STUDY PROGRAM OF NASA/GSFC WELD
QUALITY MONITOR SYSTEM

NAS5-21395

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P.O. Box 5837
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July 8, 1971

Quarterly Report for Period April - June 1971

Prepared for

Goddard Space Flight Center
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16. Abstract

The Weld Quality Monitor has been used with a recent model solid state power supply to evaluate ability to differentiate between sound and defective weld joints. The Weld Quality Monitor has been evaluated on Dumet/Nickel ribbon weld joints used in microelectronic module fabrication.

Distinct separation was achieved between low strength welds and sound welds by the Quality Monitor. Evaluation performed to date indicates a drift level at less than 2 percent on a series of 50 consecutive welds.

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PREFACE

The objective of this program is ɔ determine, by scientific methods, the stability of the GSFC weld quali‿y monitor and its ability to descriminate between sound and defective welds and to function under production line conditions. This will be achieved by establishing optimum welding conditions which are most condusive to discrimination between defective and sound weld joints, and evaluating the equipments' ability to do so. To achieve this, three power settings were chosen to produce low strength welds, optimum strength welds, and overheated welds. To achieve a shopworthy system, 2 weeks were required to adapt the monitor to a recent solid phase power supply, and to debug the new system.

Work to date on Dumet wire to nickel ribbon has demonstrated the ability of the Weld Quality Monitor to discriminate between low strength and sound welds. In addition, drift was found to be less than 2 percent during the welding of 50 consecutive welds.

It is concluded that the Weld Quality Monitor System is working very well. The balance of the evaluation will be completed and a recovery plan will be established.

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ILLUSTRATIONS

TABLES

I. INTRODUCTION

Martin Marietta Corporation has been funded by Goddard Space Flight Center to evaluate a Weld Quality Monitor built in accordance with GSFC equipment specifications. The monitor was developed and fabricated by Noetec Corporation of Rockville, Maryland. The Monitor utilizes in-process measurement of deformation during welding to predict weld quality. This deformation, termed embedment, is measured by a linear magnetic transducer (LMT) with associated circuitry to an accuracy of 0.0001 inch. This unit is used in conjunction with a standard capacitor discharge power supply to assure weld quality. Should a bad weld be made, the power supply is locked in ''hold'' position until a line supervisor reactivates the unit for welding.

Trial usage of the Weld Quality Monitor by industry was not satisfactory because insufficient time was taken to set up the equipment and evaluate it. As a result, an RFQ was finally issued seeking a company to provide an engineering evaluation and shop tryout of the GSFC Weld Quality Monitor. This report summarizes the progress made to date on evaluating the capability of the Weld Quality Monitor to differentiate, and its inherent stability.

II. DEVELOPMENT TO DATE

A. ADAPTATION TO HUGHES POWER SUPPLY

Considerable difficulty has been experienced in the initial evaluation of the equipment because of the age of the basic Sippican power supply. Current setting could not be held. Drifting occurred over a 5-second period. After considerable preliminary work had been performed, the Sippican weld head was examined closely because of reoccuring electrode aligning problems; one of the linkage bars was broken. The welding head was repaired by temporarily scavaging one of Martin Marietta's welding heads made by Sippican. Procurement of Sippican replacement parts was difficult because of design change. However, three replacement bars were located and purchased.

While it was possible to conduct a laboratory evaluation of both the GSFC Evaluator and Sippican weld power supply, the Sippican power supply was not found suitable for production usage.

Mr. William Kramar, GSFC Contracting Officer, was contacted through James Mumford, Technical Monitor, to request permission to use the quality monitor with a Hughes solid state power supply, Model HRW-100 MG and Hughes VTA-60 ball bearing head. Permission was granted verbally with the assurance that written permission was not required since the contract did not specify that GFE welding equipment had to be used.

The linear magnetic transducer (LMT) of the Weld Quality Monitor was then mounted onto the Hughes weld head as shown in Figure 1. Figure 2 shows the location of the LMT on both the Sippican and Hughes weld power supplies. A first approach produced a 1 mil error in readout so the LMT was remounted. It was placed directly in-line with the ball bearing movement, as shown, with the LMT sensing foot resting on the moving welding arm. This arrangement did not affect the momentum of the welding arm during the welding cycle. In this position, the LMT shaft followed the movement of the arm through the force exerted by its compressed LMT spring. Since the welding arms must be opened beyond the normal welding position to measure electrode pressure, the LMT spring is placed in a highly compressed state. This exerted significant force on the welding arm to effect the measured welding force. On returning the electrode arm to its normal position, the LMT spring relaxed, exerting less pressure, which lowered the preset/measured welding force. To reduce this variable, a lighter LMT spring was used to lower its maximum compression force from 1 pound to 2 or 3 ounces.

To date, the GSFC weld quality monitor is adapted to the Hughes power supply and is functioning well. However, the two familiarization periods

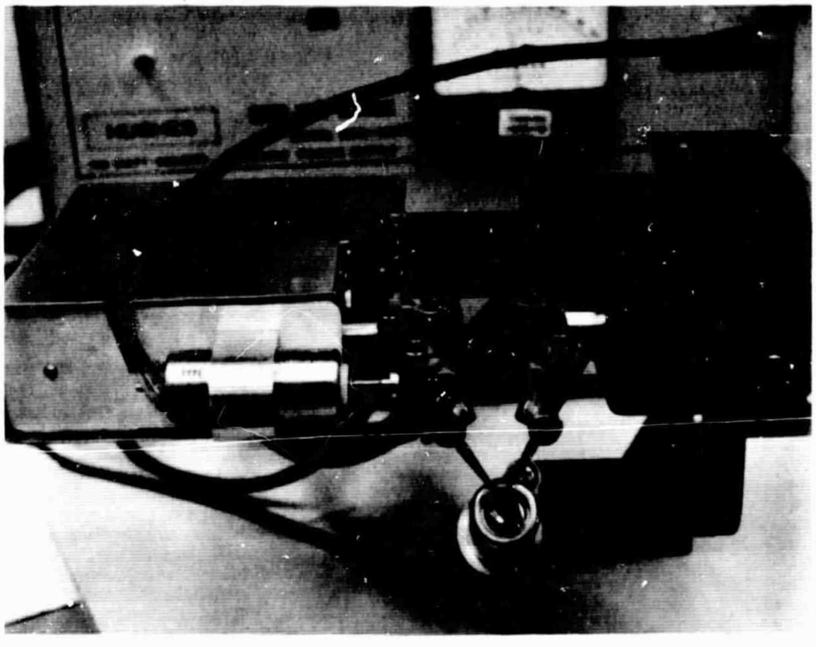

Figure 1. Detail of Mounting Arrangement of GSFC - Weld Quality Monitor LMT Embedment Sensor

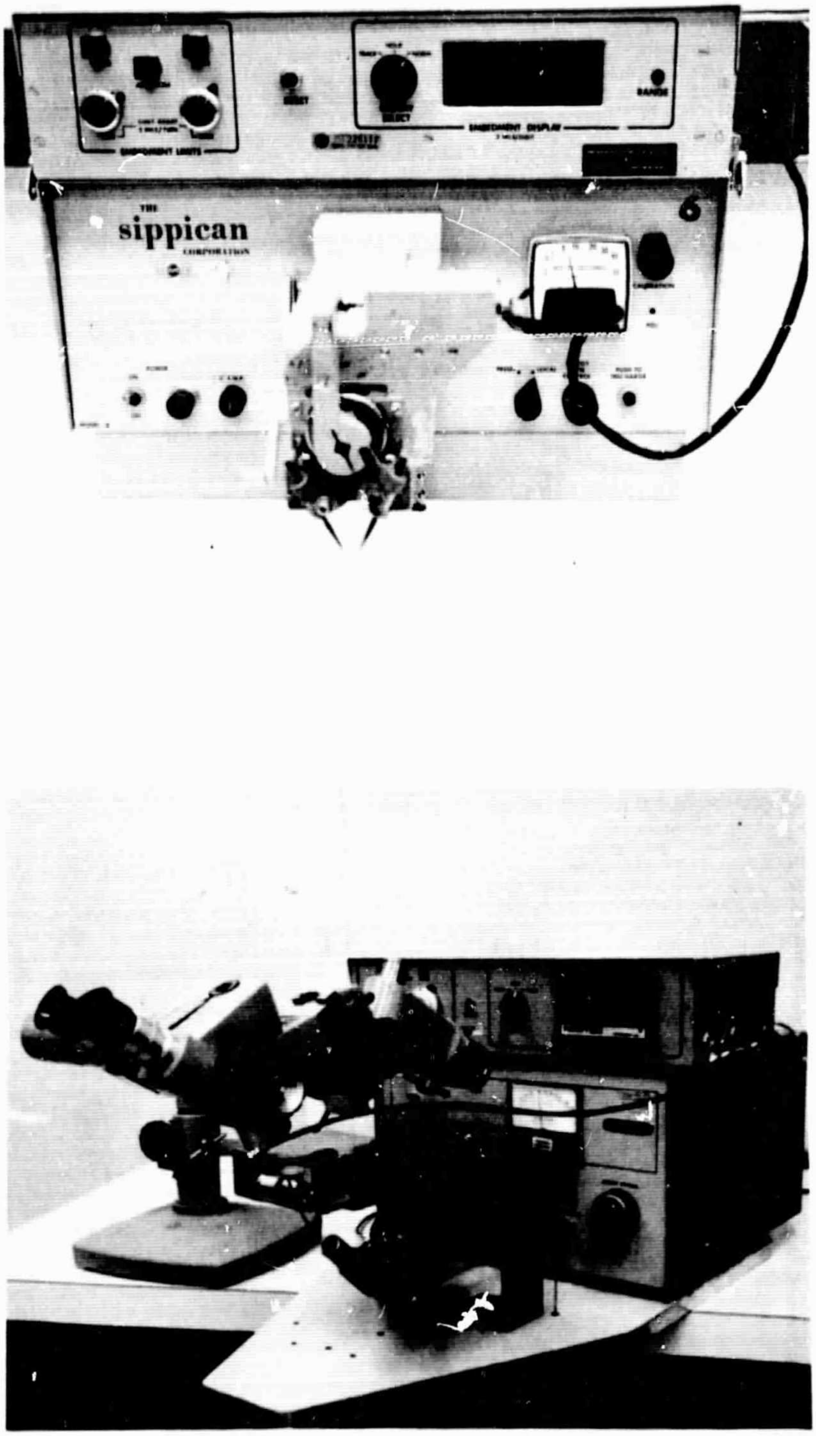

Figure 2. GSFC Weld Quality Monitor Mounted on Both Sippican and Hughes Weld Power Supplies

required modification, and standardization periods have consumed 5 weeks placing the program 2 weeks behind schedule.

