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High Cycle Fatigue Testing of Selected Materials Marked with Vericode Symbols

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Acknowledgment

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1.0 INTRODUCTION

The purpose of this test series was to investigate the effects of different Vericode marking methods on the tensile high cycle fatigue capabilities of various alloys. The alloys tested were Inconel 718, Incoloy 930, and Titanium 5.2.5. These tests were performed at MSFC by personnel supporting the EH-24 Materials and Processes lab.

2.0 TEST OBJECTIVES

The objectives of this test program were as follows:

1) To evaluate the effects of various Vericode marking methods on the tensile fatigue properties of Inconel 718, Incoloy 930, and Titanium 5.2.5.

2) Determine the optimum marking method for these alloys based on the high cycle fatigue test results.

3.0 TEST SPECIMEN DESCRIPTION

The test specimens used in this study were dumbell-type specimens per Figures 1 and 2. The Incoloy 903 specimens used MBFR-250 as shown in Figure 1 while the other specimens used MFR-200 as shown in Figure 2. The ASTM Spec. was E466-82. Descriptions of the alloys tested are shown in Table 1.

4.0 MARKING METHOD DESCRIPTIONS

The markings used in this study were produced using five different marking methods. This section describes these five methods so that one can understand how the markings were made and how the material surface of the test specimens was upset or disturbed during the marking process. Table 2 shows the settings used for each of the five marking systems.

4.1 Chemical Etch

The chemical etch system used in this testing was manufactured by Electro Chemical Etch Metal Markings Inc. of Van Nuys, CA. This system (Model 500) marks the part by locally corroding the part and using a template to control the areas to be corroded. An electrolyte salt is applied to the part and current applied to increase the corrosion rate. The variables which can be adjusted when marking a part are the electrolyte type, current, power, time, and pulse. Figure 3 shows a photograph of this system.

4.0 MARKING METHOD DESCRIPTIONS (Continued)

4.2 Laser Etch

The laser etch marking system used in this testing was manufactured by AB Laser Company of Acton, MA. This computer driven system provides the user with the capability to adjust current, traverse speed, and the frequency of the laser. Prior to marking a new material, a test pattern is produced on the material surface using the laser. From this pattern the markings which possess the most contrast with the background are selected. These markings are then viewed under a 50 power microscope to determine which of the selected markings possessed the least surface damage. The laser variables are then adjusted to the settings which produced that mark. This adjustment of variables permits the user to tailor the laser so that a readable mark is produced on most surfaces with minimum surface disruption. For example, ink can be removed from a page leaving undamaged white paper below or pigment can be removed from a feather without damaging the fibers of the feather. These examples show how extremely controllable the laser system is. Using this system, decodable Vericode symbols as small as 0.078 inch can be produced. This system marked the alloys in these tests by discoloring the part locally using heat. Figure 4 shows a photograph of this system while Figure 5 shows a photograph of symbols marked on paper and on a feather.

4.3 Micro Blast

The micro-blasting system (model PR1101-3) used in this testing was manufactured by Comco, Inc. of Burbank, CA. This computer-driven machine marks the part by directing a high velocity jet of dry air and abrasive over the surface of the part. Variables which can be adjusted are the abrasive type and size, air pressure, powder flow, traverse speed, and nozzle standoff distance. This system marked the alloys in these tests by locally removing material and increasing surface roughness. Figure 6 shows a photograph of this system.

4.4 Dot Peen

The dot peen marking system used in this testing was manufactured by the Wetzel Tool Company of Bloomfield, CN. The system utilizes a computer-driven device that drives a pointed tungsten carbide stylus into the surface to be marked. The system produces a complete Vericode symbol by repeatedly striking the surface with the stylus creating a series of cone-shaped recesses. Using the dot peen system, Vericode symbols as small as 0.25 inch square can be produced. Variables which can be adjusted are the standoff gap, and the impact force. The settings used for these variables were determined based on producing a recess which was 0.004 inch deep. This is in compliance to Rockwell

4.0 MARKING METHOD DESCRIPTIONS (CONTINUED)

SDP (Standard Design Practice) 174-0004MP, as well as MIL-STD-130G. This system marked the alloys in these tests by locally displacing material through cold working. Figure 7 shows a photograph of this system.

4.5 Mechanical Engraver

The engraving marking system used in this testing was manufactured by Newing-Hall, Inc. of Toledo, OH. The system model number was NH-300. The system is computer controlled and allows the user to adjust the variables of speed, feed rate, dwell, and air pressure. Again, The setting of these variables was based on producing a depth of cut of 0.004 inch in compliance with MIL-STD-130G. This system marked the alloys in these tests by locally cutting into the surface of the material. Figure 8 shows a photograph of this system.

5.0 HIGH CYCLE FATIGUE TEST PROCEDURE

The high cycle fatigue tests were conducted by first determining a stress level that the specimen was to be tested. Next, the specimen was loaded into the MTS (Material Testing Systems) machines and the cycle begun. The machines used applied the load at the rate of 30 Hz (30 cycles per sec). All tests were conducted at 72° F. The ASTM Spec. for this testing was E466-82.

6.0 TEST RESULTS

The results of these tests are shown in Tables 3 through 5. The results have been plotted to show the failure curves for each of the marking methods. Plots were produced for each of the three alloys tested. These plots are shown in Figures 9 through 11.

7.0 DISCUSSION OF RESULTS

Before discussing the results of this test series, it should be noted that when marking the test specimens, the marking variables used to mark the specimens were determined per the values in Rockwell report number SSD92-M-0024 (see Table 2). The values in these tables were determined from earlier testing which was based only on making an easily readable symbol. How the settings effected the material was not considered in this initial testing. Therefore, optimization of the marking variables used for all five of the marking systems based on readability as well as the effects on the material has not been performed. As a result, the test data from this series of tests is questionable since the effects on the materials was not considered when selecting the

7.0 DISCUSSION OF RESULTS (Continued)

variable settings. For example, in this test series the laser etch system was the worst performer of the five methods. We feel this was due to the improper settings being used, which drove excess heat into the specimens thereby causing damage. Our experience has shown that the thermal damage induced in a part can be reduced in highly conductive materials (like metals) if the traverse speed of the laser is increased. The traverse setting used to mark the specimens in these tests was only 50 on a scale of (1-999). Increasing the traverse rate decreases the amount of heat driven into the part while still producing a readable Vericode symbol.

For the Inconel 718 alloy, all methods except chemical and laser etch were acceptable. The micro-blast and engraving methods were the highest performers. It should also be noted that the control specimens which had no markings fell in the middle of the data set as shown in Figure 9. This is a good indication that the marking methods used are acceptable (except laser and chem etching) and do not have a great impact on the fatigue properties for this alloy. At runout ($1x10^7$ Cycles), the specimens which were chem etched showed a 20% decrease (extrapolated) in the high cycle fatigue strength when compared to the control set. The laser etched specimens showed a 41% decrease (extrapolated) in the high cycle fatigue strength when compared to the control set.

For the Incoloy 903 alloy, laser etching was the only non-acceptable method. The best performers were engraving, micro-blast and dot peen. Again, it should be noted that the control specimens which had no markings fell in the middle of the data set as shown in Figure 10. This is a good indication that the marking methods used are acceptable (except laser etching) and do not have a great impact on the fatigue properties for this alloy. At runout ($1x10^7$ Cycles), the specimens which were laser etched showed a 17% decrease (extrapolated) in the high cycle fatigue strength when compared to the control set.

