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TECHNICAL REPORT ECOM-03742-8

MICROBONDS for HYBRID MICROCIRCUITS (U) PROGRESS REPORT

BY

A. R. RIBEN — S. L. SHERMAN

MAY 20, 1966

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N.J.
CONTRACT DA 36-039 AMC-03742 (E)

HAMILTON STANDARD ELECTRONICS DEPARTMENT
DIVISION OF UNITED AIRCRAFT CORPORATION
BROAD BROOK, CONNECTICUT

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MICROBONDS FOR HYBRID MICROCIRCUITS(U)

PROGRESS REPORT

1 November 1965 to 31 January 1966

REPORT NO. 8

CONTRACT NO. DA 36-039 AMC-03742 (E)

DA PROJECT NO. IP6-22001-A-057, TASK 03, SUB-TASK 21

PREPARED BY

A. R. RIBEN - S. L. SHERMAN

HAMILTON STANDARD

ELECTRONIC DEPARTMENT

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1.0 PURPOSE

Since the advent of miniaturization, development of joining techniques to bond metal conductors has become an essential step toward the achievement of reliability. In addition, the proximity and number of connections demanded by thin film and semiconductor microcircuits have presented particularly unique problems. Not only are the areas available for bonding extremely small, but bonding film thicknesses are often of the order of a few hundred angstroms. The need for a suitable bonding process has led to the investigations of many techniques. Both the recently developed resistance welders, and the even newer ultrasonic bonder appear to be suited for the solution of some of these problems.

The objective of this program is the development and evaluation of microbonding techniques for welded interconnections within hybrid microcircuits with thin film terminations. The resistance welder and the ultrasonic bonder are to be employed to develop and demonstrate joining techniques which result in bonds denoted by high yield and reliability; furthermore, the process must be compatible with the low cost objectives of microelectronics.

More specifically, microbonds between fine wires of gold and aluminum 0.001 inch, 0.002 inch, and 0.005 inch in diameter to thin films on various substrates will be developed and evaluated. The thin film terminations are either Au/Cr or Aluminum vacuum deposited on substrates of Vycor, as-fired and glazed alumina, oxidized silicon, sapphire and beryllia. Specific material combinations to be investigated will be discussed in subsequent sections.

The development of optimum microbonding techniques will include an investigation of bonding equipment parameters, film thicknesses, materials, and evaluation techniques, and other variables through a comprehensive testing program.

The information acquired during Phase I (3) of this program will be used to guide the work carried out in this second phase.

In addition to fine wire bonding, fabrication of Micro Circuit Modules (MCM) by means of resistance welding will be developed and evaluated. MCM stacks, with copper or nickel riser wires welded to Ni/Au/Cr terminations on substrates of as-fired and glazed alumina, Sapphire, and Beryllia will be studied.

A third study involving welding of flat packs to multilayer circuit boards will be carried out. In this case again, the parameters required for reliable welding will be developed and the subsequent bonds evaluated.

The technique of room temperature ultrasonic bonding of flip chip transistors will also be evaluated. The chips will be bonded to Au/Cu/Cr films on as-fired alumina.

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The ultimate objective of this program is the establishment of reliable high yield microbonding processes which are equivalent or more reliable than current state-of-the-art thermo-compression bonding. In this respect we are attempting to achieve a 90% confidence level such that not more than 3 microbonds per 1000 fail a specified minimum pull strength limit. The experience gained during this development and the conclusions in the comparison of different techniques as well as the material combinations will be published in the form of a Weld Handbook at the conclusion of the program.

2.0 ABSTRACT

The overall objective of this program is the development of reliable high yield processes for bonding fine wires of gold and aluminum to gold-chromium and aluminum films on various substrates such as alumina, sapphire, and oxidized silicon. Furthermore, techniques are to be developed and evaluated for fabricating MCM stacks and joining standard flat-packs to multilayer circuit boards by means of resistance welding and for ultrasonic bonding of flip-chip transistors to gold-chromium films on as-fired alumina.

During this quarter, the mechanical strengths of Type K (0.001 inch Al wire ultrasonically bonded to Au/Cr films on as-fired alumina), Type A'_5 (0.005 inch Au wire resistance welded to Au/Cr films on sapphire, Type A''_2 (0.002 inch Au wire resistance welded to Au/Cr films on beryllia), Type A''_5 (0.005 inch inch wire resistance welded to Au/Cr films on beryllia), Type B'_1 (0.001 inch Al wire ultrasonically bonded to Au/Cr films on sapphire), Type B'_2 (0.002 inch Al wire ultrasonically bonded to Au/Cr films on sapphire) and Type B''_2 (0.002 inch Al wire ultrasonically bonded to Au/Cr films on beryllia) were evaluated. The reliability goal of an expected failure of no more than 3 bonds per thousand at the 90% confidence level was met for the Types A''_2 and A''_5 microbonds.

Electrical resistance measurements have shown that all bonds completed to date met the contractual goal of SCL-7746A. Thermal aging tests indicated that bond Types E, F, G, H, A'_1, A'_2 and A''_1 all met the contractual goal for a temperature of 125° C, and all but Type G met the goal at 200° C.

Type V stack welded microbonds were completed and the maximum number of expected bond failures was 5 per thousand. The Type V average pull strength was 96% of the nickel riser wire tensile strength.

3.0 CONFERENCES AND MEETINGS

Messrs. A. R. Riben, R. J. Green and J. S. Warner visited Fort Monmouth on January 18, 1966. The purpose of this meeting was to discuss the replacement of P. R. Amlinger by A. R. Riben as Program Manager. Also included in the discussion was a general review of the progress of the program and revisions of the 5th Quarterly Report.

4.0 FACTUAL DATA

4.1 Introduction

The work presented in this report was accomplished during the period from 1 November 1965 to 31 January 1966. The major effort during this period was concentrated on completion of the microbonds under Tasks I and IA. Procurement procedures for materials necessary for Tasks II, III, and IV were also completed.

The following sections will report the work details in the order of specific tasks.

4.2 Task I - Microbonds

The bond requirements for this task are shown in Table I. Types E, F, G, and H microbonds have been completed and were reported previously.[1, 2] Type K microbonds were completed during this quarter and are reported in the following sections.

4.2.1 Materials

4.2.1.1 Substrates

The Type K Microbonds required as-fired alumina substrates which were identical to those used in the fabrication of the Hamilton Standard MicroCircuit Module. A surface tracing of a typical substrate is shown in Figure 1. The surface roughness is 9 to 13 microinches. Later is this report, the alumina wafers will be compared to the beryllia wafers used in Task IA.

4.2.1.2 Wires

Aluminum wire, 0.001 inch in diameter, was used to form the Type K microbonds. The manufacturer* of the ultrasonic bonding equipment used in this task recommends using a harder wire than pure aluminum. The wire employed in this task was 99% Al 1% Si, stress-relieved, 0.001 inch diameter, with an elongation of 2% and a resistance of 18 ohms per foot. It was supplied by Secon Metals. The pull strength distribution for this wire is shown in Figure 2. The average pull strength was 14.5 grams

4.2.1.3 Film Deposition

The total gold/chromium film thickness for these bonds was approximately 23,000 Å and was the same deposition run as that made for the wafers used for the Type F microbonds

* Axion Corp., Commerce Park, Danbury, Conn.

TABLE I

BONDS REQUIRED FOR TASK I

Bond Type	Wire	Wire Size	Film	Bonding Technique	Substrate Material
E	Au	0.001"	Au/Cr	Split-Tip	Vycor
F					Alumina (As-fired)
G					Glazed Alumina
H					Oxidized Silicon
K	Al			Ultrasonic	Alumina (as-fired)
R'			Al		Vycor
S'					Oxidized Silicon
T'					Sapphire

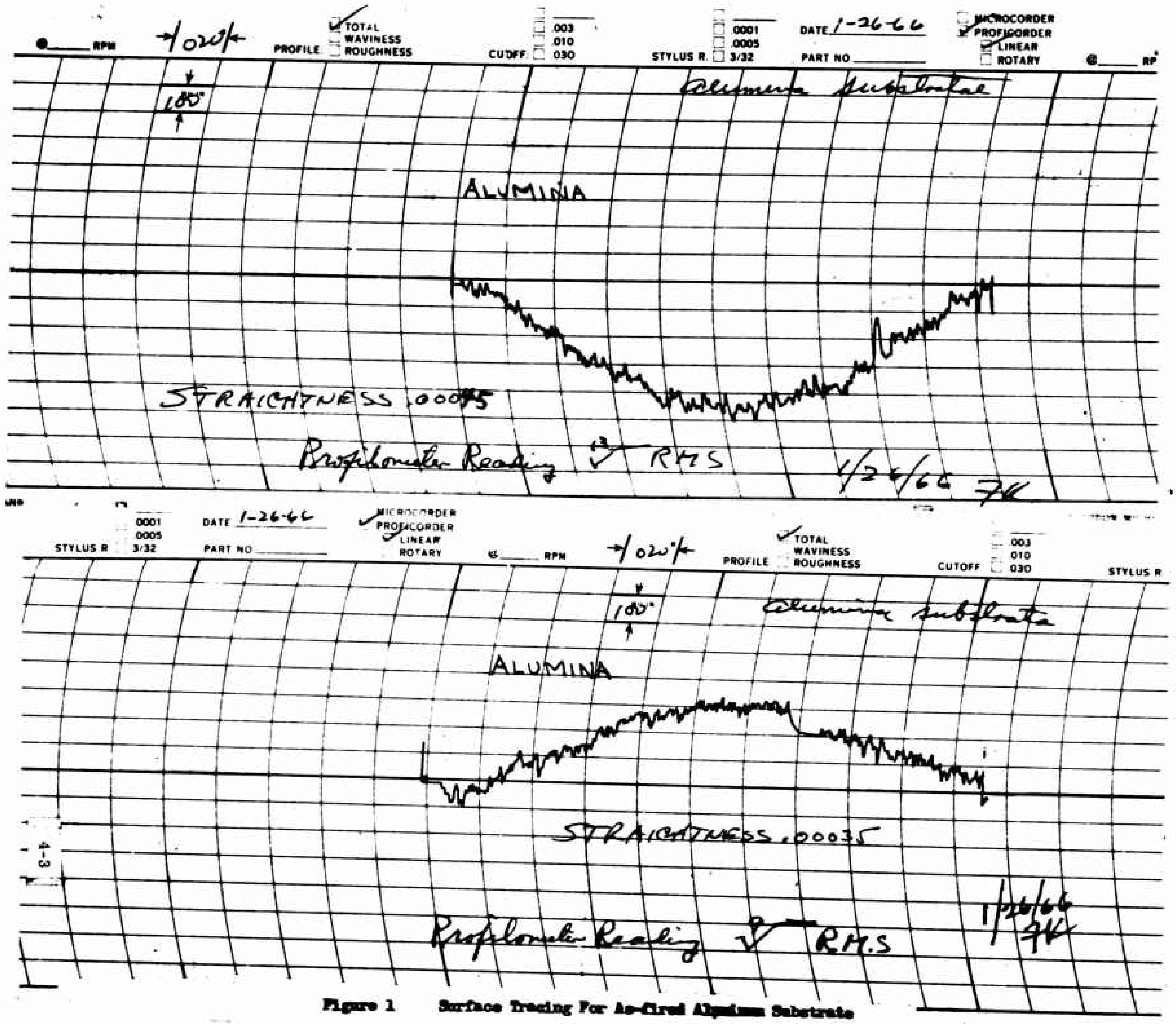


Figure 1 Surface Tracing For As-fired Alumina Substrate

Substrate 2

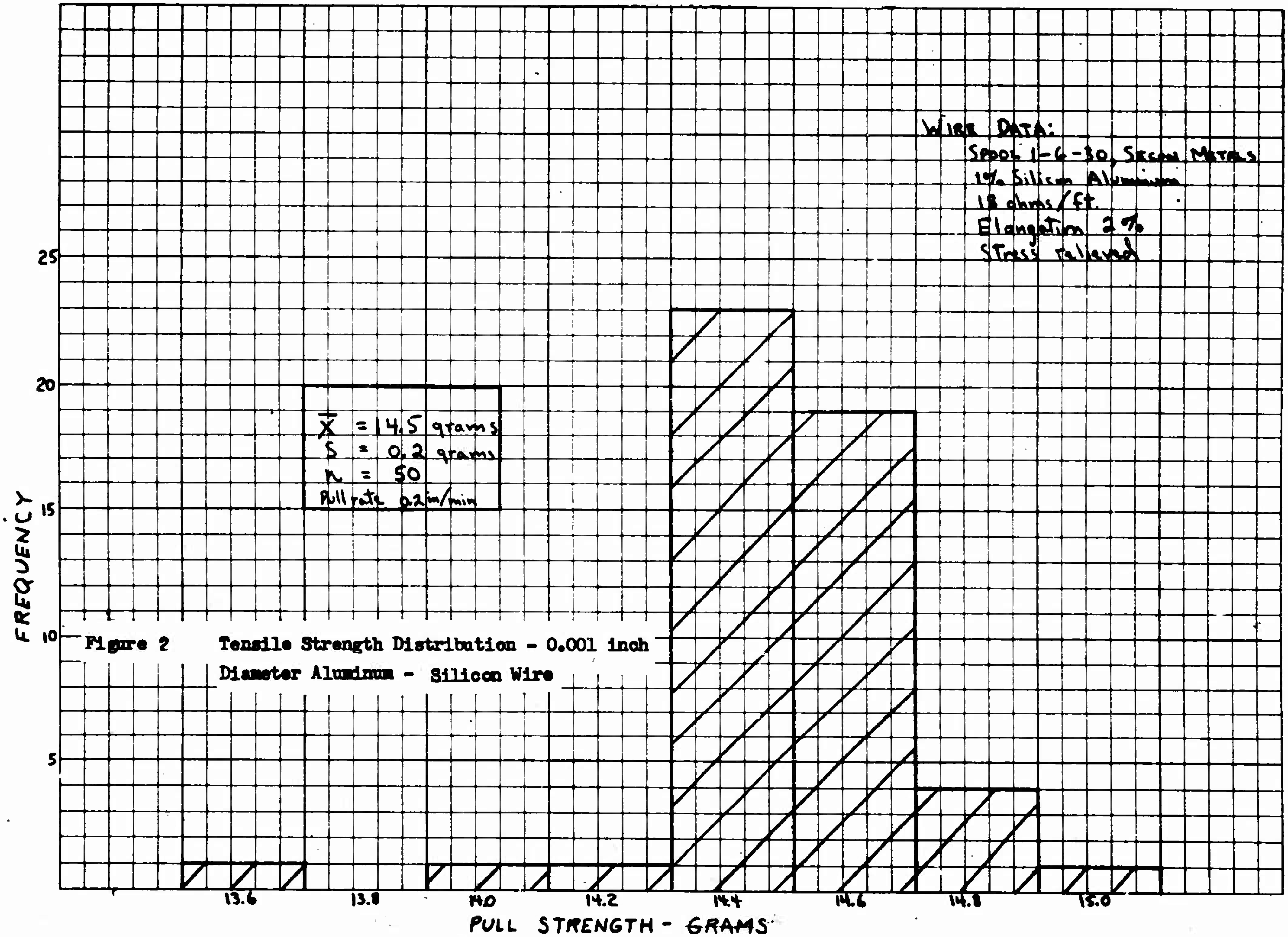


Figure 2 Tensile Strength Distribution - 0.001 inch Diameter Aluminum - Silicon Wire

4.2.2 Bonding Equipment

4.2.2.1 Ultrasonic Bonder

Ultrasonic bonding techniques were employed to form the microbonds of aluminum wire to gold/chromium films. An Axion Corporation ultrasonic wire bonder was used for this study. The bonder, illustrated in Figure 3, consists of a 10 watt, 40 KHz, vertical action, ultrasonic transducer, a Bausch & Lomb Stereozoom microscope, an X-Y and 360° rotational manipulator, and a vacuum-operated clamping chuck.

The machine variables are:

Power	The setting is continuously variable from 0 to 10 in two ranges (the high range is ten times the low range)
Pulse Time	Continuously variable from 0.10 to 0.35 seconds
Bonding Force	Approximate range from 25 to 600 grams for 0.001 inch to 0.005 inch diameter wire.

The transducer head and column, the wire feed, the 2-axis lever for raising and lowering the transducer, the bonding tip and the work holder are shown in Figure 4 in the normal operating (i.e., bond being made) position. Weights can be added at two positions in any required amount. Provided on the transducer head is a knurled screw which allows adjustment of the bonding tip angle. Also visible in Figure 4 is the vacuum clamp which is used to break the wire after a bond has been made.

Figure 5 shows the operator's view of the substrate through the micro-scope. The multipad alumina substrate is shown with several 0.001 inch aluminum wire microbonds. Also shown is the manner in which the wire feeds down through a center hole in the bonding tip and underneath along a groove in the bottom of the tip. Figure 6 is a photomicrograph of the bonding tip for 0.001 inch diameter wire. The groove in the bottom of the bonding tip under which the bond is formed by vertical compression is approximately 0.004 inch long. It appears from this photograph that the groove is machined to a smoother surface finish than the bottom of the bonding tip. A smoother finish would tend to increase the useage allowable between cleanings.

4.2.2.2 Substrate Hold-Down Fixture

During the preliminary investigations of the weld schedule development, it was observed that the substrate vacuum hold-down fixture supplied with the bonder did not hold the substrates tightly enough. When the ultrasonic power

Figure 3 Axion Ultrasonic Bonder

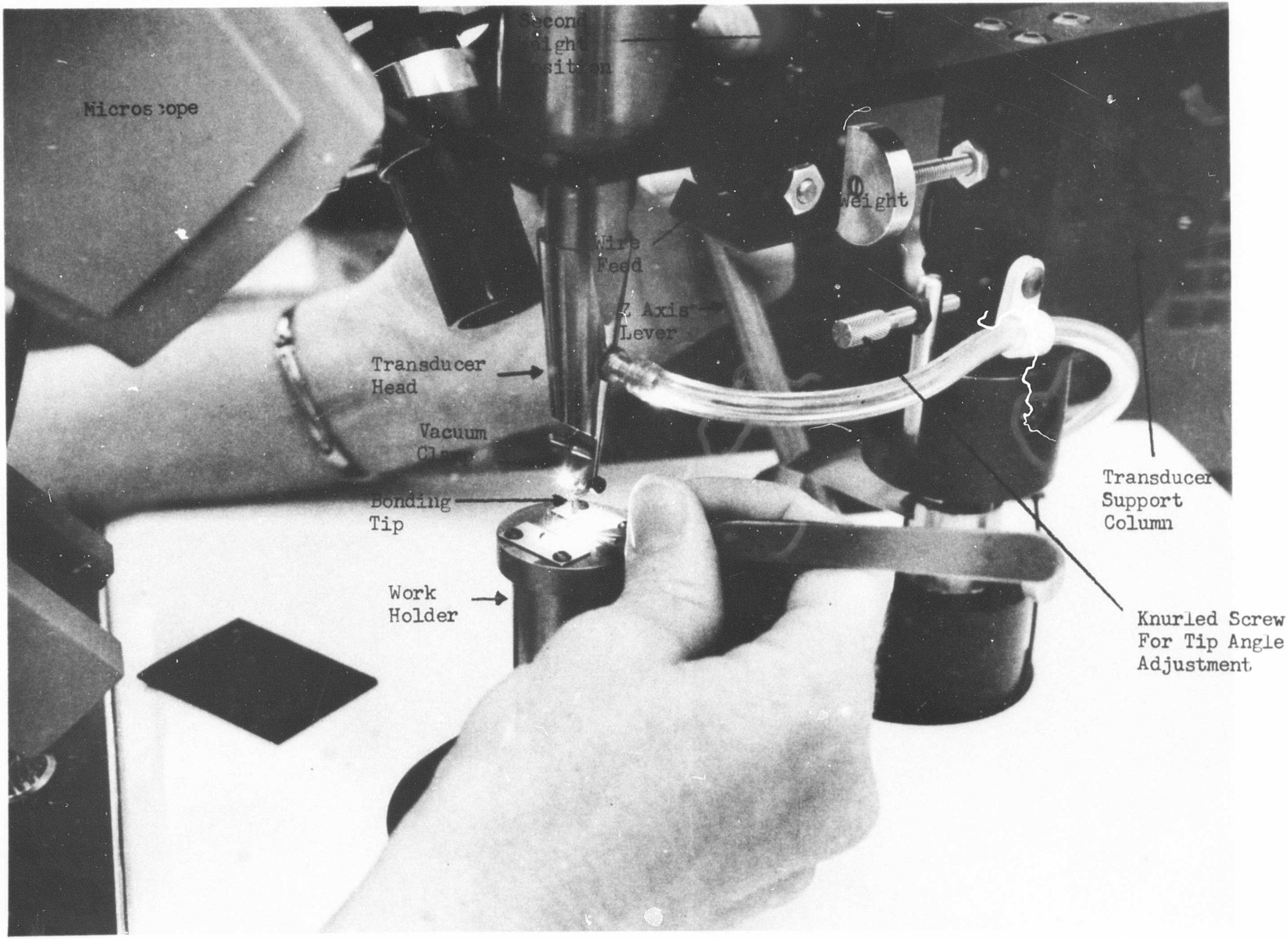
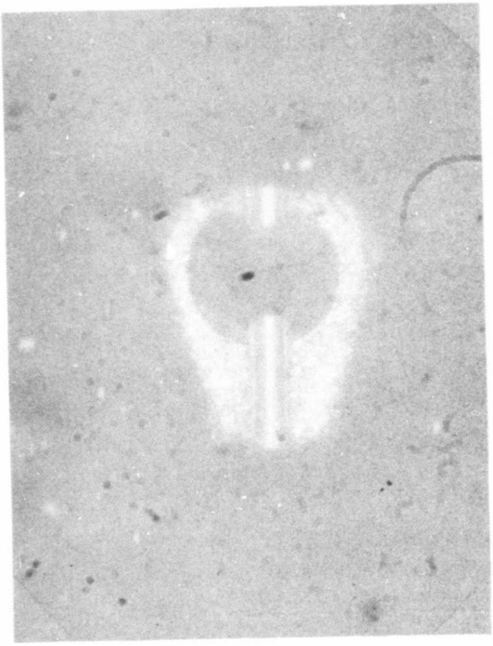


Figure 4 Close-up of the Axion Transducer

Figure 5 Operator's View of Substrate on Ultrasonic Bonder



Vertical Illumination

Oblique Illumination

Magnification ~ 203X
Scale: 0.05 mm

Figure 6 Microphotograph of Bonding Tip for 0.001 inch Diameter Wire was applied, the substrate would slide, which would either weaken or entirely destroy the bond. A modified hold-down fixture which combined both vacuum and mechanical clamping was designed. This is illustrated in Figure 7, with a bonded substrate in position. This fixture eliminated any substrate movement during the bonding process.

4.2.3 Weld Schedule Development

In order to establish the optimum parameter settings for the ultrasonic bonder, the weld profile method was employed. The starting point was to set the machine power to zero, the time to 0.10 seconds, and the bonding force to a value such that the wire was slightly deformed when the bonding tip was lowered but no ultrasonic energy was applied. This deformation could be observed in a small mirror which was attached to the substrate hold-down fixture as shown in Figure 7. The machine parameters were gradually increased until the optimum parameters could be deduced from the weld profile diagrams.

A change in experimental procedure was made for the aluminum wire bonds. Instead of a 90° pull test, such as that used in previous work, (1, 2, 3) a 45° pull test was employed. The 45° pull test was selected to avoid preliminary weakening of the bond at the weld-affected zone (i.e., the deformed region of the wire comparable to the heat-affected zone in resistance welded microbonds). This weakening would occur due to the hardening of the aluminum wire as it is cold-worked. Although the 45° pull test is not as sensitive as a 90° pull test, it is still more sensitive than a straight (bond in shear) pull test. The fixture used for the 45° pull test technique is shown in Figure 8.

In addition, the pull rate of the Instron Tensile Tester was reduced to 0.2 inch/minute from 0.5 inch/minute used previously (1, 2, 3). This was deemed necessary because of the lower ductility of the aluminum wire as compared to gold wire. Initial experiments showed that a higher pull strength was obtained at the lower pull rate.