B. MATERIALS EVALUATION

The first material combination selected for evaluation of the Weld Quality Monitor was 0.020 diameter gold plated Dumet to 0.010 x 0.031 nickel ribbon. A complete evaluation has been made showing that complete separation can be obtained from the low strength region, but an overlap occurs at the defective high region. Lowering of the welding current to 9 watt-seconds does not achieve separation from either the defective high or low strength region. The 10 Ws setting assures separation from the low strength region, but may produce occasional spitting. Statistical analysis assures that all welds made at 10 Ws will exceed minimum strength requirements.

C. TEST RESULTS

An isostrength was run for 0.020 diameter gold plated Dumet to 0.010 x 0.032 nickel ribbon. Ten bits of data were taken at Ws intervals at 2, 4, 6, and 8 pound welding pressures. This data was plotted for further analysis as:

1 Tensile versus embedment - Figures 3 to 6;

2 Tensile versus weld energy - Figures 7 to 10.

All points were plotted on the first plot, while only maximum and minimum points were plotted on the second to establish trends and data variation.

As may be seen on the tensile versus embedment plots, large vertical lines are drawn 0.1 mil to the right of the lowest observed tensile value, and another line 0.1 mil to the left of the lowest expulsion embedment tensile value. This was repeated at each welding pressure. The distance between these lines (in ''embedment'' units) is the preliminary optimum weld region. The observed values obtained at each pressure level are given in Table I.

TABLE I

Preliminary Optimum Weld Regions

Isopressure (pounds)	Sound Weld Range (mils)
2	0.30
4	0.40
6	0.50
8	0.70

A welding pressure of 8 pounds was selected for Dumet/Ni ribbon welds because it produced the largest sound weld range. Watt/second settings were selected

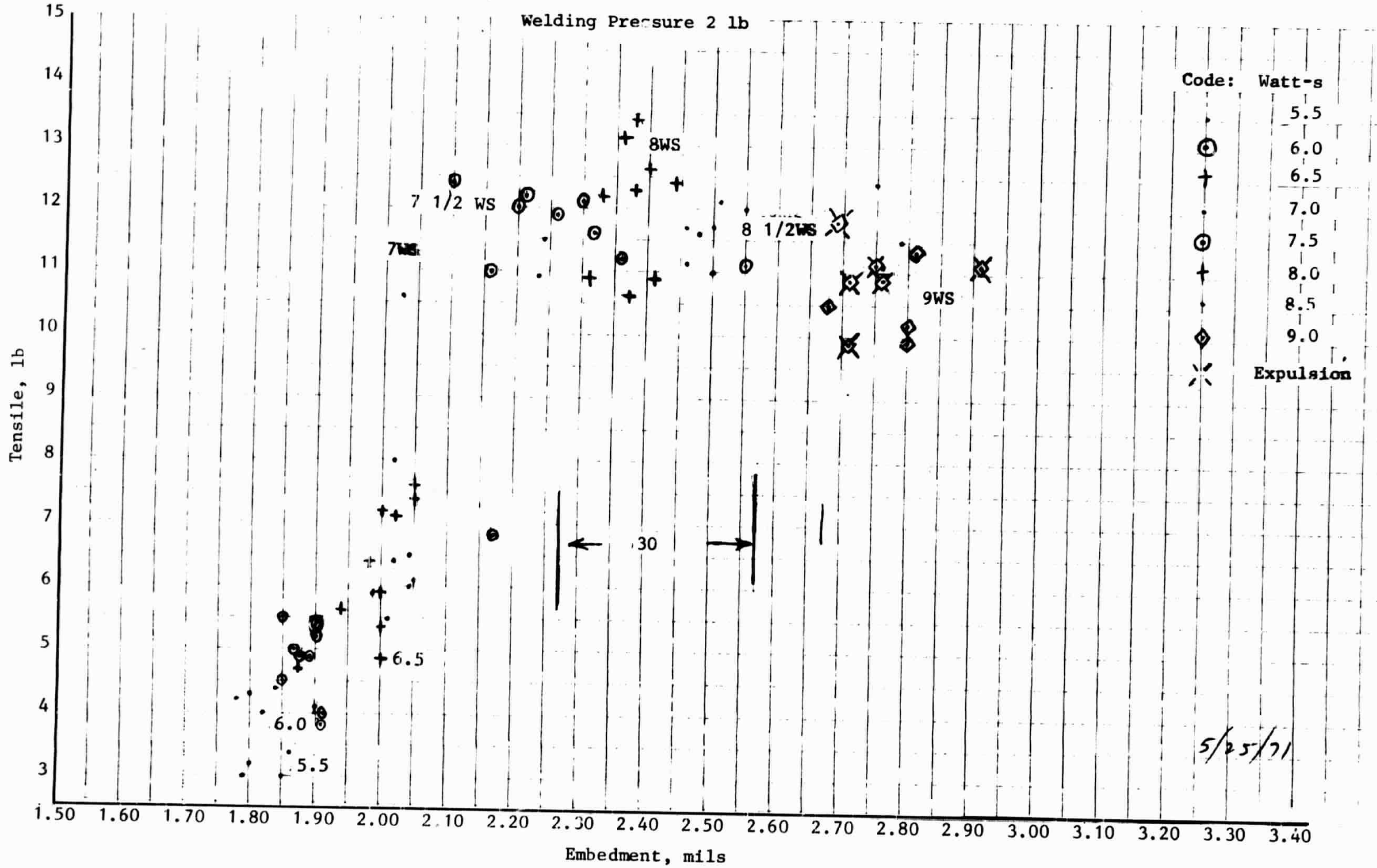

Figure 3. Correlation of Tensile Strength with Embedment 0.020 Dia Dumet (Au) to 0.010 x 0.032 Ni

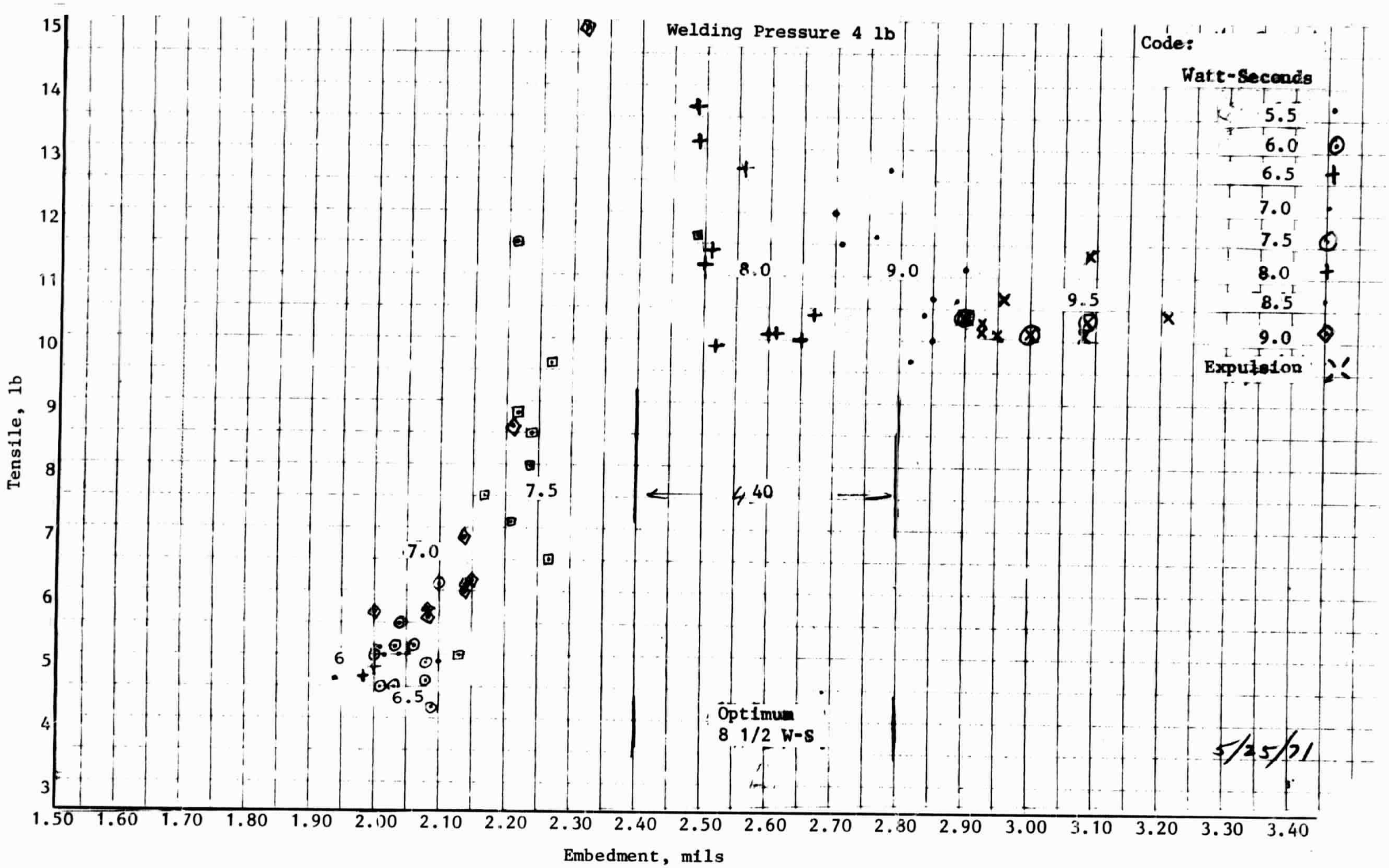

Figure 4. Correlation at Tensile Strength with Embedment 0.020 Dia Dumet (Au) to 0.010 x 0.032 Ni

