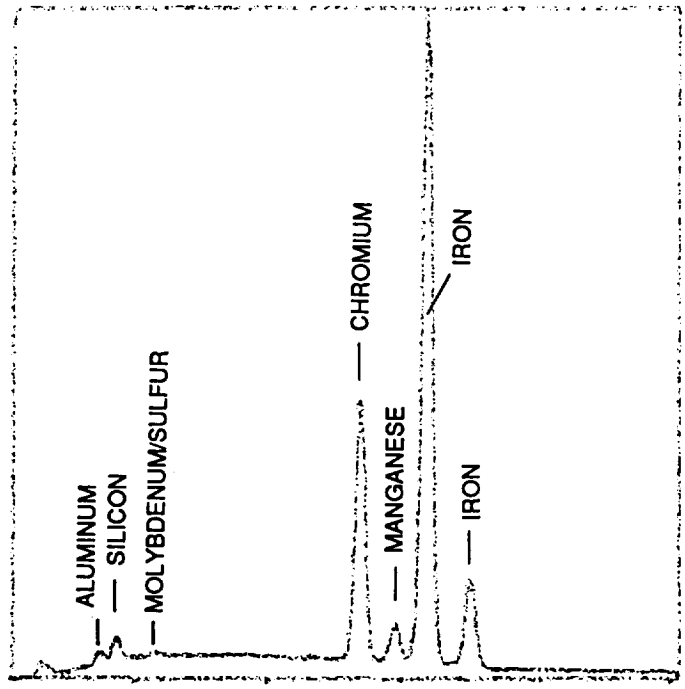
TSA 8409

Figure 11. SEM/EDAX of particulate from 7-1004A races and balls.

```
LIST-%-ZAF:
LABEL = 1004A IR OWT
19-MAR-91    10:15:37
  120.001  LIVE SECONDS
KV= 20.    TILT=45.    TKOFF=45.
           ZAF CORRECTION

 ELEM    K       Z       A       F

 ALK 0.0032  1.084   0.445   1.001
 SIK 0.0072  1.115   0.575   1.002
 MOL 0.0041  0.899   0.891   1.002
 CRK 0.2289  0.997   0.993   1.194
 MNK 0.0055  0.979   0.998   1.000
 FEK 0.7592  0.999   0.978   1.000
```

ELEM	CPS	WT % ELEM
AL K	17.1332	0.67
SI K	43.0497	1.12
MO L	9.0916	0.51
CR K	657.8534	19.37
MN K	13.9582	0.57
FE K	1691.2957	77.76
		100.00

DATA COLLECTED FROM RACE SURFACE OUTSIDE OF TRACK



TSA 8410

Figure 12. SEM/EDAX of particulate from 7-1004A races and balls.

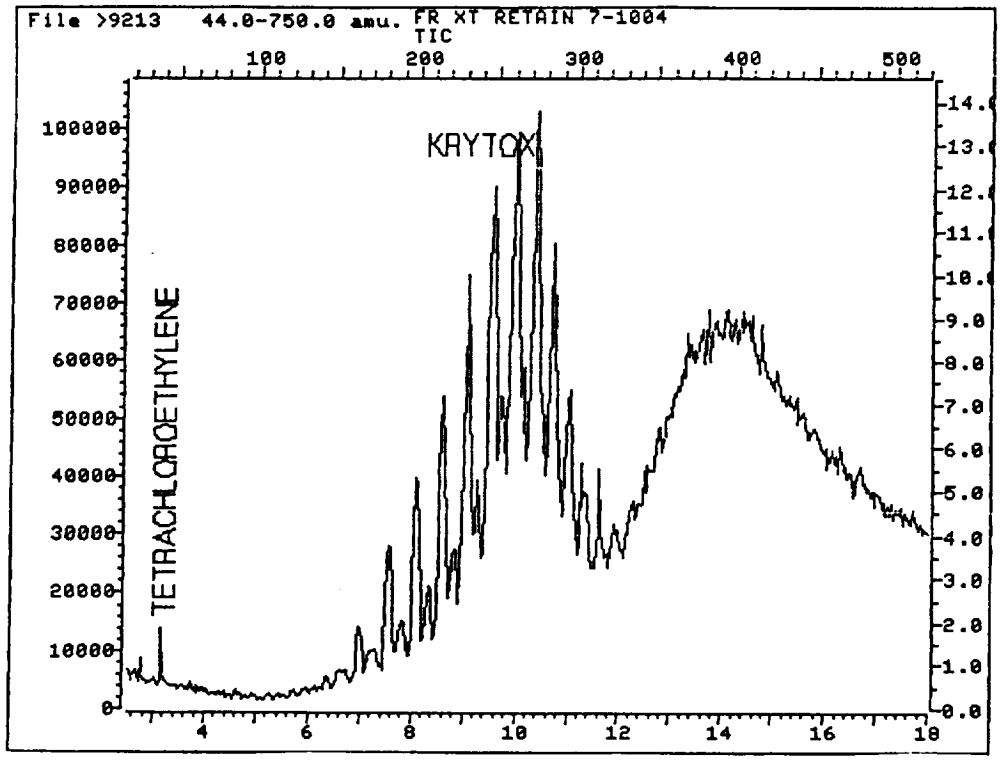


Figure 13. Mass spectrum of Freon extraction of 7-1004 retainer.