The weld profile developed for Type K microbonds is shown in Figure 9. The parameters chosen for obtaining the reliability data on 23,000 Å gold/chromium films were:

Bond Force	25 grams
Power Setting	0
Pulse Width	0.15 seconds
Bonding Tip	AC 10 GF (0.001 inch wire)

4.2.4 Type K Microbonds - 0.001 inch Aluminum Wire to Gold/Chromium Films on As-fired Alumina

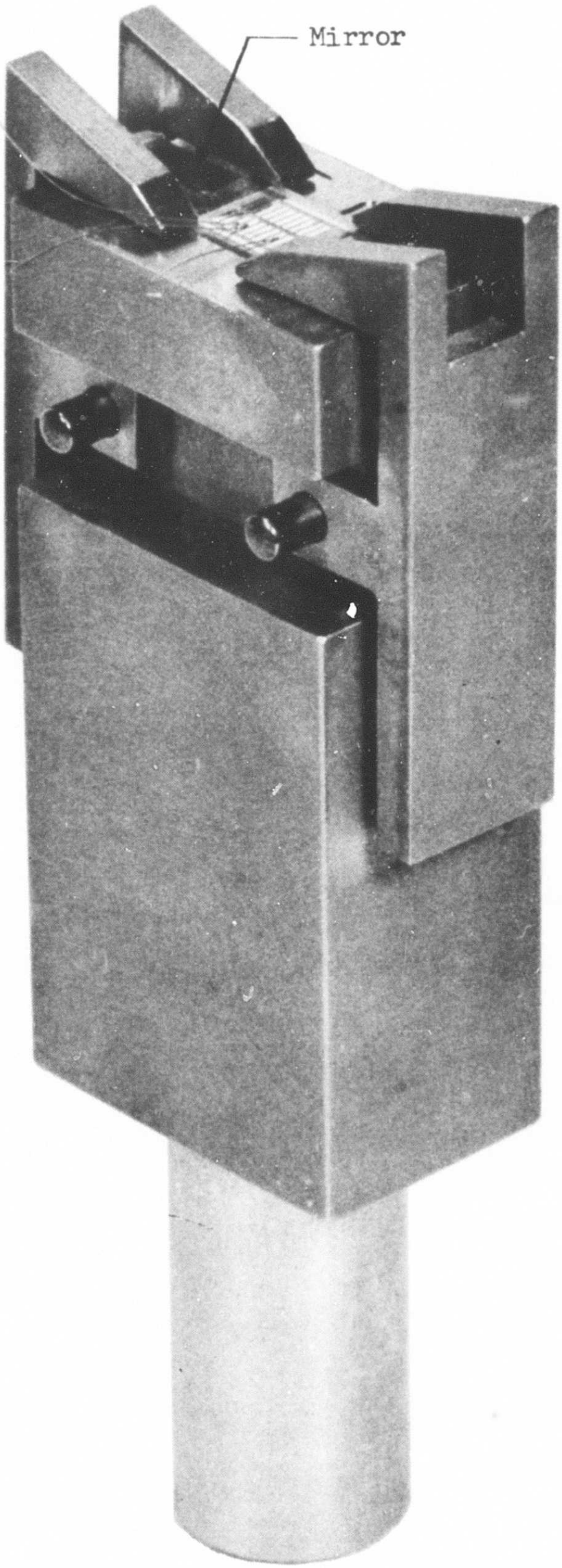


Figure 7 Modified Substrate Hold-down Fixture

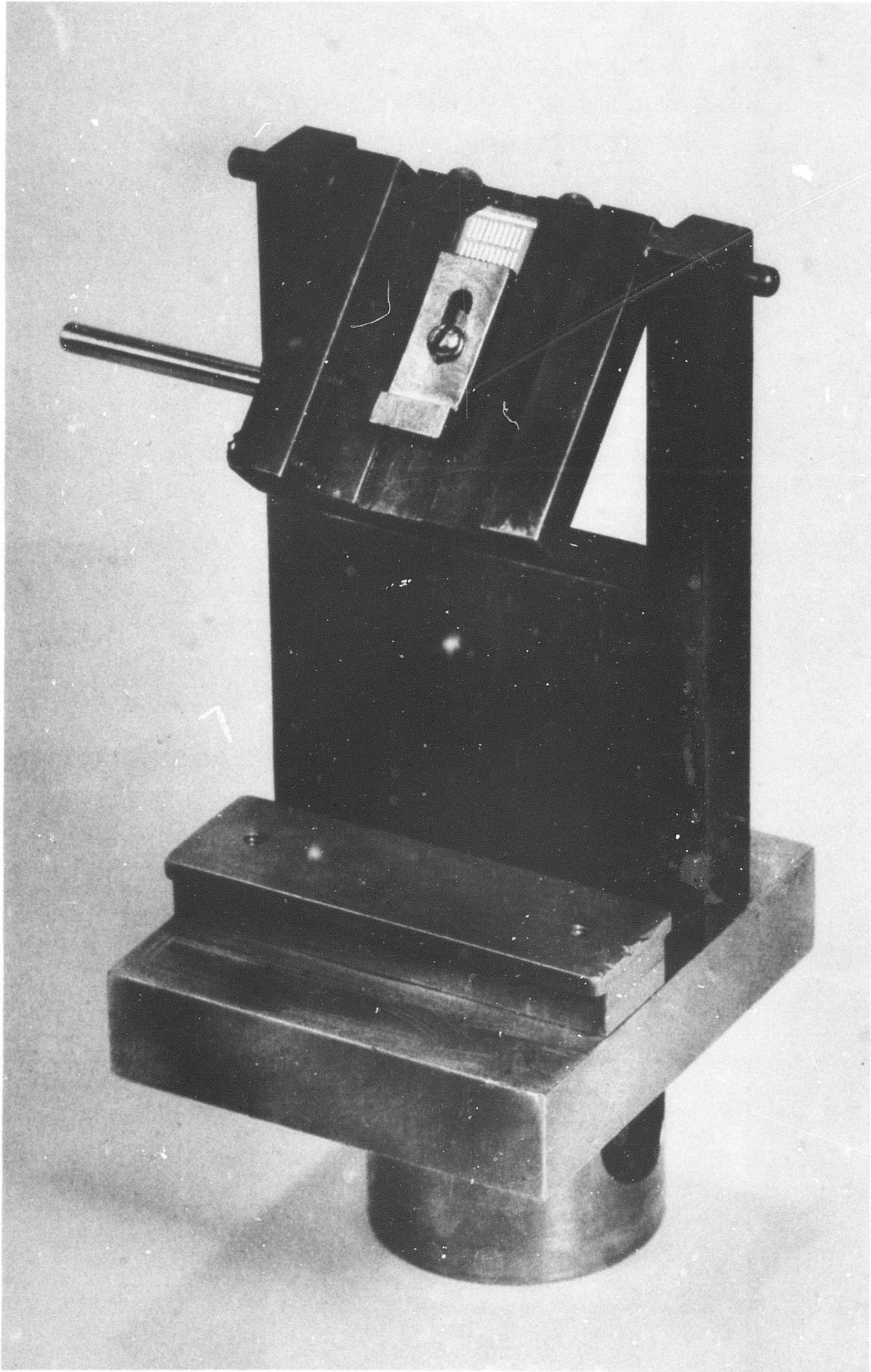


Figure 8 45° Pull Test Fixture

0.001" Aluminum Wire on Gold/Chromium over As-Fired Alumina

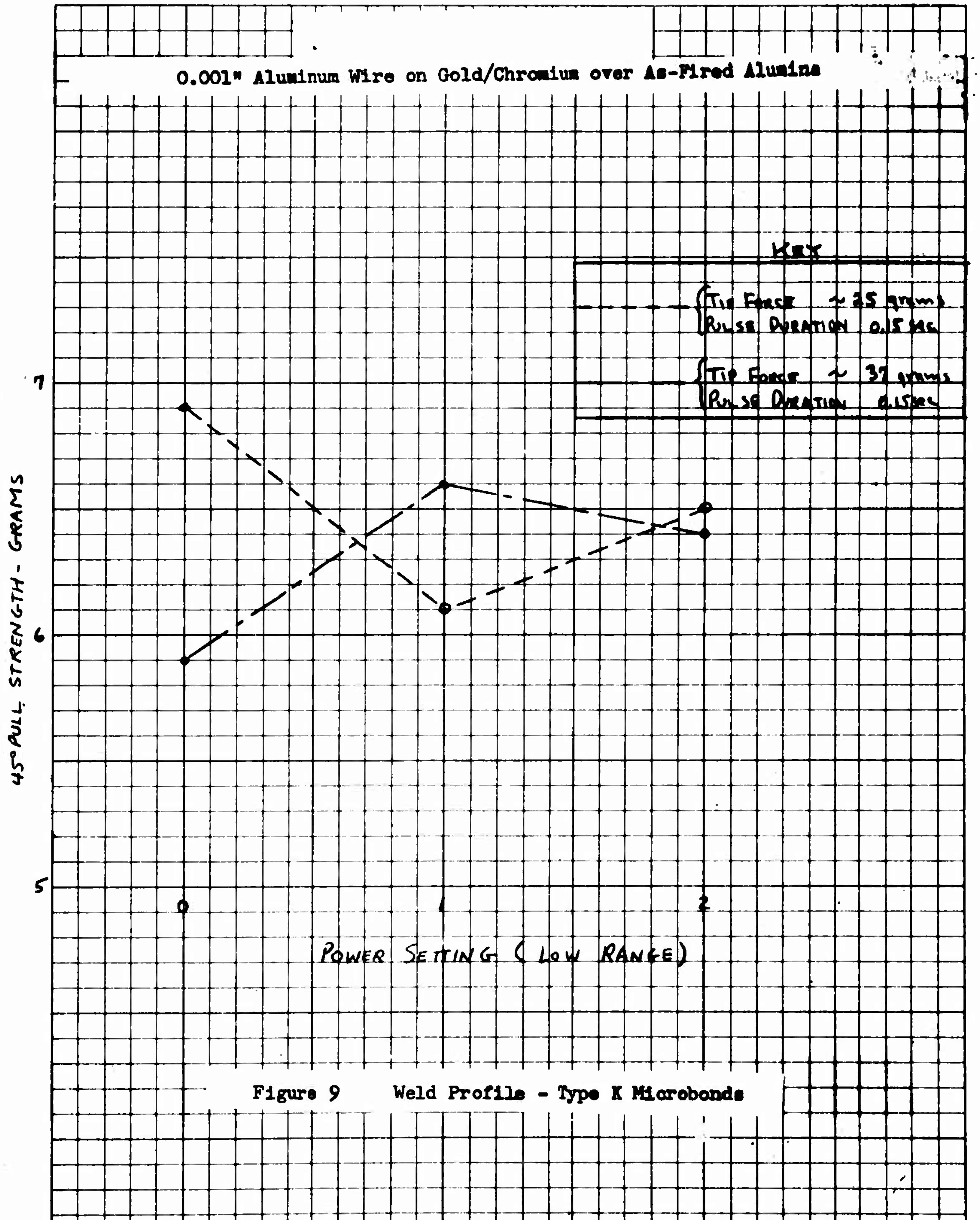


Figure 9 Weld Profile - Type K Microbonds

4.2.4.1 Evaluation of Mechanical Pull Strength by 45° Pull Test

A typical Type K microbond is illustrated in Figure 10. It can be seen that the bond is relatively symmetrical; this was found to be a good visual indication of high bond strength. During the reliability testing, the bonds were visually inspected prior to pull testing and rejections were made on the following basis:

1. Squashed bonds

2. Wire pushed to the side or pinched

3. Bond width less than 150% of the wire diameter (i.e., less than 1.5 mils)

The pull strength distribution for the Type K microbonds is shown in Figure 11. Calculations of the mean value and standard deviation were made from the equation:

$$s^2 = \frac{\sum f_i x_i^2 - \frac{(\sum f_i x_i)^2}{N}}{N-1}$$

where

s^2 = sample variance

S = standard deviation

f_i = number of observations having the value x_i

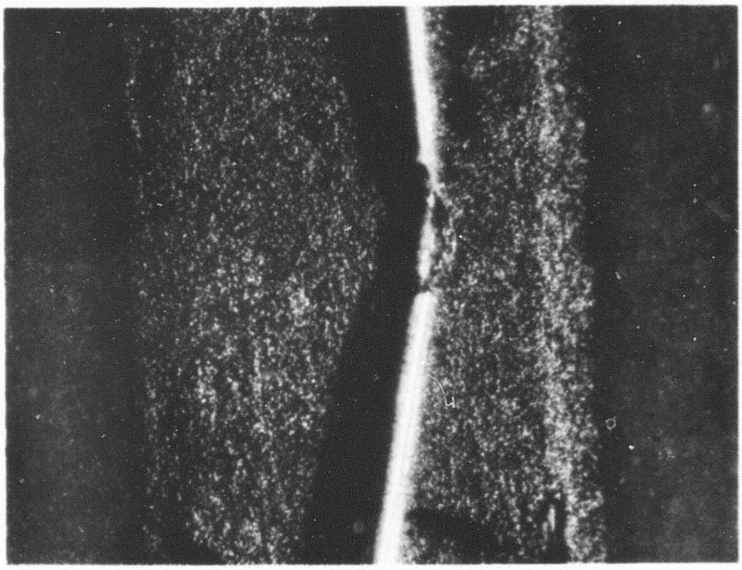
x_i = bond strength value of the ith sample

N = $\sum f_i$ = total number of observations

$\bar{X}$ = $\frac{\sum f_i x_i}{N}$ = mean pull strength

The bond strength requirement of SCL-7746A was met (i.e., the mean pull strength of the bonds was greater than 30% of the mean tensile strength). However, since the sample size is too small to apply non-parametric statistical techniques, the evaluation of the maximum expected number of failures at a 90% confidence level must be carried out on the basis of a normal distribution. Figure 12 shows the cumulative pull strength distribution and it is seen to be very near a normal distribution.

0.001" Aluminum Wire on Gold/Chromium over As-Fired Alumina



Oblique Illumination
Magnification ~ 128X
Scale .1 mm
~ .004"

Weld Schedule:
Tip Force ~ 25 grams
Power Setting 0
Pulse Duration .15 sec.

Film Thickness ~ 23 x 10^3 Å

Figure 10 Type K Microbond

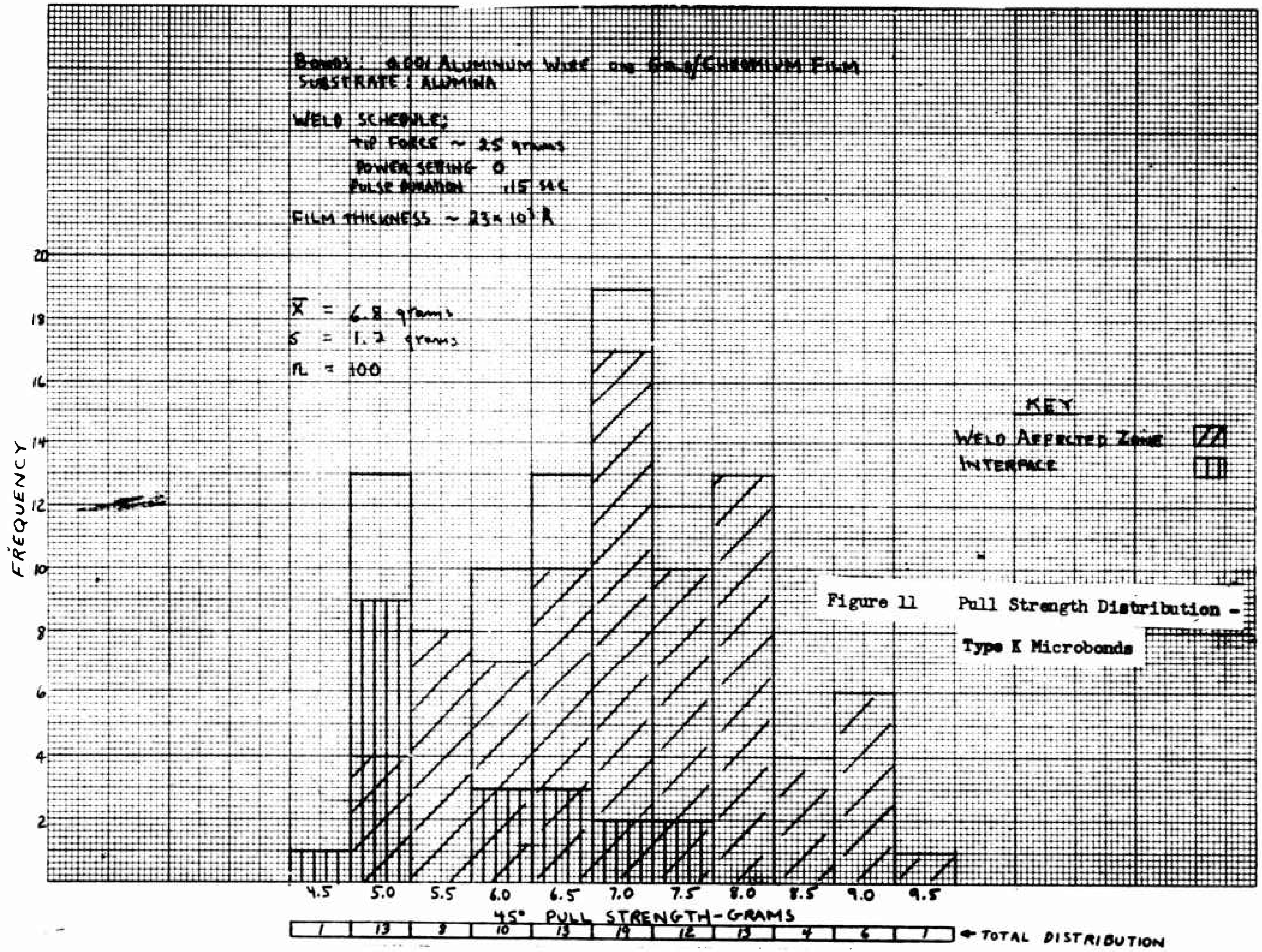


Figure 11 Pull Strength Distribution - Type K Microbonds

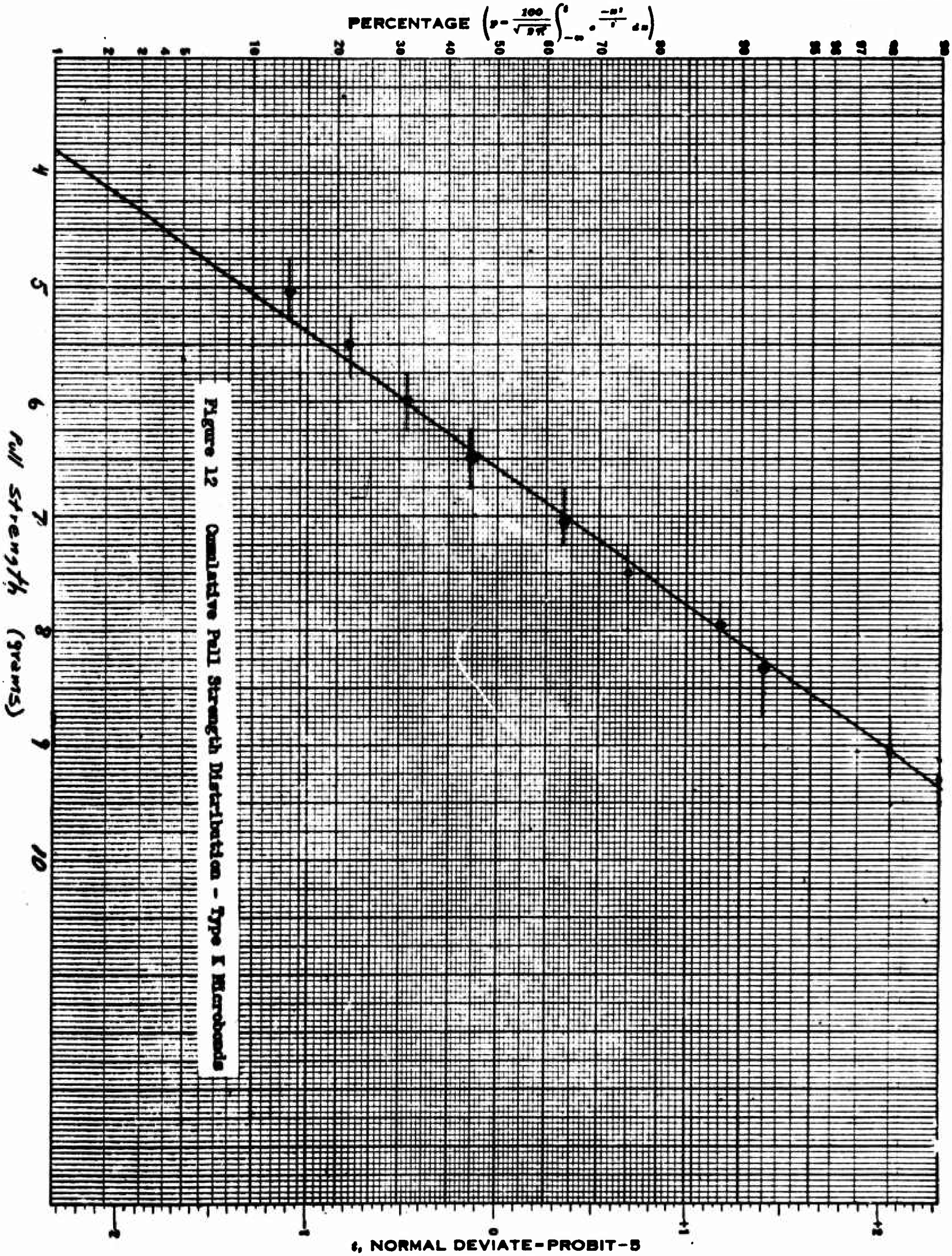


Figure 12 Cumulative Pull Strength Distribution - Type I Microbonds

In order to apply normal statistics as discussed in Appendix IV of Reference 3, a computer is required to carry out the calculations. Because of this, failure expectation will be analyzed for the aluminum wire bonds in Tasks I and IA when all bonds are completed, and this information will be presented in the Final Report for Phase II of this program.

4.2.4.2 Microbond Resistance

The bond resistance of Type K microbonds is plotted as a function of the bond pull strength in Figure 13. Again, as experienced with the other Task I microbonds, there was no correlation between resistance and pull strength. The maximum bond resistance measured was 16 milliohms which was well below the contractual goal of 181 milliohms. The value of 181 milliohms is equal to 1.50 $(F_s + W)$ where F_s is the film resistance per square and W is the resistance of 0.1 inch of the base wire.

4.2.4.3 Thermal Aging

Results of elevated temperature aging of Task I microbonds, Types E, F, G and H are reported along with the Task IA microbonds in Section 4.3.11.

4.3 Task IA Microbonds

The bond requirements for Task IA are shown in Table II. Microbonds completed during this Quarter, and discussed in the succeeding sections are Types A'_5, A''_2, A''_5, B'_1, B'_2 and B''_2. Bond Types A'_1, A'_2 and A''_1 were completed and reported previously.[1, 2]

4.3.1 Materials

4.3.1.1- Substrates

Surface tracings of both the sapphire and beryllia wafers were shown in a previous report.[1] The surface roughness values for these wafers are listed below along with the data for the As-fired alumina substrates used in the Type K microbonds.

Substrate	Surface Roughness
Sapphire	1 - 3 microinches
Alumina	9 - 13 microinches
Beryllia	16 - 24 microinches

This information is used in a later section discussing the weld schedule development for aluminum wire to gold film.

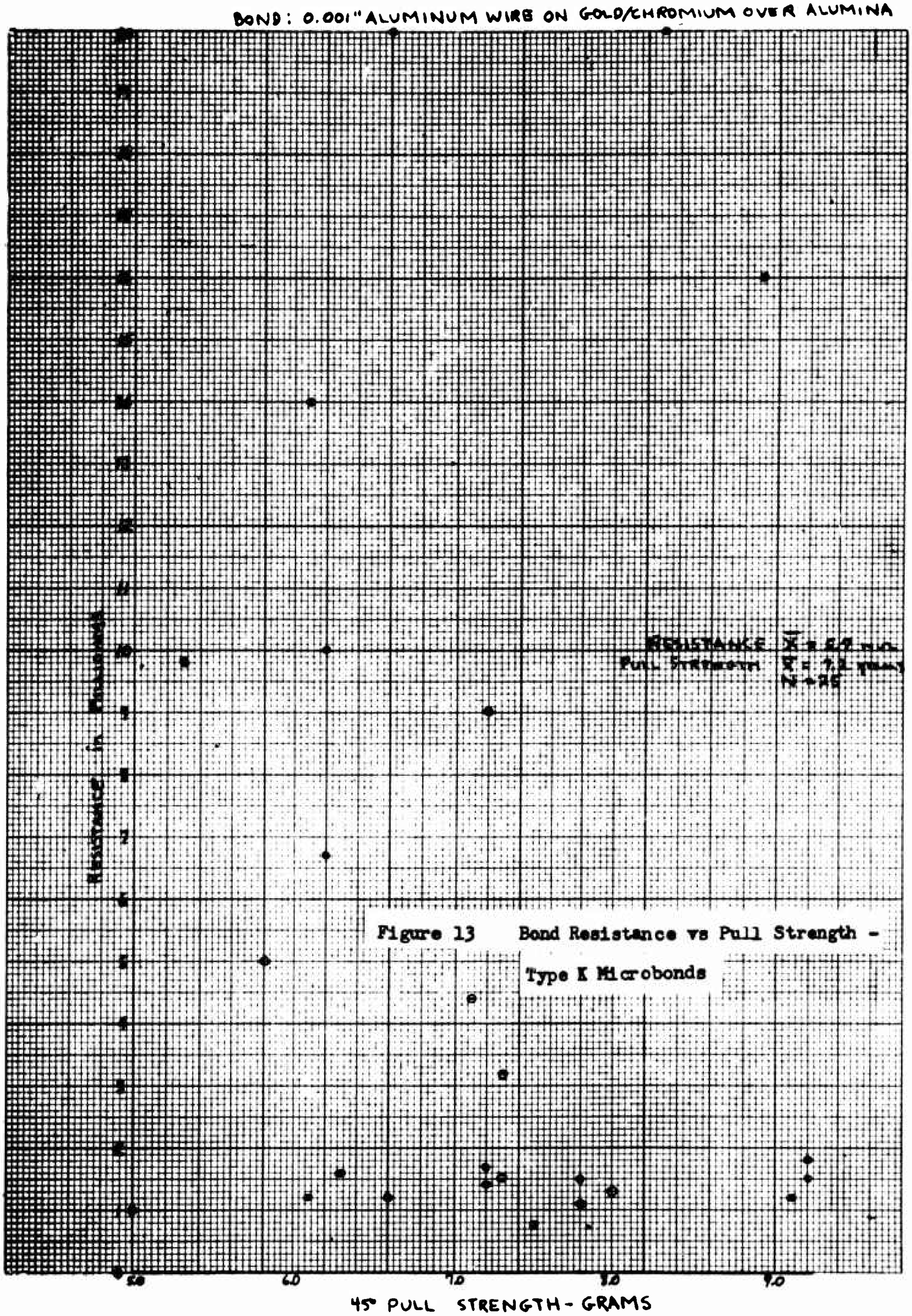


Figure 13 Bond Resistance vs Pull Strength - Type K Microbonds

TABLE II

BONDS REQUIRED FOR TASK IA

Bond Type	Wire	Wire Size	Film	Bonding Technique	Substrate
A'_1	Au	0.001"	Au/Cr	Split-Tip	Sapphire
A'_2		0.002"			
A'_5		0.005"			
A''_1		0.001"			Beryllia
A''_2		0.002"			
A''_5		0.005"			
B'_1	Al	0.001"		Ultrasonic	Sapphire
B'_2		0.002"			
B'_5		0.005"			
B''_1		0.001"			Beryllia
B''_2		0.002"			
B''_5		0.005"			

4.3.1.2 Wires

The 0.002 inch diameter gold wire used for the Type A''_2 microbonds was reported previously,[2] and had a resistance of 3.25 ohms per foot and a mean tensile strength of 26.5 grams.