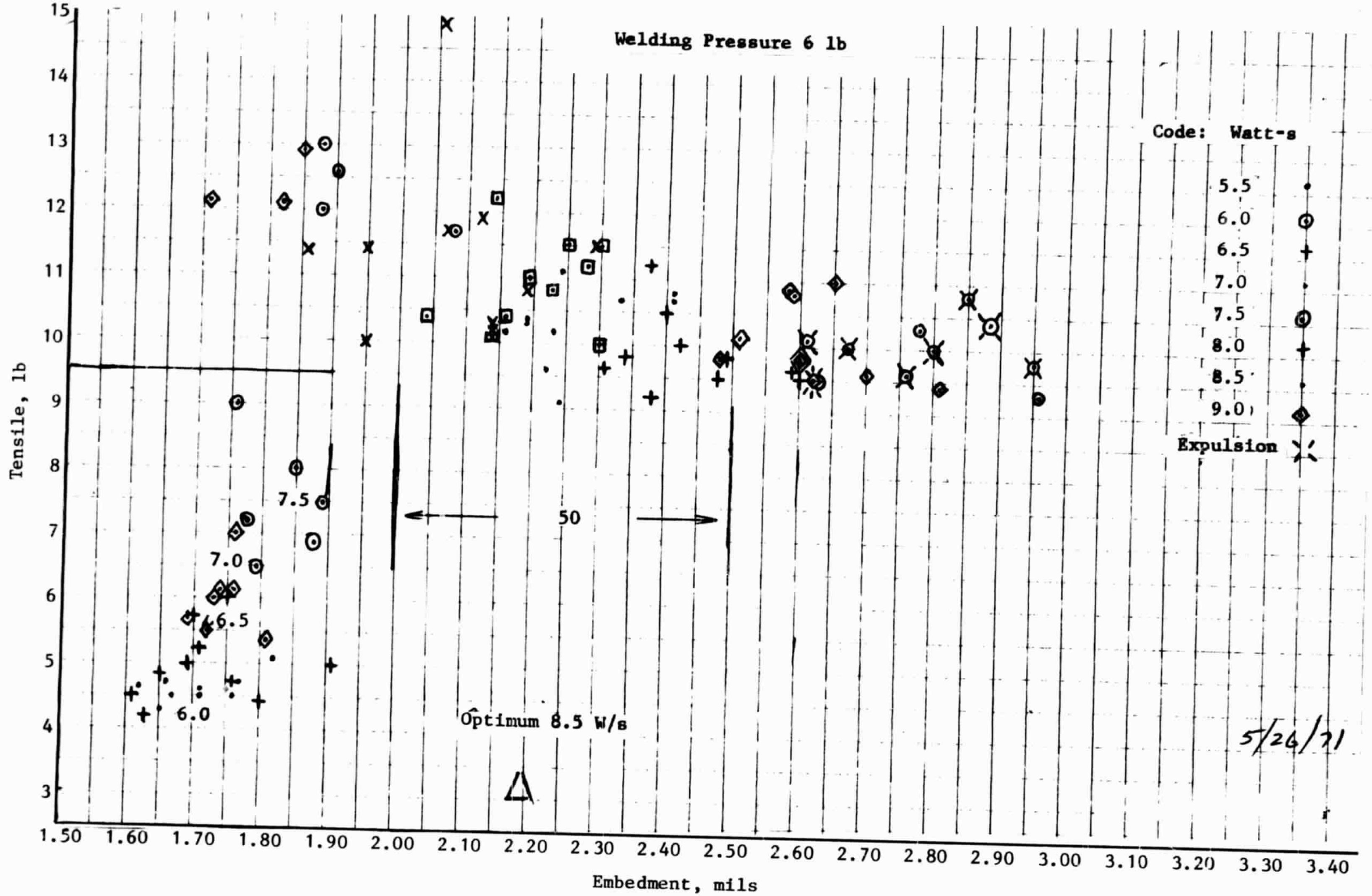

Figure 5. Correlation of Tensile Strength with Embedment 0.020 Dia Dumet (Au) to 0.010 x 0.032 Ni

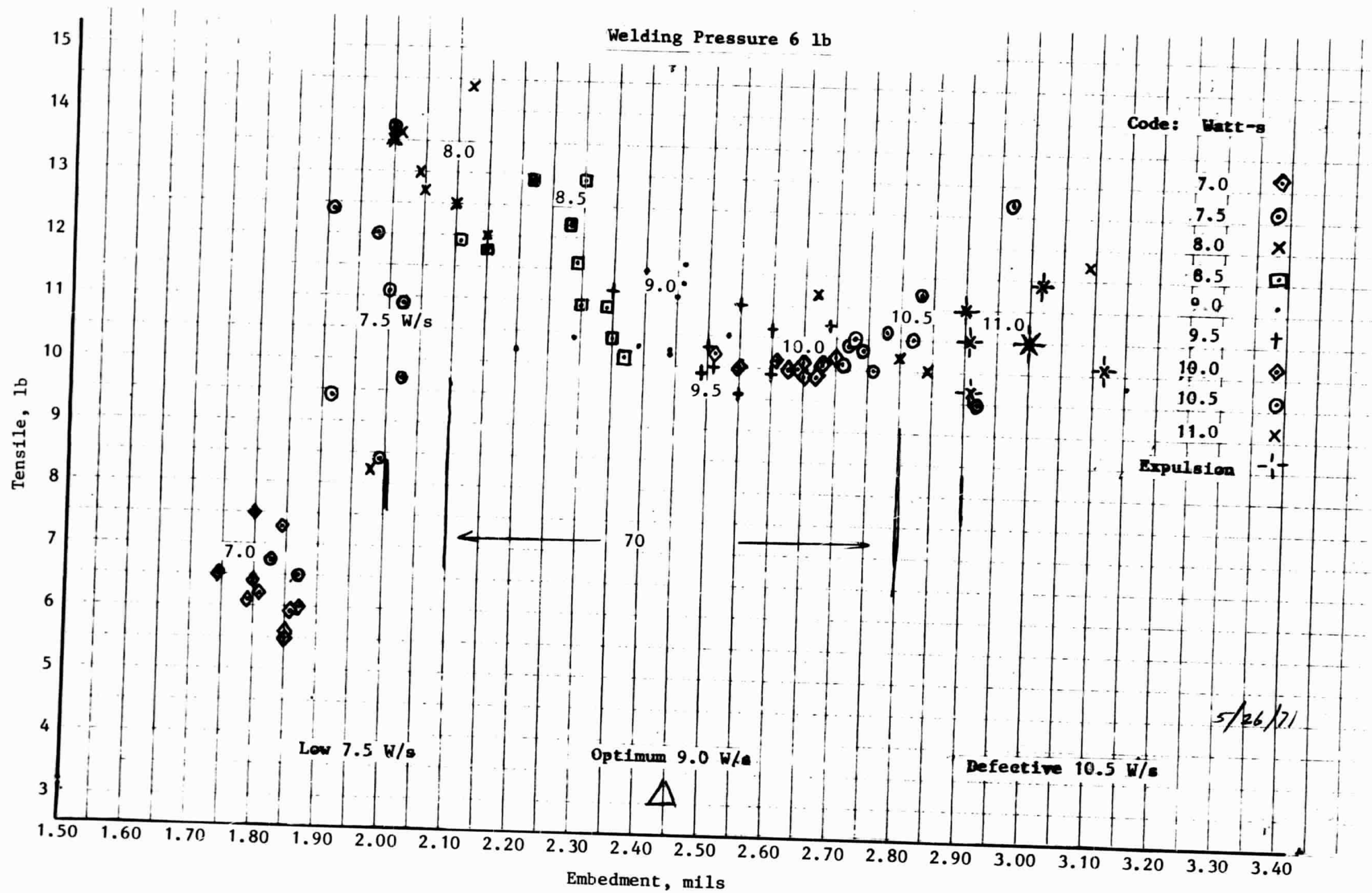

Figure 6. Correlation of Tensile Strength with Embedment 0.020 Dia Dumet (Au) to 0.010 x 0.032 Ni