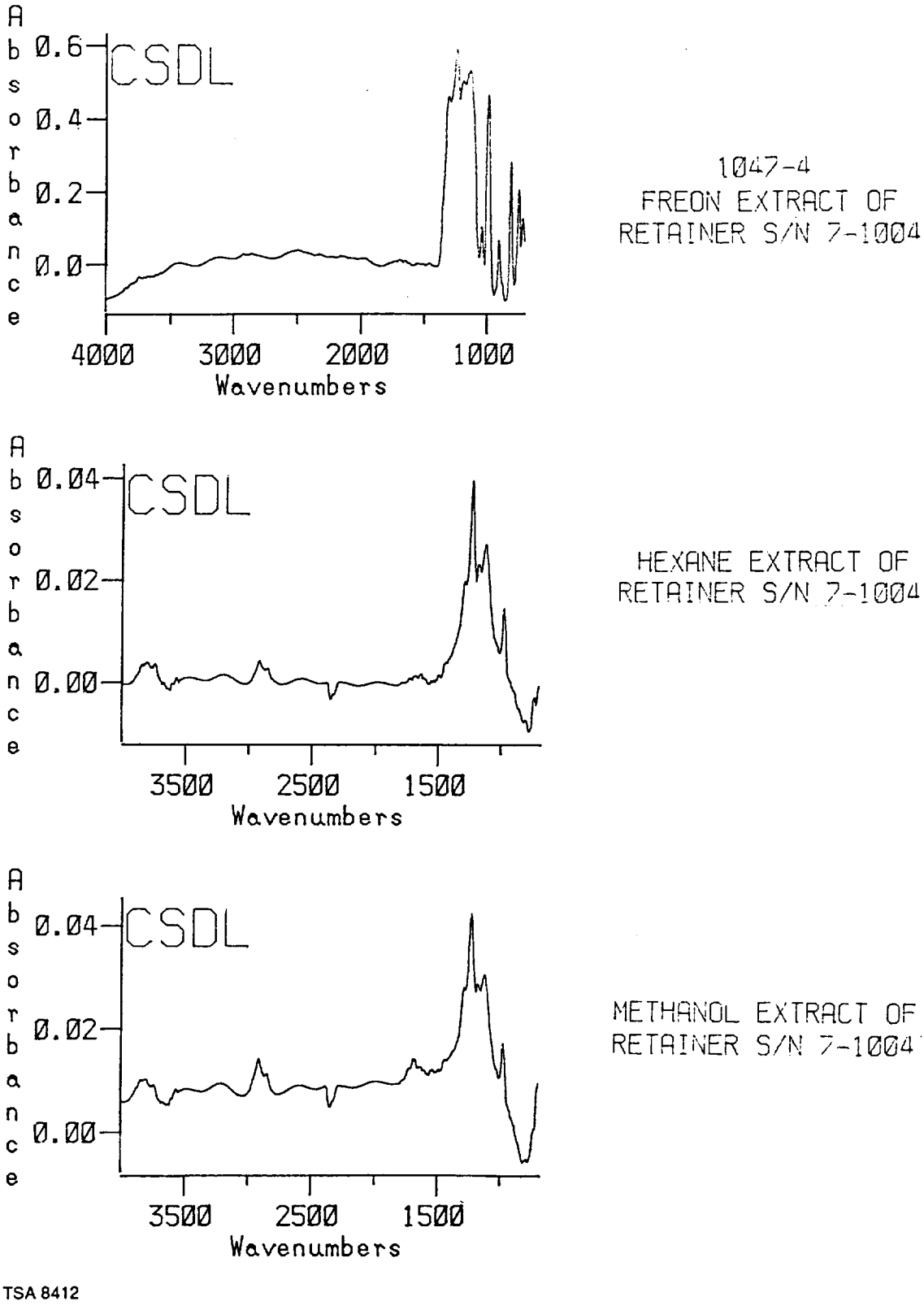


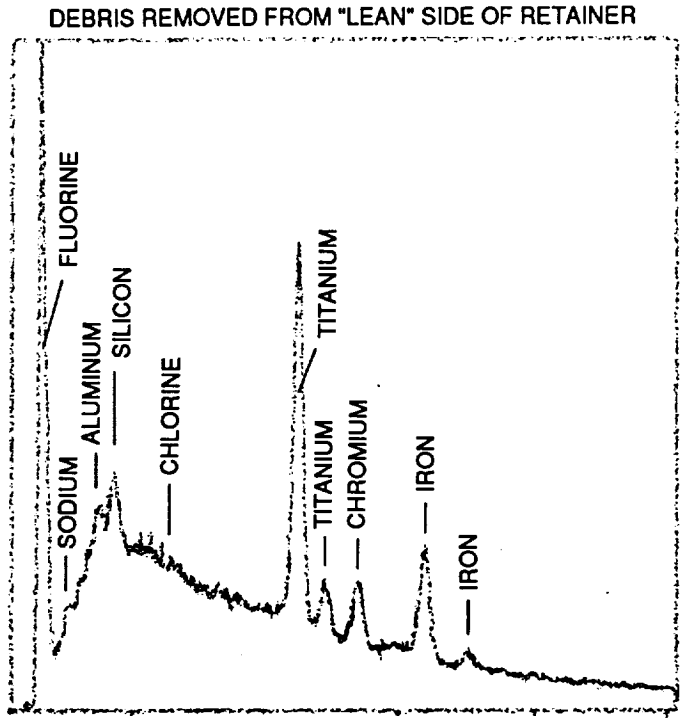
Figure 14. FTIR on extractions of 7-1004 retainer.

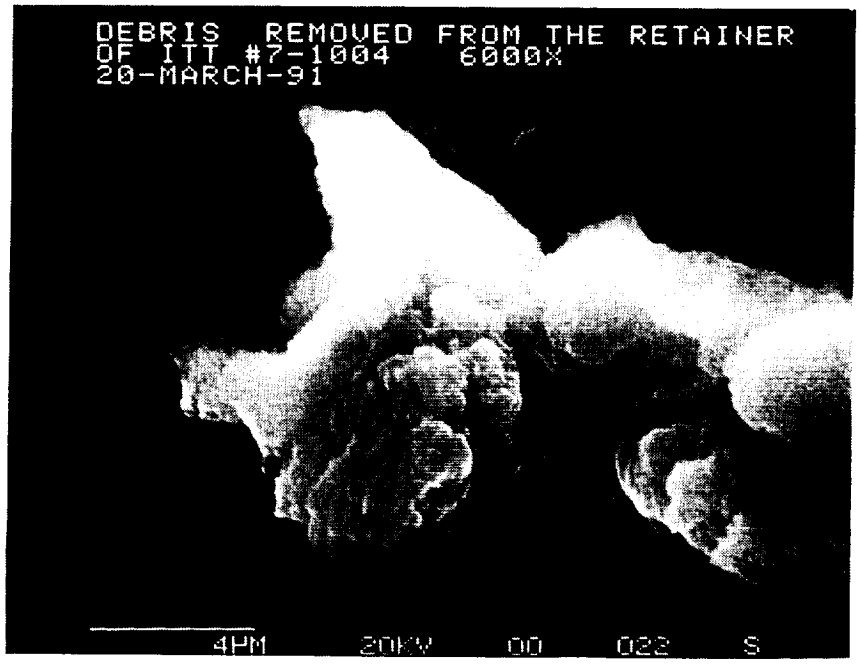
10049

LIST-%-ZAF:
LABEL = ITT 7-1004 9
20-MAR-91 10:38:00
120.001 LIVE SECONDS
KV= 20. TILT=45. TKOFF=45.
ZAF CORRECTION

ELEM	K	Z	A	F
NAK	0.0142	1.075	0.279	1.001
ALK	0.0314	1.069	0.556	1.003
SIK	0.0407	1.099	0.652	1.004
CLK	0.0089	1.049	0.869	1.021
TIK	0.4765	0.982	0.986	1.034
CRK	0.0921	0.980	0.927	1.035
FEK	0.2414	0.981	0.948	1.000

ELEM	CPS	WT % ELEM
NA K	5.0083	4.73
AL K	22.2832	5.28
SI K	32.7331	5.66
CL K	6.3000	0.95
TI K	220.8485	47.62
CR K	35.4248	9.79
FE K	71.9995	25.97
		100.00



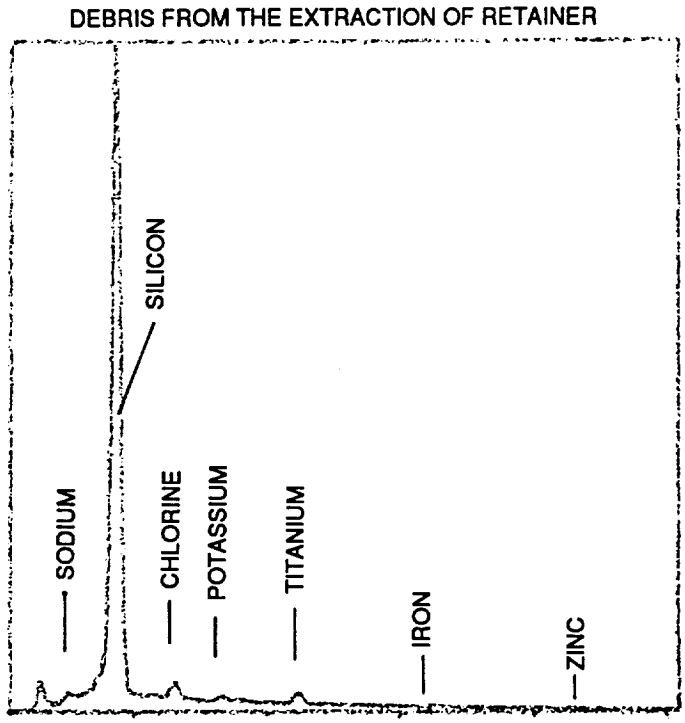


TSA 8413

Figure 15. SEM/EDAX of particulate from 7-1004 retainer.

```
LIST-%-ZAF:
LABEL = ITT 7-1004 3
26-FEB-91    14:41:39
  200.003  LIVE SECONDS
KV= 20.    TILT=45.    TKOFF=45.
           ZAF CORRECTION

 ELEM    K       Z       A       F

 NAK  0.0139  0.985  0.720  1.016
 SIK  0.8417  1.009  0.953  1.001
 CLK  0.0246  0.954  0.738  1.002
 K K  0.0117  0.959  0.853  1.003
 TIK  0.0300  0.897  0.944  1.001
 FEK  0.0083  0.893  0.984  1.002
 ZNK  0.0101  0.863  0.998  1.000
```

```
                                    WT %
ELEM          CPS                   ELEM
NA K        16.8297                 1.92
SI K      2329.7749                87.51
CL K        60.2541                 3.49
K  K        25.1846                 1.42
TI K        47.8443                 3.54
FE K         8.5749                 0.95
ZN K         5.2649                 1.17
                                    ------
                                    100.00
```



TSA 8414

Figure 16. SEM/EDAX of particulate from 7-1004 retainer.