For the Titanium 5.2.5 alloy, laser etch was again the only non-acceptable method. The highest performers for this alloy were chemical etch, micro blast, and dot peen. The control specimens which had no markings fell at the top of the data set as shown in Figure 11. However, all marking methods (except laser etch) produced data all within 15% of the control at runout. Also, at runout ($1x10^7$ Cycles) the specimens which were laser etched showed a 51% decrease in the high cycle fatigue strength when compared to the control set.

8.0 CONCLUSIONS AND RECOMMENDATIONS

It is recommended that re-testing of the laser etched specimens for all three alloys be performed. This should be conducted by first running test patterns on the three alloys at higher laser traverse speeds from the selection range of (1-999). From these initial tests it can be determined how quickly the

8.0 CONCLUSIONS AND RECOMMENDATIONS (Continued)

laser can traverse across the surface while still producing a readable symbol. These quicker traverse speeds will decrease the thermal damage evident in the specimens tested. Also, lower power settings should be investigated to reduce the amount of heat pumped into the test specimen. In addition, passive cooling techniques such as heat sinking, liquid baths, etc, should be investigated to remove heat from the specimen as rapidly as possible.

As mentioned, when marking the test specimens, the marking variables used to mark the specimens were determined per the values in Rockwell report number SSD92-M-0024 (see Table 2). How the settings effected the materials was not considered in this initial testing. Therefore, optimization of the marking variables used for all five of the marking systems based on readability as well as the effects on the material has not been performed. We recommend that these marking variables be updated and re-standardized to include this. This fine tuning of variables is needed to determine the optimum settings that should be used which effect the material properties the least while still producing a marking that is easily readable to the Vericode system. Once the optimization of each method has been performed, selection of the optimum marking method can then be performed.

Table 1 Test Specimen Material Description

MATERIAL	UNS DESIGNATION	DESCRIPTION	CHEMICAL COMPOSITION
Inconel 718	NO7718	Ni-Cr Alloy Precipitation Hardenable Alloy	Al 0.20-0.80; B 0.006 max; C 0.08max Cb 4.75-5.50; Co 1.00max; CR 17.0-21.0; Cu 0.30 max; Fe rem; Mn 0.35 max Mo 2.80-3.30; Ni 50.0-55.0; P0.015 max S 0.015 max; Si 0.35 max; Ti 0.65-1.15
Incoloy 903	N19903	Ni-Fe-Co Alloy Precipitation Hardenable Alloy	Al 0.30-1.15; B 0.012 max; C 0.06 max Cb 2.40-3.5; Co 13.0-17.0; Cr 1.0 max Cu 0.50max; Fe rem; Mn 1.00 max Ni 36.0-40.0; S 0.015 max; Si 0.35 max Ti 1.00-1.25
Titanium 5.2.5	R54521	Titanium Alloy	Al 5; Sn 2.5; Ti rem

UNS - Unified Numbering System

Table 2 Vericode Marking Variable Settings

ALLOY	ELECTROLITE (TYPE)	CURRENT (TYPE)	POWER (%)	TIME (SEC)	PULSE (%)
INCONEL 718	F10	AC	~~50~~ 60	~~5~~ 10	25
INCONELY 903	F10	AC	~~50~~ 60	~~5~~ 10	25
TITANIUM 5.2.5	F10	AC	30	~~7~~ 3	~~25~~ MAX

CHEMICAL ETCH MARKING PARAMETERS

HIGH CYCLE FATIGUE COMPLETE — NOT ACCEPTABLE, FELL BELOW CHEM-ETCH. REMARK AND REPEAT SEM/FATIGUE TESTS TEST SETTINGS!

ALLOY	CURRENT (AMPS 1-250)	SPEED (1-999)	FREQUENCY (KHZ 1-32,000)
INCONEL 718	150	50	25,000
INCONELY 903	~~160~~ 170	50	~~25,000~~ 22,000
TITANIUM 5.2.5	~~160~~ 170	50	~~25,000~~ 22,000

LASER ETCH MARKING PARAMETERS

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ALLOY	ABRASIVE (TYPE)	ABRASIVE SIZE (MICRON)	AIR PRESSURE (PSI)	POWDER FLOW (MIN-MAX)	TRAVERSE SPEED (1-99)
INCONEL 718	ALUMINUM OXIDE	25	~~85~~ 90	MAX	75
INCONELY 903	ALUMINUM OXIDE	25	~~85~~ 90	MAX	75
TITANIUM 5.2.5	ALUMINUM OXIDE	25	~~85~~ 90	MAX	75

MICRO BLAST MARKING PARAMETERS

ALLOY	GAP (mm)	FORCE (1-9)
INCONEL 718	1	6
INCONELY 903	~~0.5~~ 1.0	~~8~~ 6
TITANIUM 5.2.5	~~1.5~~ 1.0	6

DOT PEEN MARKING PARAMETERS

ALLOY	SPEED (1-100)	FEED RATE (1-100)	DWELL (1-100)	AIR PRESSURE (PSI)
INCONEL 718	40	5	30	25
INCONELY 903	40	5	30	25
TITANIUM 5.2.5	40	5	30	25

ENGRAVER MARKING PARAMETERS

Table 3 Inconel 718 High Cycle Fatigue Test Results

VERICODE MARKING METHOD	STRESS LEVEL (KSI)	NO. CYCLES TO FAILURE
CONTROL (NO MARKING)	90	5.3919E+04
	80	9.6556E+04
	80	1.0762E+05
	75	1.0321E+05
	75	1.8902E+05
	60	3.1691E+05
	60	3.4048E+05
	60	3.8785E+05
	50	6.1636E+05
	50	7.1315E+05
	45	1.0000E+07
	40	1.0000E+07
CHEMICAL ETCHING	85	7.7213E+04
	80	1.0213E+05
	75	1.2244E+05
	70	1.9661E+05
	45	1.5272E+06
	40	2.5462E+06
YAG LASER	80	1.1672E+05
	70	2.2108E+05
	60	3.2213E+05
	45	7.6753E+05
	40	1.7781E+06
	35	2.1514E+06
MICRO BLAST	80	7.8515E+04
	70	1.6981E+05
	60	6.1081E+05
	50	1.0000E+07
	55	1.7482E+06
	53	1.7337E+06
DOT PEEN	80	1.2332E+05
	70	2.2481E+05
	60	5.1101E+05
	50	3.7540E+06
	47	3.8703E+06
	44	1.0000E+07
ENGRAVER	78	1.1865E+05
	70	2.0467E+05
	60	5.4970E+05
	55	1.3747E+06
	52	1.0000E+07
	50	1.0000E+07

Table 4 Incoloy 903 High Cycle Fatigue Test Results

VERICODE MARKING METHOD	STRESS LEVEL (KSI)	NO. CYCLES TO FAILURE
CONTROL (NO MARKING)	70	9.5733E+04
	60	1.3749E+05
	55	2.5934E+05
	47	4.4829E+05
	45	7.1825E+05
	38	2.7166E+06
	35	1.1719E+06
	32	1.0000E+07
CHEMICAL ETCHING	70	8.9580E+04
	60	2.2252E+05
	50	3.7290E+05
	45	6.3876E+05
	37	2.6273E+06
YAG LASER	70	8.8064E+04
	60	1.8041E+05
	45	4.3523E+05
	35	5.1661E+05
	30	1.9116E+06
MICRO BLAST	70	9.3198E+04
	60	1.2491E+05
	50	4.8762E+05
	40	2.0254E+06
	35	1.0000E+07
DOT PEEN	70	9.9651E+04
	60	2.3407E+05
	50	1.7677E+05
	45	6.0131E+06
	40	2.4731E+06
ENGRAVER	70	6.8631E+04
	60	1.4875E+05
	50	4.2820E+05
	45	6.1451E+05
	40	1.0000E+07