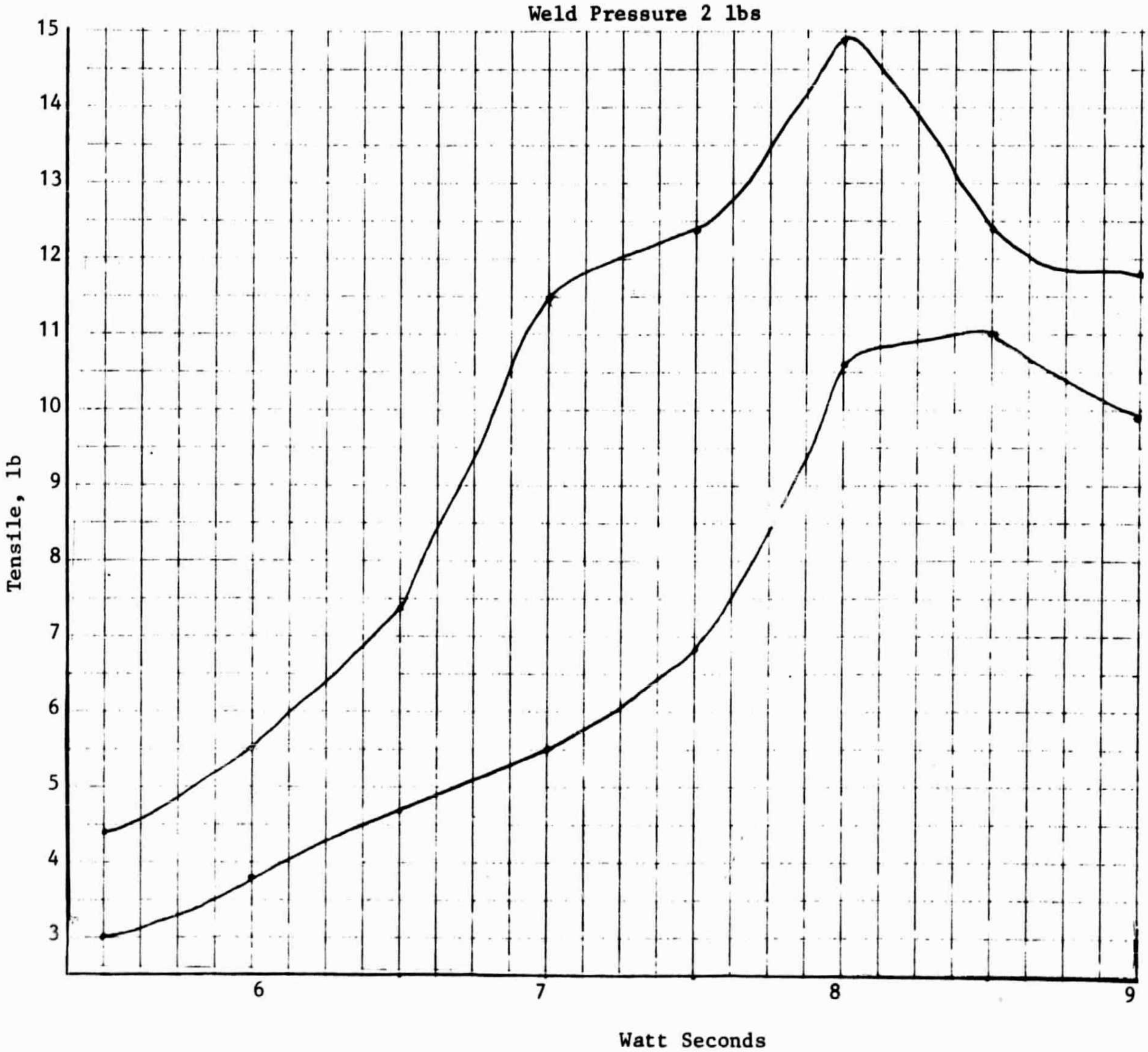

Figure 7. Plot of Tensile Strength versus Weld Energy 0.020 Dumet (Au) to 0.010 x 0.032 Ni

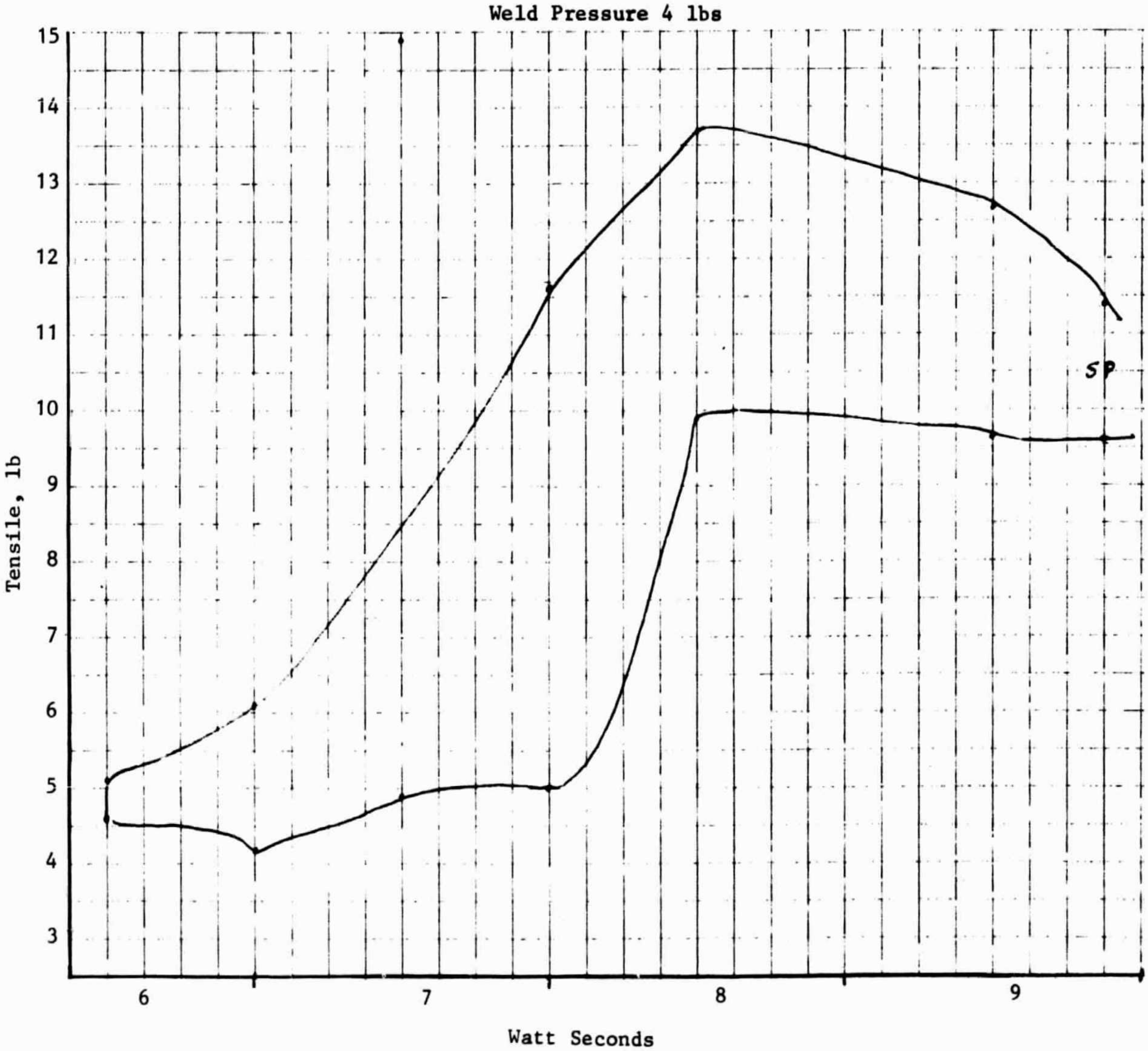

Figure 8. Plot of Tensile Strength versus Weld Energy 0.020 Dumet (Au) to 0.010 x 0.032 Ni

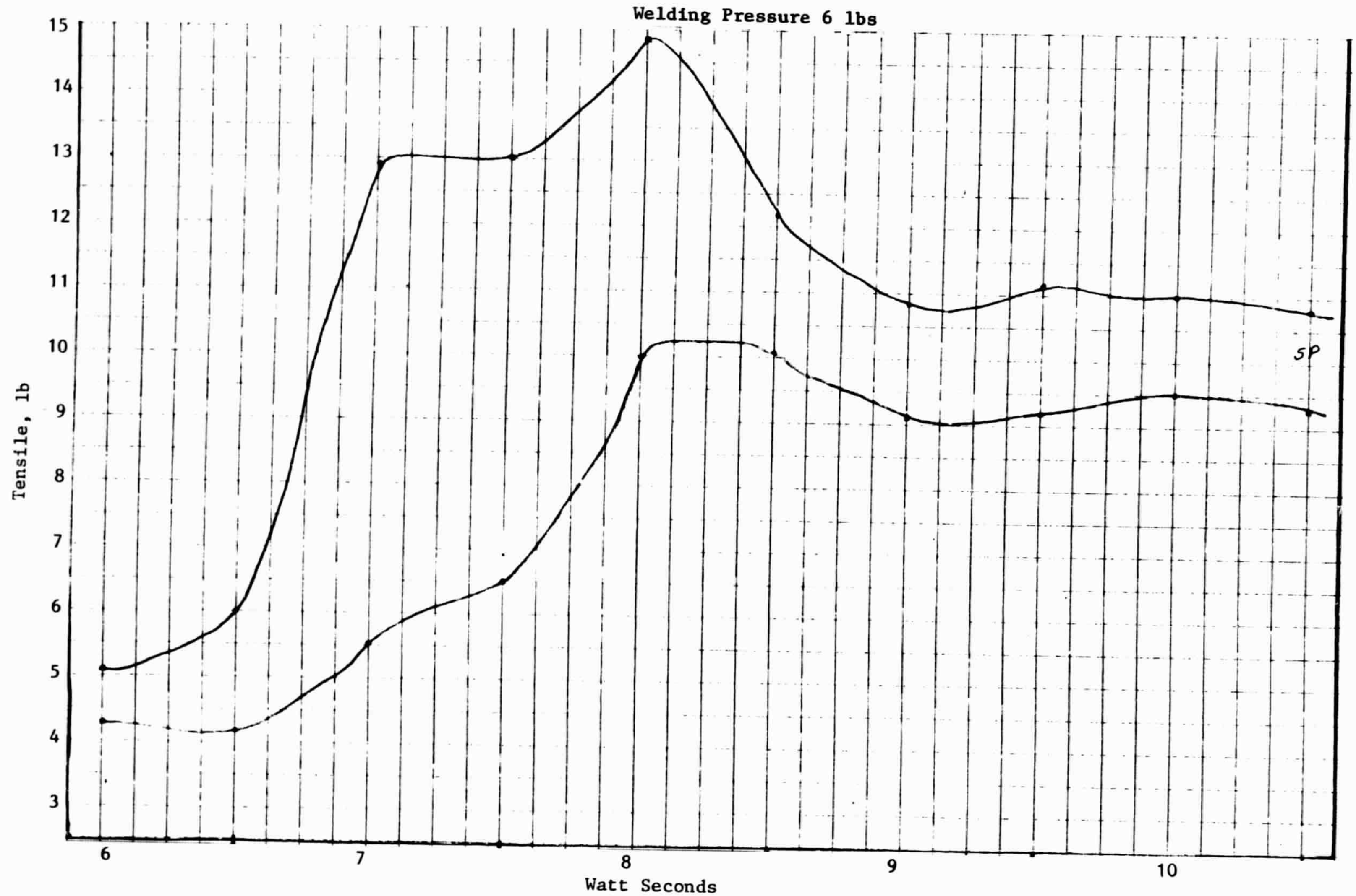

Figure 9. Plot of Tensile Strength versus Weld Energy 0.020 Dumet (Au) to 0.010 x 0.032 Ni