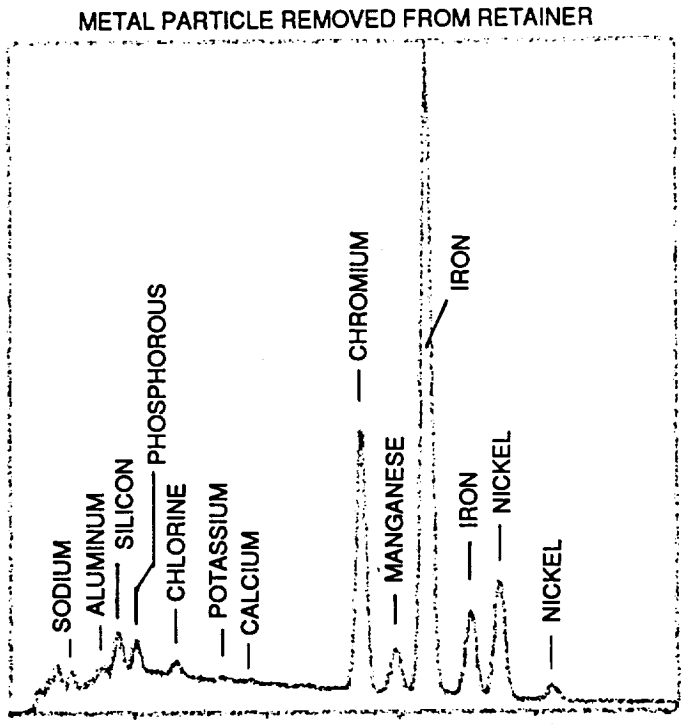
10647

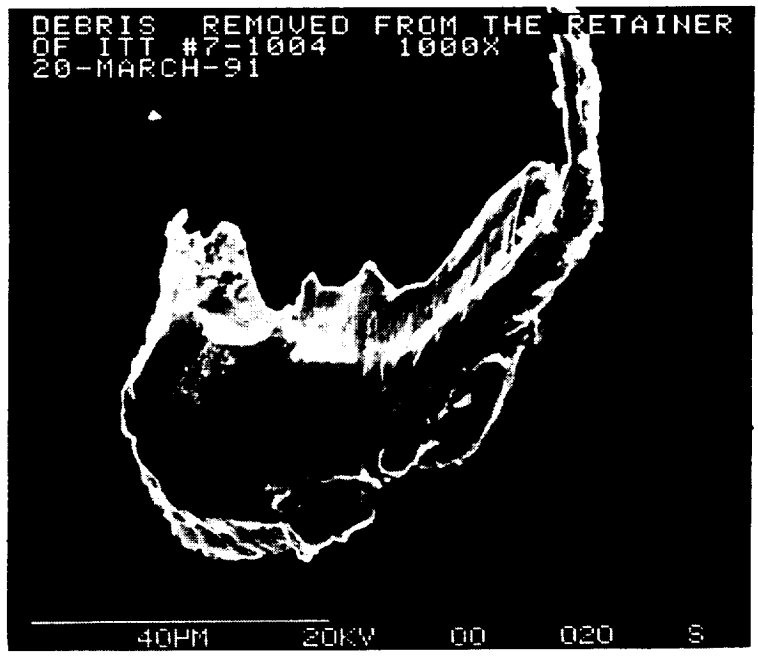
LIST-%-ZAF:
LABEL = ITT 7-1004 7
20-MAR-91 08:00:22
120.003 LIVE SECONDS
KV= 20. TILT=45. TKOFF=45.
ZAF CORRECTION

ELEM	K	Z	A	F
NAK	0.0074	1.080	0.178	1.000
ALK	0.0022	1.074	0.432	1.001
SIK	0.0086	1.105	0.564	1.002
P K	0.0064	1.078	0.672	1.003
CLK	0.0043	1.059	0.831	1.009
K K	0.0008	1.059	0.917	1.026
CAK	0.0012	1.082	0.944	1.041
CRK	0.1797	0.987	0.992	1.168
MNK	0.0035	0.970	0.996	1.020
FEK	0.5954	0.989	0.981	1.025
NIK	0.1590	1.006	0.940	1.000

ELEM	CPS	WT % ELEM
NA K	16.4413	3.85
AL K	9.9581	0.48
SI K	43.4074	1.38
P K	31.4660	0.88
CL K	19.2579	0.49
K K	3.1166	0.08
CA K	4.4249	0.11
CR K	435.0489	15.71
MN K	7.4998	0.36
FE K	1117.3591	59.84
NI K	224.2618	16.82

		100.00





TSA 8415

Figure 17. SEM/EDAX of particulate from 7-1004 retainer.

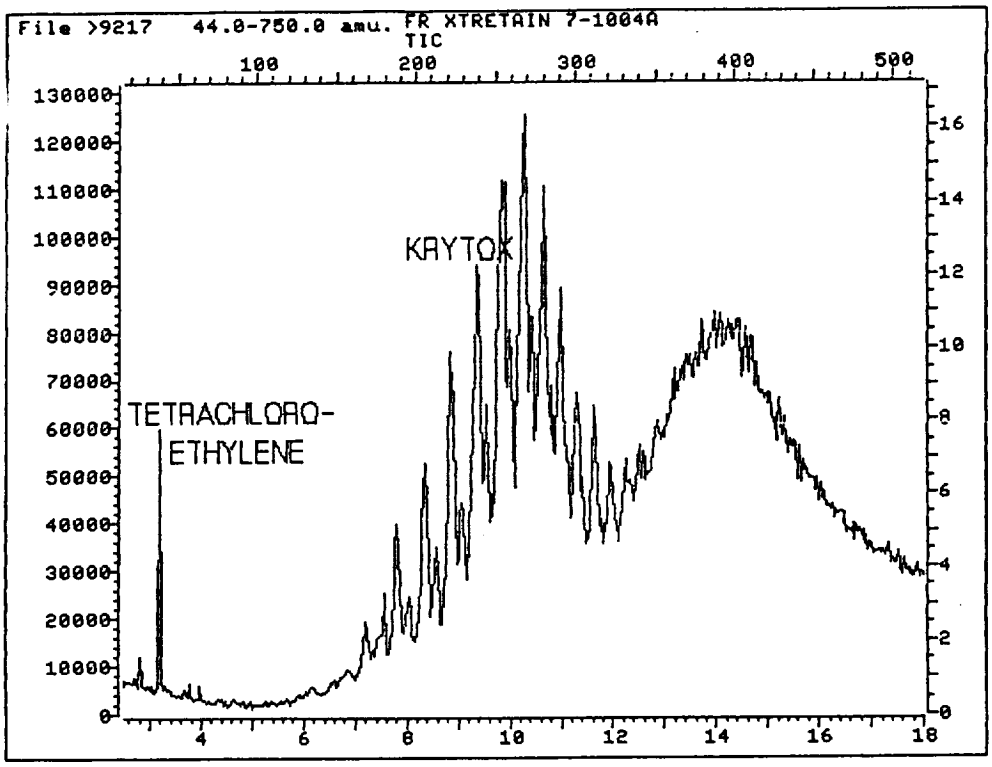


Figure 18. Mass spectrum of Freon extraction of 7-1004A retainer.