Table 5 Titanium 5.2.5 High Cycle Fatigue Test Results

VERICODE MARKING METHOD	STRESS LEVEL (KSI)	NO. CYCLES TO FAILURE
CONTROL (NO MARKING)	86	2.3000E+04
	83	2.0800E+04
	78	3.8800E+04
	73	6.4500E+04
	67	1.1020E+05
	65	2.8032E+06
	63	4.0760E+05
	62	9.9600E+04
	62	2.1070E+05
	61	9.3170E+05
	61	1.0000E+07
CHEMICAL ETCHING	75	2.6115E+04
	60	3.1120E+05
	57	4.3634E+05
	56	2.0929E+05
	56	9.9081E+04
	54	1.0000E+07
YAG LASER	70	2.0800E+04
	57	6.1739E+04
	40	1.6952E+05
	36	3.5059E+05
	34	6.4079E+05
	30	1.4643E+07
MICRO BLAST	70	7.9614E+04
	60	9.2420E+04
	57	1.7480E+05
	53	1.0000E+06
	52	1.0000E+07
	50	1.0000E+07
DOT PEEN	70	5.2106E+04
	60	1.3845E+05
	57	1.5195E+05
	53	3.7190E+05
	51	1.2644E+06
	50	3.2067E+05
ENGRAVER	70	4.4285E+04
	57	1.0699E+05
	55	1.3450E+05
	53	2.1592E+05
	50	1.0000E+07
	48	1.0000E+07