The tensile strength distribution for the 0.005 inch diameter gold wire used for the Type A'_5 and A''_5 microbonds is shown in Figure 14. This wire had a mean tensile strength of 200 grams and a resistance of 0.48 ohms per foot.

The 0.001 inch diameter aluminum wire used for the Type B'_1 microbonds was the same as that discussed under Task I in Section 4.2.1.2. This wire had a mean tensile strength of 14.5 grams and a resistance of 18 ohms per foot. However, some experiments were performed with a pure aluminum wire whose tensile strength distribution is shown in Figure 15. The mean strength for this wire was 9.5 grams.

Figure 16 gives the tensile strength distribution for the 0.002 inch diameter aluminum (1% silicon) wire used for Type B'_2 and B''_2 microbonds. The wire had a mean strength of 54.2 grams and a resistance of 4.7 ohms per foot. Another wire was also employed for experimental testing. This was 99% Al 1% Mg composition wire that had a mean tensile strength of 87.2 grams. The tensile strength distribution is shown in Figure 17.

4.3.1.3 Film Deposition

A summary of the characteristics of the gold/chromium film depositions for the Task IA microbonds is given below.

Bond Type	Total Film Thickness (Angstrom Units)
A'_5	19,000
A''_2	45,000
A''_5	24,000
B'_1	24,000
B'_2	24,000
B''_2	36,000

The film thickness measurements were made with thallium light on a Zeiss Interference Microscope as discussed in Quarterly Report No. 6.[1]

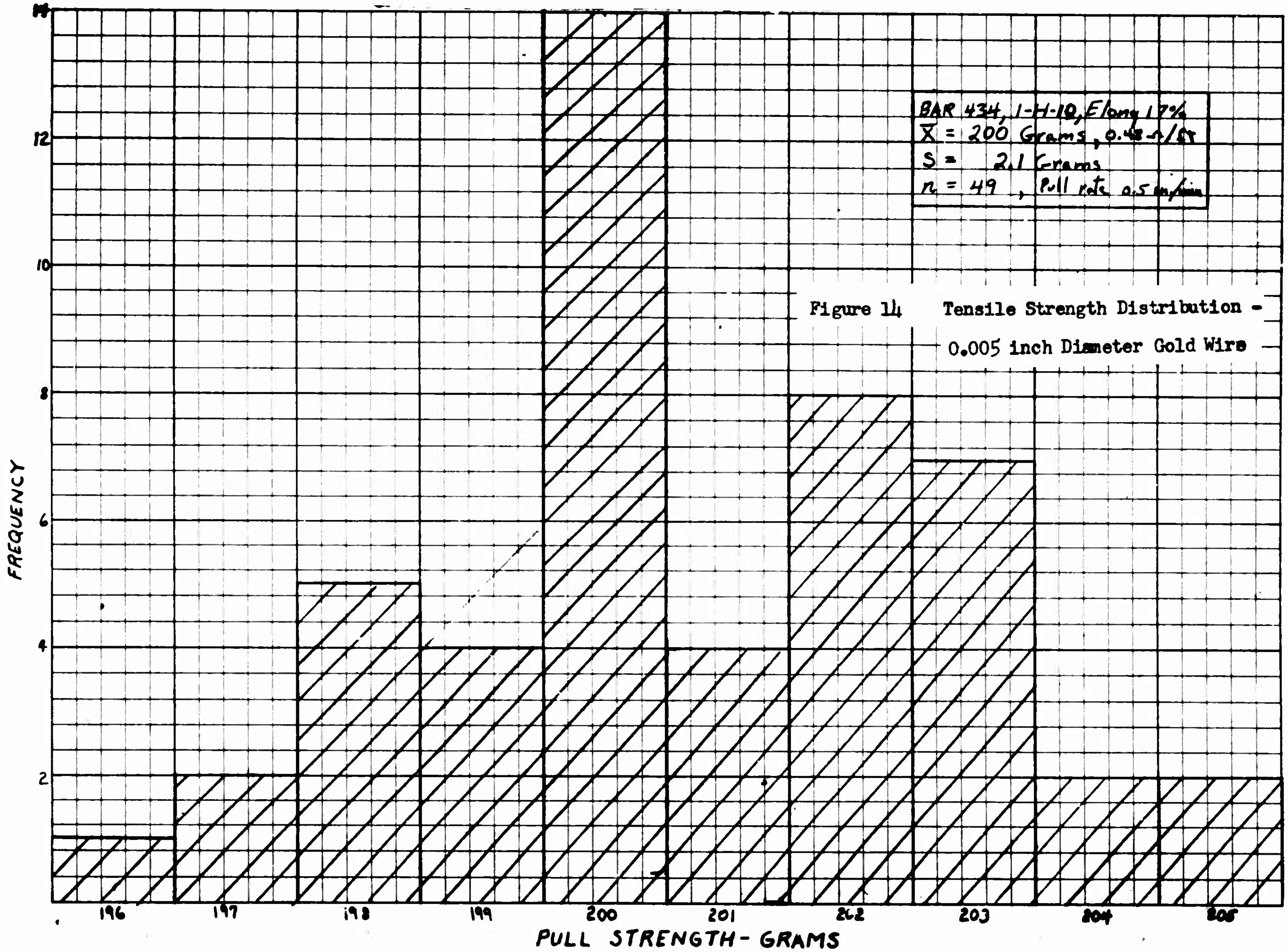


Figure 14 Tensile Strength Distribution - 0.005 inch Diameter Gold Wire

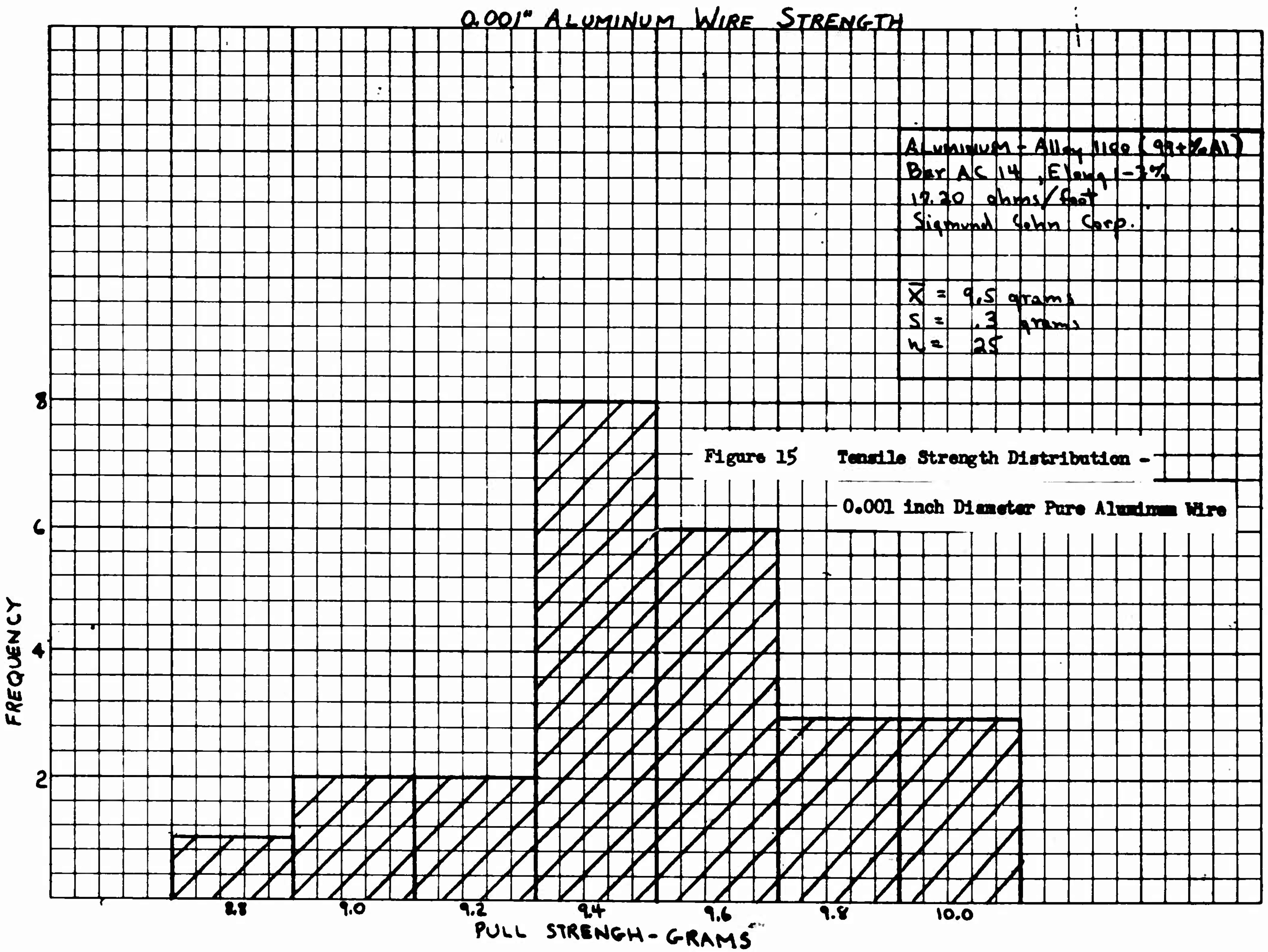


Figure 15 Tensile Strength Distribution - 0.001 inch Diameter Pure Aluminum Wire

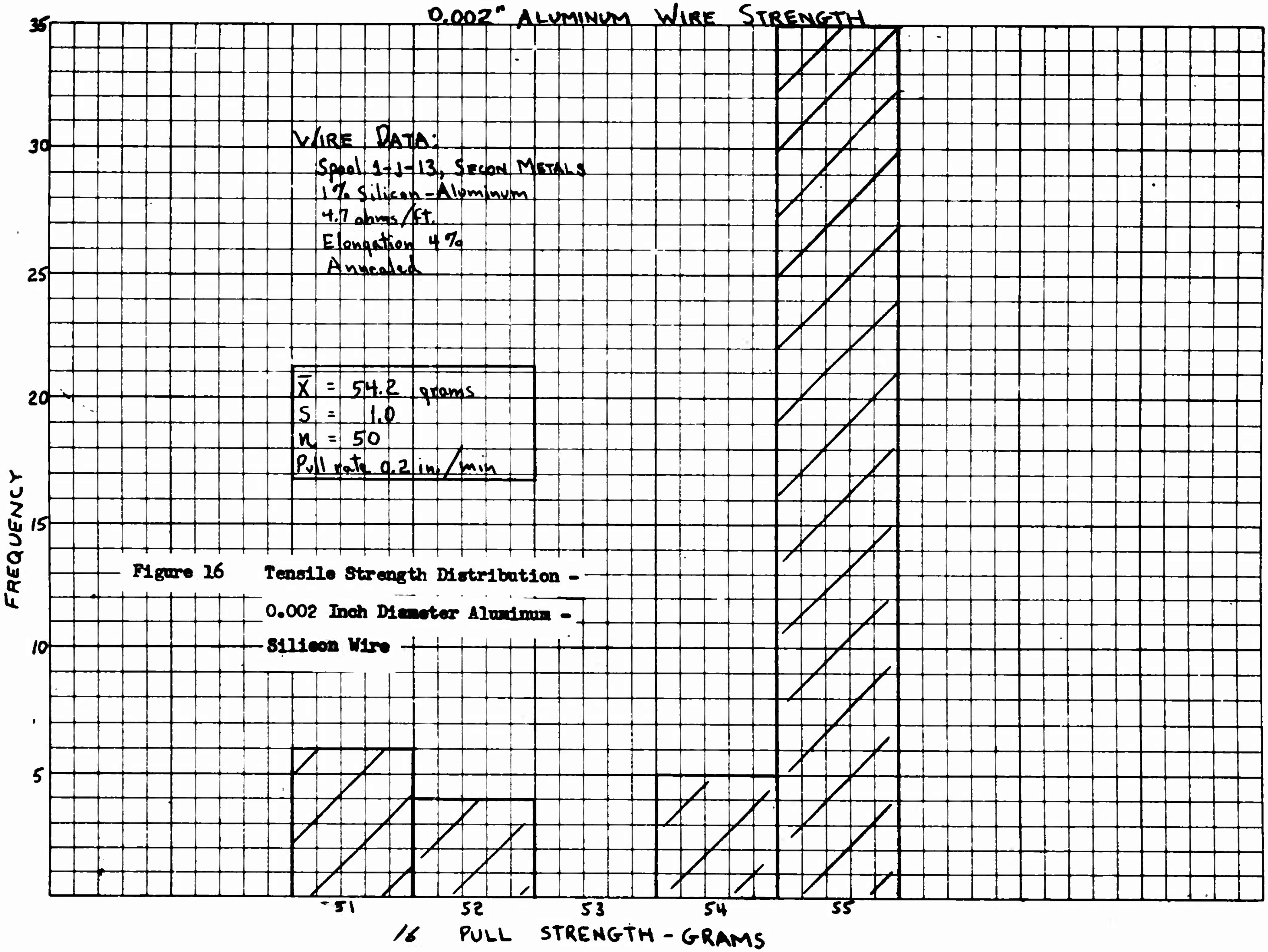


Figure 16 Tensile Strength Distribution - 0.002 Inch Diameter Aluminum - Silicon Wire

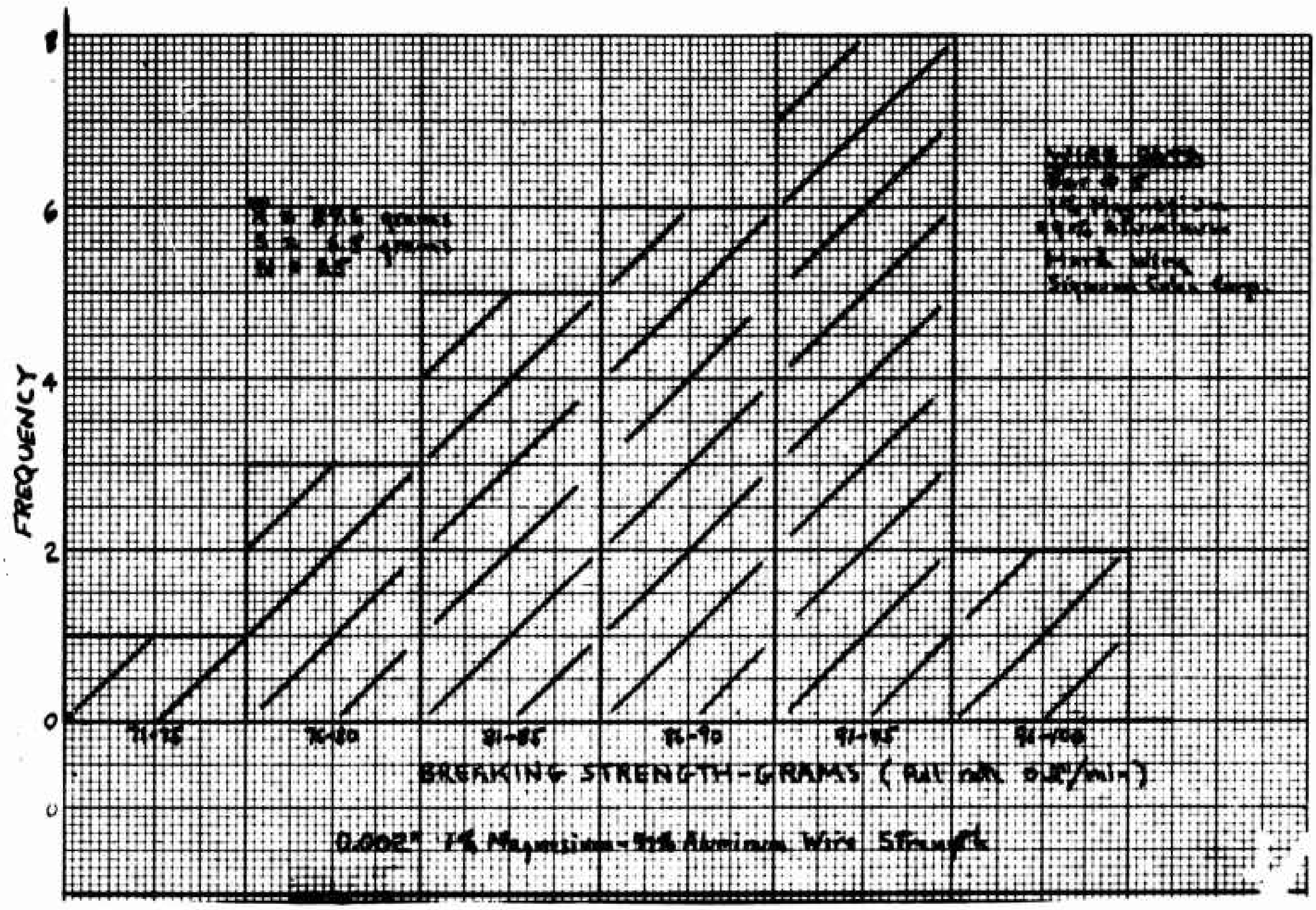


Figure 17 Tensile Strength Distribution - 0.002 inch Diameter Aluminum - Magnesium Wire

4.3.2 Welding Equipment

The gold wire to gold film microbonds were accomplished on the Weldmatic 1090C split tip resistance welder described in earlier reports (1, 2, 3)

The ultrasonic bonding of the Task IA aluminum wire to gold/chromium films was carried out on the Axion bonder discussed under Task I in Section 4.2.2.1. However, a different bonding tip was required for 0.002 inch diameter wire and this is illustrated in the photomicrograph in Figure 18. This tip is larger but identical in shape to the 0.001 inch wire tip.

4.3.3 Weld Schedule Development

4.3.3.1 Gold Wire Microbonds

The weld profiles made for the Type A'_5 microbonds are shown in Figure 19. The parameters chosen for the reliability data for 19,000 Å films were:

Electrode Force	370 grams
Pulse Width	150 msec.
Pulse Amplitude	39.5 amps
Electrode	EM 1002 (0.020 x 0.020 x 0.004)

Figure 20 illustrates the weld profiles developed for the Type A''_2 microbonds. In this case, the film thickness was 45,000 Å and the machine parameters chosen for the reliability data were:

Electrode Force	370 grams
Pulse Width	80 msec.
Pulse Amplitude	33 amps
Electrode	EM 1002

The weld profiles developed for Type A''_5 microbonds are shown in Figure 21. In this case preheat and postheat side pulses were necessary since there was not enough energy in a single pulse to form strong microbonds. This seems to be caused by the increased surface roughness of the beryllia films. The parameters chosen for the reliability data for 24,000 Å films are given below.

Electrode Force	520 grams
Pulse Widths	300 (preheat - 500 (center)-300 (postheat) msec.