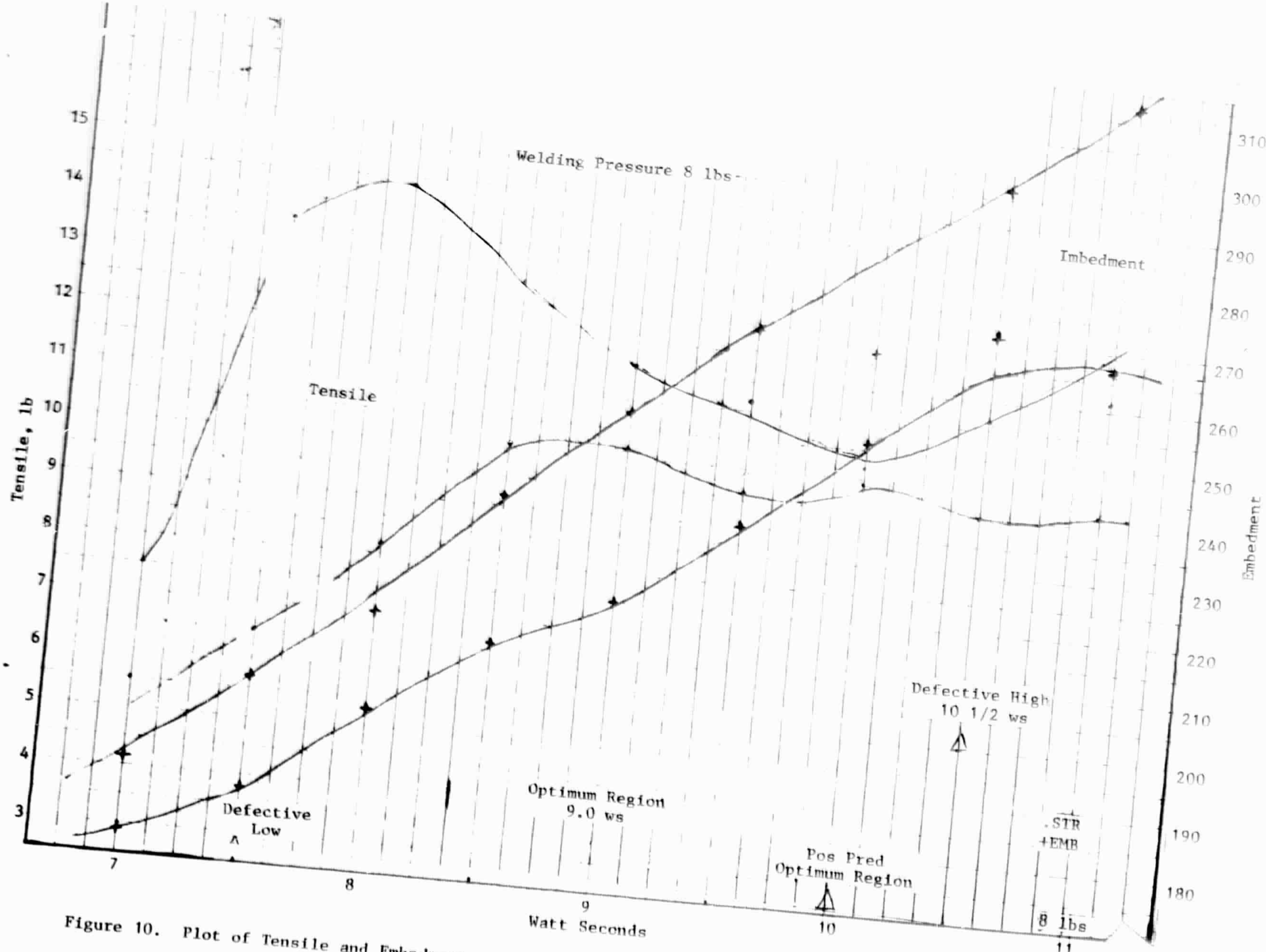

Figure 10. Plot of Tensile and Embedment versus Welding Energy 0.020 Dia Dumet (Au) to 0.010 x 0.032 Ni

for the three region separation test. Values were 7 3/4 Ws, 9 Ws, and 10 3/4 Ws for low, optimum and defective regions, respectively. Fifty bits of data were run consecutively at the selected Ws settings, recording embedment and subsequent tensile strength values, reference Tables A-I to A-III in the Appendix. Results were statistically analyzed and presented in Table II with ranges for the three regions presented in Table III. Because of the resultant overlap of ranges predicted by statistical analysis, a second power setting was selected and an additional 50 bits of data run, reference Table A-IV. These were run at 10 Ws within the optimum weld region.

TABLE II

Summary of Statistical Analysis of Three Region Separation Test (0.020 Diameter Dumet (Au) to 0.010 x 0.032 Inch Ni Ribbon)

Region	Average $\bar{X}$	Biased σ	Unbiased σ	99 Percent Probability with 95 Percent Confidence Level (3.126σ)
Low_{18}	1.845	0.0768	0.0790	1.845 ± 0.247
Low_{50}	1.901	0.0845	0.0854	1.901 ± 0.267
Optimum 9 Ws	2.313	0.0636	0.0642	2.313 ± 0.201
Optimum 10 Ws	2.577	0.0837	0.0845	2.577 ± 0.264
High	2.835	0.1103	0.1114	2.835 ± 0.348

TABLE III

Ranges Established for Three Region Separation Test from Table II for Weld Embedment of Dumet Wire to Nickel Ribbon

Low_{18}	Low 7 3/4 Ws	Optimum 9 Ws	Optimum 10 Ws	High 10 3/4 Ws
1.598	1.634	2.112	2.313	2.487 mils
2.092	2.168	2.514	2.841	3.183 mils

As may be observed, a low_{18} region was also statistically analyzed to see if embedment in this region was much less than the total 50 bits of data run in the low strength region, reference Table V. This low_{18} region consisted of embedment values of 18 bits of the total 50 bits of data produced by welds which did not meet minimum strength requirements. No significant difference was apparent between the selected population of 18 versus the total population of 50 since the average embedment values of the low_{18} and low_{50} were 1.85 and 1.90 mils respectively. Minimum/maximum values were 1.60/2.09 and 1.63/2.17, respectively. Welds made at the 7 3/4 Ws setting can produce good and bad welds with embedment values so close that it is impossible to separate the good welds from the bad. It is apparent that the optimum weld setting must be made at a higher value such as the 10 watt/second level where measured embedment can be associated with a high quality weld.

The results of the three region separation test is summarized in Table IV. Note separation is achieved only between the low strength region and the 10 Ws setting in the optimum weld region.

TABLE IV

Conclusions of the Three Region Separation Test

Optimum Weld Region	Low Strength Region	High Defective Region
9 Ws	Overlap	Overlap
10 Ws	Separation	Overlap

This close proximity of data is further illustrated by plotting the resultant of the three region separation tests on strength versus embedment plots in Figure 11. A group of 20 bits of data are selected from each population of 50 bits of data by plotting the five high and five low of both embedment and strength values at their corresponding embedment-strength points. Also, embedment was plotted consecutively for each 50 bits of data run, and is presented in Figures 12 to 15. Very little drift was experienced during each run. A high level of stability is indicated.