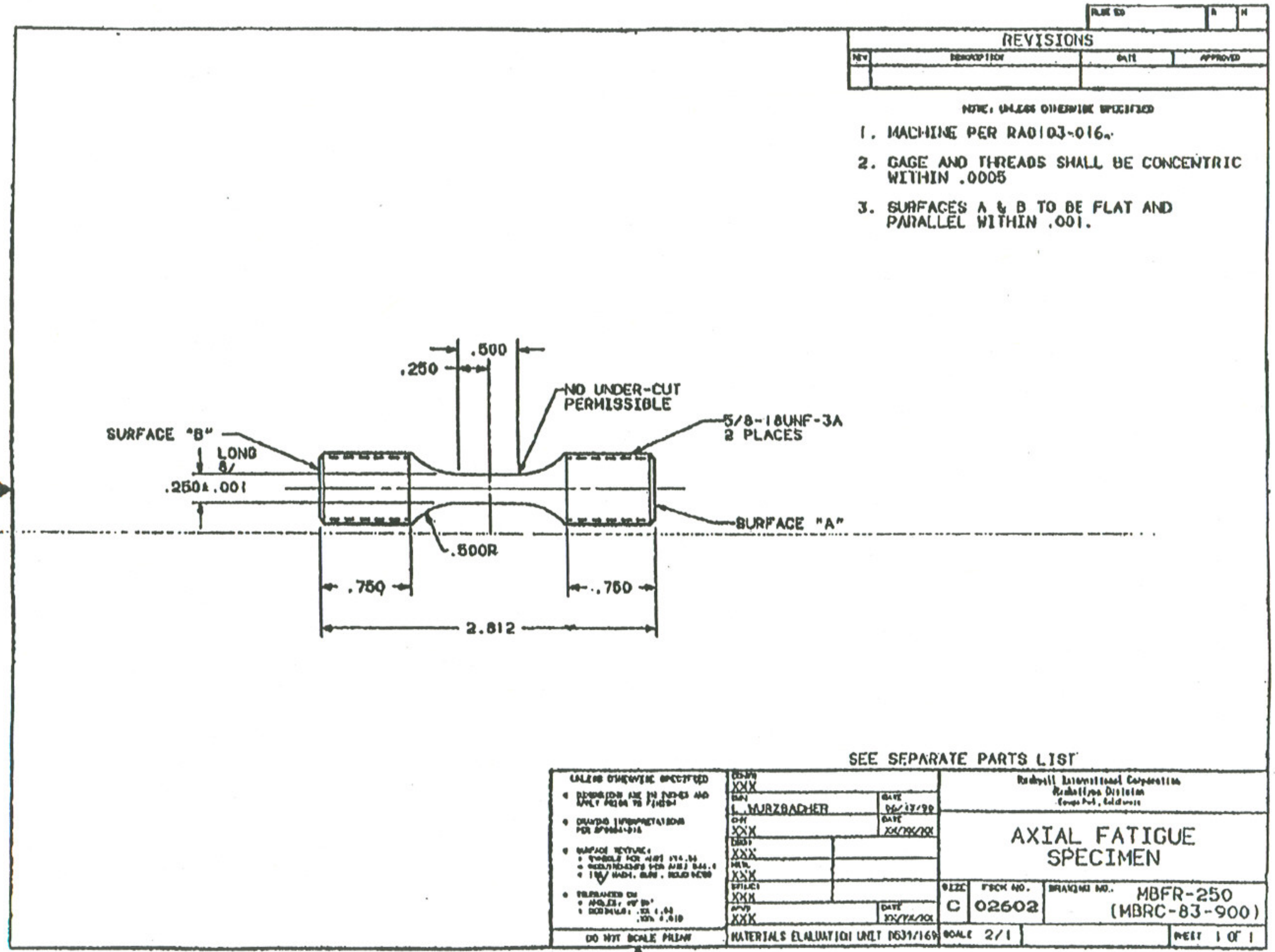


Figure 1 Test Specimen Configuration per MBFR-250

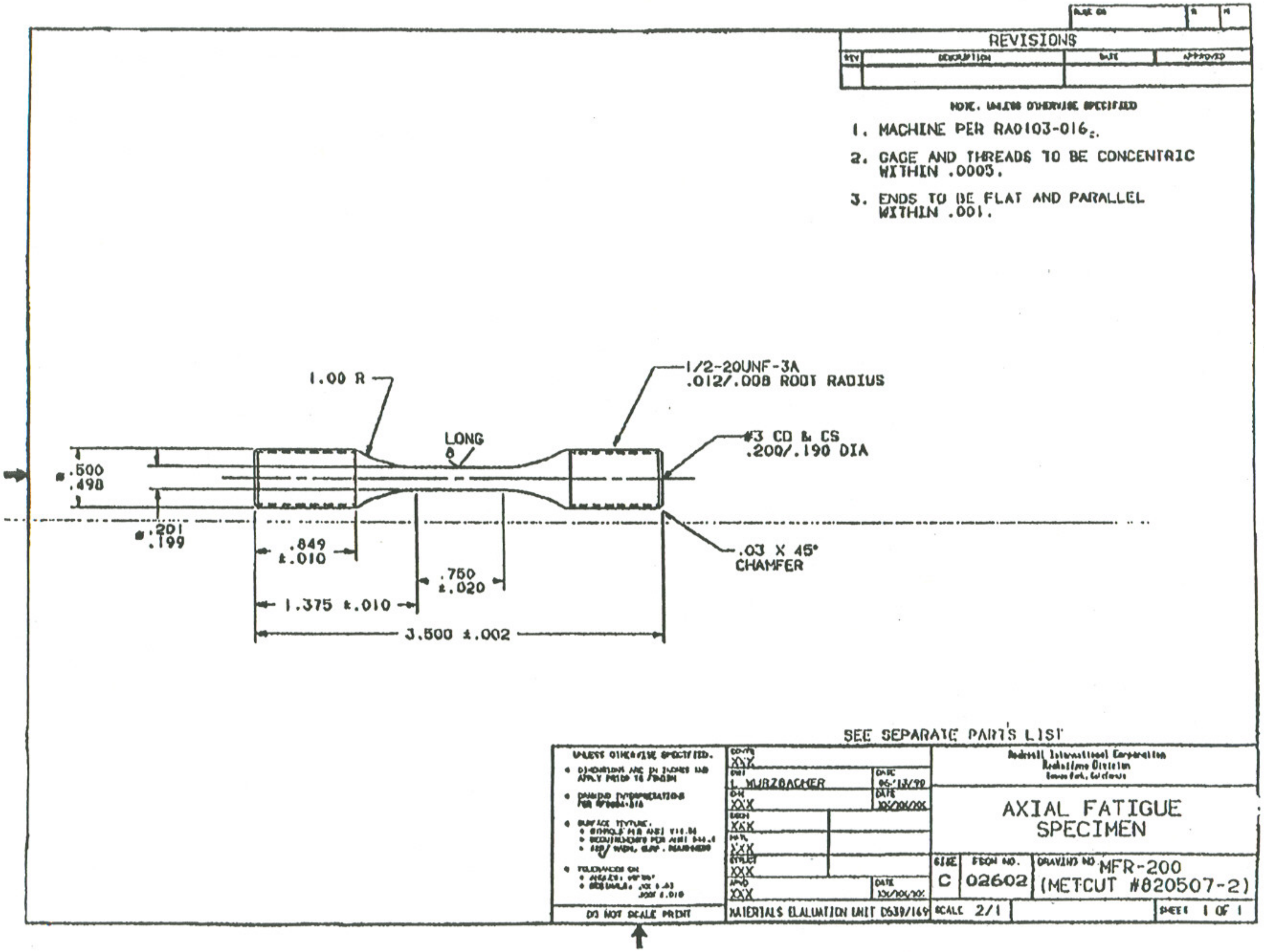


Figure 2 Test Specimen Configuration per MFR-200

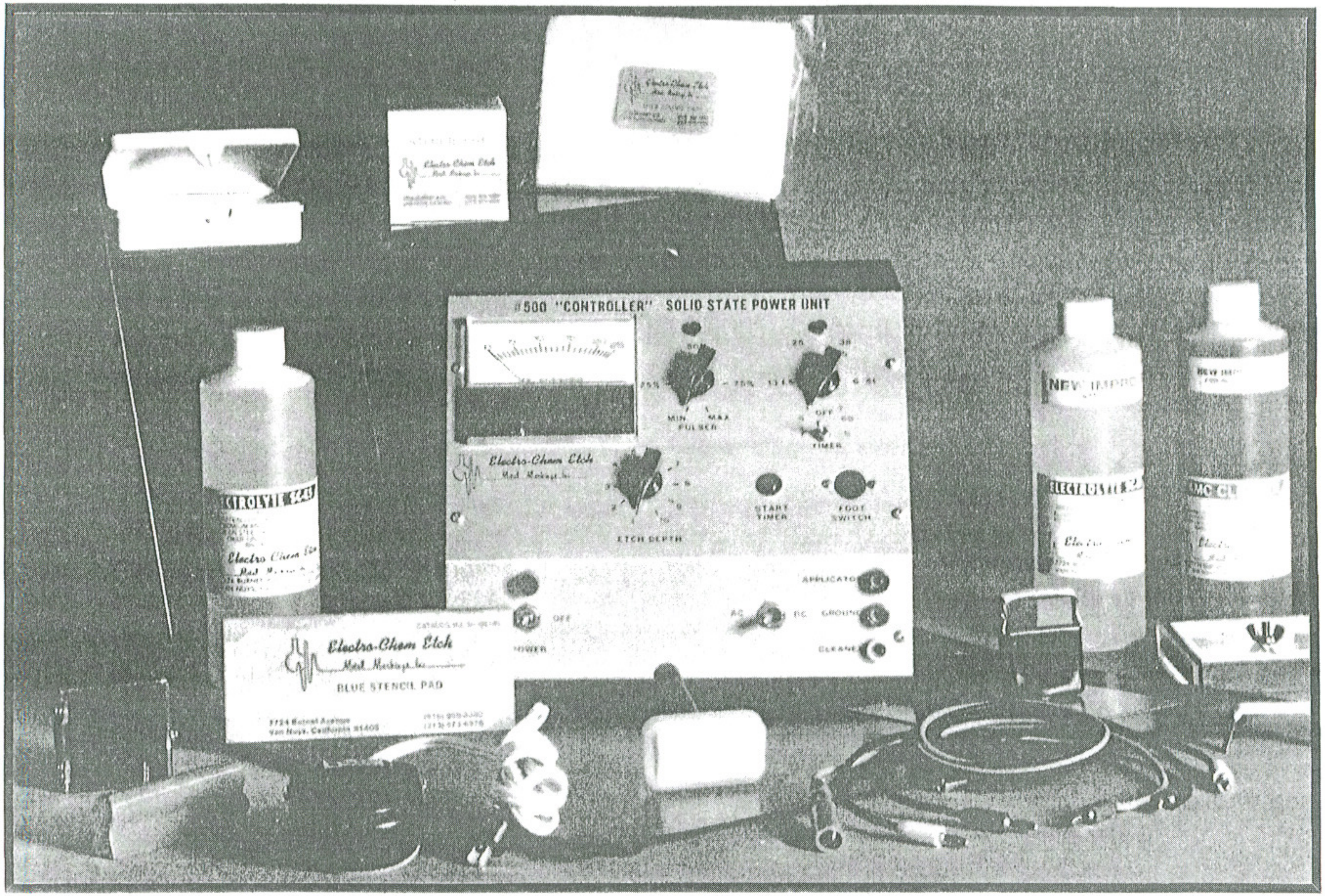


Figure 3 Chemical Etch Marking System

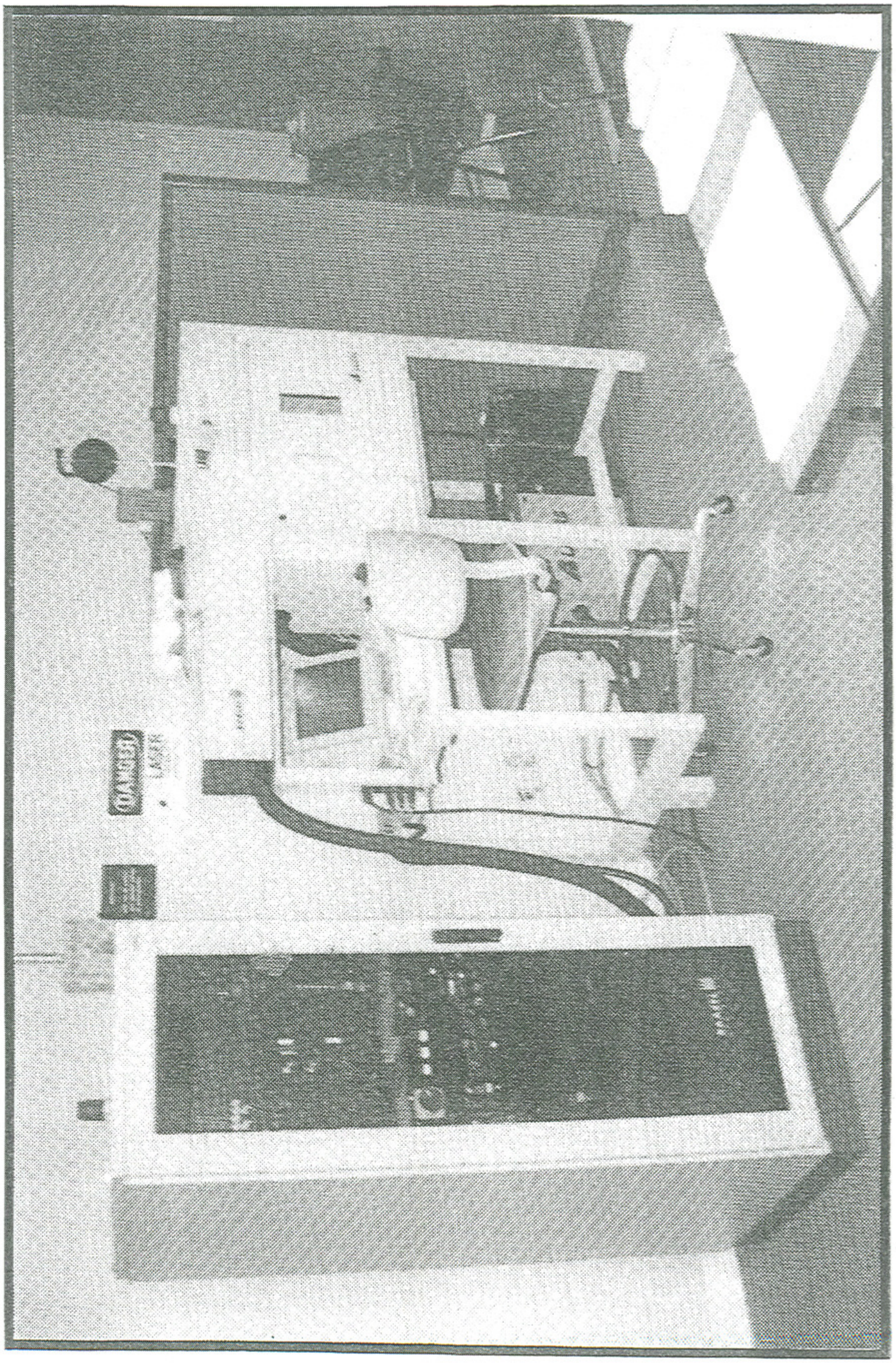