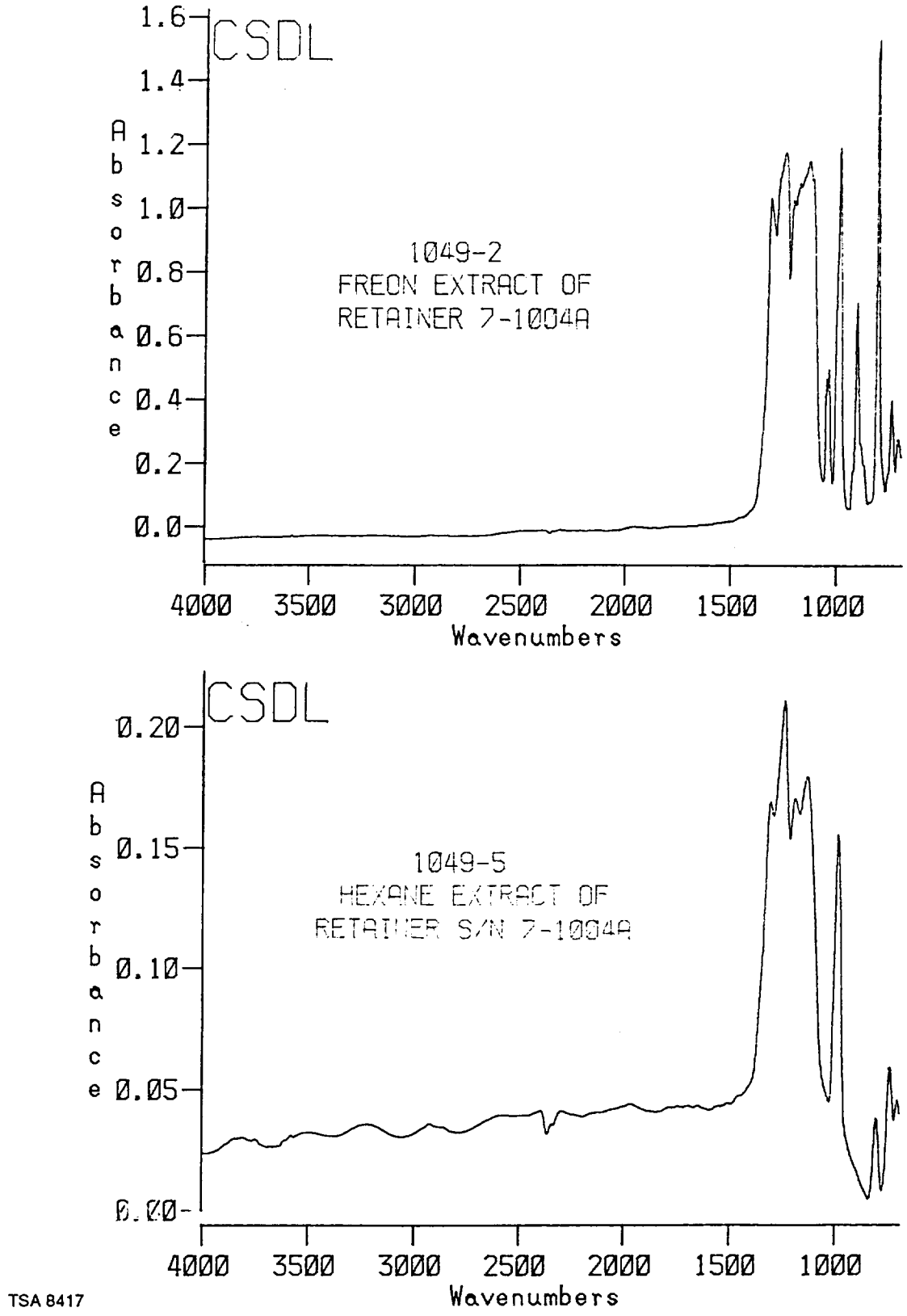


Figure 19. FTIR on extractions of 7-1004A retainer.

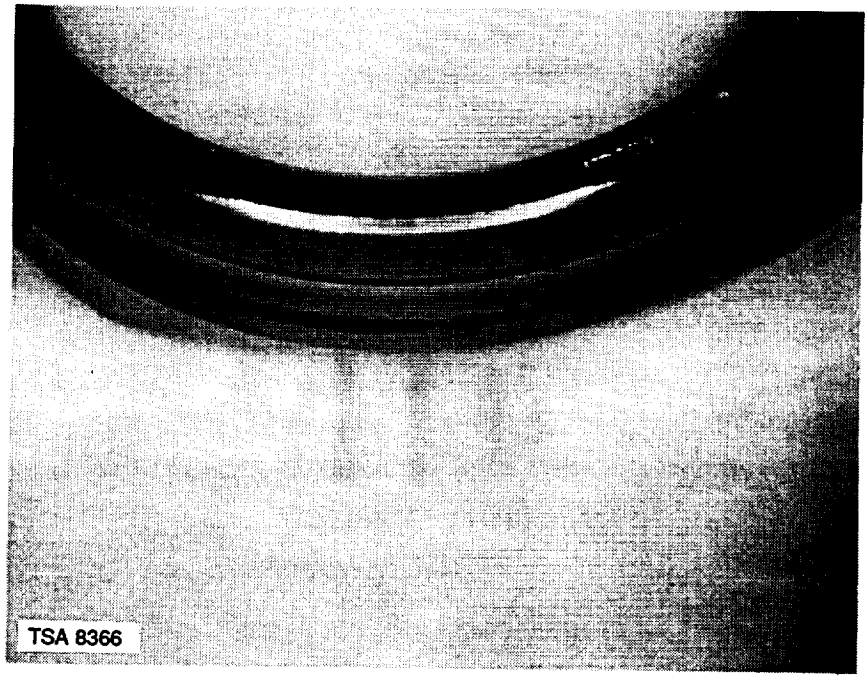


Figure 20. Bearing No. 1004, Inner Race, 10X Magnification.

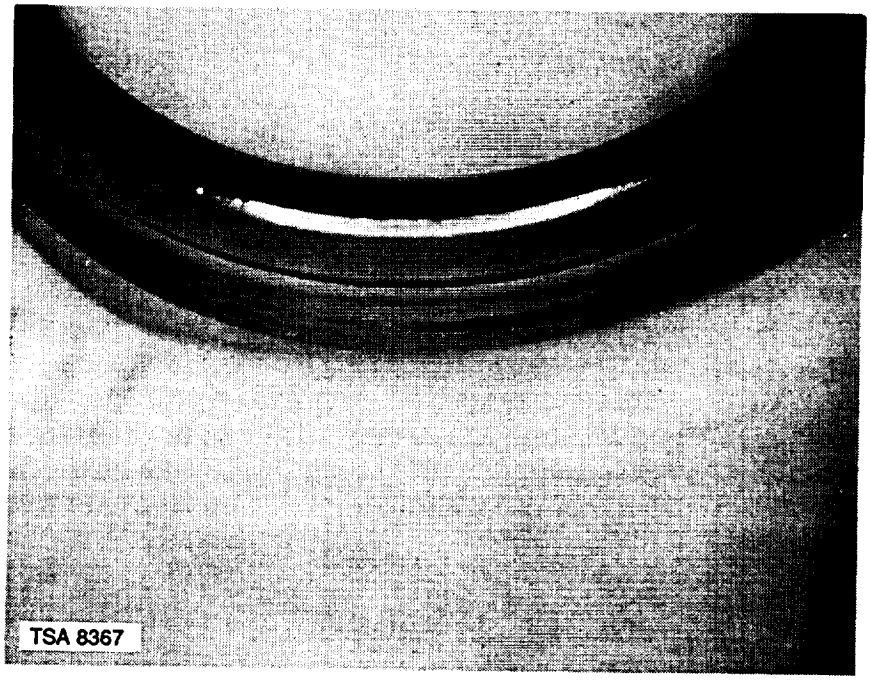


Figure 21. Bearing No. 1004, Inner Race, 10X Magnification.

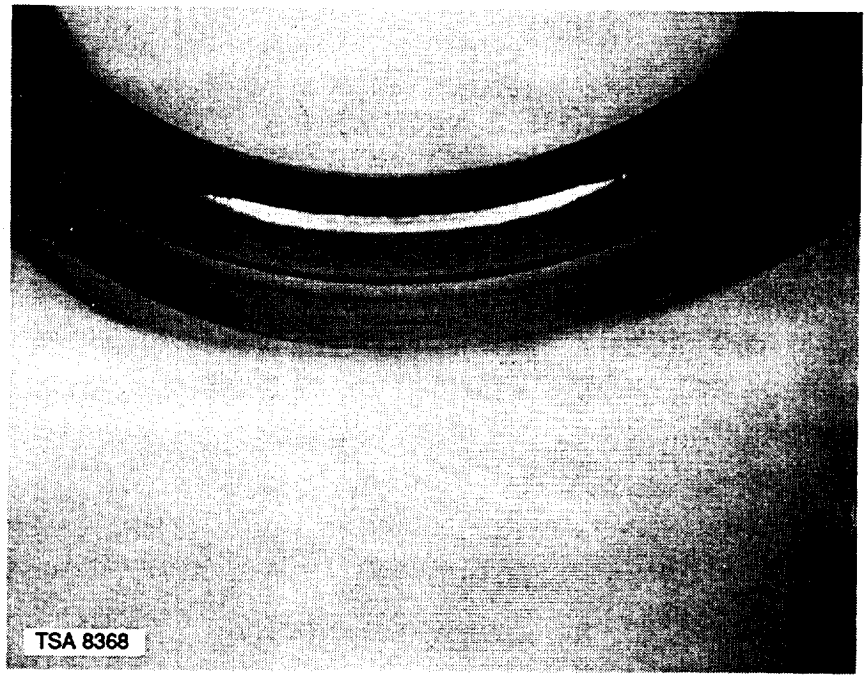


Figure 22. Bearing No. 1004, Inner Race, 10X Magnification.

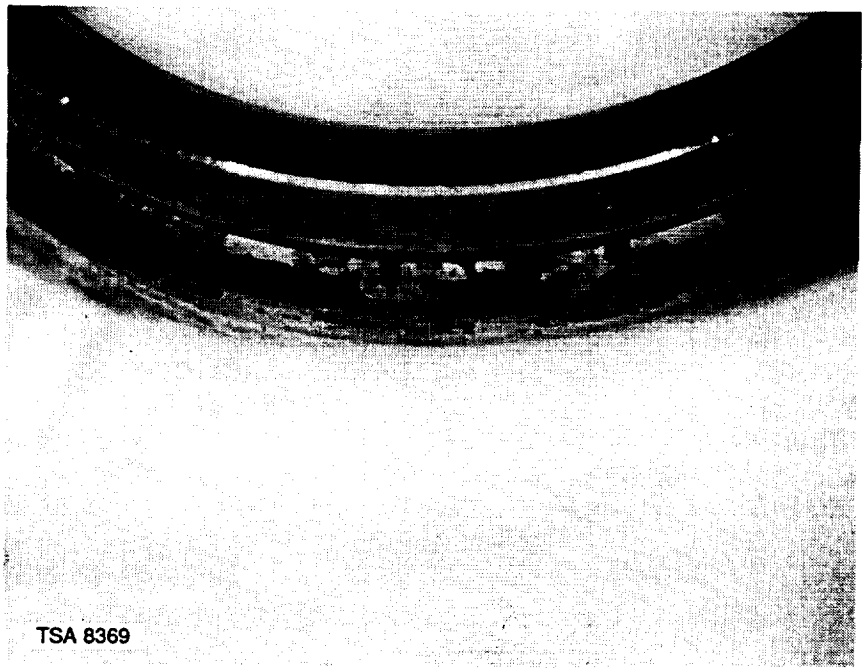


Figure 23. Bearing No. 1004A, Inner Race, 12X Magnification.