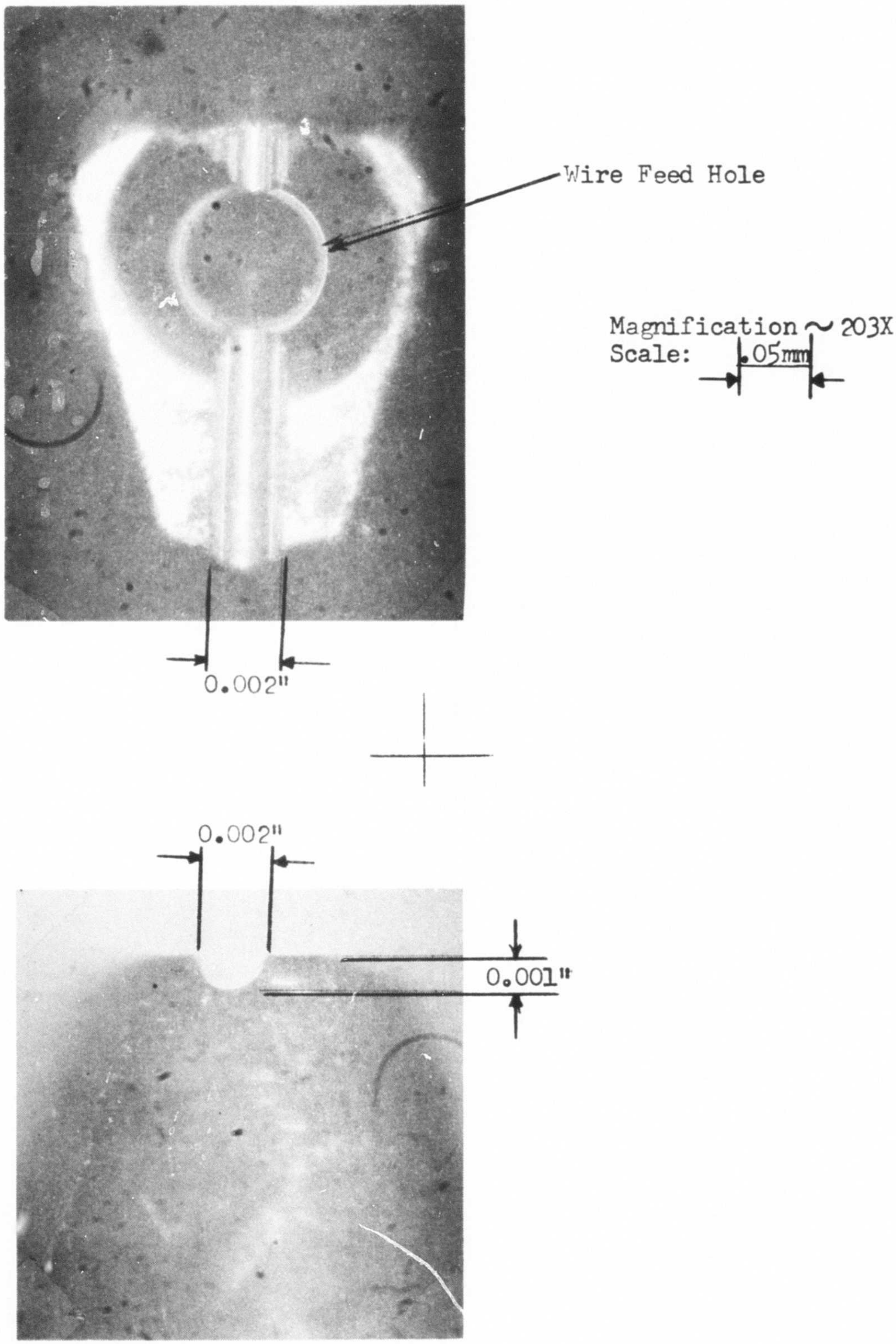


Figure 18 Photomicrograph of Bonding Tip for 0.002 inch Diameter Wire

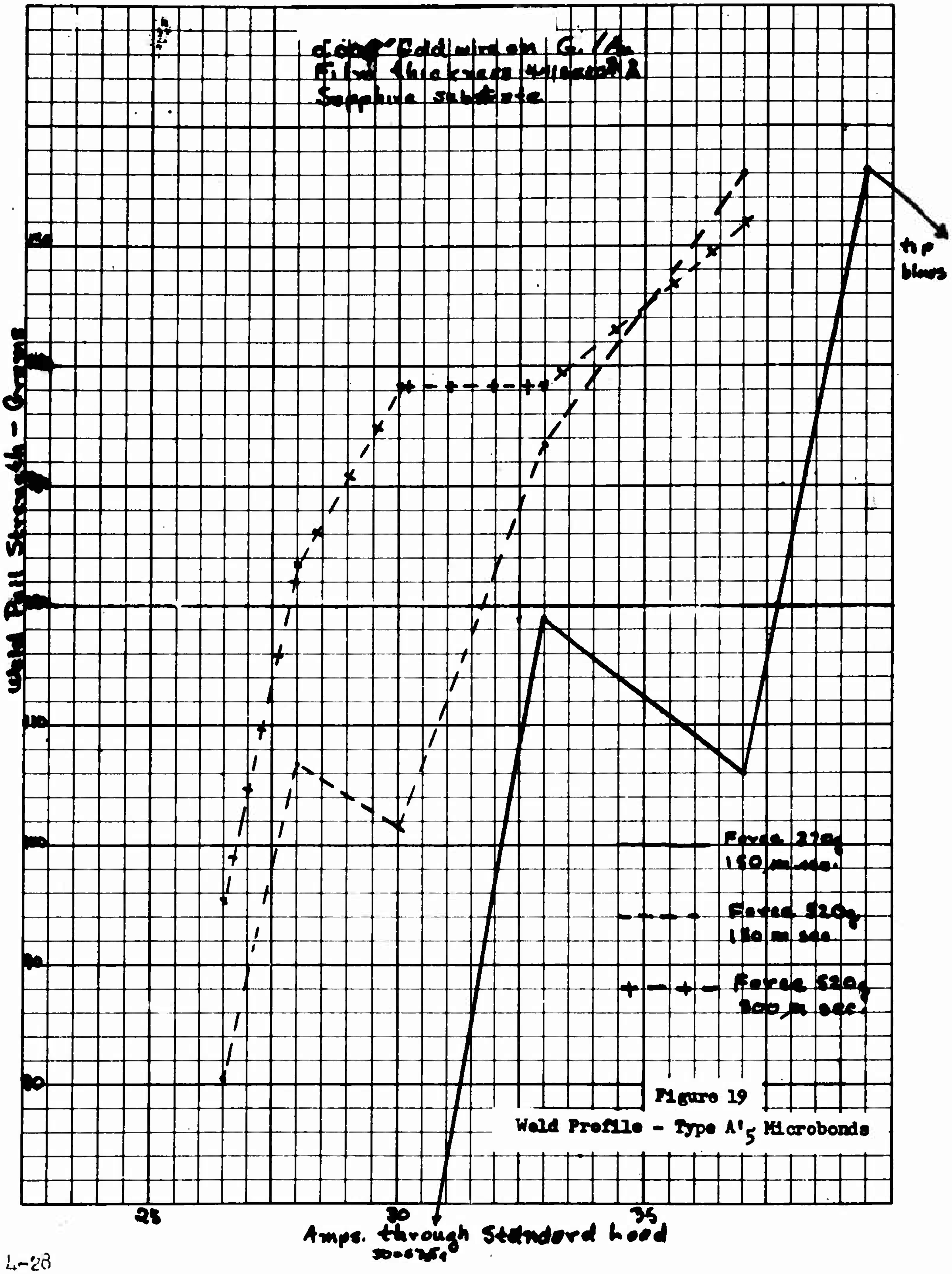


Figure 19

Weld Profile - Type A'_5 Microbonds

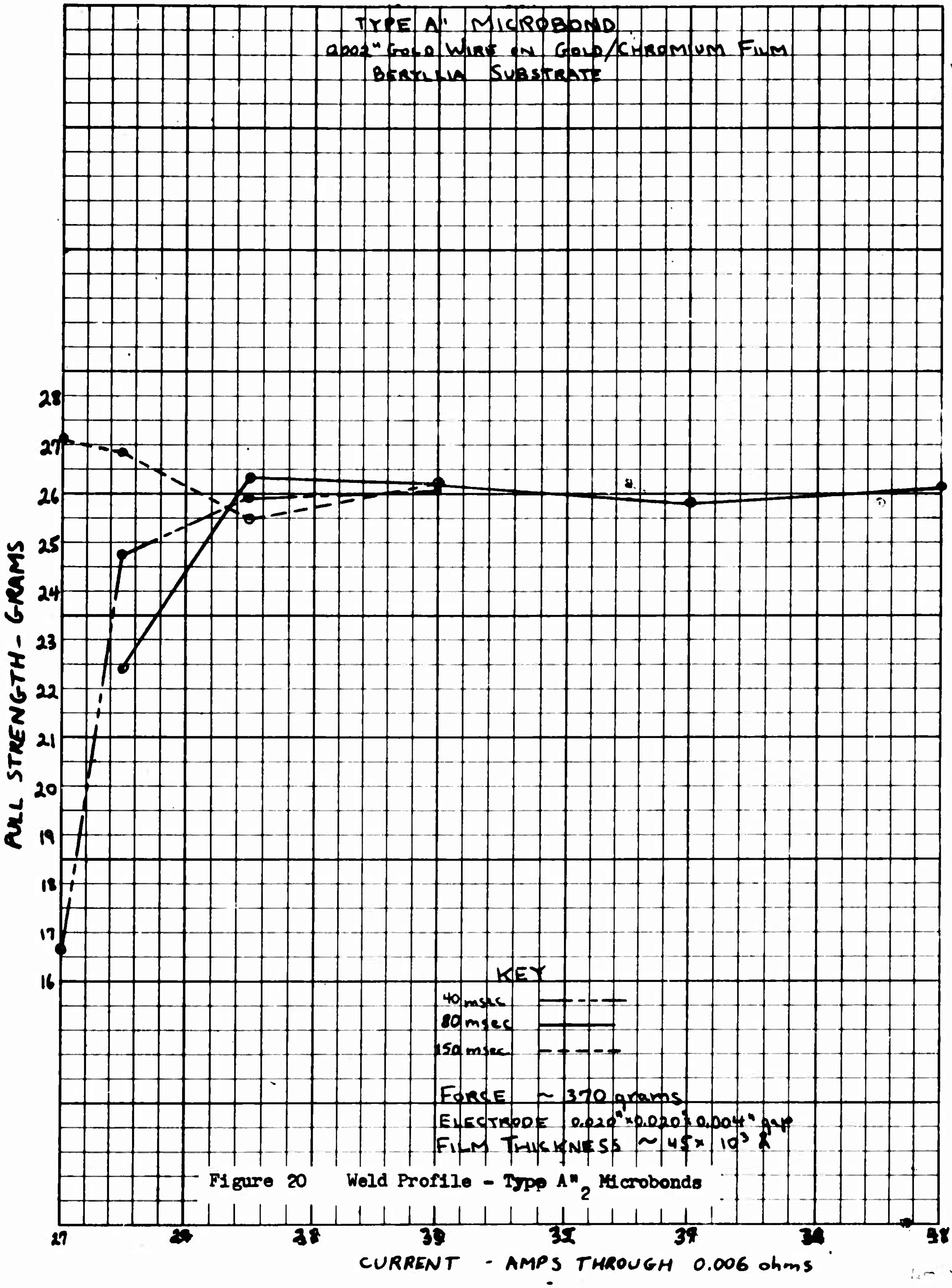


Figure 20 Weld Profile - Type A"$_2$ Microbonds

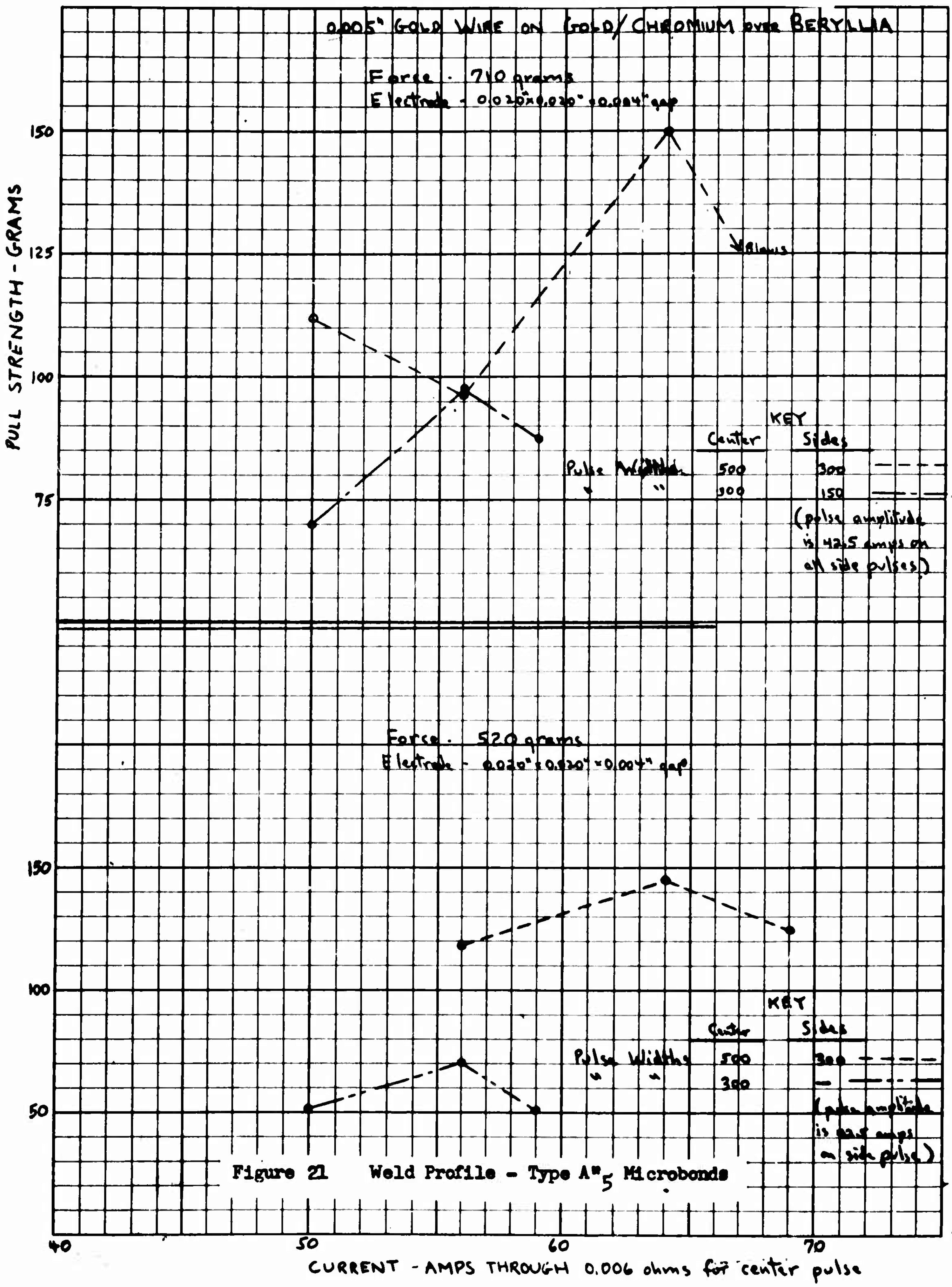


Figure 21 Weld Profile - Type A#5 Microbonds

Pulse Amplitude	43 - 64 - 43 amps.
Electrode	EM 1002

4.3.3.2 Aluminum Wire Microbonds

The weld profiles developed for the Type B'_1 microbonds are shown in Figure 22. The machine parameters chosen as those that yield the optimum bonds on 24,000 Å film were:

Bond Force	30 grams
Pulse Width	0.15 seconds
Power Setting	0 (low range)

Figure 23 illustrates the weld profiles developed for the Type B'_2 microbonds and the parameters chosen for the reliability measurements on 24,000 Å films were:

Bond Force	90 grams
Pulse Width	0.15 seconds
Power Setting	2 (high range)

Figure 24 shows the weld profiles established for the Type B''_2 microbonds. The machine parameters selected in this case as yielding optimum bonds for reliability data on 36,000 Å films were:

Bond Force	95 grams
Pulse Width	0.15 seconds
Power Setting	5 (high range)

In addition to the above weld schedule development, some effort was utilized to study the effect of variation in wire composition and film thickness. This work had the added advantage of increasing our knowledge of the ultrasonic bonder characteristics and capabilities.

For the Type B'_1 microbonds, the first microbonds were made with a pure aluminum wire that had a mean tensile strength of 9.5 grams. The weld profiles for these bonds are shown in Figure 25. It is seen that the maximum pull strength achieved was well above 30% of the mean wire tensile strength and was a higher percentage of the mean value than the bonds made with 99% Al 1% Si wire. However, as shown by Picture C in Figure 26, Typical Type B'_1 Microbonds, this softer wire had a tendency to squash out. Because of this, more bonds were visually rejected and this would become costly on a production basis. Thus, the pure aluminum wire was rejected.

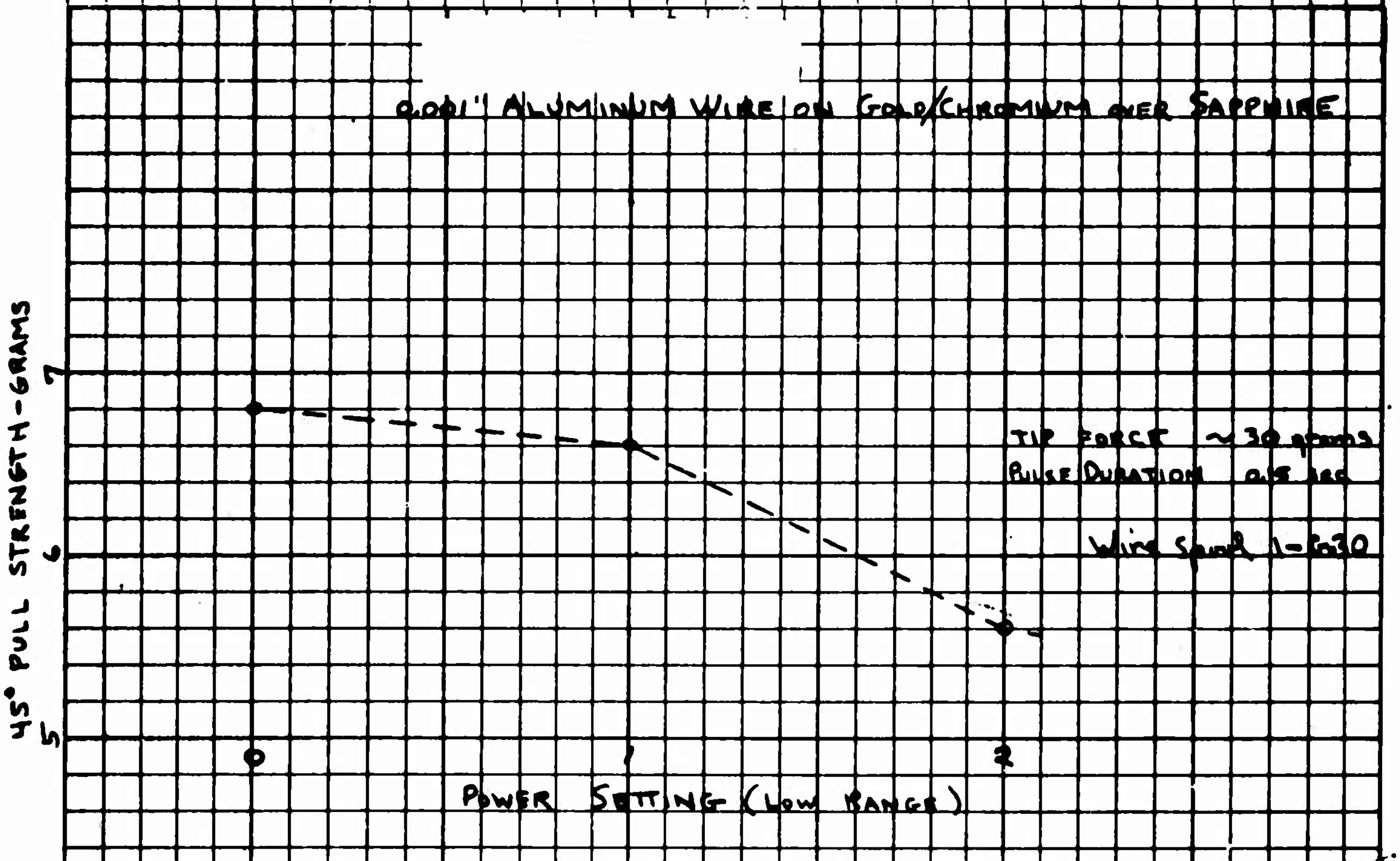


Figure 22 Weld Profile - Type B'_1 Microbonds

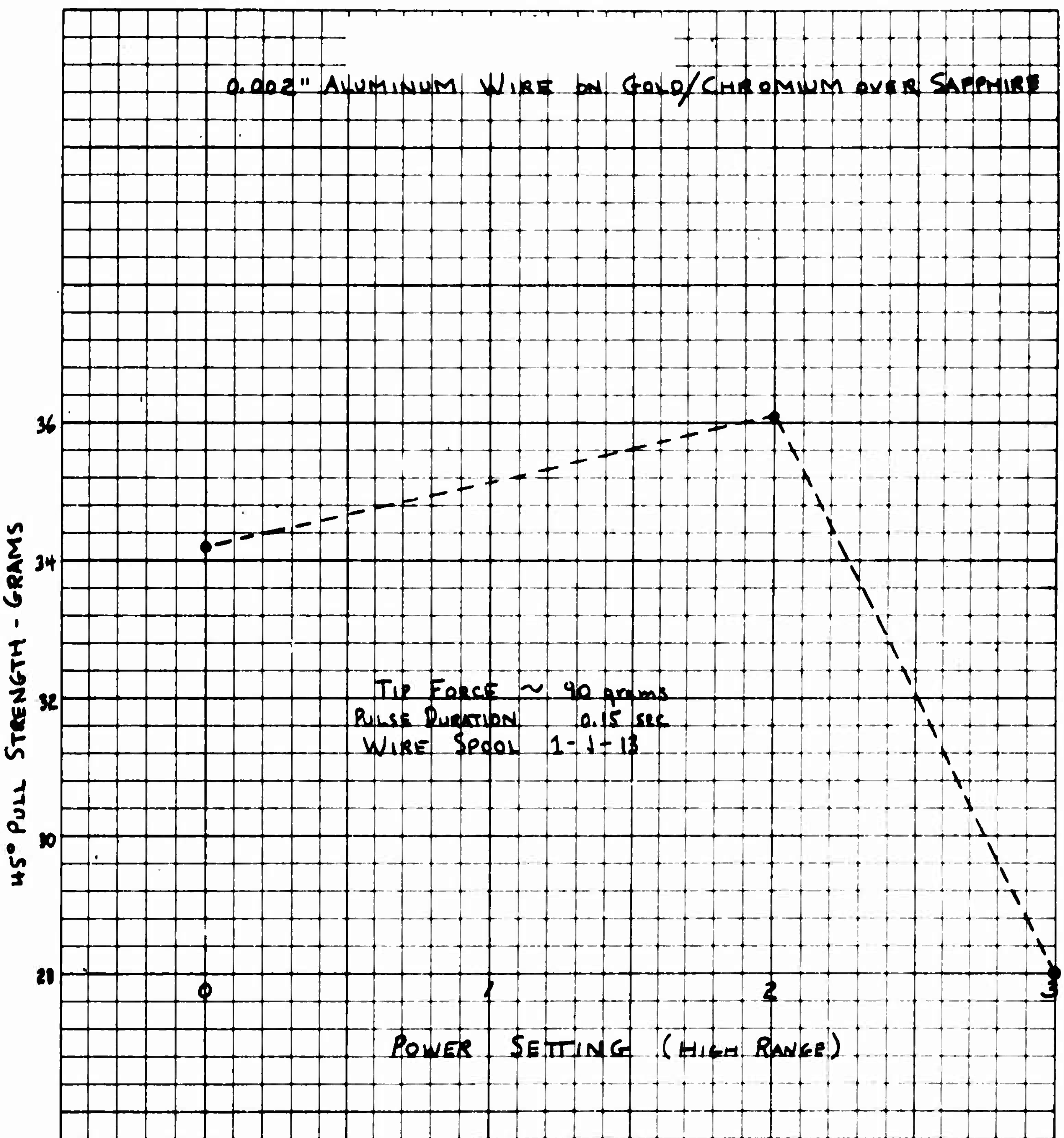


Figure 23 Weld Profile - Type B'$_2$ Microbonds

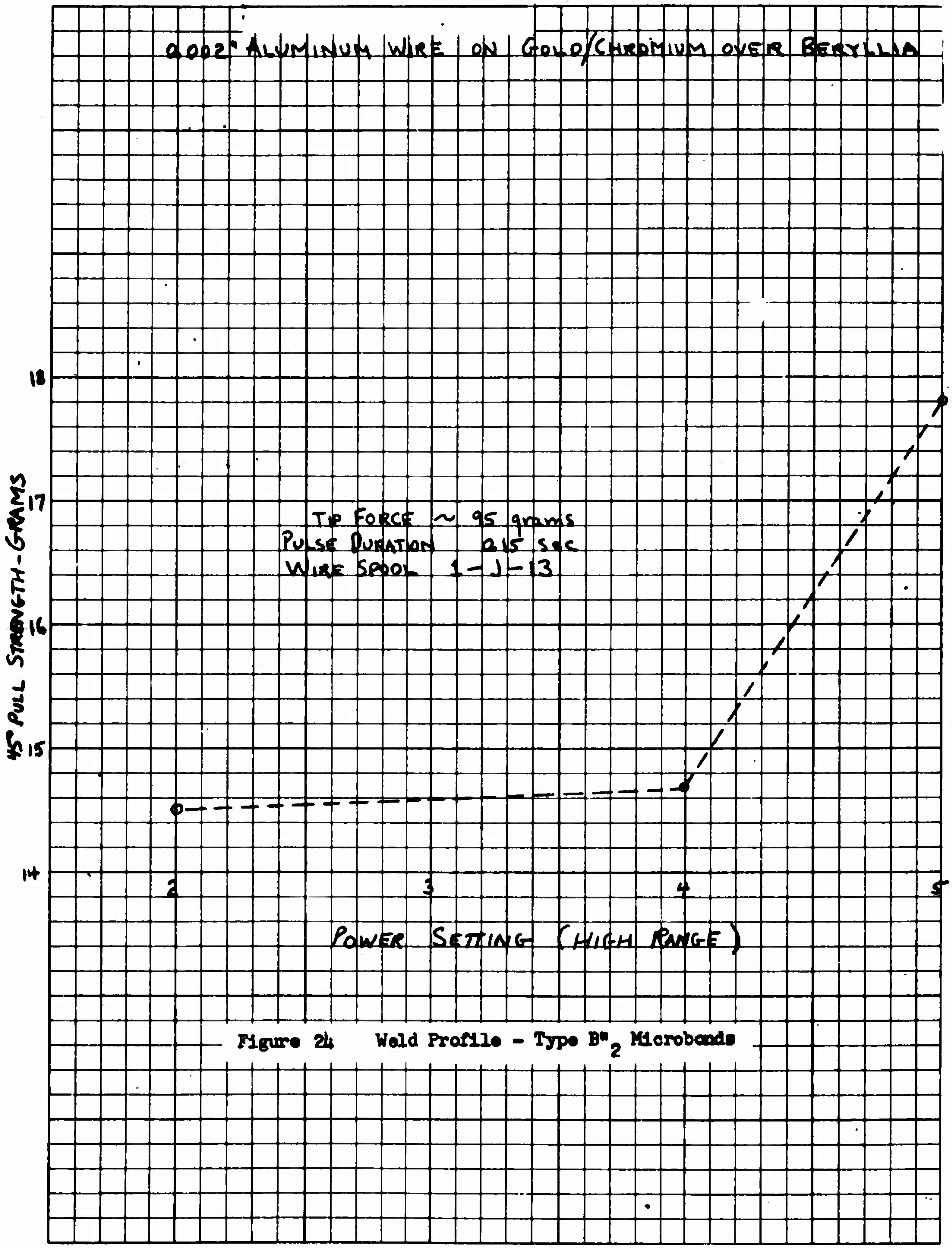


Figure 24 Weld Profile - Type B"$_2$ Microbonds

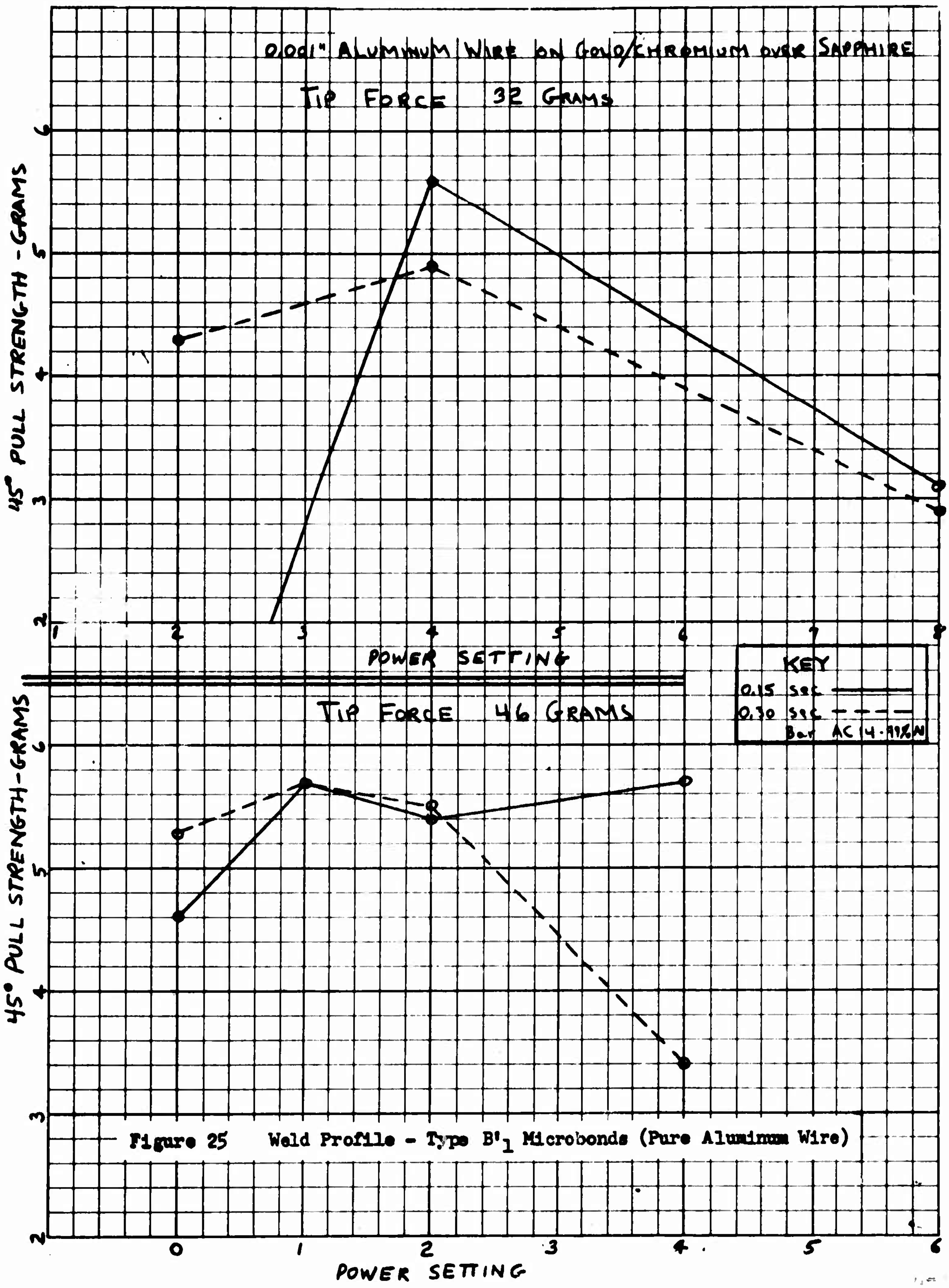
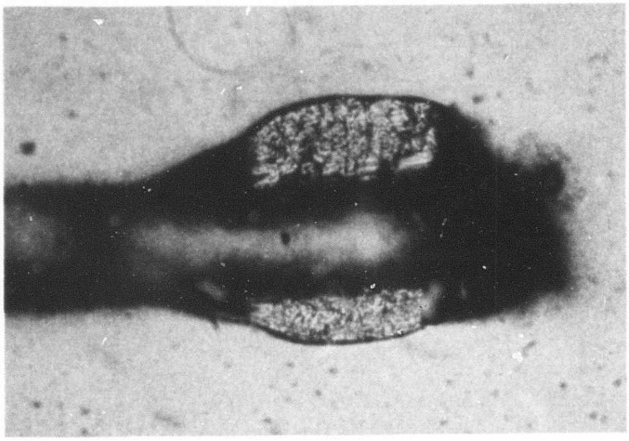