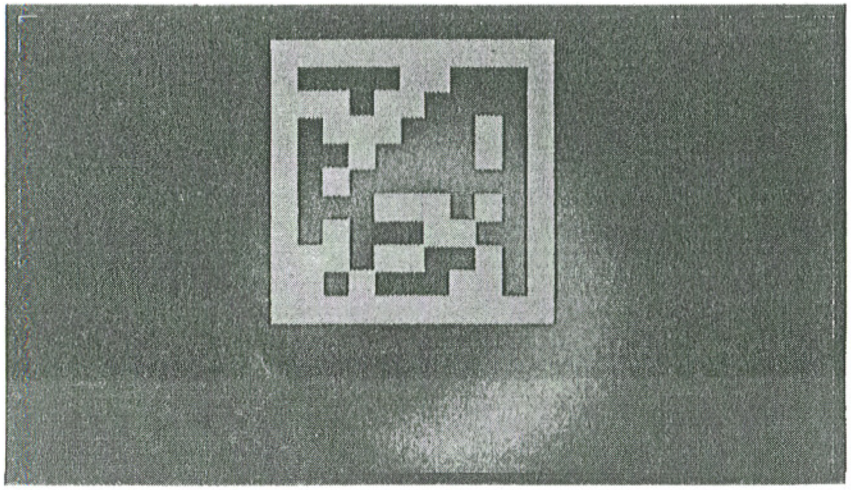


Figure 4 Computer Driven Laser Etch Marking System



THIS IS A SAMPLE OF VERICODE SYMBOL THAT HAS BEEN LASER ETCHED ONTO A BLACK PAPER SURFACE. NOTICE THAT THE BLACK SURFACE INK HAS BEEN REMOVED WITHOUT BURNING THE WHITE SURFACE OF THE PAPER BELOW.