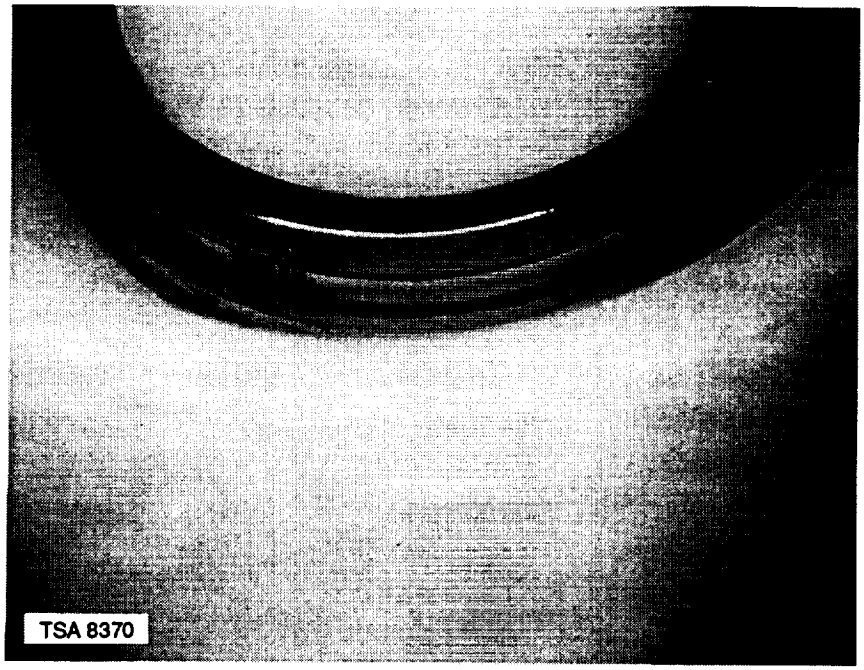


Figure 24. Bearing No. 1004A, Inner Race, 7.5X Magnification.

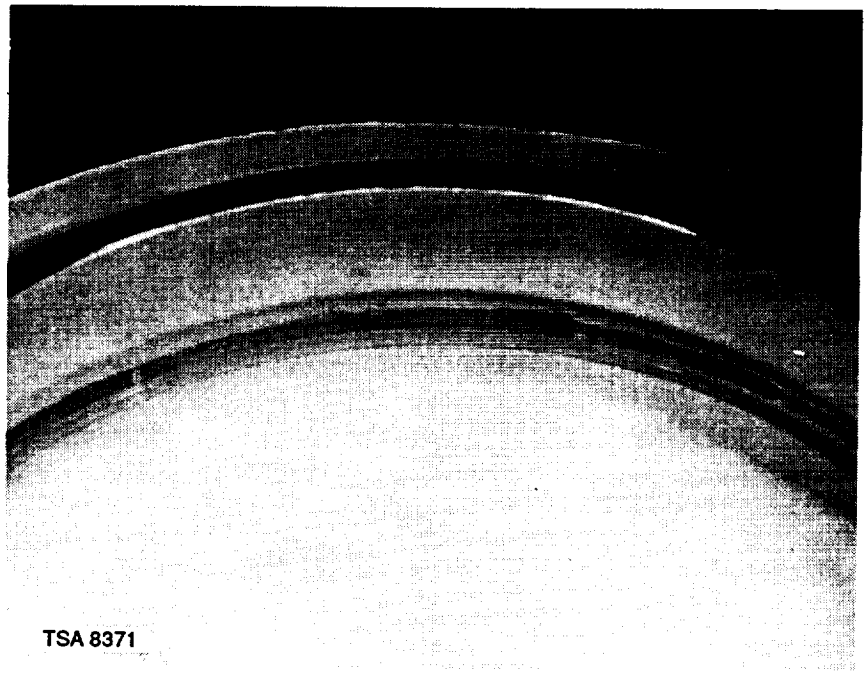


Figure 25. Bearing No. 1004, Outer Race, 10X Magnification.

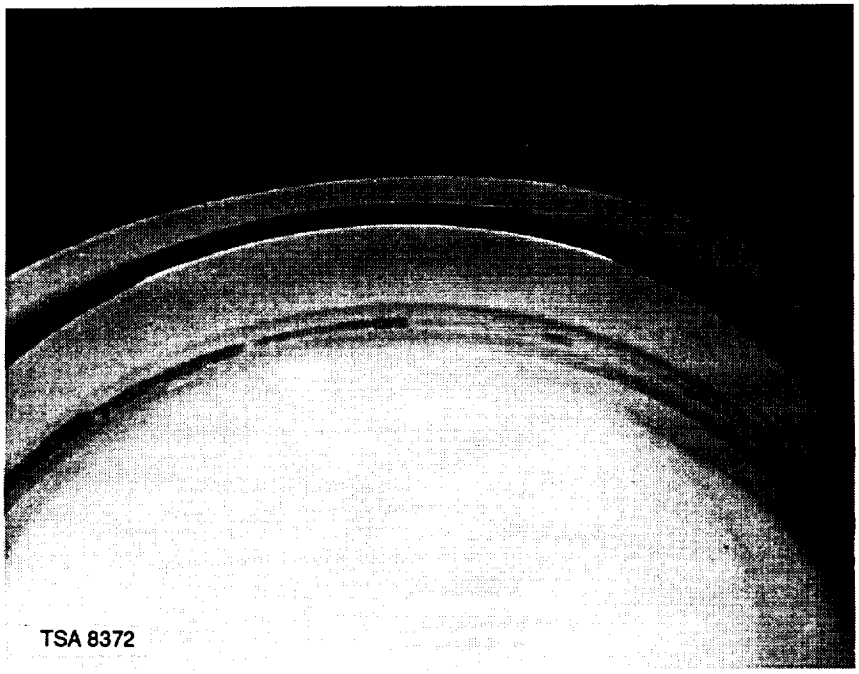


Figure 26. Bearing No. 1004, Outer Race, 7.5X Magnification.

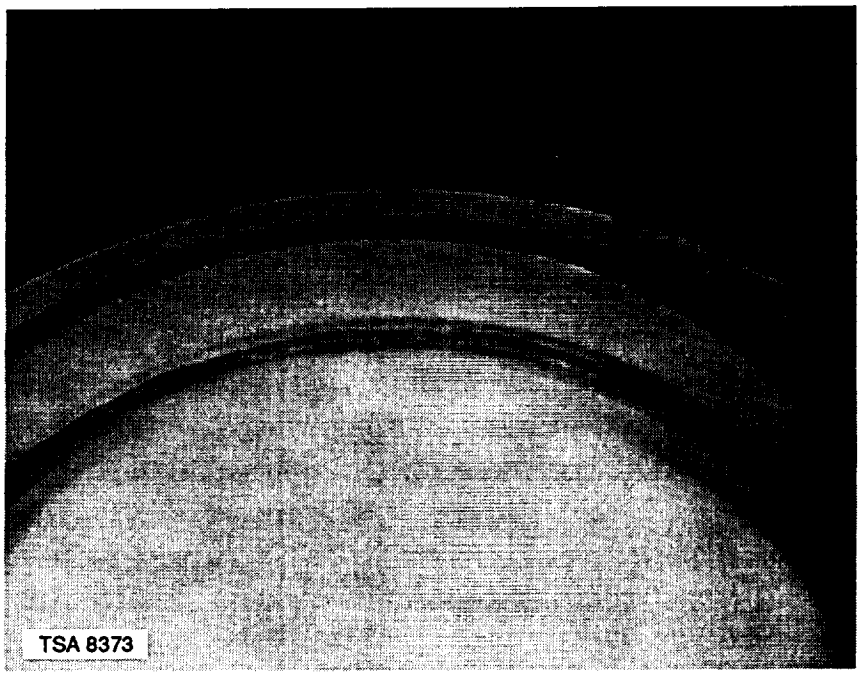


Figure 27. Bearing No. 1004A, Outer Race, 7.5X Magnification.