Figure 25 Weld Profile - Type B'_1 Microbonds (Pure Aluminum Wire)

0.001" Aluminum Wire on Gold/Chromium Over Sapphire

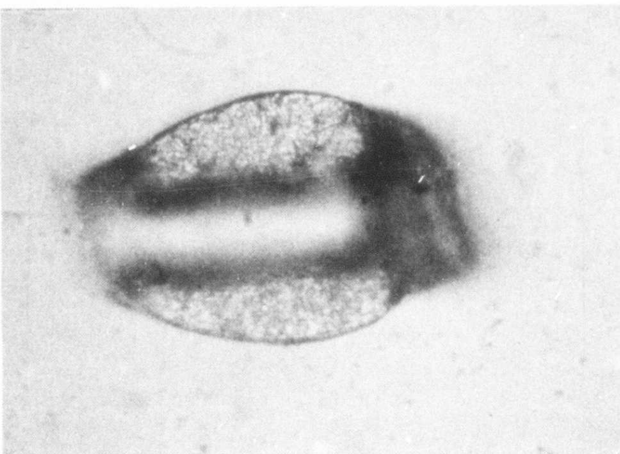
Bond Pull Direction ⟶ (45° To Substrate)



Bond Pull Strength 6.2 grams
(a)

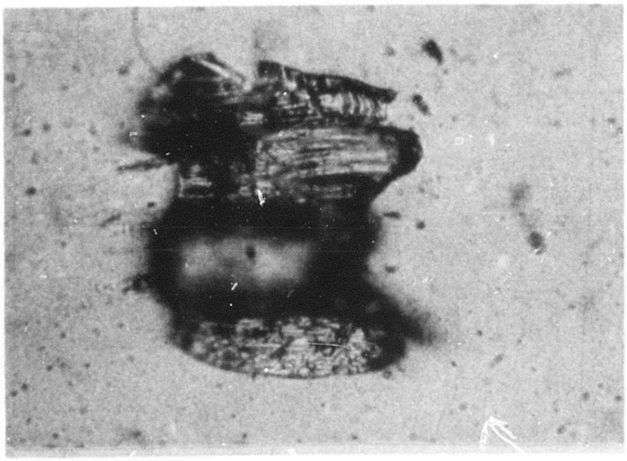
Magnification ~ 570X
Scale | .05 mm | ~.002"

Bond Data
Film Thickness ~ 45×10^{3} Å
Weld Schedule:
Tip Force ~ 46 grams
Power Setting 1
Pulse Duration 0.15 sec.



Bond Pull Strength 4.4 Grams
(b)

Wire Data
1100 Aluminum Alloy (99+%)
Bar AC14 Elong 1-3%
17.20 Ω/ft.
Sigmund Cohn Corp
Mean Wire Pull Strength
9.5 grams



Bond Pull Strength 3.2 Grams
(c)

Figure 26 Typical Type B'_1 Microbonds
Made with Pure Aluminum Wire

Experiments were carried out on the B'_2 microbonds with hard temper 99% Al 1% Mg wire whose tensile strength was approximately twice that of the annealed 99% 1% Si 0.002 inch aluminum wire. The weld profile for these bonds is shown in Figure 27, and the pull strength distribution for 50 samples is shown in Figure 28. This wire had an average pull strength 6.6 grams higher than the average achieved with the Al-Si wire. However, since the 99% Al 1% Si wire was on hand in 0.001 inch, 0.002 inch and 0.005 inch diameter sizes, it was decided to run all reliability data with the same composition wire.

Since the beryllia substrates had a much rougher surface than the sapphire substrates, exploratory pull strength measurements were carried out on films of different thicknesses and on films where the surface was smoothed by burnishing. The parameters chosen for the 0.001 inch aluminum wire bonds on 36,000 Å films and 50,000 Å films, and on burnished 36,000 Å films were:

Bond Force	47 grams
Pulse Width	0.15 msec.
Power Setting	4 (low range)

Figure 29 shows the results for two different thickness films and Figure 30 shows the results after burnishing. As expected, the thicker film which would tend to be smoother, had a larger bond strength. Also, the bonds on burnished film showed an even larger increase in bond strength. This is understandable since more bond area is available in a smoother film. A comparison of the optimized bond pull strength was made for the Type K, Type B'_1 and Type B''_1 microbonds as a function of surface roughness. This is illustrated in Figure 31 and it can be seen that bond strength appears to be a linear function of surface roughness. Although there are not enough data points to show a definite linear relation, the increase of bond strength with decreasing surface roughness is obvious. We may conclude, therefore, that the ultrasonic bonding technique is much more sensitive to substrate surface roughness and that stronger bonds are achievable either by obtaining smoother surfaces or increasing film thickness.

4.3.4 Type A'_5 Microbonds - 0.005 inch Gold Wire to Gold/Chromium Films on Sapphire Substrates

4.3.4.1 Evaluation of Mechanical Strength by 90° Pull Test

Typical Type A'_5 microbonds are shown in Figure 32. The pull strength distribution for these bonds is given in Figure 33. The mean pull strength of 782 bonds was 159 grams which was 79% of the mean wire tensile strength. However, there was one failure below the criteria of SCL-7746A which was a film-to-substrate failure. Thus, these bonds did not meet the reliability goal and the maximum number of expected bond failures at the 90% confidence level is 5 per thousand Type A'_5 microbonds.

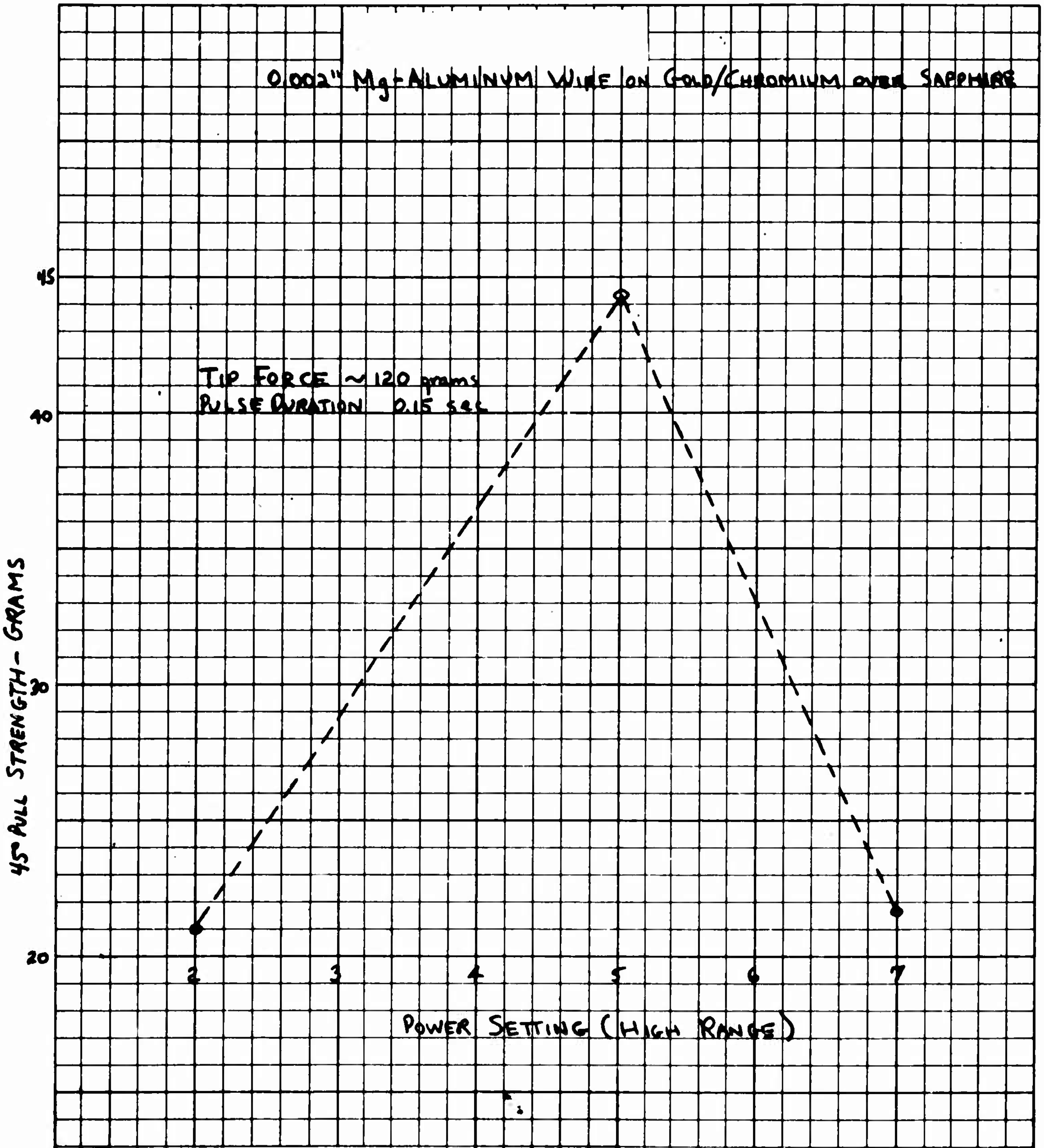


Figure 27 Weld Profile - Type B'$_2$ Microbonds (Aluminum - Magnesium Wire)

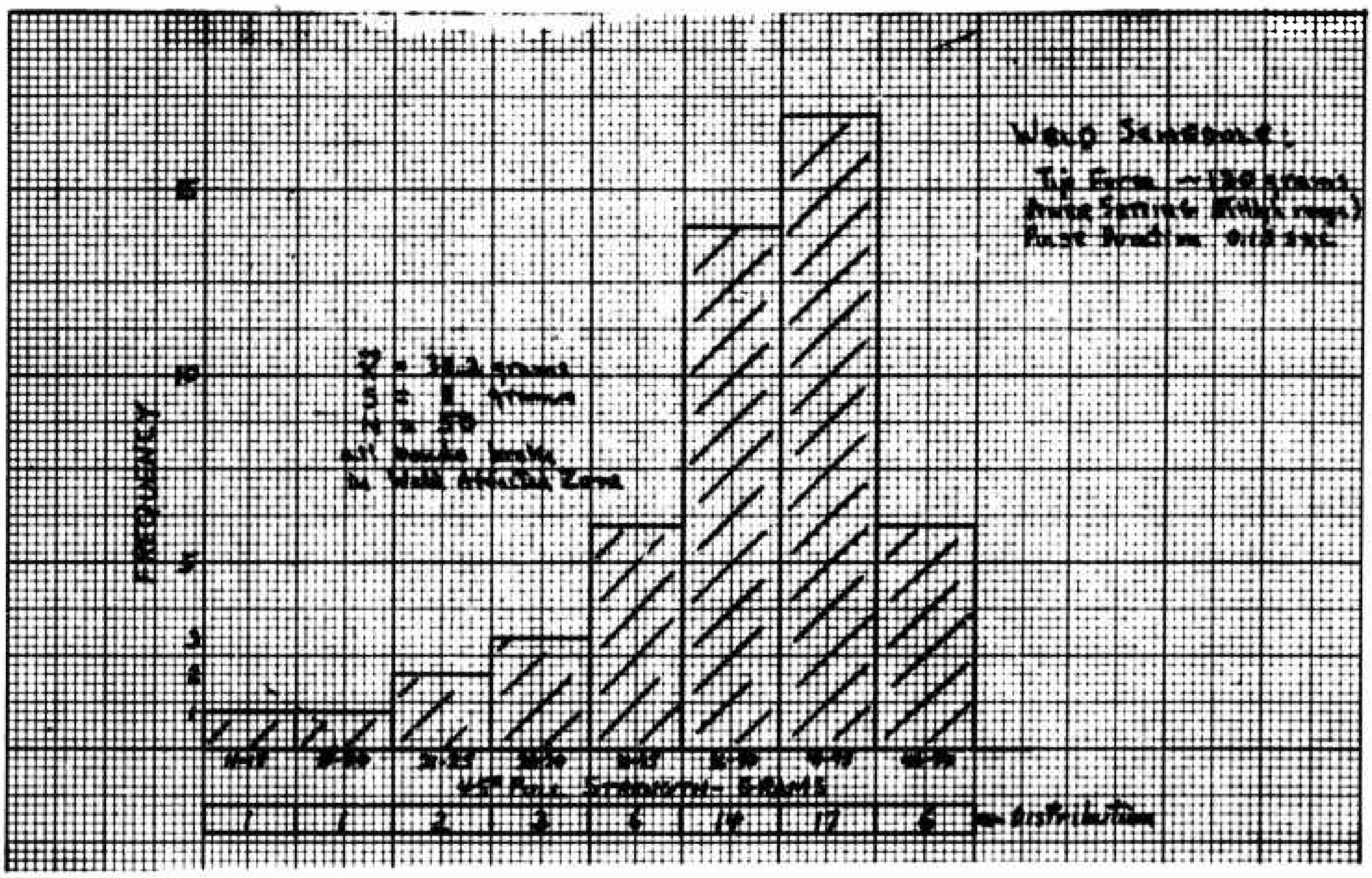


Figure 28 Pull Strength Distribution - Type B'$_2$ Microbonds

(Aluminum - Magnesium Wire)

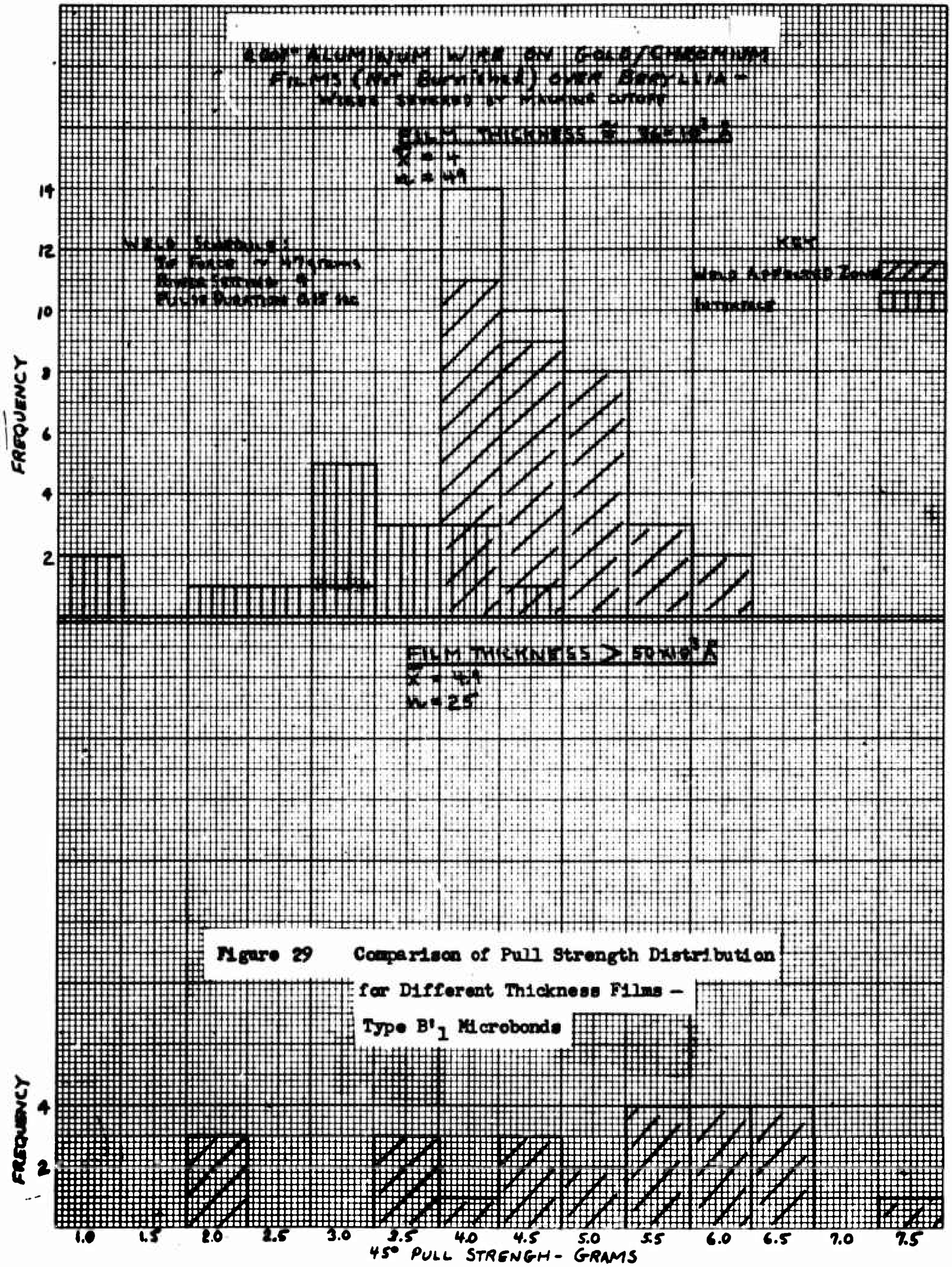


Figure 29 Comparison of Pull Strength Distribution for Different Thickness Films – Type B'_1 Microbonds