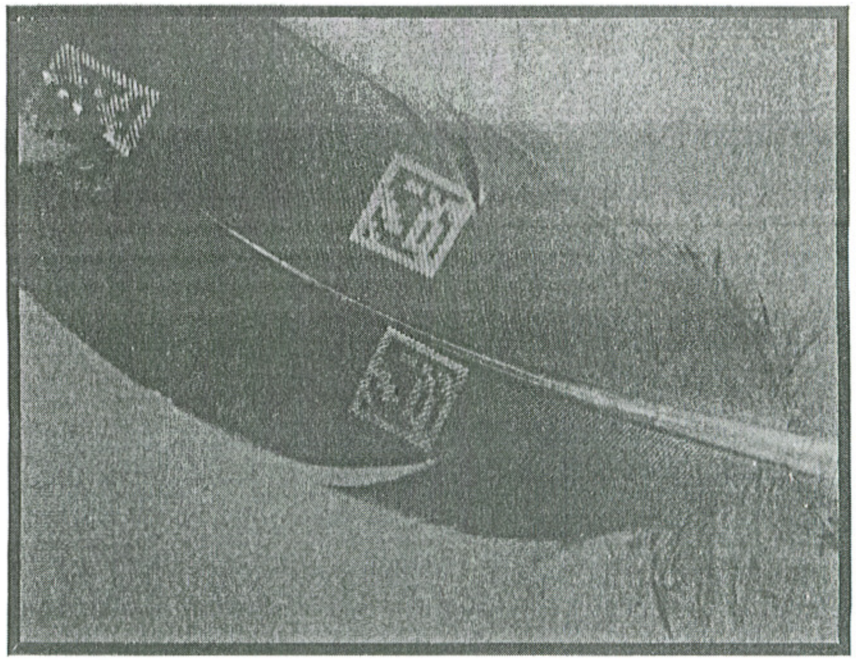


Figure 5 Laser Etch of Ink on Panel and Pigment in Feather

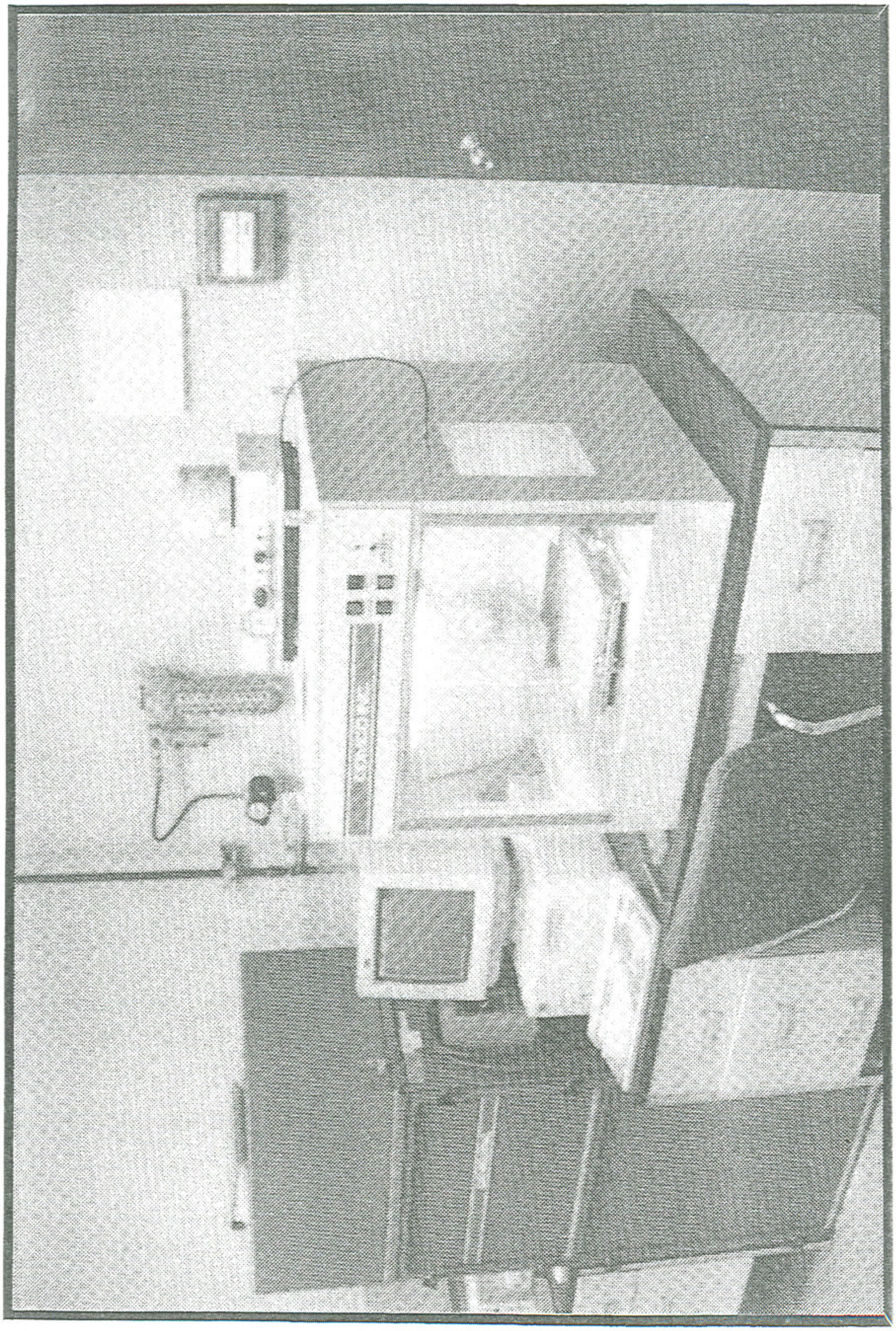


Figure 6 Computer Driven Micro-sand Blaster Marking System