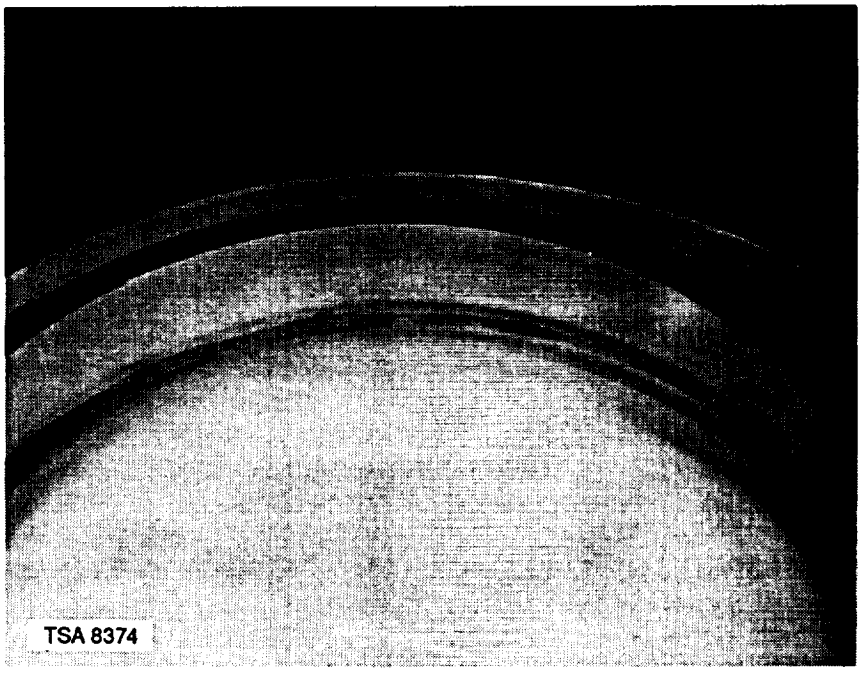


Figure 28. Bearing No. 1004A, Outer Race, 7.5X Magnification.

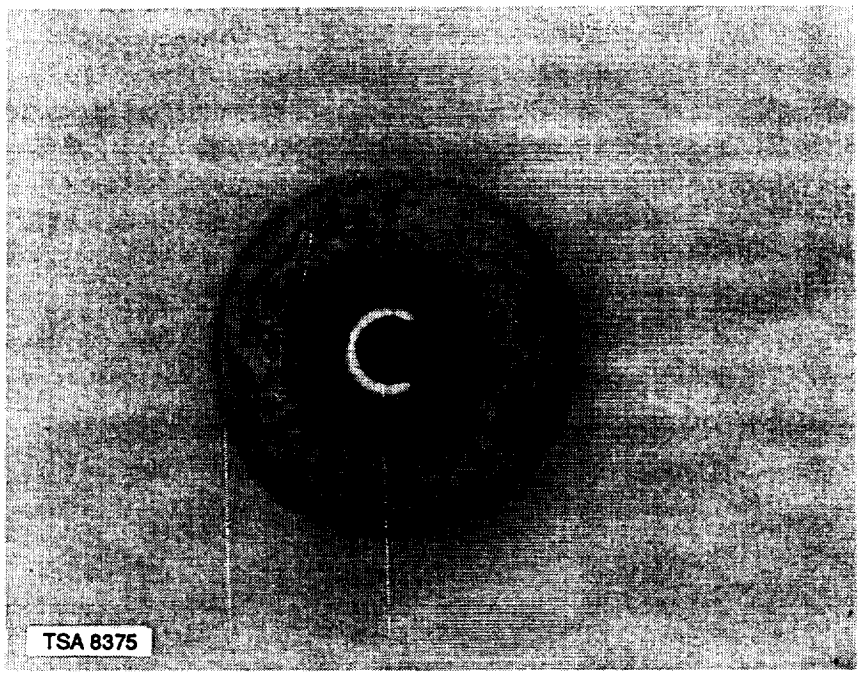


Figure 29. Bearing No. 1004, Ball Surface, 25X Magnification (4/10/91).

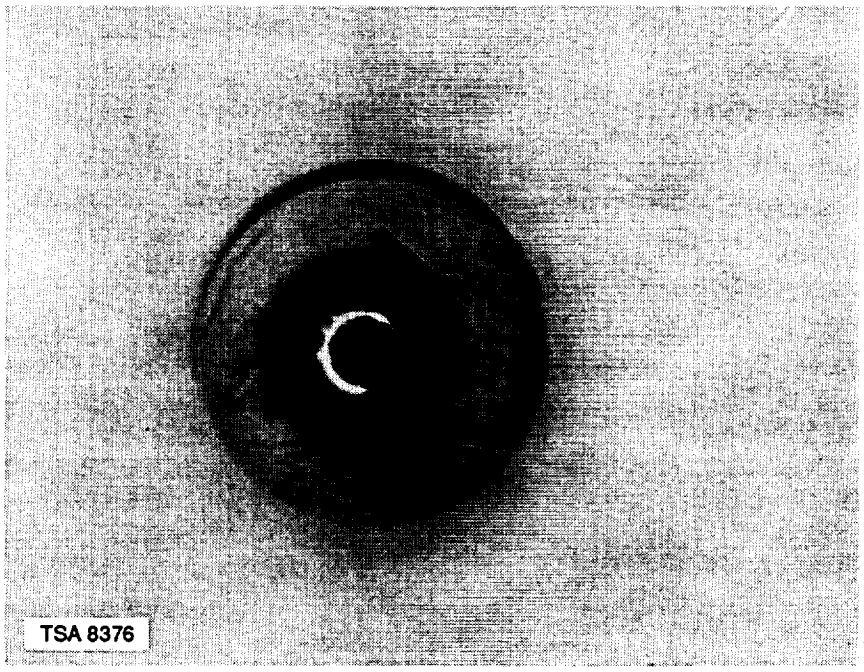


Figure 30. Bearing No. 1004, Ball Surface, 25X Magnification (4/10/91).

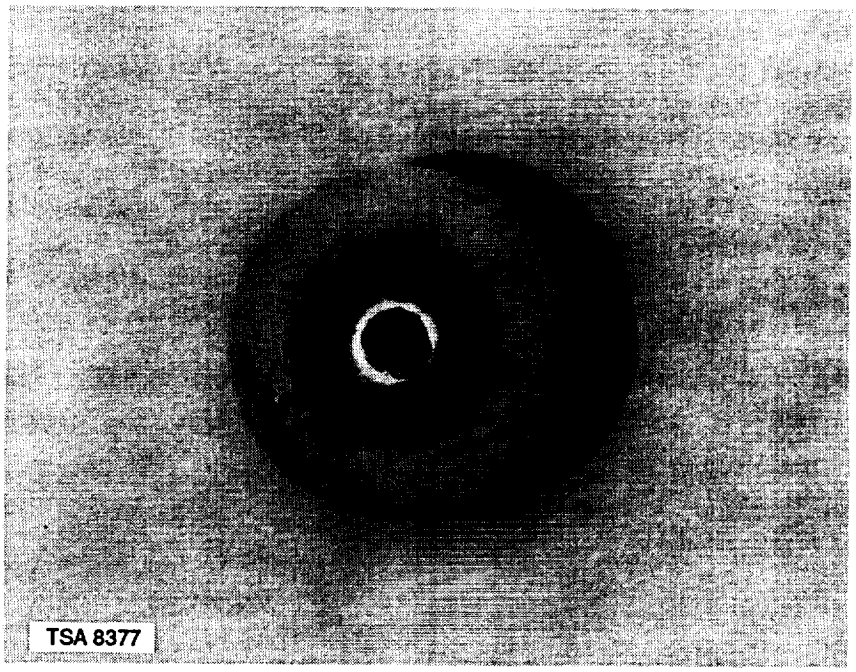


Figure 31. Bearing No. 1004A, Ball Surface, 25X Magnification (4/10/91).