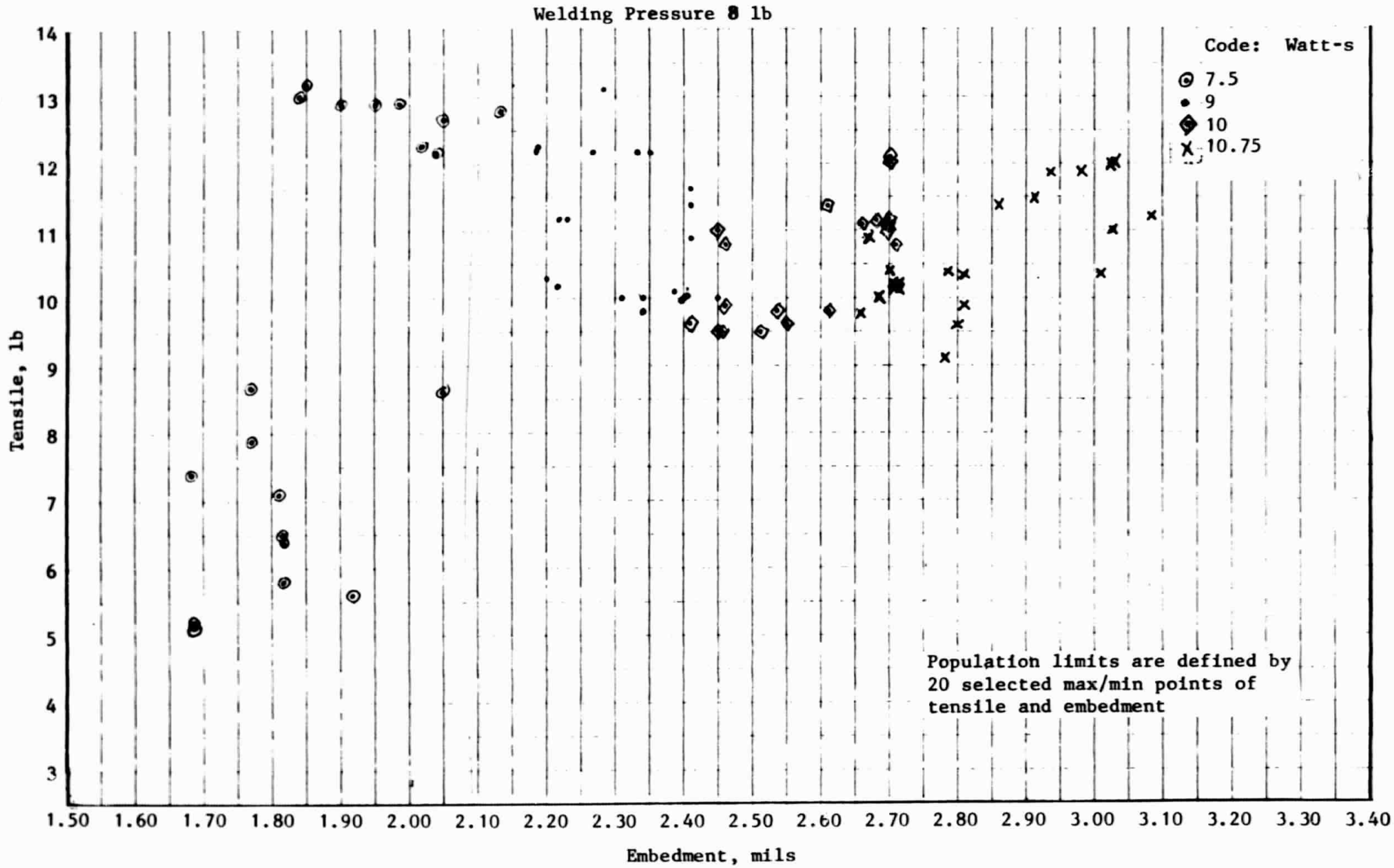

Figure 11. Three Region Separation Test Data for 0.020 Dia Dumet (Au) to 0.010 x 0.032 Ni

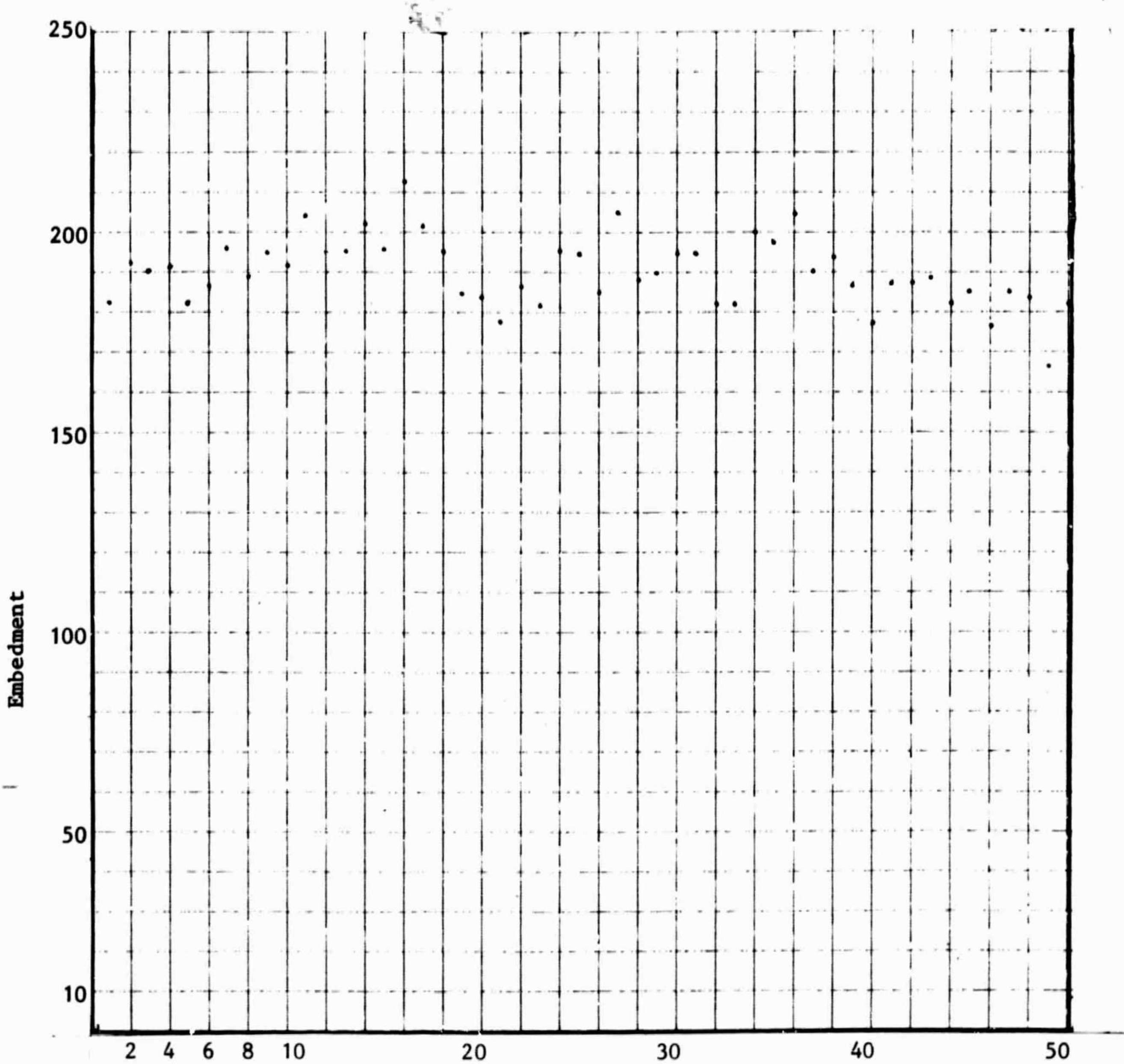

Figure 12. Consecutive Plot of Embedment Data to Display Drift During Welding of 0.020 Dumet (Au) to 0.010 x 0.032 Ni

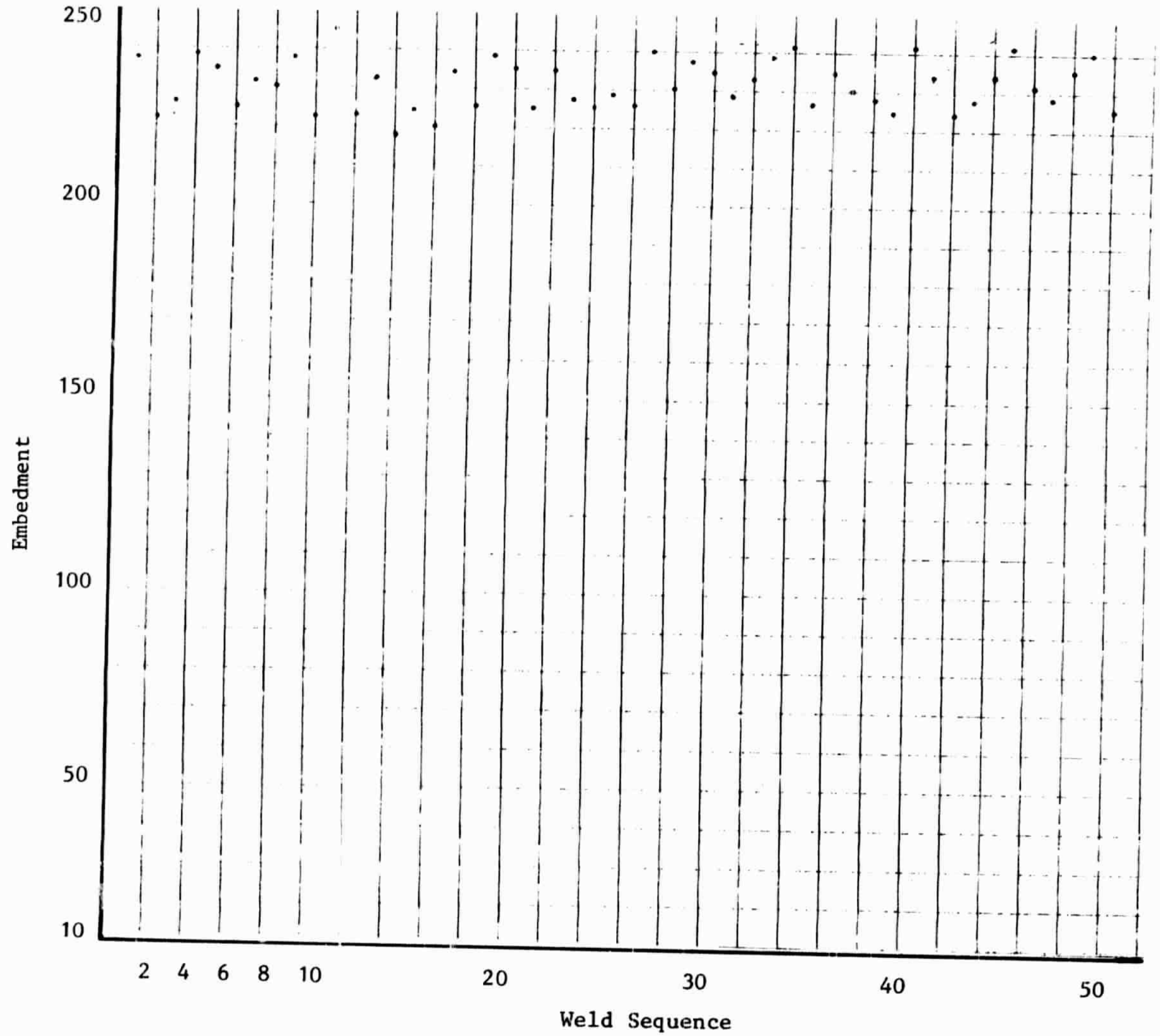

Figure 13. Consecutive Plot of Embedment Data to Display Drift During Welding of 0.020 Dumet (Au) to 0.010 x 0.032 Ni