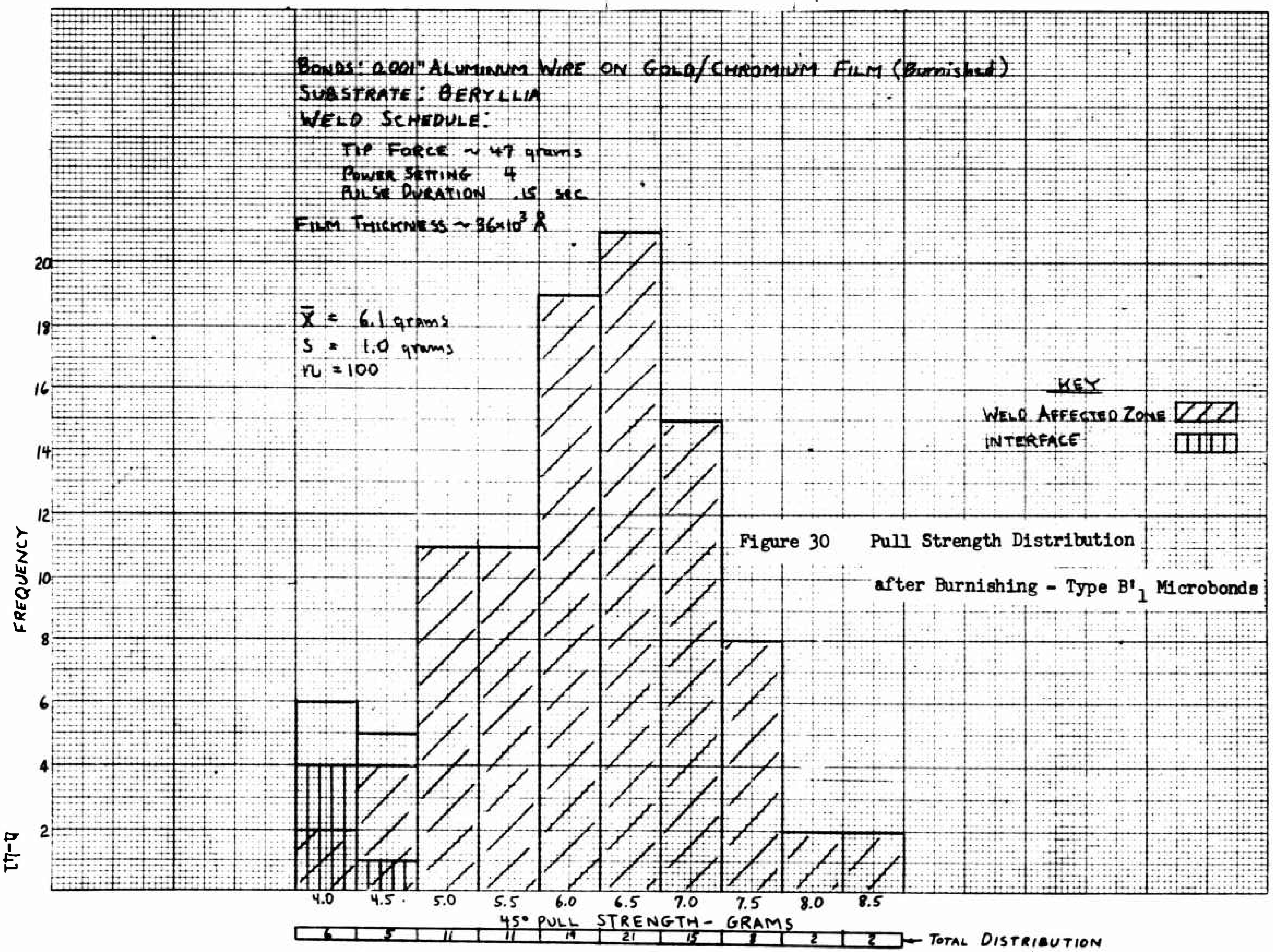


Figure 30 Pull Strength Distribution after Burnishing - Type B'_1 Microbonds

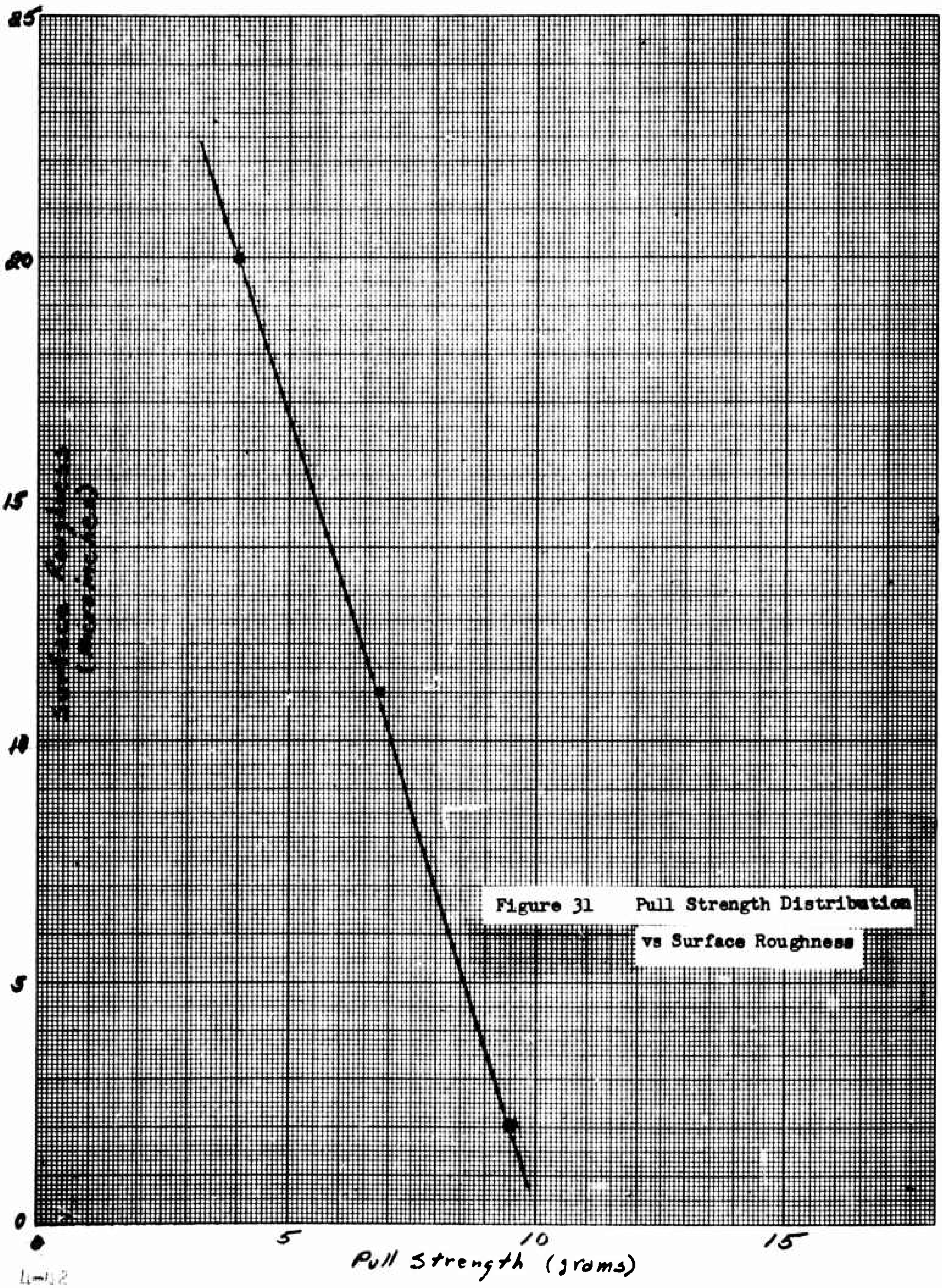
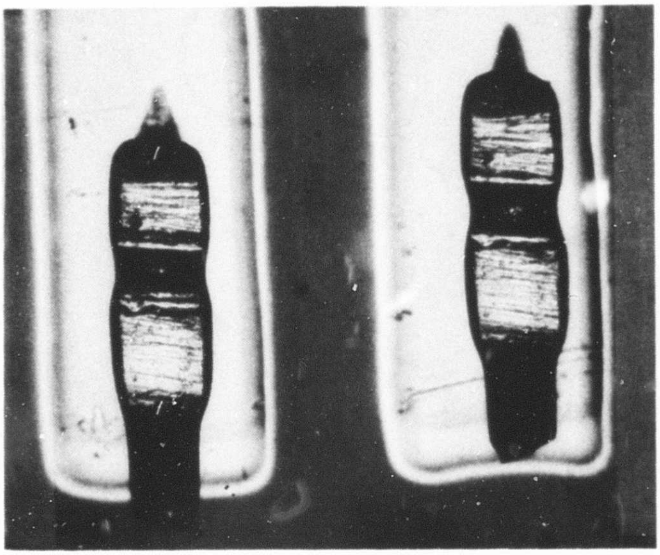
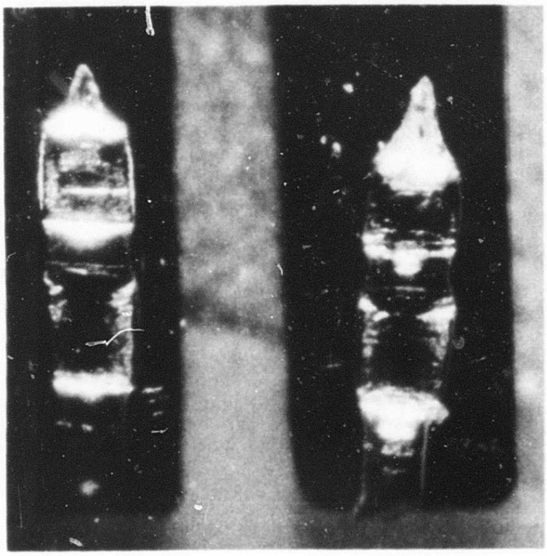


Figure 31 Pull Strength Distribution vs Surface Roughness

0.005" Gold Wire on Gold/Chromium over Sapphire





Vertical Illumination

Oblique Illumination

Magnification ~ 70X
Scale

Mean Pull Strengths: $\overline{X}$ = 158 grams
Mean Base Wire Strength $\overline{X}$ = 200 grams
Type of Breaks: Heat Affected Zone

Film Thickness ~ 19 X 10^3 Å

Weld Schedule

Pulse Amplitude 39.5 amps through 0.006 Ω
Pulse Width 150 msec
Electrical Force 370 grams
Electrode 0.020" x 0.020" x 0.004"

Figure 32 Typical A'_5 Microbonds

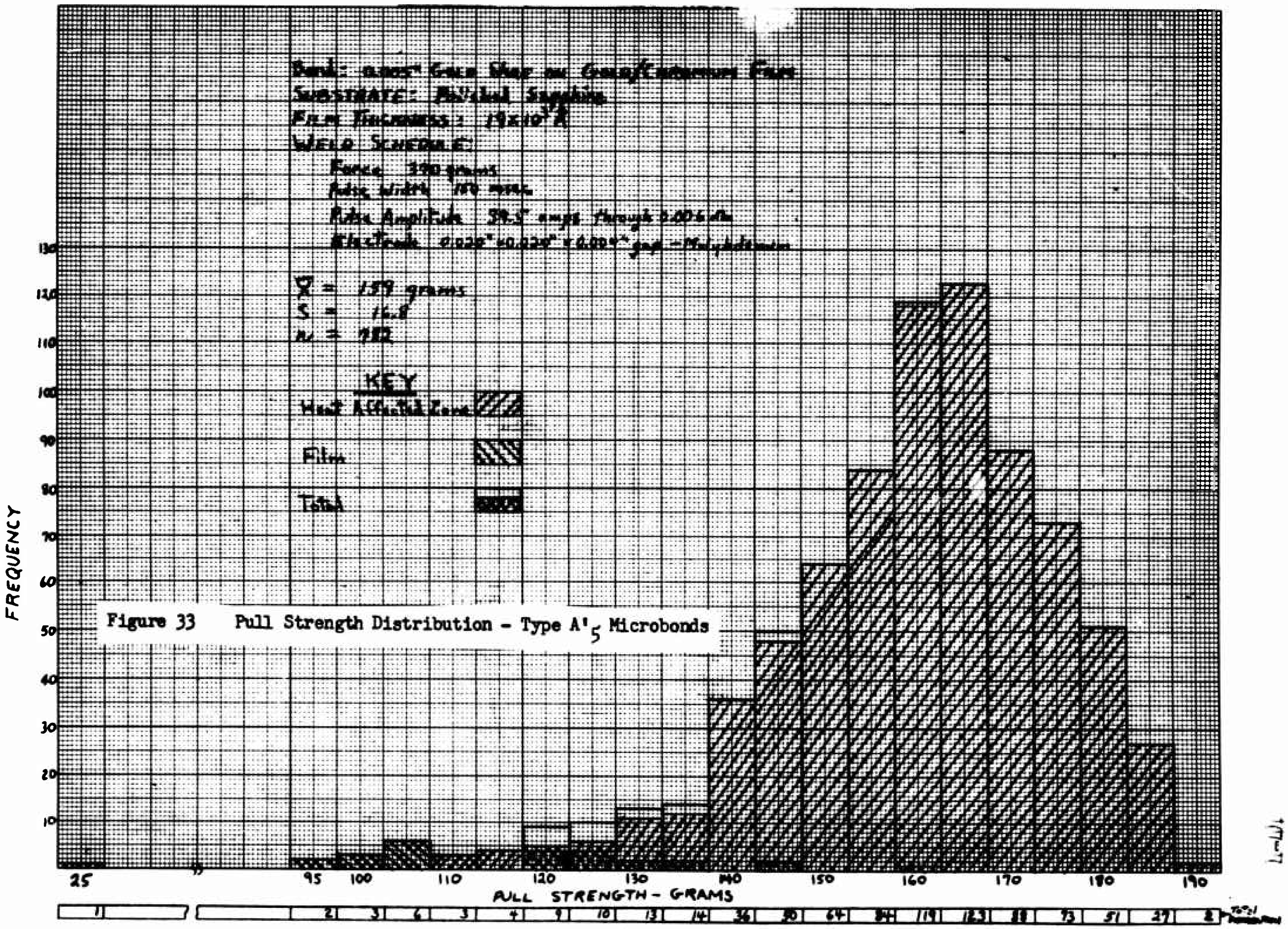


Figure 33 Pull Strength Distribution - Type A'_5 Microbonds

4.3.5 Type A''_2 Microbonds - 0.002inch Gold Wire to Gold/Chromium Films on Beryllia Substrates

4.3.5.1 Evaluation of Mechanical Strength by 90° Pull Test

Figure 34 illustrates typical Type A''_2 microbonds with both vertical and oblique illumination. The pull strength distribution is shown in Figure 35. The mean pull strength was 25 grams which is 94% of the mean tensile strength of the base wire. There were no pull strengths below 12.5 grams so the contractual reliability goals were met. The maximum number of expected bond failures at the 90% confidence level is 3 per thousand Type A''_2 microbonds.

4.3.6 Type A''_5 Microbonds - 0.005 inch Gold Wire to Gold/Chromium Films on Beryllia Substrates

A single remaining Type A''_5 microbond along with two film failures is illustrated in Figure 36. Due to the surface roughness of the beryllia substrates, there was a majority of film-to-substrate breaks in the reliability data. The pull strength distribution is given in Figure 37. The average pull strength was 141 grams and there were no pull strengths below 70.5 grams. Therefore, the criteria of SCL-7746A were met and the maximum number of expected bond failures at the 90% confidence level is 3 per thousand Type B''_5 microbonds.

4.3.7 Type B'_1 Microbonds - 0.001 inch Aluminum Wire to Gold/Chromium Films on Sapphire Substrates

4.3.7.1 Evaluation of Mechanical Strength by 45° Pull Test

Although it has been shown (3) that the 90° pull test is the most sensitive test for bond strength, the 45° pull test was used on aluminum wire bonds for the same reasons discussed for Task I microbonds. Other workers (4) have shown that in order not to make a peel test, a single bond must be made in the center of a wire, the two ends bent at right angles and the wires twisted together and pulled. However, it is felt that this treatment itself would weaken the bond.

Figure 38 shows a typical Type B'_1 microbond. The pull strength distribution for 100 bonds is shown in Figure 39. The mean pull strength was 9.2 grams, which was 63% of the base wire tensile strength, and only one bond did not fail in the weld-affected zone. There were no failures below 50% of the mean pull strength. The failure expectation at the 90% confidence level will be calculated on the basis of a normal distribution as outlined during Phase I (3) of the program, and discussed previously for the Type K Microbonds. The results of this calculation and the calculations for all the aluminum wire microbonds which only have sample sizes of 100 will be presented in the Final Report.

0.002" Gold Wire on Gold/Chromium over Beryllia

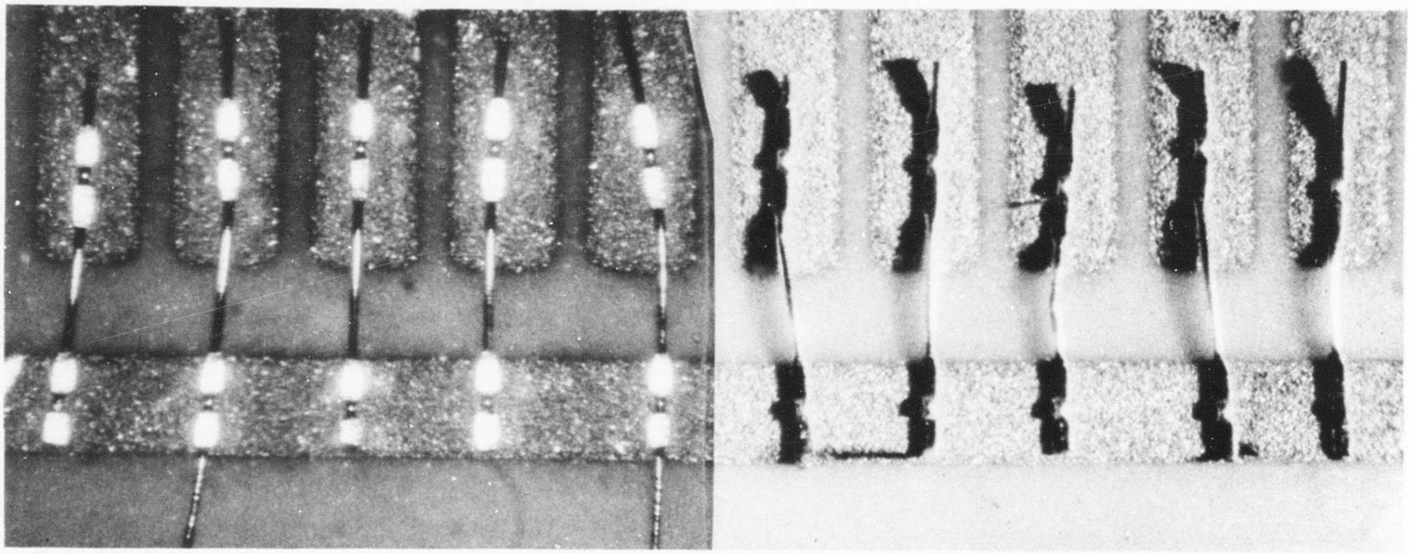


Illustration of Bonds After Pull Test

Pull Strength - Grams

26.5	26.5	25.9	22.0	26.6	25.5	25.7	25.5	24.2	24.9
Type of Break:									
HAZ	WIRE	HAZ	HAZ	WIRE	HAZ	WIRE	HAZ	HAZ	HAZ

Vertical Illumination

Oblique Illumination

Magnification ~ 30X

Film Thickness ~ 45×10^3 Å

Weld Schedule:
- Pulse Amplitude 33 amps thru 0.006 amps
- Pulse Width 80 msec
- Electrode Force ~ 370 grams
- Electrode 0.020" X 0.020" x 0.004" gap

Figure 34 Typical Type A''_2 Microbonds

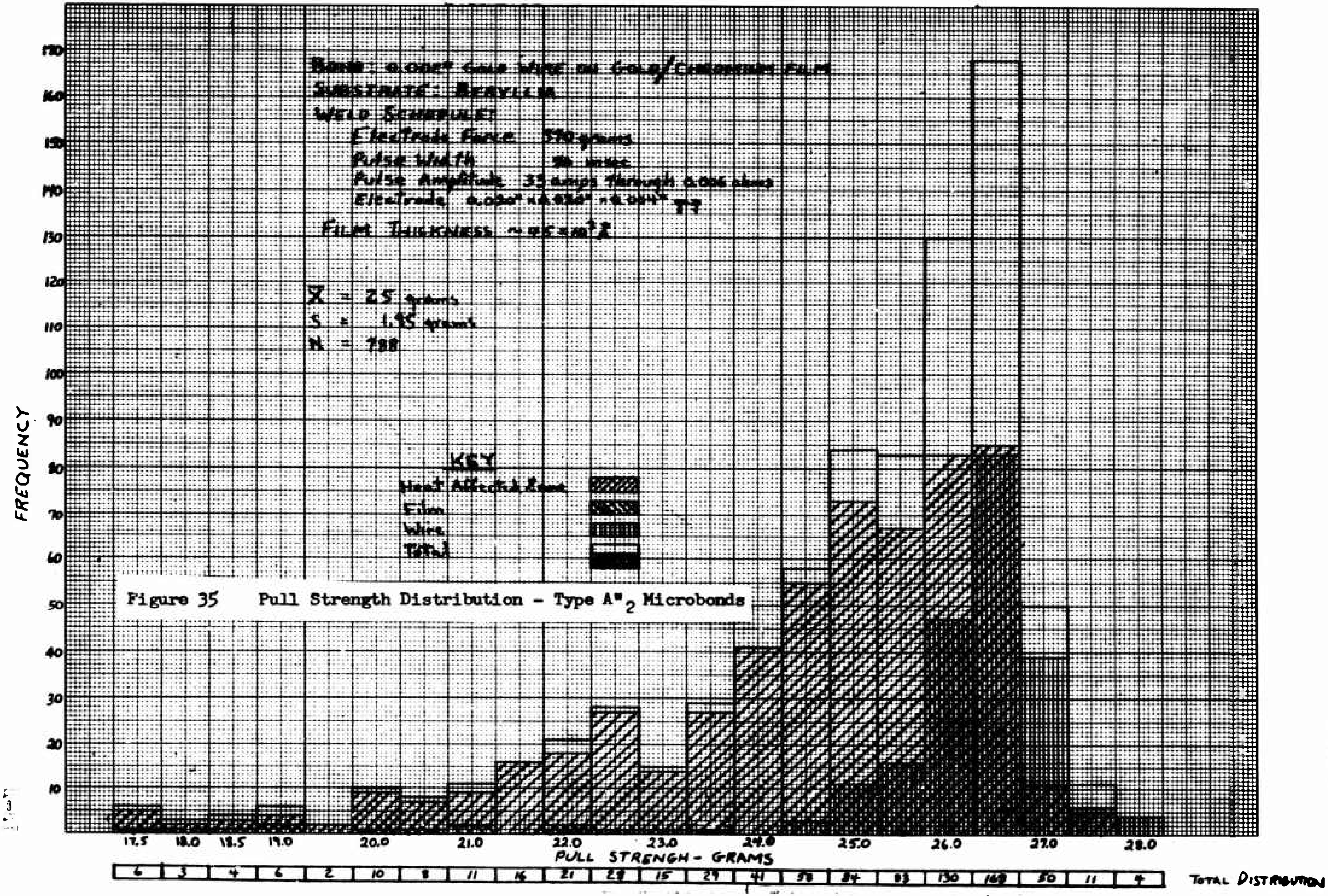
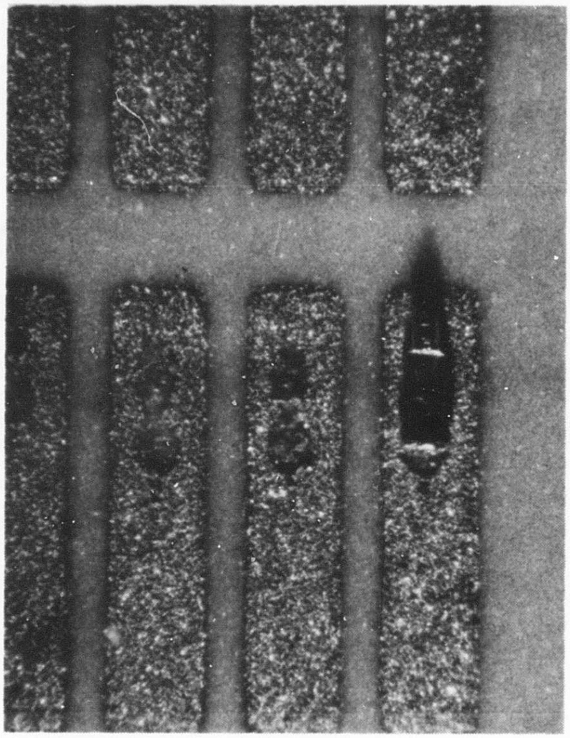


Figure 35 Pull Strength Distribution - Type A"$_2$ Microbonds

0.005" Gold Wire on Gold/Chromium over Beryllia



Pull Strength In Grams	110	140	145
Type of Break	FILM	FILM	HAZ

Magnification ~ 30X
Film Thickness ~ 19 X 10^3 Å

Weld Schedule:

Pulse Amplitudes:	64 amps through 0.006Ω - Center pulse
	43 amps through 0.006Ω - Side pulses
Pulse Widths:	500 msec - Center pulse
	300 msec - Side Pulse
Electrode Force	500 grams
Electrode	0.020" x 0.020" x 0.004" gap

Figure 36 Typical Type A"$_5$ Microbond

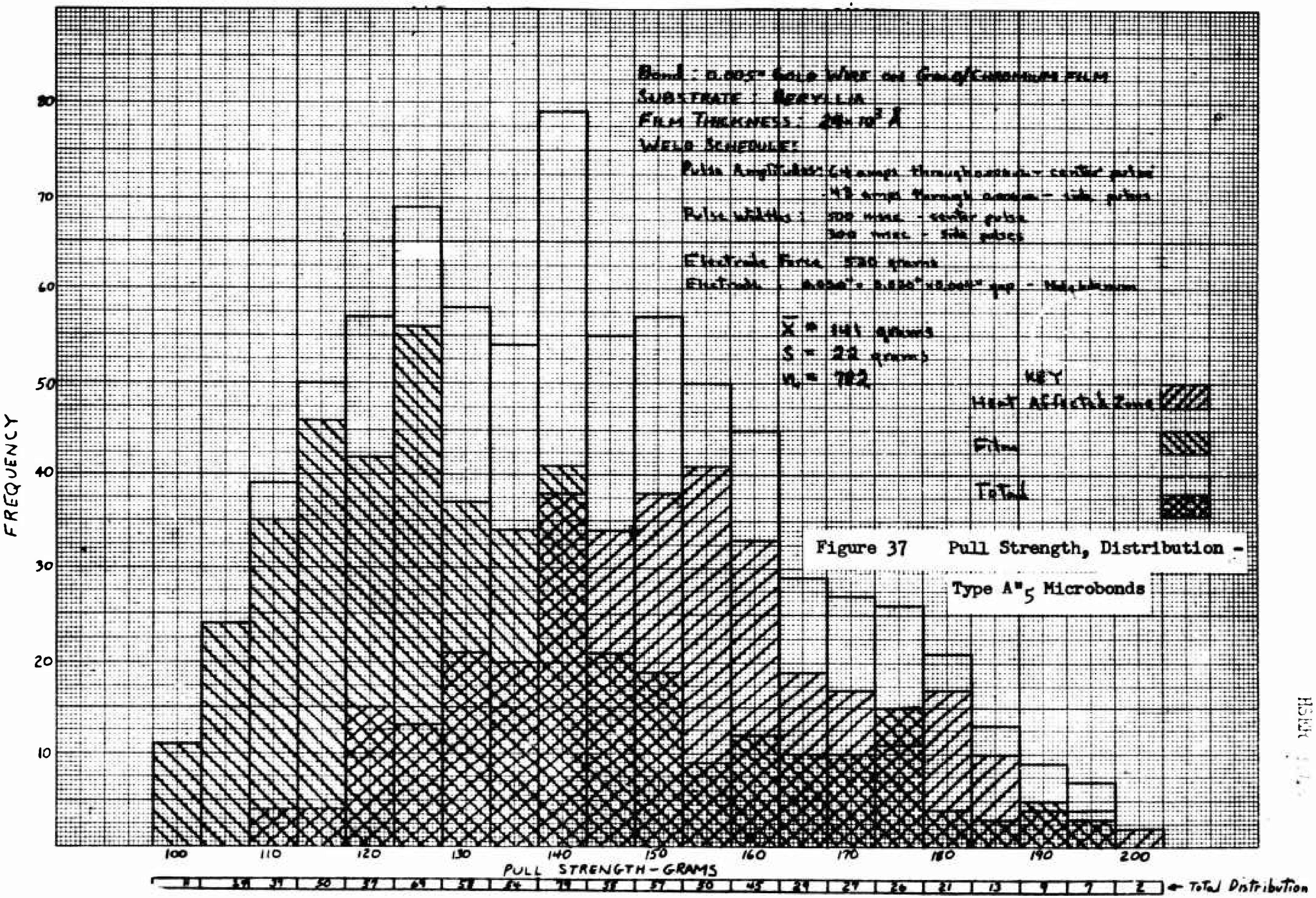
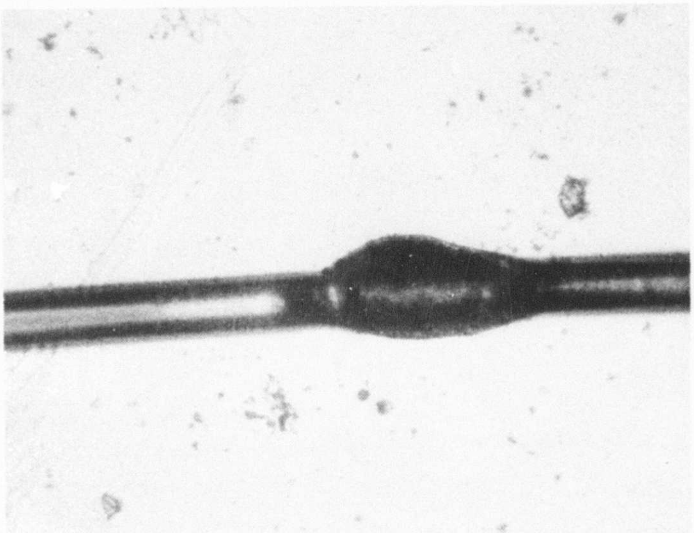