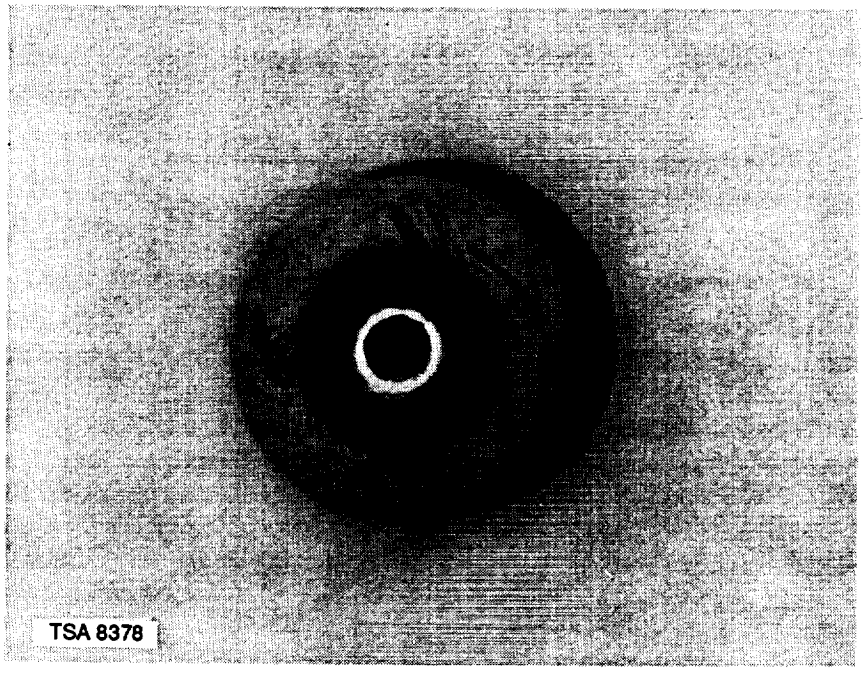


Figure 32. Bearing No. 1004A, Ball Surface, 25X Magnification (4/10/91).

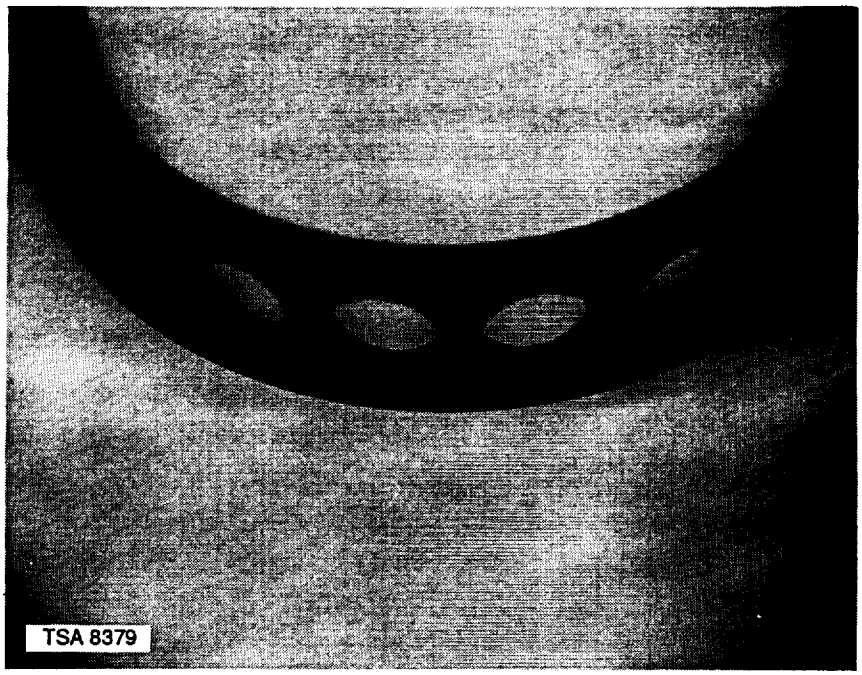


Figure 33. Bearing No. 1004, Retainer, 7.5X Magnification.

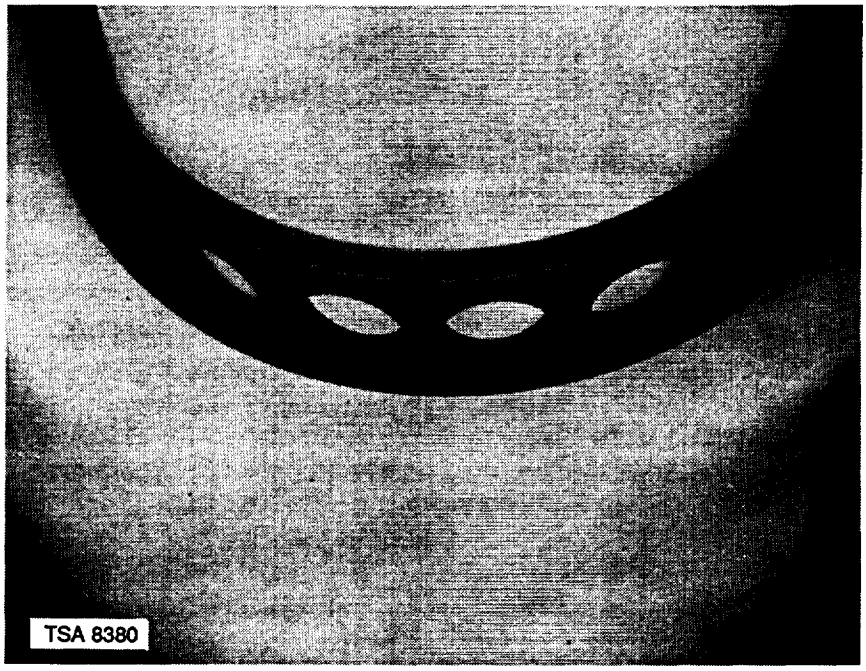


Figure 34. Bearing No. 1004, Retainer, 7.5X Magnification.

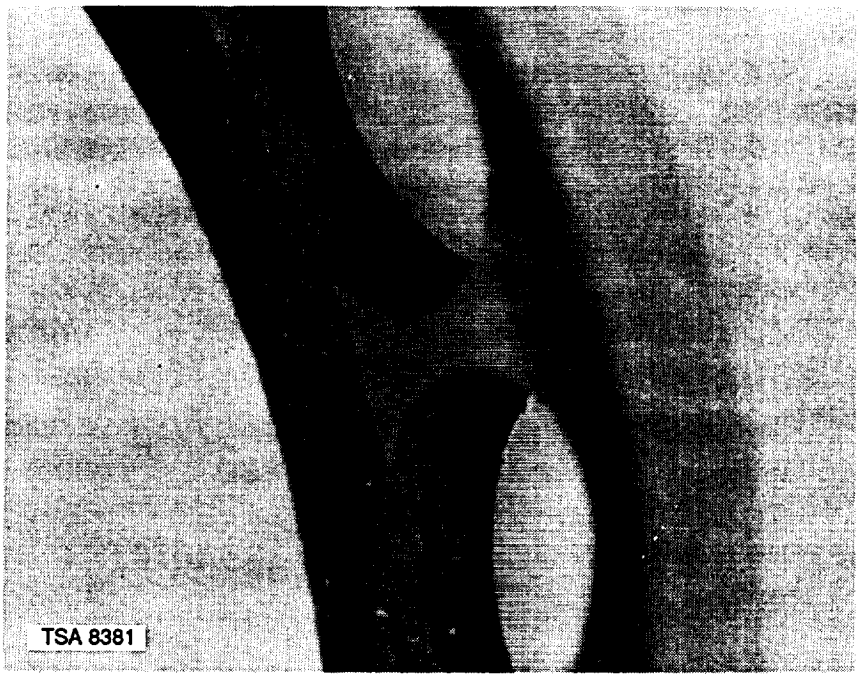


Figure 35. Bearing No. 1004, Retainer, 25X Magnification.

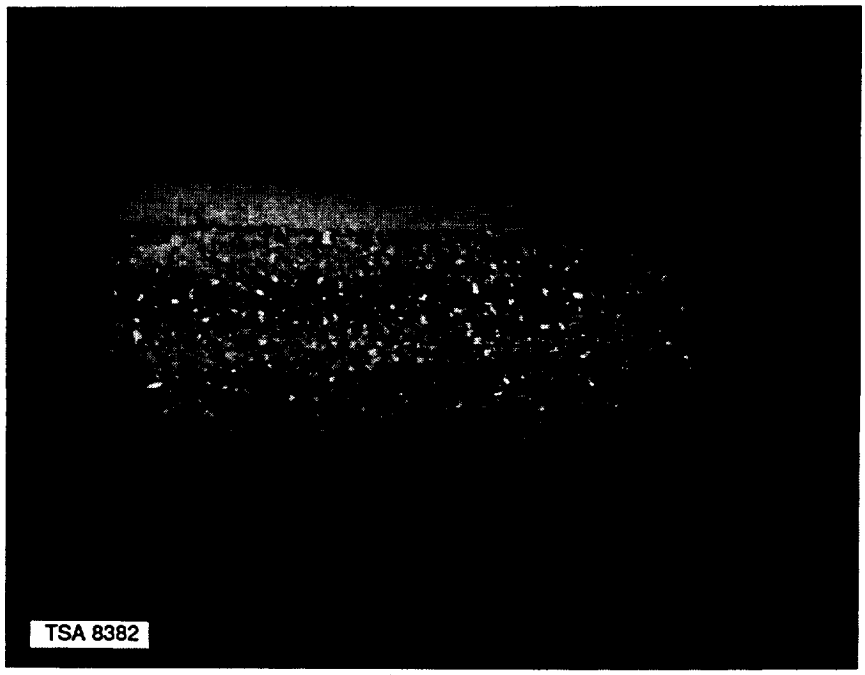


Figure 36. Bearing No. 1004, Inner Race, 125X Magnification (3/22/91).