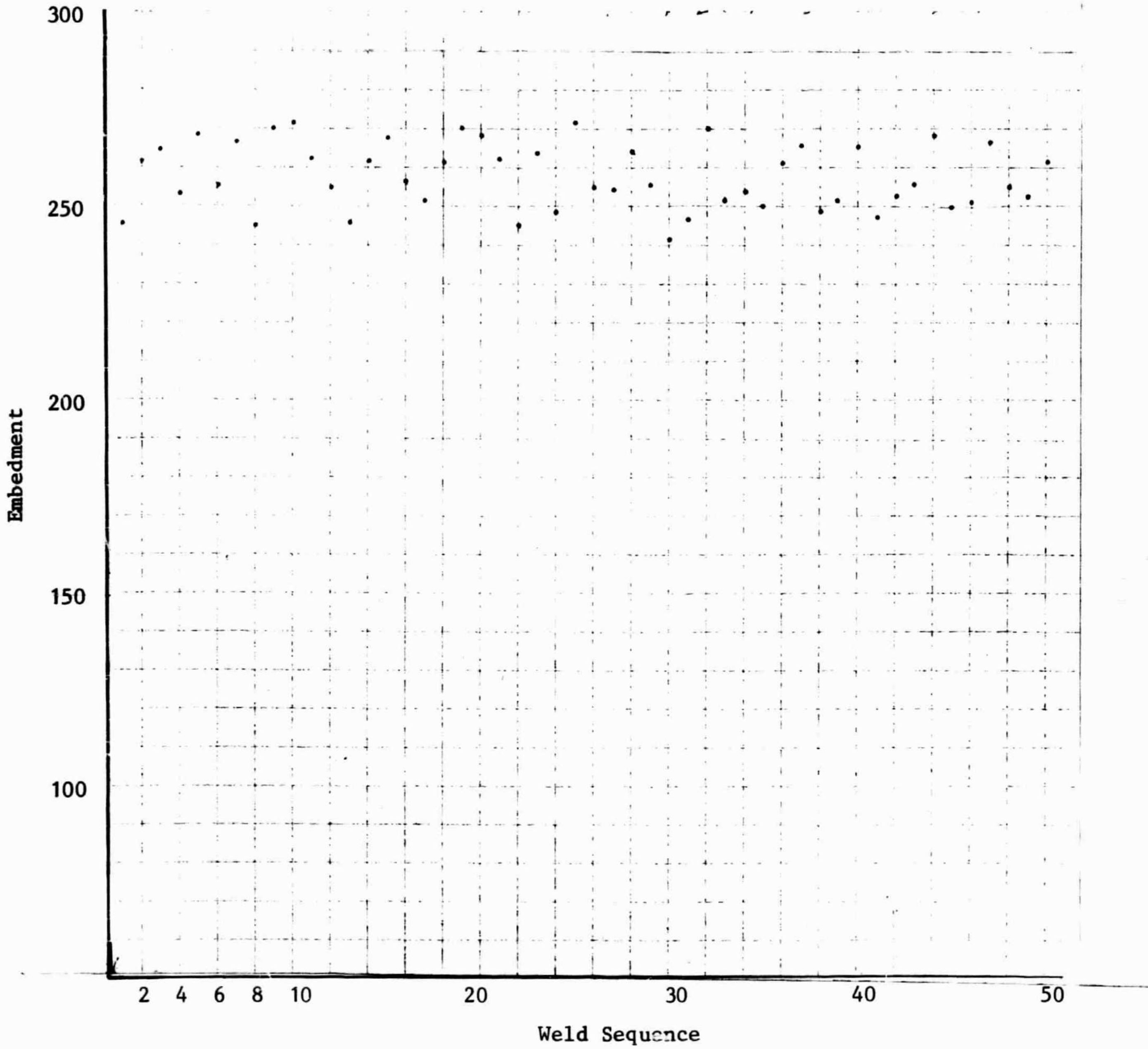

Figure 14. Consecutive Plot of Embedment Data to Display Drift During welding of 0.020 Dumet (Au) to 0.010 x 0.032 Ni

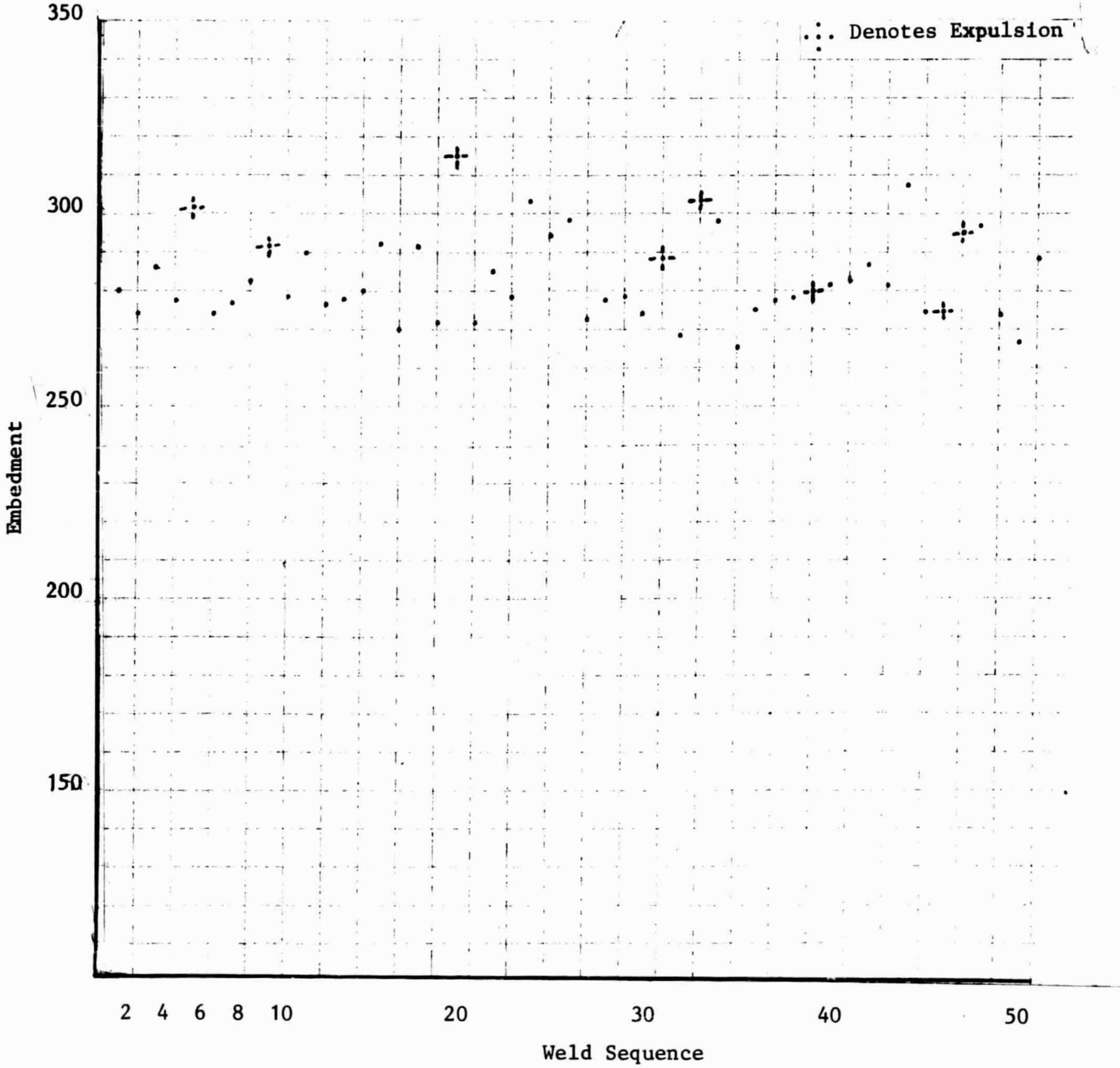

Figure 15. Consecutive Plot of Embedment Data to Display Drift During Welding of 0.020 Dumet (Au) to 0.010 x 0.032 Ni

III. NEW TECHNOLOGY

The weld quality monitor did not discriminate between sound and overheated welds on welding Dumet to nickel ribbon. It is proposed that an infrared control system be incorporated to provide control of pulse power while the GSFC Weld Quality Monitor assure freedom from low strength welds. This particular IR system has been built and demonstrated in Martin Marietta's Advanced Manufacturing Technology Laboratories. The IR control was so effective that sound welds were consistently produced whether the weld power supply was set at 20 watt-seconds or 100 watt-seconds.

IV. PROGRAM FOR NEXT REPORTING PERIOD

Develop recovery plan and proceed with Kovar-to-nickel ribbon weld evaluation, and evaluate Weld Quality Monitor in a production environment.

V. CONCLUSIONS AND RECOMMENDATIONS

The Weld Quality Monitor has demonstrated ability to differentiate between low strength welds and sound weld. The equipment has demonstrated little draft (less than 2 percent) indicating a high level of stability if the equipment is allowed to run continually to stabilize thermally.