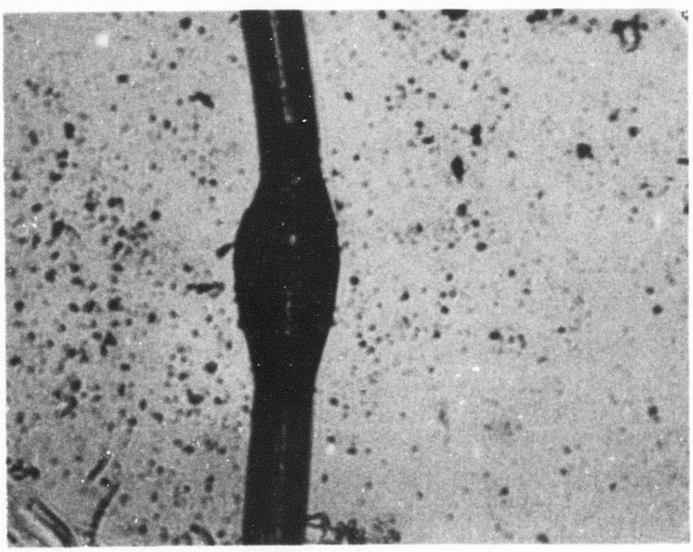
Figure 37 Pull Strength, Distribution - Type A"5 Microbonds

0.001" Aluminum Wire on Gold/Chromium over Sapphire



Magnification ~ 285
Scale: .05mm
~.002"

Bond Resistance ~ .8m
Pull Strength ~ 10.2 grams
Break Occurred in the Weld Affected Zone



Scale: .05 mm

Pull Strength ~ 8.8 grams

Figure 38 Typical Type B'_1 Microbond

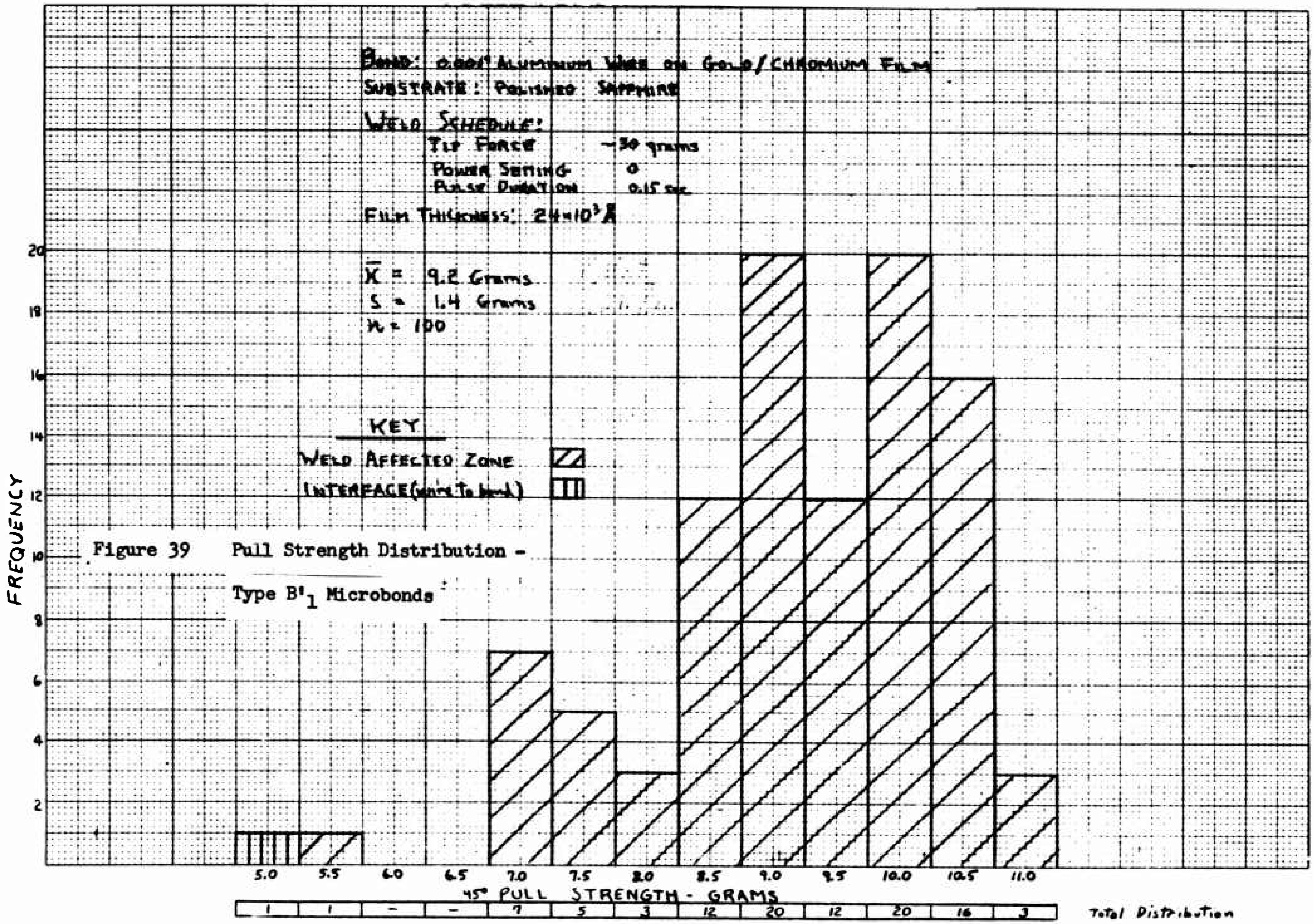


Figure 39 Pull Strength Distribution - Type B'$_1$ Microbonds

4.3.8 Type B'_2 Microbonds - 0.002 inch Aluminum Wire to Gold/Chromium Films on Sapphire Substrates

4.3.8.1 Evaluation of Mechanical Strength by 45° Pull Test

Typical Type B'_2 microbonds are illustrated in Figure 40. The pull strength distribution for these bonds is given in Figure 41. The average pull strength was 58% of the base wire tensile strength and had a value of 31.6 grams. Figure 41 also shows that one bond failure, which was an interface failure, occurred.

4.3.9 Type B''_2 Microbonds - 0.002 inch Aluminum Wire to Gold/Chromium Films on Beryllia Substrates

Photomicrographs of two typical Type B''_2 microbonds are shown in Figure 42 with vertical and oblique illumination. These photographs have been included to indicate bonds which pass the initial visual inspection. The pull strength distribution is given in Figure 43. The mean pull strength in this case was 17.4 grams, which just barely met the goal of the SCL-7746A requirement that $\bar{X}$ (the mean pull strength) exceed 30% of the base wire tensile strength. As mentioned previously, this was due to the surface roughness of the beryllia wafers. There was one bond failure (i.e., pull strength less than $\bar{X}/2$) at 8 grams and again it was an interface failure.

4.3.10 Microbond Resistance

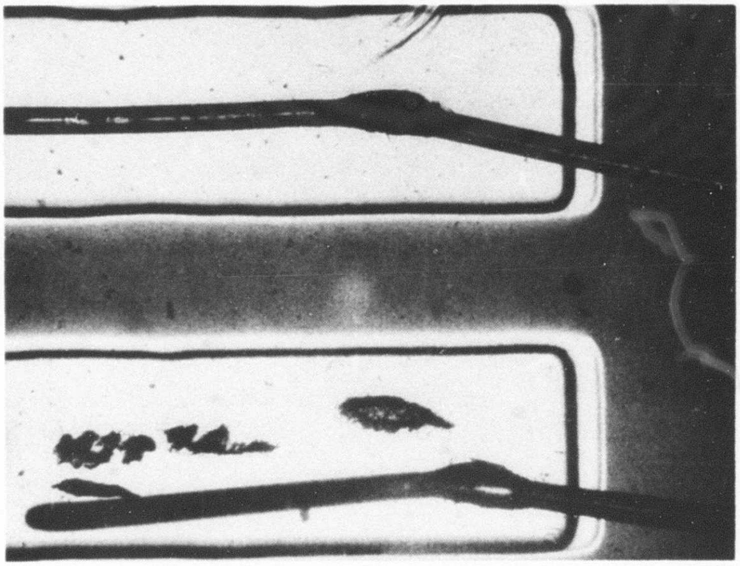
All bonds in Task IA completed during this period easily surpassed the resistance requirement set forth in SCL-7746A. The resistance distribution for Types A'_5, A''_2 and A''_5 microbonds are shown in Figure 44 as a function of pull strength. Similar plots for Types B'_1 and B'_2 bonds are shown in Figure 45 and Type B''_2 microbonds are shown in Figure 46. As was the case for all bonds in both Phase I and Phase II of this program, there was no correlation between bond pull strength and bond resistance.

4.3.11 Thermal Aging

All Task I and Task IA microbonds completed prior to this quarter were thermally aged according to contractual specifications of SCL-7746A. Ten bonds of each type were aged for 1000 hours at temperature of 125° C, 200° C, 300 °C, 400° C and 500° C. The bond resistance was monitored at 100-hour intervals during the aging. The microbonds that completed this aging test are Types E, F, G, H, A'_1, A'_2 and A''_1. These are all gold wire to gold film microbonds.

Figures 47 through 53 show the microbond resistance as a function of time. Although most of the bonds increased in resistance, this increase was not monotonic. No unique conclusions can be drawn from these results. Table III gives a summary of the resistance aging data along with the results of pull testing following thermal aging. The contractual goal in this case was to

0.002" Al. Wire on Gold/Chromium over Sapphire



Vertical Illumination
Magnification ~ 70X
Scale: 0.1mm

Weld Schedule

Tip Force ~ 90 grams
Power Setting: 2 (High Range)
Pulse Duration: 0.15 sec

Film Thickness: ~ 24 x 10^3 Å

Figure 40 Typical Type B'_2 Microbonds

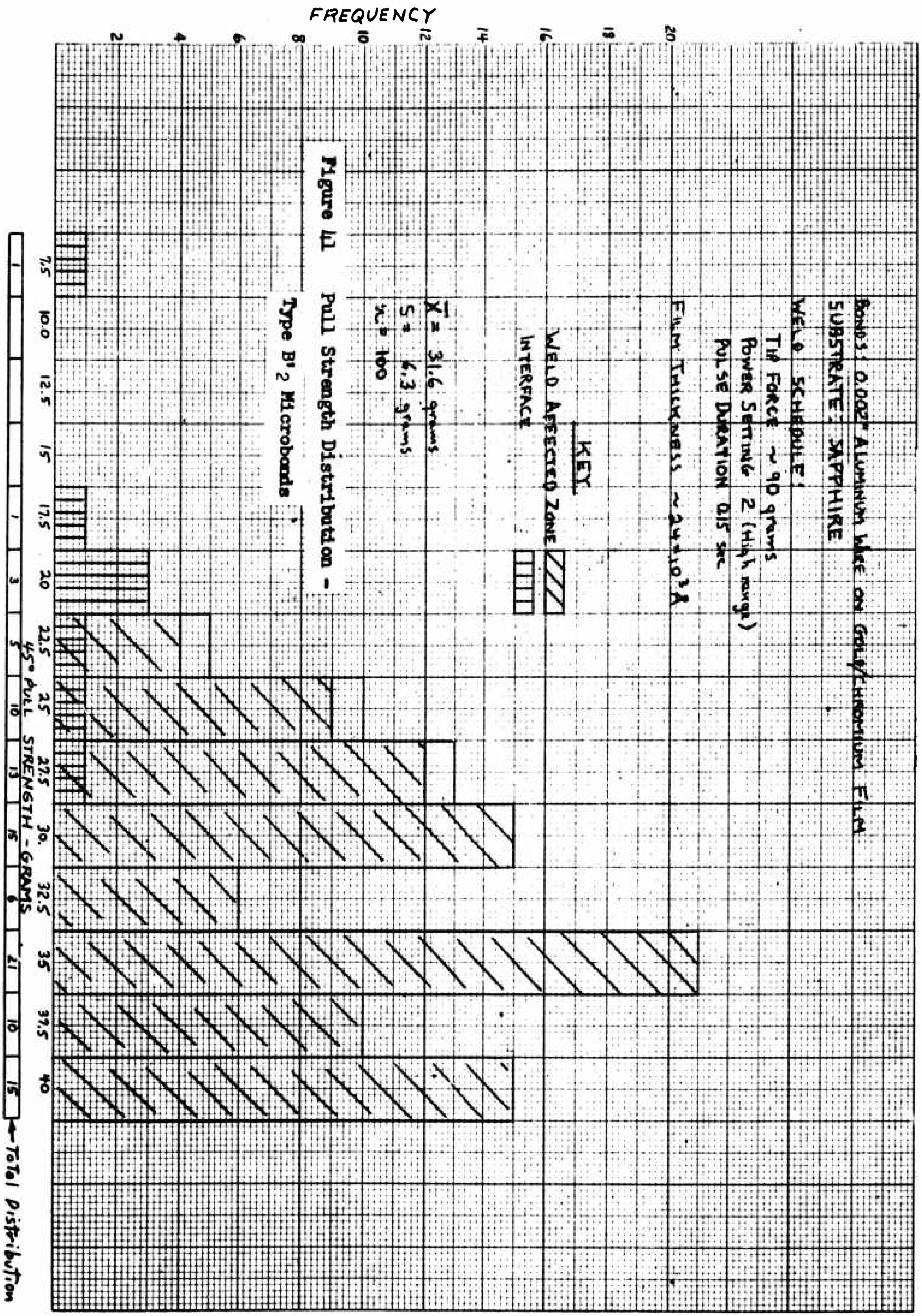
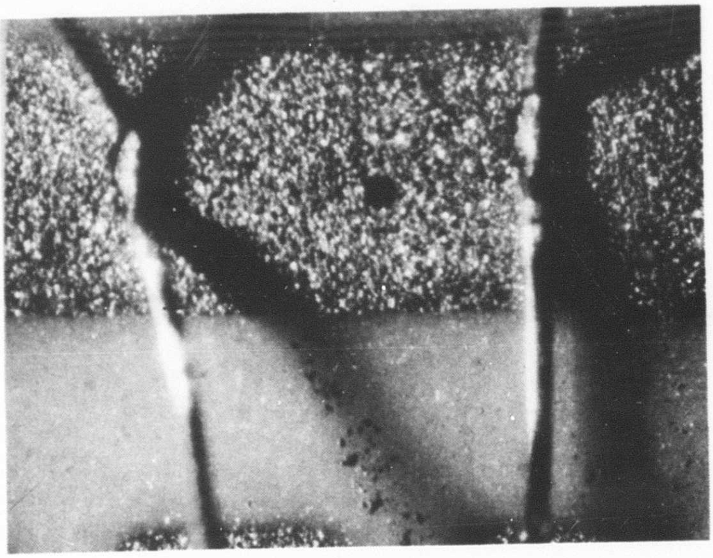


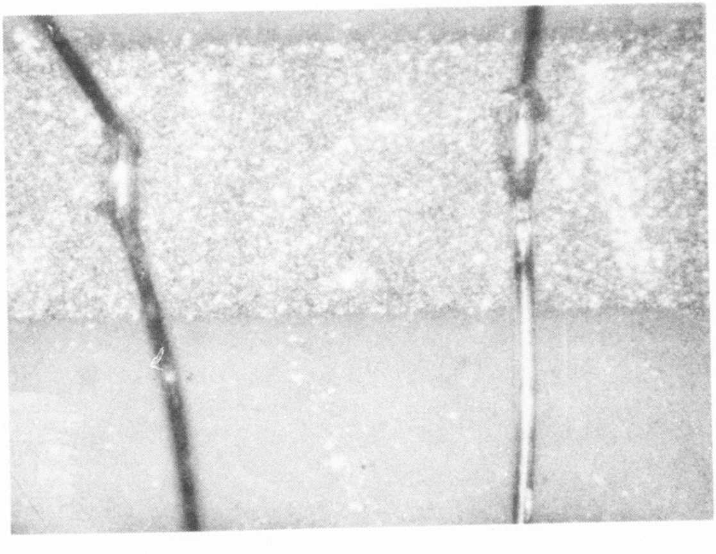
Figure 41 Pull Strength Distribution - Type B'$_2$ Microbonds



Oblique Illumination

Weld Schedule:
Tip Force ~ 95 grams
Pulse Duration 0.15 sec.
Power Setting 5 (High)

45° Pull Strength	16.5 grams	18.5 grams
Type of Break	Weld Affected Zone	Weld Affected Zone