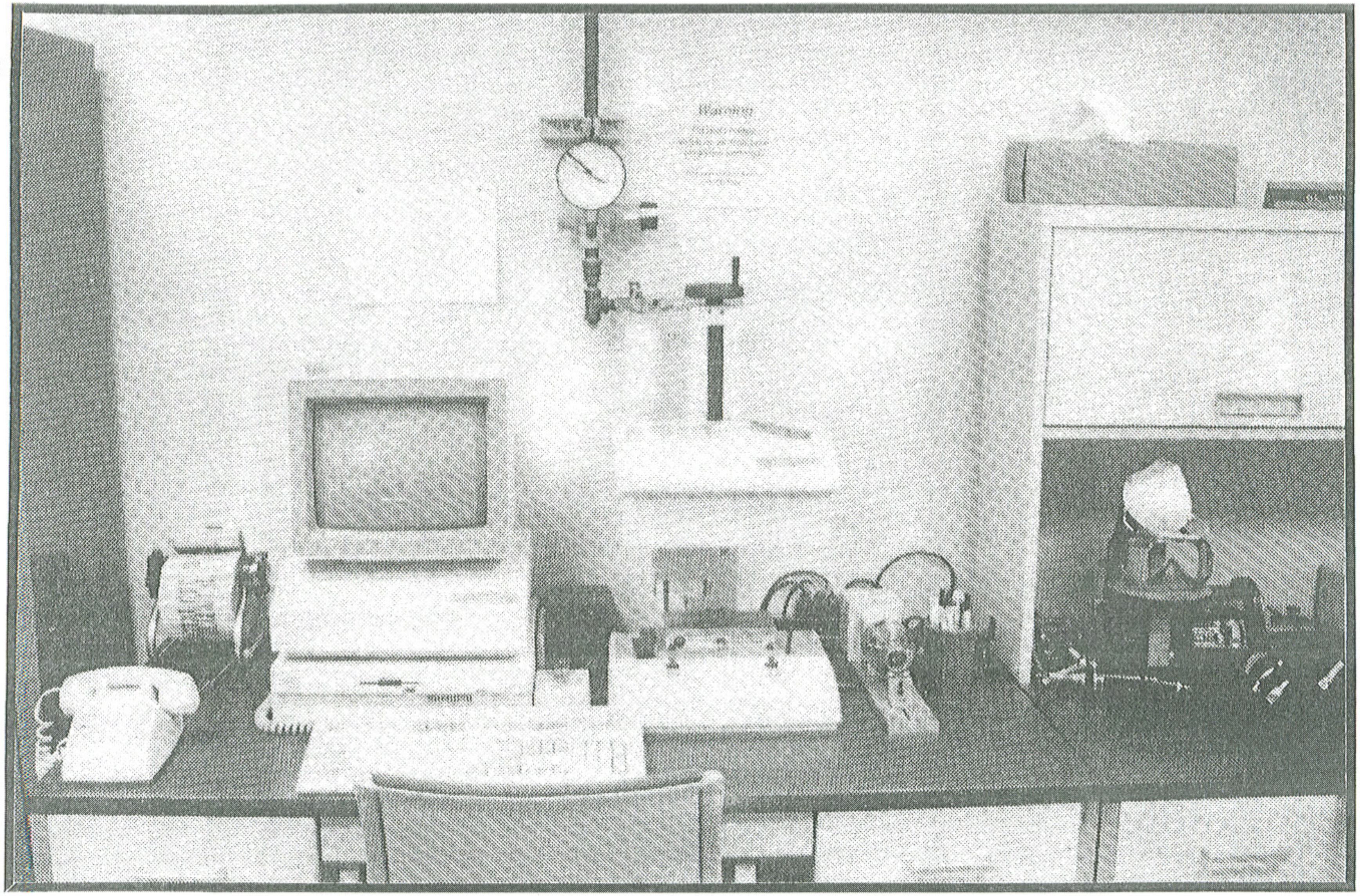


Figure 7 Computer Driven Dot Peen Marking System

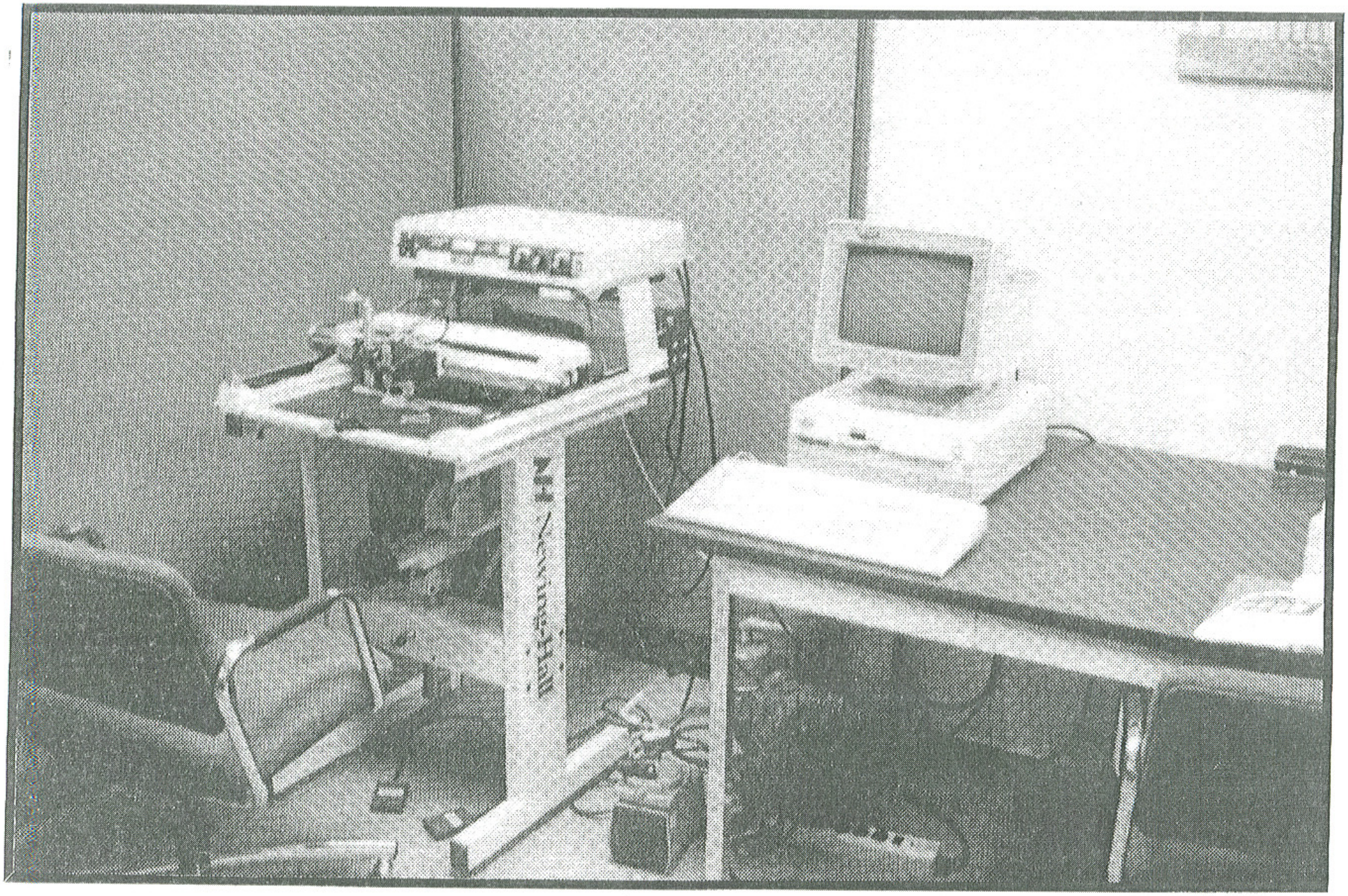


Figure 8 Computer Driven Engraving Marking System

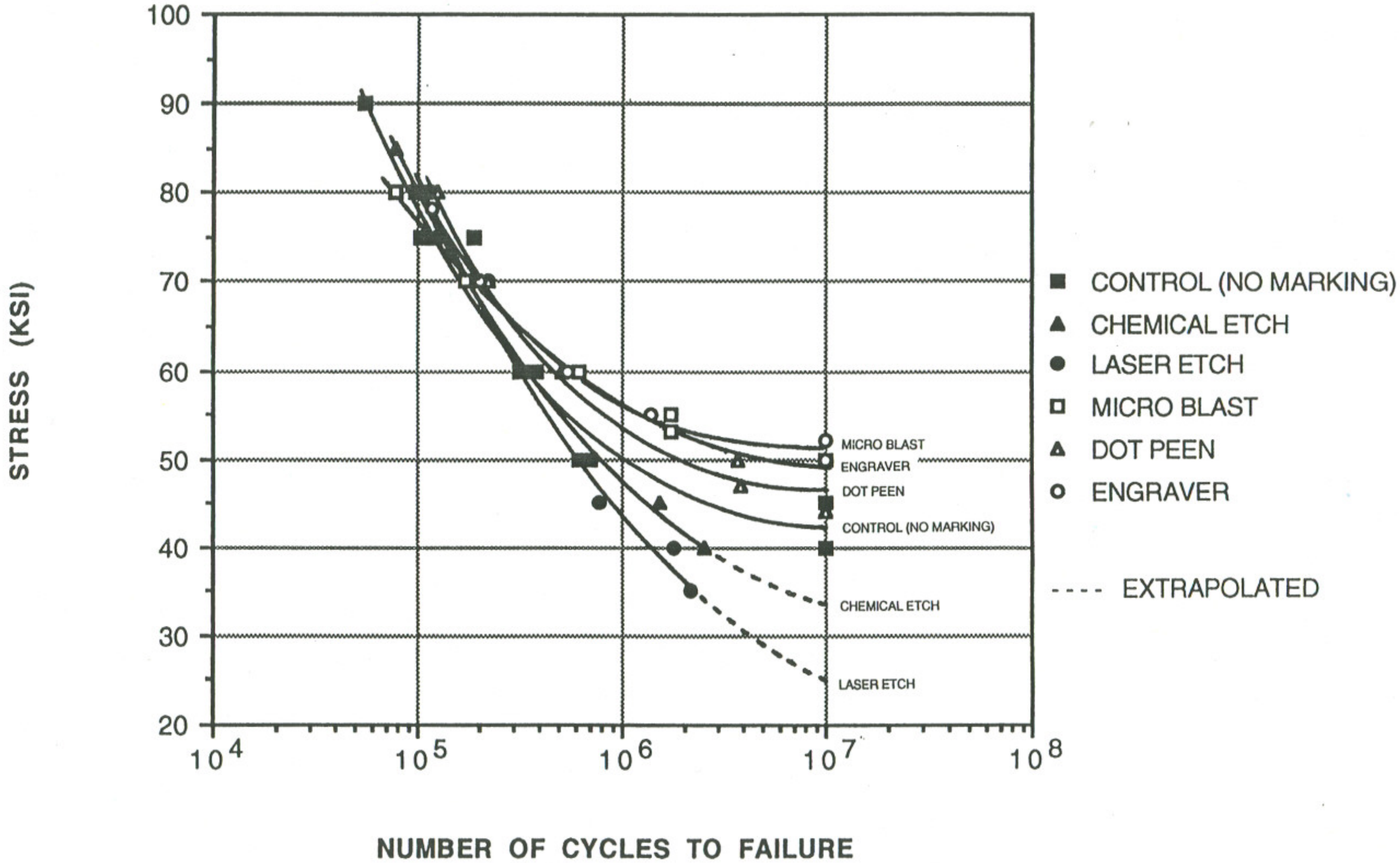