Figure 37. Bearing No. 1004A, Inner Race, 125X Magnification (3/22/91).

Figure 38. Bearing No. 1004, Outer Race, 125X Magnification (3/20/91).

Figure 39. Bearing No. 1004A, Outer Race, 125X Magnification (3/20/91).

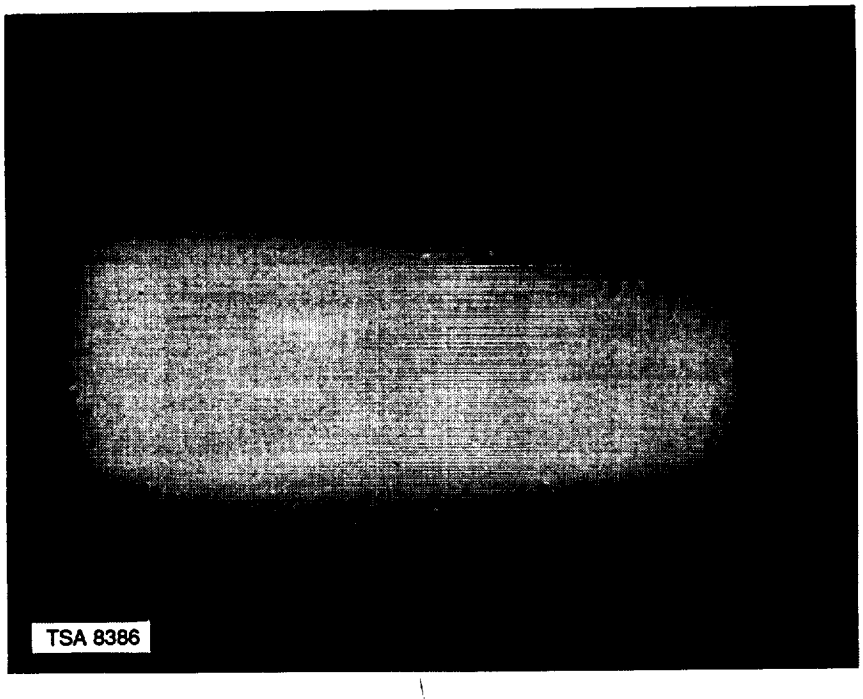


Figure 40. Bearing No. 1004, Inner Race, 125X Magnification (3/22/91).

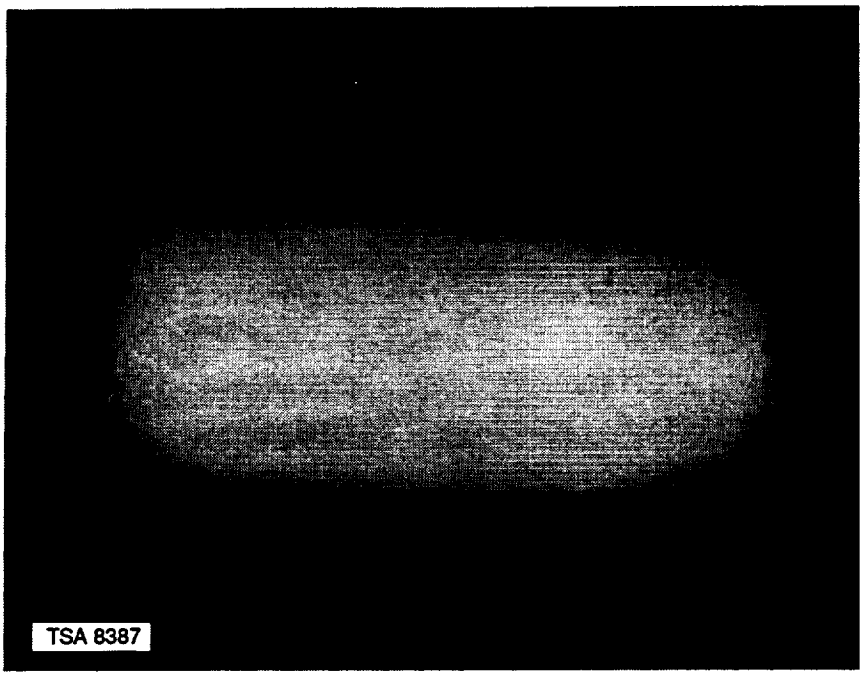


Figure 41. Bearing No. 1004A, Inner Race, 125X Magnification (3/22/91).

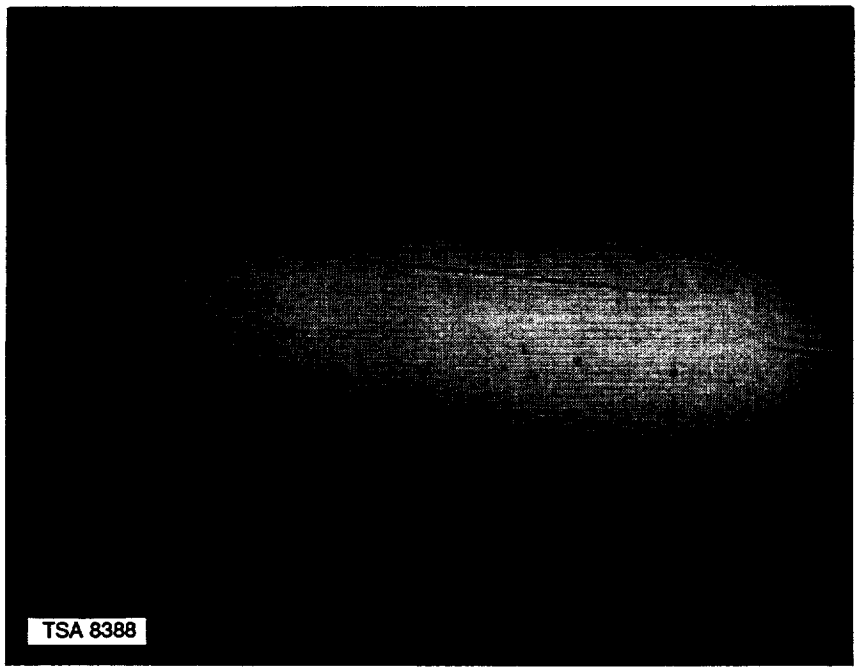


Figure 42. Bearing No. 1004, Outer Race, 125X Magnification (3/20/91).

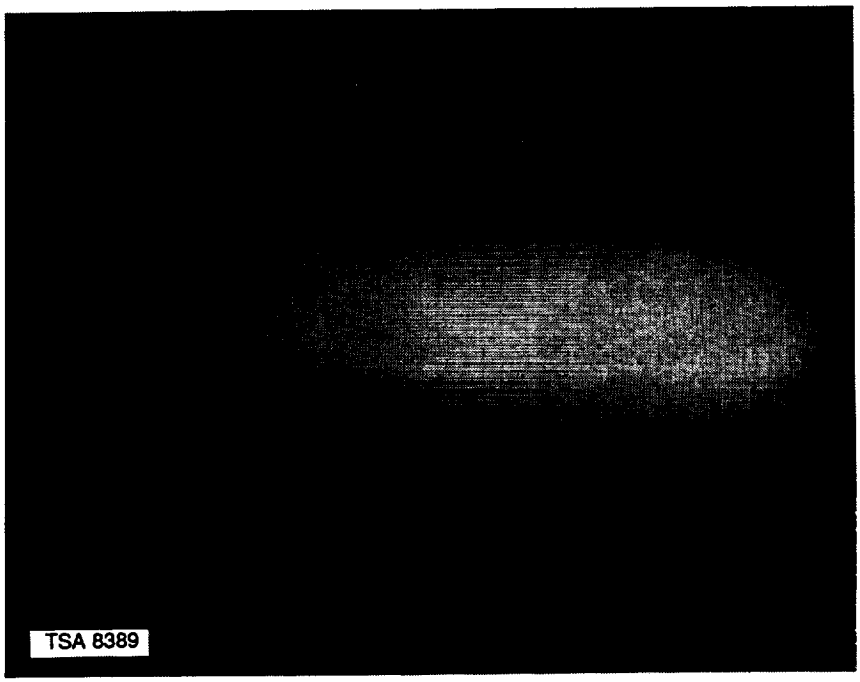


Figure 43. Bearing No. 1004A, Outer Race, 125X Magnification (3/22/91).