APPENDIX

TABLE A-I

Dumet (Au)/Ni Ribbon
Weld Schedule Test Data

Material: Positive Side 0.020D Neg. Side .010 X .032 N1
Electrodes: Top #2 Bottom #2 Machine HRW100 Heat VTA60
Heat 7.75W/S Pressure 8lbs

Sample	Embed-ment	Pull
1	182	5.8 L
2	192	10.4
3	190	12.9 H
4	191	11.6
5	182	6.5 L
6	187	7.5
7	197	9.6
8	189	8.2
9	195	12.1
10	192	5.6 L
11	H 204	12.2
12	195	11.6
13	195	12.2
14	H 202	12.3
15	196	11.5
16	H 213	12.8
17	201	11.0
18	196	12.6
19	185	9.7
20	184	12.4
21	L 178	7.4
22	187	9.5
23	L 181	7.6
24	196	13.5
25	195	12.9 H
26	185	7.4
27	H 205	8.6
28	188	7.9
29	190	10.2
30	195	11.3
31	195	9.5
32	182	6.8
33	182	11.4
34	200	10.4
35	198	12.9 H
36	H 205	12.7
37	190	7.2
38	194	9.7
39	187	8.7
40	L 177	7.9
41	188	11.4
42	188	11.0
43	189	7.2
44	182	12.4
45	185	13.2 H
46	L 177	8.7
47	186	12.4
48	184	13.0 H
49	L 168	5.2 L
50	182	6.4 L

Embedment

$n = 50$

$\Sigma X^2 = 1811231$

$\Sigma X = 9507$

$\frac{\Sigma X^2}{n} = 36224.62$

$\bar{X} = \frac{\Sigma X}{n} = 190.14$

$\bar{X}^2 = 36153.2196$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{71.4004} = 8.4498$

$3\sigma = 25.3494$

Limits $\bar{X} \pm 3\sigma$

$=164.8$ to 215.4

Remarks

Pull Strength

$n = 50$

$\Sigma X^2 = 534355$

$\Sigma X = 5029$

$\frac{\Sigma X^2}{n} = 106.871$

$\bar{X} = \frac{\Sigma X}{n} = 10.0580$

$\bar{X}^2 = 101.163364$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{5.708} = 2.389142$

$3\sigma = 7.167$

Limit $\bar{X} \pm 3\sigma$

$=2.9$ to 17.2lbs

Code:

H – One of 5 high data
L – One of 5 low data

TABLE A-II

Dumet (Au)/Ni Ribbon
Weld Schedule Test Data

Material: Positive Side 0.020D Neg. Side 0.010 x 0.032 Ni
Electrodes: Top No. 2 Bottom No. 2 Machine HRW 100 Head VTA 60
Heat 9.0 Pressure 8

Sample	Embed-ment	Pull
1	238	10.7
2	L 222	11.2
3	227	11.1
4	239	10.1 L
5	235	11.0
6	225	12.1
7	231	11.5
8	230	11.2
9	238	11.4
10	L 222	10.2
11	H 245	10.0
12	L 223	11.2
13	232	11.4
14	L 218	12.2H
15	224	11.1
16	L 220	10.3
17	234	10.0L
18	226	11.6
19	239	12.1
20	236	11.2
21	225	11.4
22	235	12.2H
23	228	13.1H
24	226	12.2
25	229	11.1
26	227	12.2H
27	H 240	10.0L
28	230	10.2
29	237	10.9
30	235	11.4
31	229	12.1
32	233	12.2H
33	239	10.2
34	H 241	10.9
35	227	10.1
36	235	12.0
37	230	11.2
38	228	11.0
39	224	11.8
40	H 241	11.6
41	234	11.0
42	224	11.9
43	228	10.9
44	234	9.8L
45	H 241	11.4
46	231	10.0L
47	229	11.3
48	236	10.2
49	240	12.0
50	226	11.7

Embedment

$n = 50$

$\Sigma X^2 = 2677472$

$\Sigma X = 11566$

$\frac{\Sigma X^2}{n} = 53549.44$

$\bar{X} = \frac{\Sigma X}{n} = 231.32$

$\bar{X}^2 = 53508.9424$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{40.4976} = 6.3637$

$3\sigma = 19.0911$

Limits $\bar{X} \pm 3\sigma$

$= 250.41$ to 212.23

Remarks

Pull Strength

$n = 50$

$\Sigma X^2 = 6312.64$

$\Sigma S = 559.6$

$\frac{\Sigma X^2}{n} = 126.2528$

$\bar{X} = \frac{\Sigma X}{n} = 11.1920$

$\bar{X}^2 = 125.2608$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.922} = 0.995991$

$3\sigma = 2.987973$

Limit $\bar{X} \pm 3\sigma$

$= 11.490$ to 10.894

Code:

H - One of 5 high data
L - One of 5 low data

TABLE A-III

Dumet (Au)/Ni Ribbon
Weld Schedule Test Data

Material: Positive Side 0.020D Neg. Side 0.010 x 0.032M
Electrodes: Top 2 Bottom 2 Machine HRW 100 Head VTA 60
Heat 10.75 Pressure 8

Sample	Embed-ment	Pull
1	280	9.6L
2	274	11.0
3	287	10.3
4	278	10.0
5	HE 301	10.4
6	274	11.1
7	277	10.1
8	282	10.0
9	E 291	10.4
10	279	9.9L
11	290	10.3
12	277	11.1
13	278	10.9
14	280	11.2
15	292	11.5H
16	L 270	10.4
17	291	10.1
18	H 281	10.4
19	E 315	11.7
20	L 271	10.2
21	286	11.4H
22	279	11.2
23	H 303	11.0
24	294	11.9H
25	298	11.1
26	272	10.5
27	278	11.2
28	279	10.4
29	274	10.3
30	E 239	10.6
31	L 269	10.0
32	HE 303	12.0H
33	298	11.9H
34L	266	9.8L
35	275	11.0
36	277	10.3
37	278	9.1L
38	E 280	10.2
39	281	9.9L
40	282	10.5
41	287	10.9
42	281	10.0
43	H 208	11.2
44	274	10.0
45	E 274	11.0
46	E 296	10.9
47	297	11.1
48	274	10.6
49	L 267	10.9
50	289	11.3

Pull Strength

$n = 50$

$\Sigma X^2 = 5697.36$

$\Sigma X = 532.8$

$\frac{\Sigma X^2}{n} = 113.9472$

$\bar{X} = \frac{\Sigma X}{n} = 10.656$

$\bar{X}^2 = 113.5503$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.3969} = 0.6300$

$3\sigma = 1.89$

Limits $\bar{X} \pm 3\sigma$

$= 8.766$ to 12.546

Remarks

Embedment

$n = 50$

$\Sigma X^2 = 4025268$

$\Sigma X = 14176$

$\frac{\Sigma X^2}{n} = 80505.360$

$\bar{X} = \frac{\Sigma X}{n} = 283.520$

$\bar{X}^2 = 80383.5904$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{121.7696} = 11.0349$

$3\sigma = 33.1047$

Limit $\bar{X} \pm 3\sigma$

$= 250.416$ to 316.624

Code:

H – One of 5 high data
L – One of 5 low data
E – Expulsion

TABLE A-IV

Dumet (Au)/Ni Ribbon
Weld Schedule Test Data

Material: Positive Side 0.020D Neg. Side 0.010 x 0.032 Ni
Electrodes: Top No. 2 Bottom No. 2 Machine HRW 100 Head VTA 60
Heat 10.0 Pressure 8

Sample Sample	Embed-ment	Pull
1	L 246	9.9
2	261	10.7
3	264	10.0
4	253	9.8L
5	269	10.7
6	256	9.8L
7	267	10.8
8	L 245	9.5L
9	H 270	11.0
10	H 271	10.8
11	262	9.9
12	255	10.0
13	L 246	10.8
14	261	9.9
15	268	11.2H
16	257	10.0
17	251	10.2
18	261	9.8L
19	H 270	11.1H
20	269	10.6
21	262	10.2
22	L 245	11.0
23	264	10.0
24	249	9.9
25	H 271	10.2
26	255	9.6L
27	254	10.9
28	264	10.9
29	256	10.0
30	L 241	9.6
31	247	10.1
32	H 270	12.1H
33	251	9.5L
34	253	9.8
35	250	9.9
36	261	10.0
37	266	11.1H
38	249	9.8
39	251	10.6
40	266	10.1
41	247	9.9
42	252	10.8
43	256	10.7
44	268	9.5
45	250	10.5
46	251	10.3
47	267	10.5
48	255	10.2
49	252	10.3
50	261	11.4H

Pull Strength

$n = 50$

$\Sigma X^2 = 5338.79$

$\Sigma X = 515.9$

$\frac{\Sigma X^2}{n} = 106.7758$

$\bar{X} = \frac{\Sigma X}{n} = 10.318$

$\bar{X}^2 = 106.4611$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{0.3147} = 0.56098$

$3\sigma = 1.68294$

Limits $\bar{X} \pm 3\sigma$

$= 8.64$ to 12.0

Remarks

Embedment

$n = 50$

$\Sigma X^2 = 3324484$

$\Sigma X = 12886$

$\frac{\Sigma X^2}{n} = 66489.68$

$\bar{X} = \frac{\Sigma X}{n} = 257.72$

$\bar{X}^2 = 66419.5984$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{70.08} = 8.37137$

$3\sigma = 25.11411$

Limits $\bar{X} \pm 3\sigma$

$= 232.61$ to 282.83

Code:

H – One of 5 high data
L – One of 5 low data

TABLE A-V

Dumet (Au)/Ni Ribbon
Weld Schedule Test Data

Material: Postive Side 0.020D Neg. Side 0.010 x 0.032 Ni
Electrodes: Top 2 Bottom 2 Machine HRW100 Head VTA 60
Heat 7 3/4 Pressure 81b

Sample	Embed-ment	Pull
1	182	5.8
2	182	6.5
3	187	7.5
4	189	8.2
5	192	5.6
6	178	7.4
7	181	7.6
8	185	7.4
9	205	8.6
10	188	7.9
11	182	6.8
12	190	7.2
13	187	8.7
14	177	7.9
15	189	7.2
16	177	8.7
17	168	5.2
18	182	6.4

Pull Strength

$n = 18$

$\Sigma X^2 = 613761$

$\Sigma X = 3321$

$\frac{\Sigma X^2}{n} = 34097.83333$

$\bar{X} = \frac{\Sigma X}{n} = 184.5$

$\bar{X}^2 = 34040.25$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{57.5833} = 7.68$

$3\sigma = 23.04$

Limits $\bar{X} \pm 3\sigma$

$= 161.5$ to 207.5

Embedment

$n = 18$

$\Sigma X^2 = 96610$

$\Sigma X = 1306$

$\frac{\Sigma X^2}{n} = 53.672222$

$\bar{X} = \frac{\Sigma X}{n} = 7.26$

$\bar{X}^2 = 52.643$

$\sigma = \sqrt{\frac{\Sigma X^2}{n} - \bar{X}^2}$

$= \sqrt{1.029} = 1.01$

$3\sigma = 3.03$

Limit $\bar{X} \pm 3\sigma$

$= 4.23$ to 10.29

Remarks

Eighteen defective weld were selected from this group of 50 run at the above watt-second setting.