Figure 9 Plot of Inconel 718 Test Results

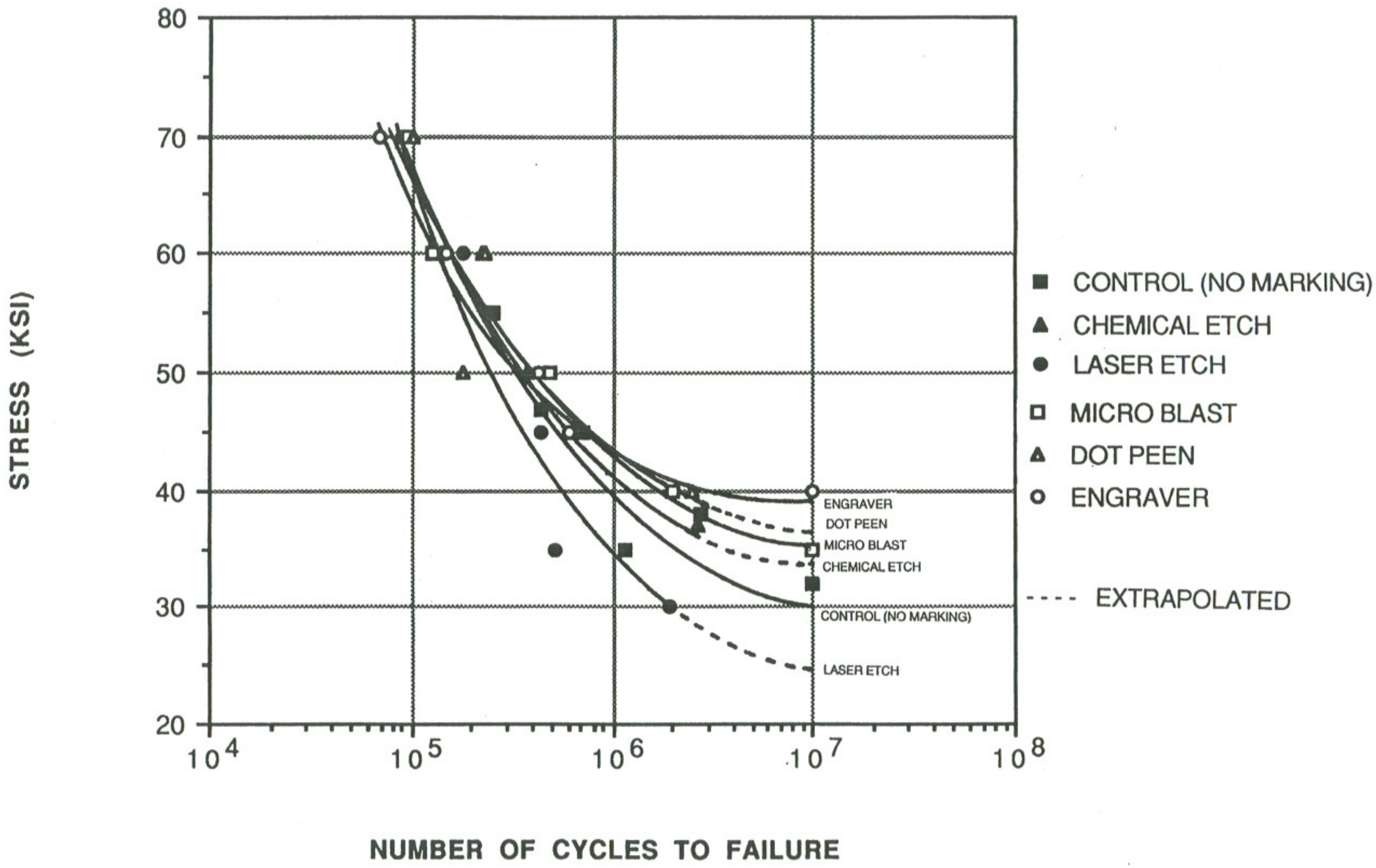


Figure 10 Plot of Incoloy 903 Test Results

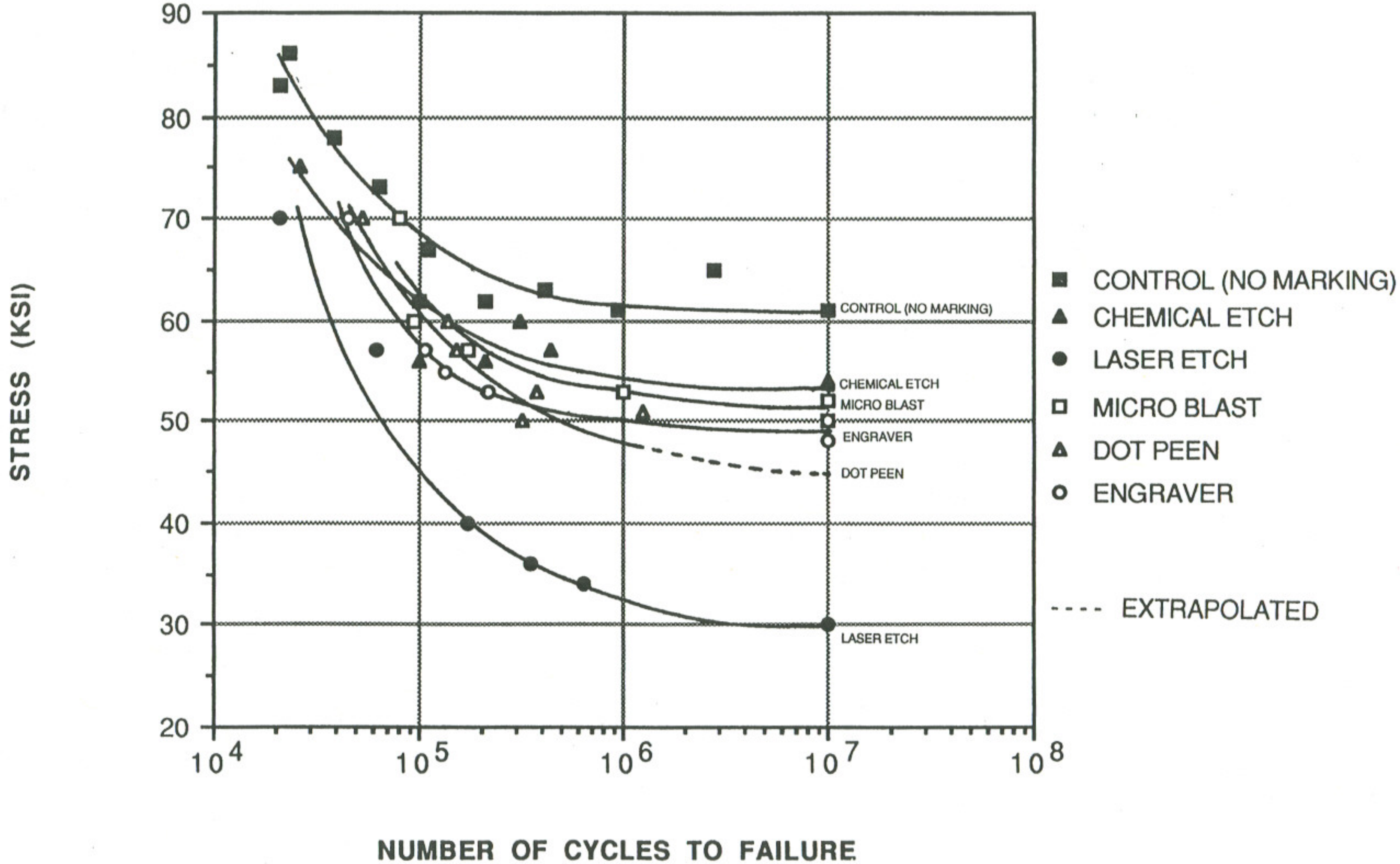


Figure 11 Plot of Titanium 5.2.5 Test Results