Vertical Illumination

Magnification ~ 70X

0.002" Aluminum Wire on Gold/
Chromium over Beryllia

Figure 42 Typical Type B"2 Microbonds

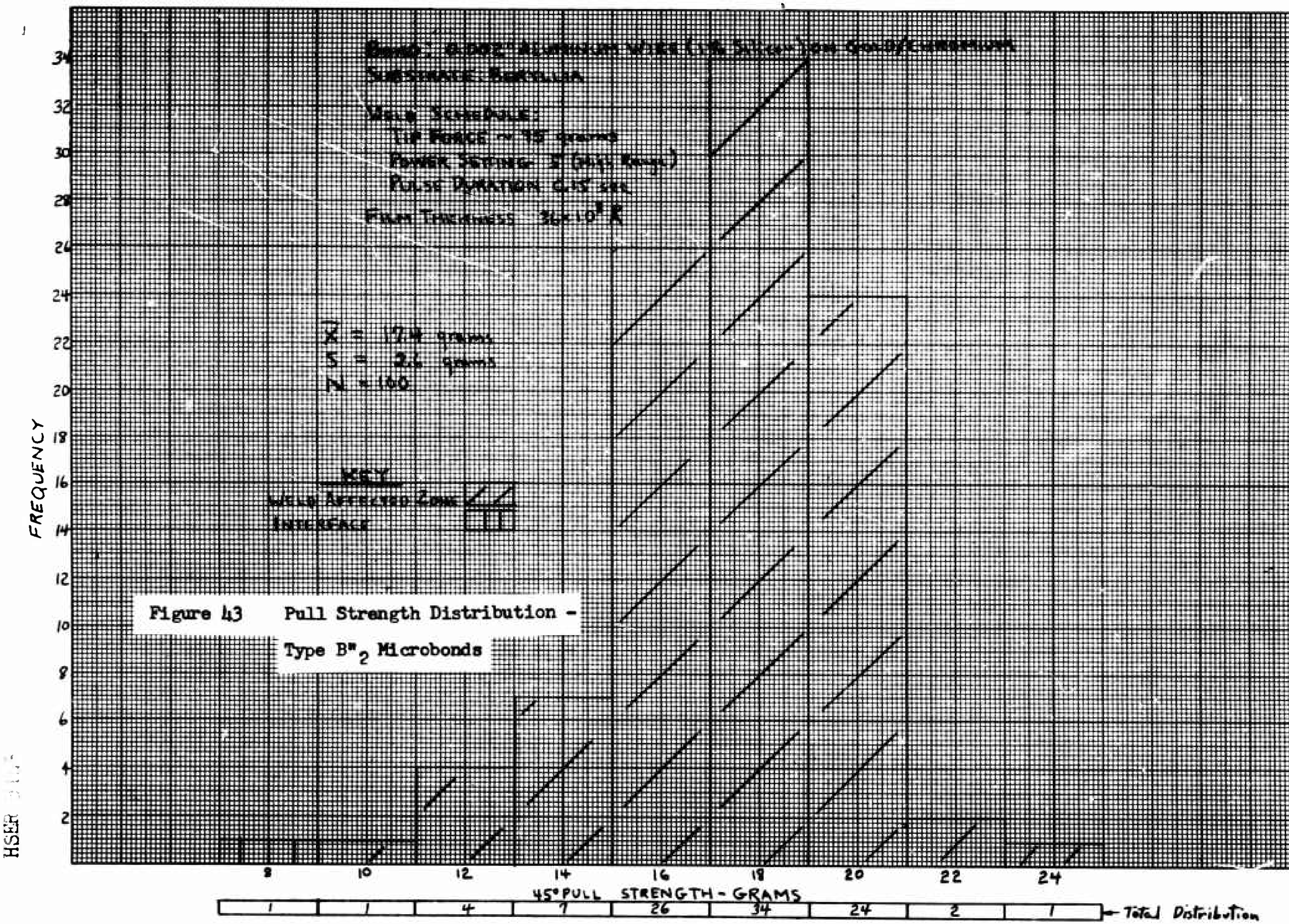


Figure 43 Pull Strength Distribution - Type $B"_2$ Microbonds

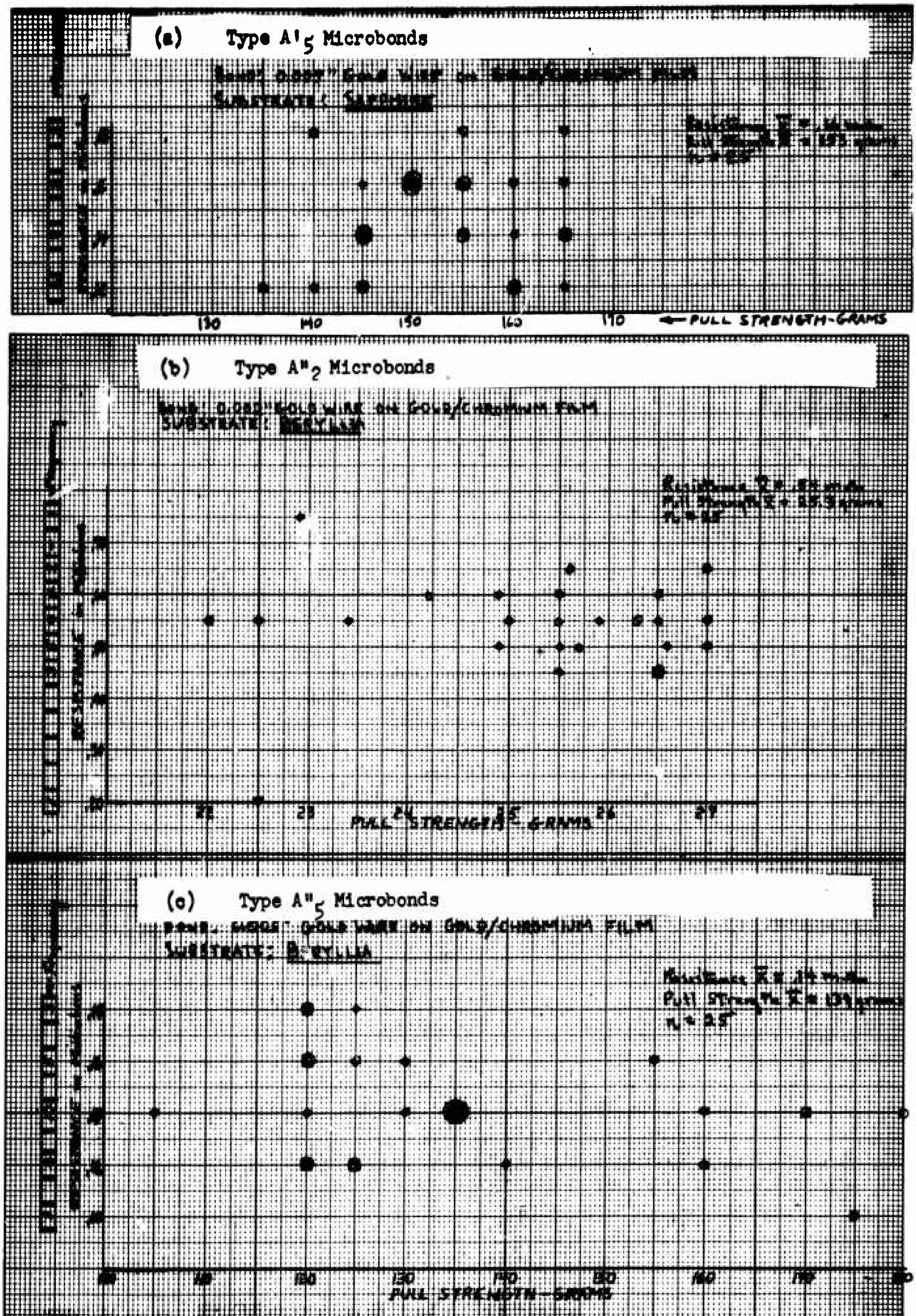


Figure 44 Resistance vs Pull Strength

(a) Type B'$_1$ Microbonds

(b) Type A'$_2$ Microbonds

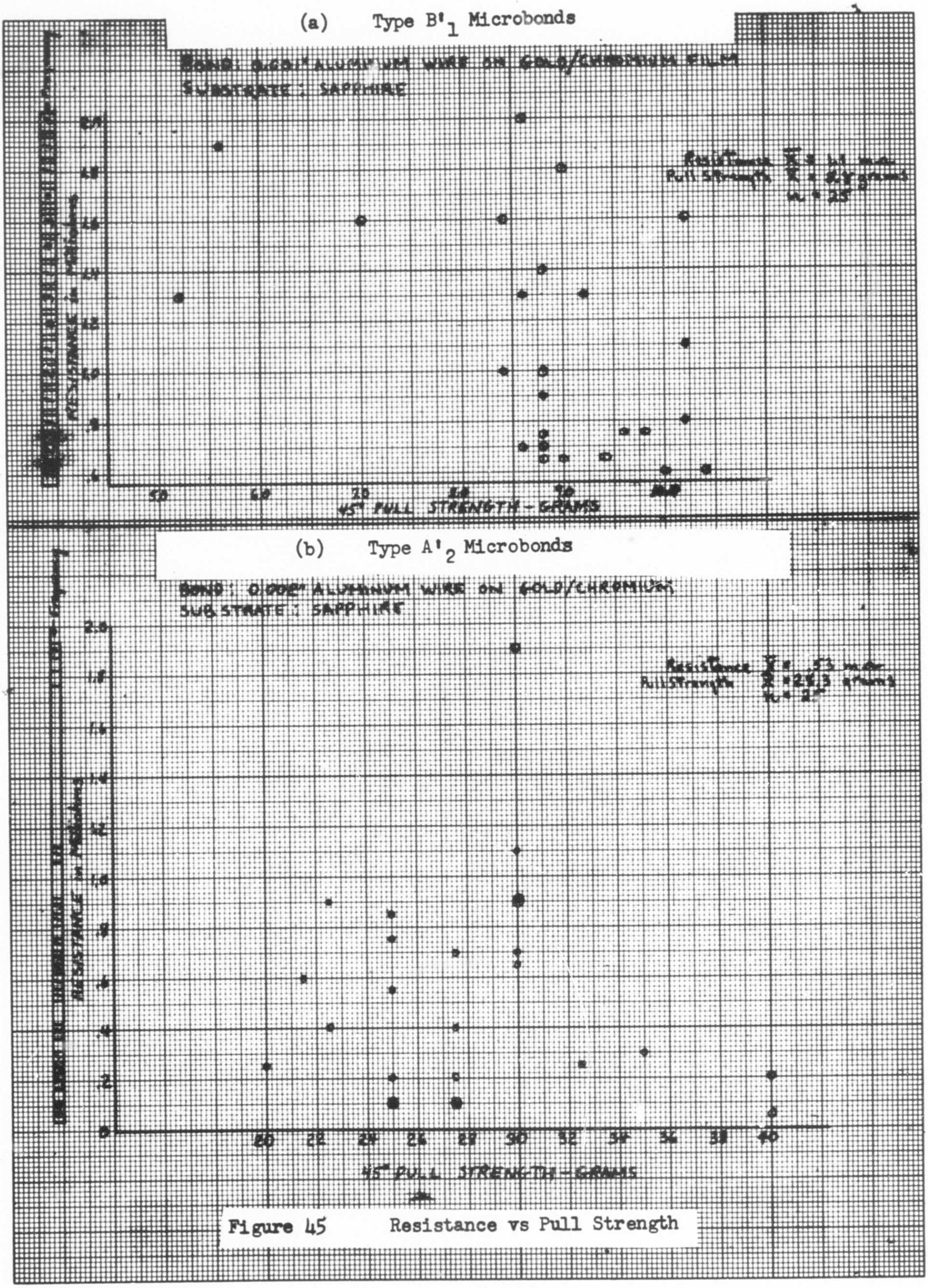


Figure 45 Resistance vs Pull Strength

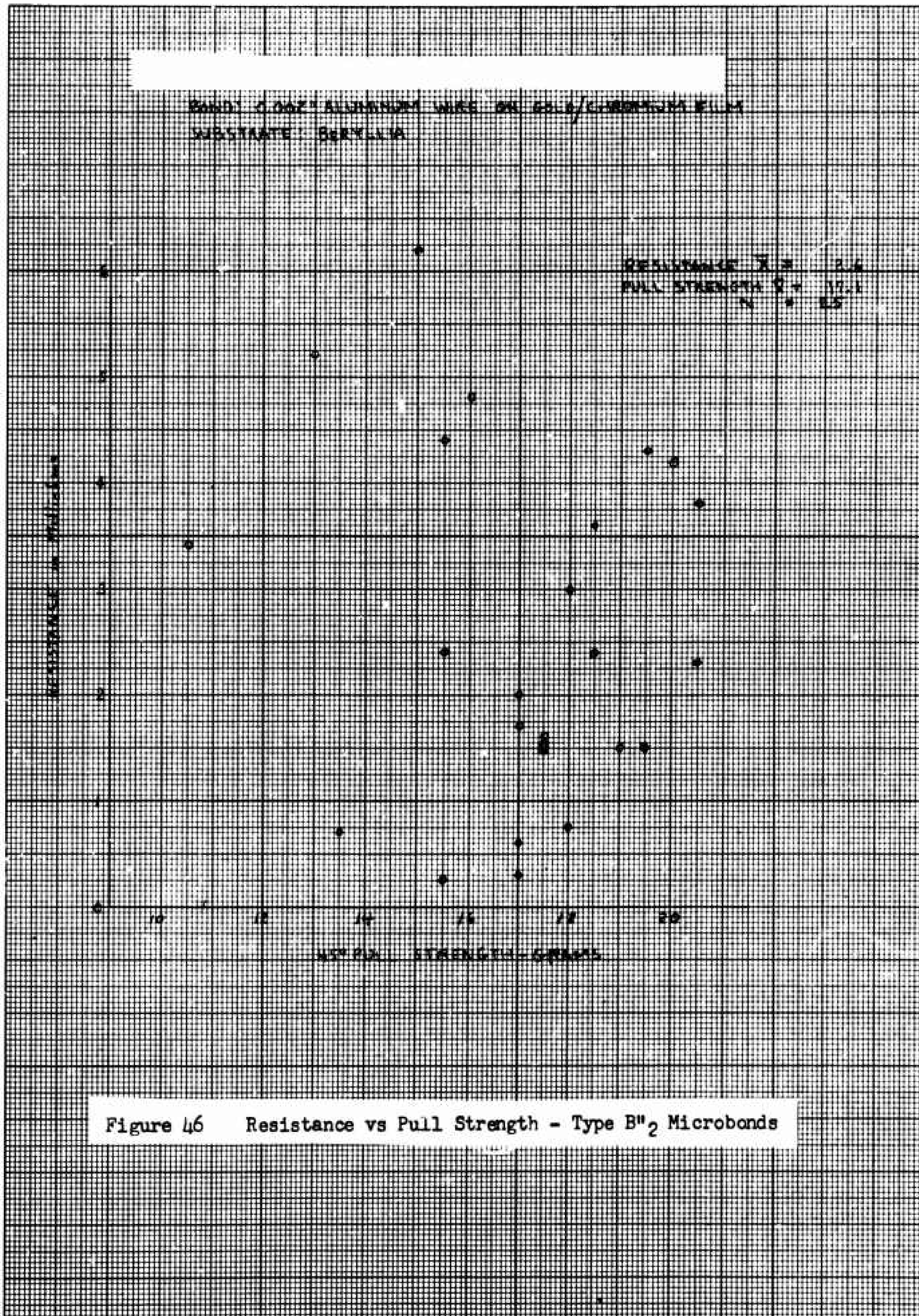


Figure 46 Resistance vs Pull Strength - Type B"$_2$ Microbonds

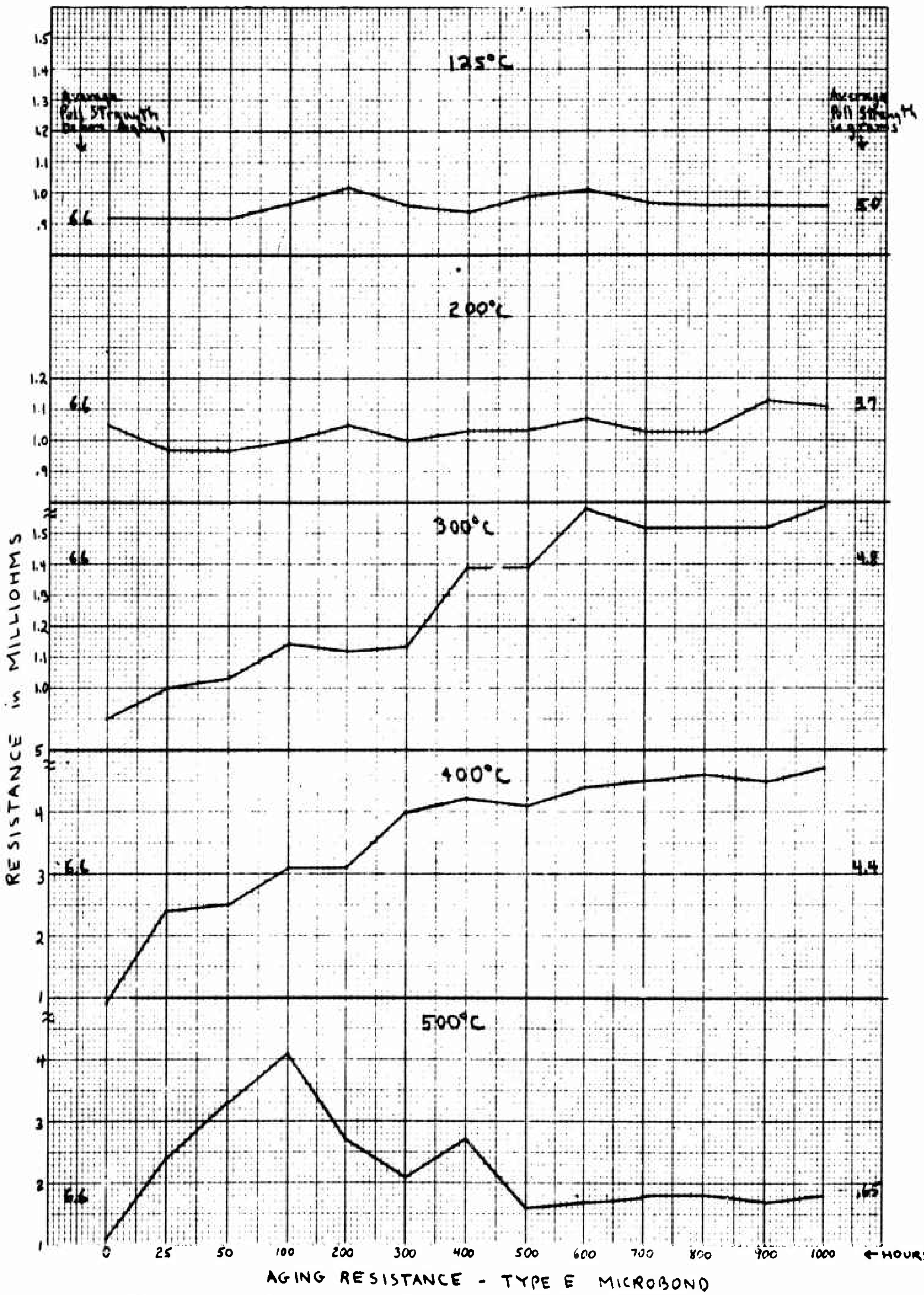


Figure 47 Resistance vs Thermal Aging Time - Type E Microbonds

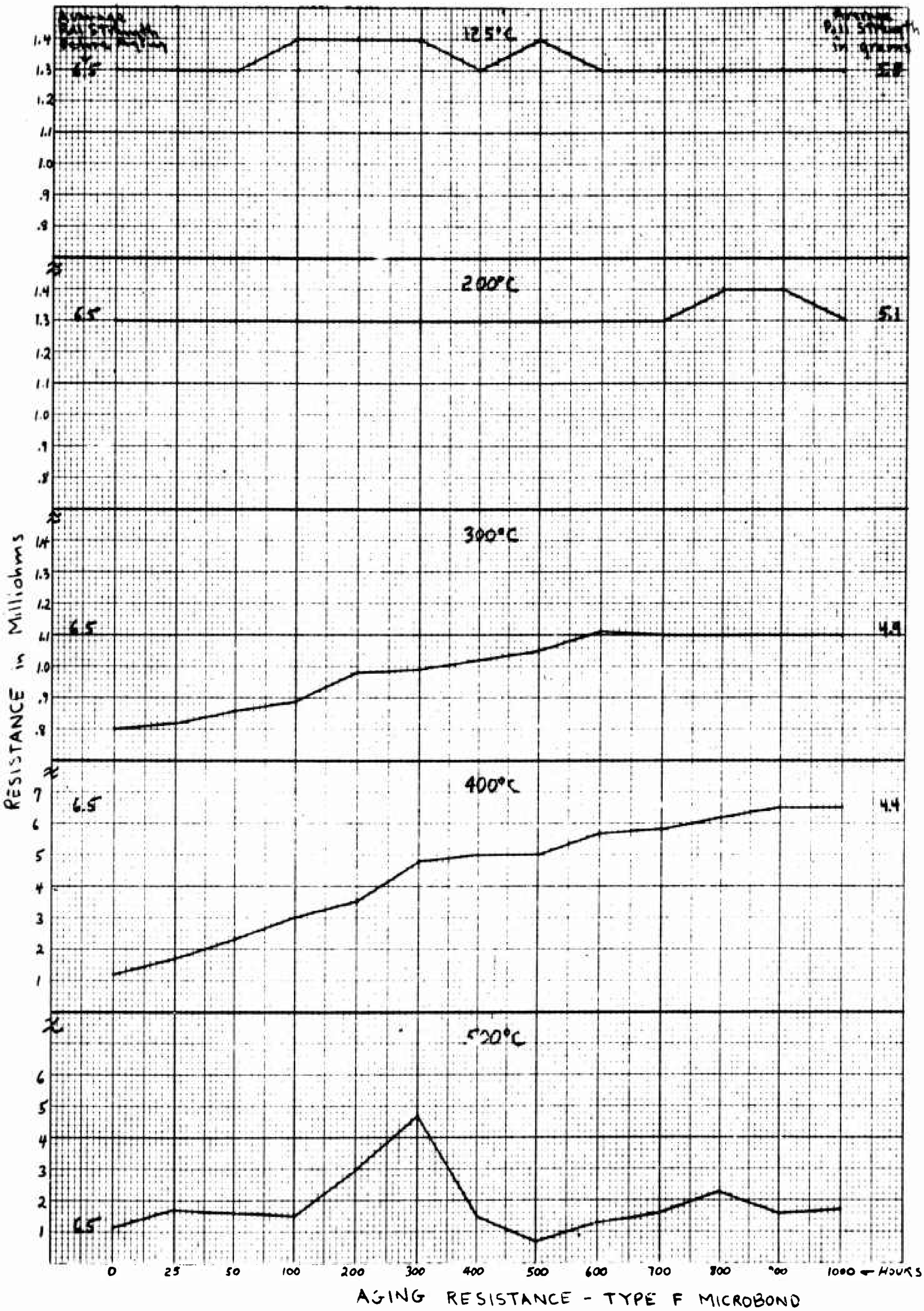


Figure 48 Resistance vs Thermal Aging Time - Type F Microbonds

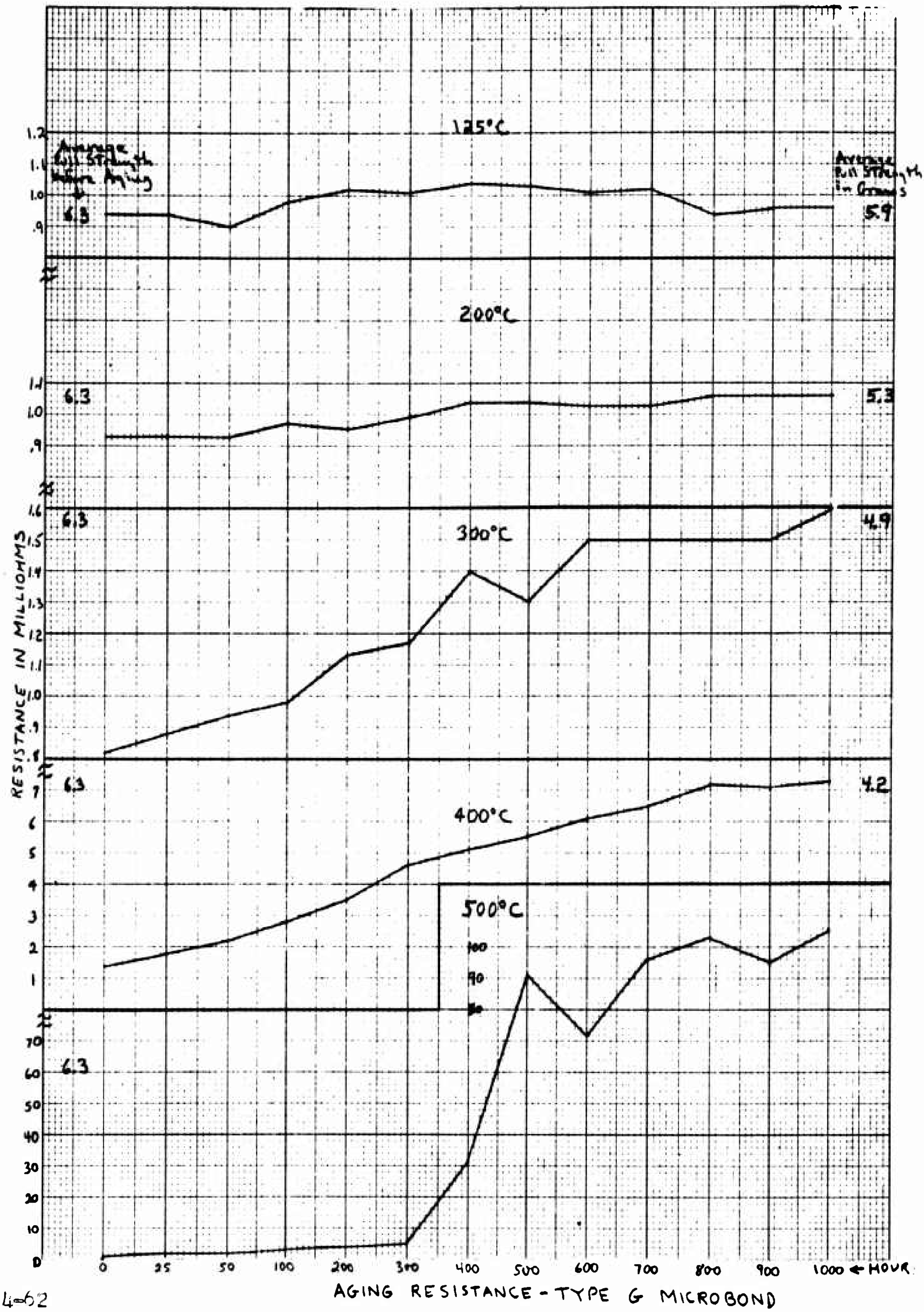


Figure 49 Resistance vs Thermal Aging Time - Type G Microbonds

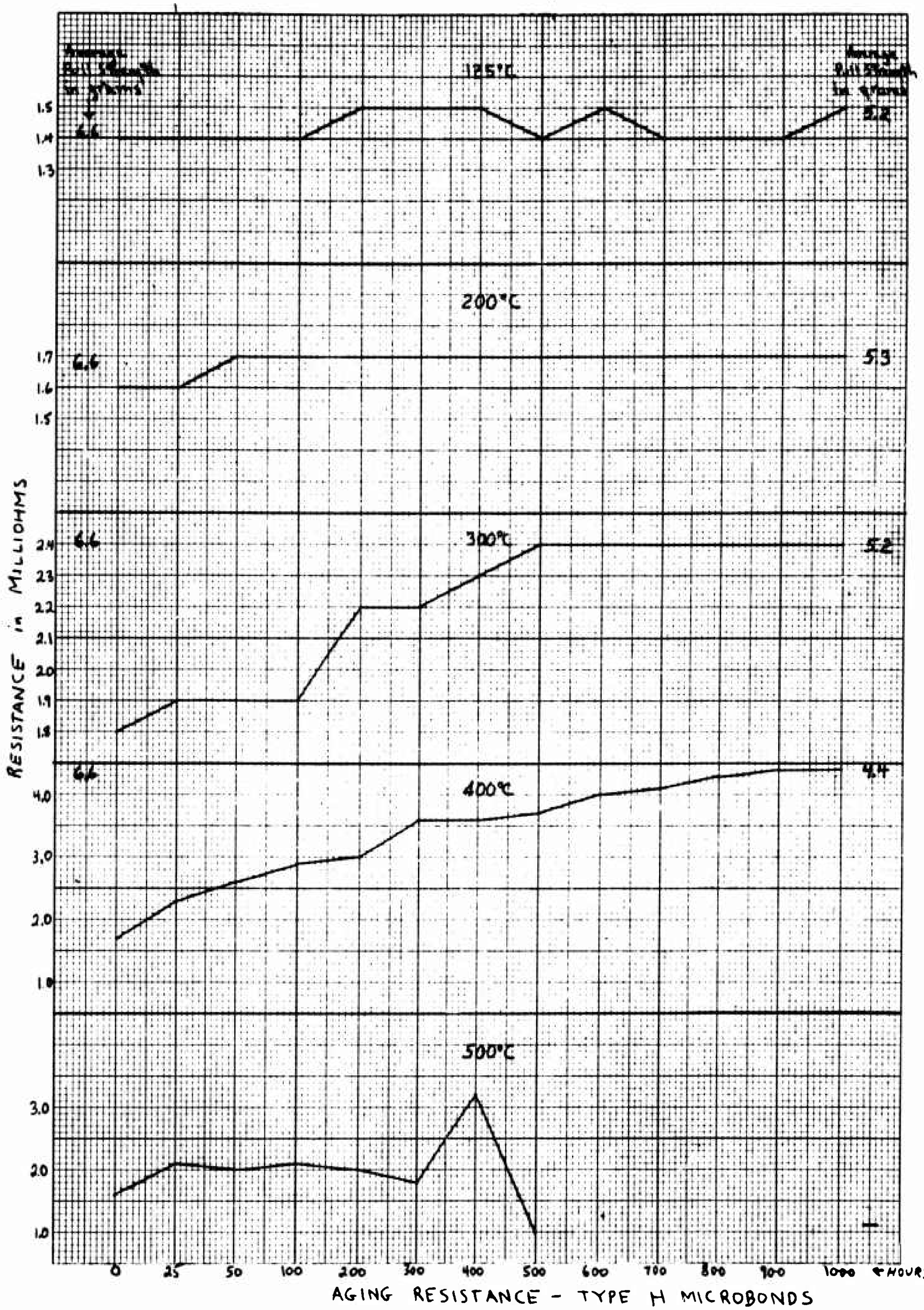


Figure 50 Resistance vs Thermal Aging Time - Type H Microbonds

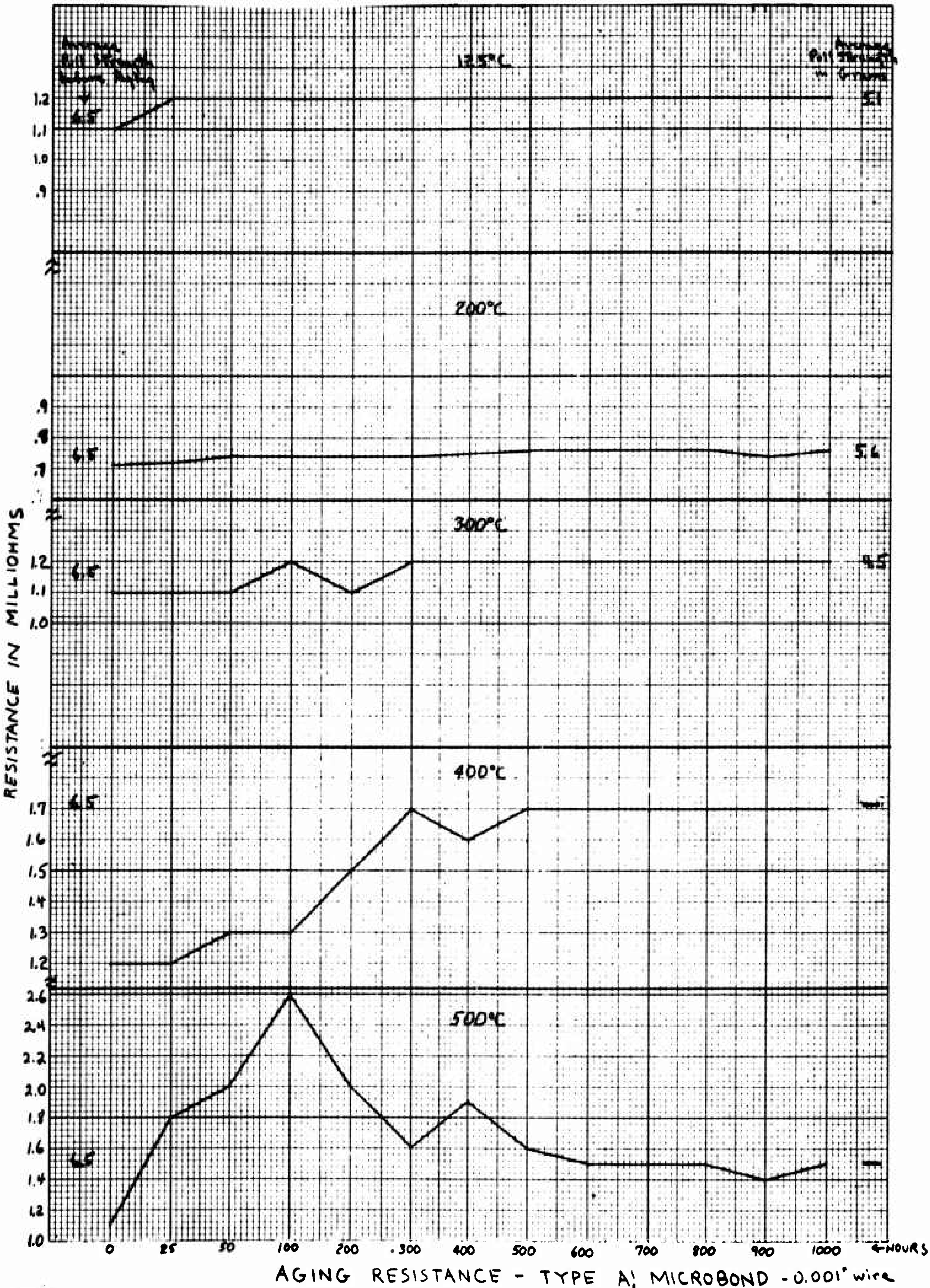


Figure 51 Resistance vs Thermal Aging Time Type A'_1 Microbonds

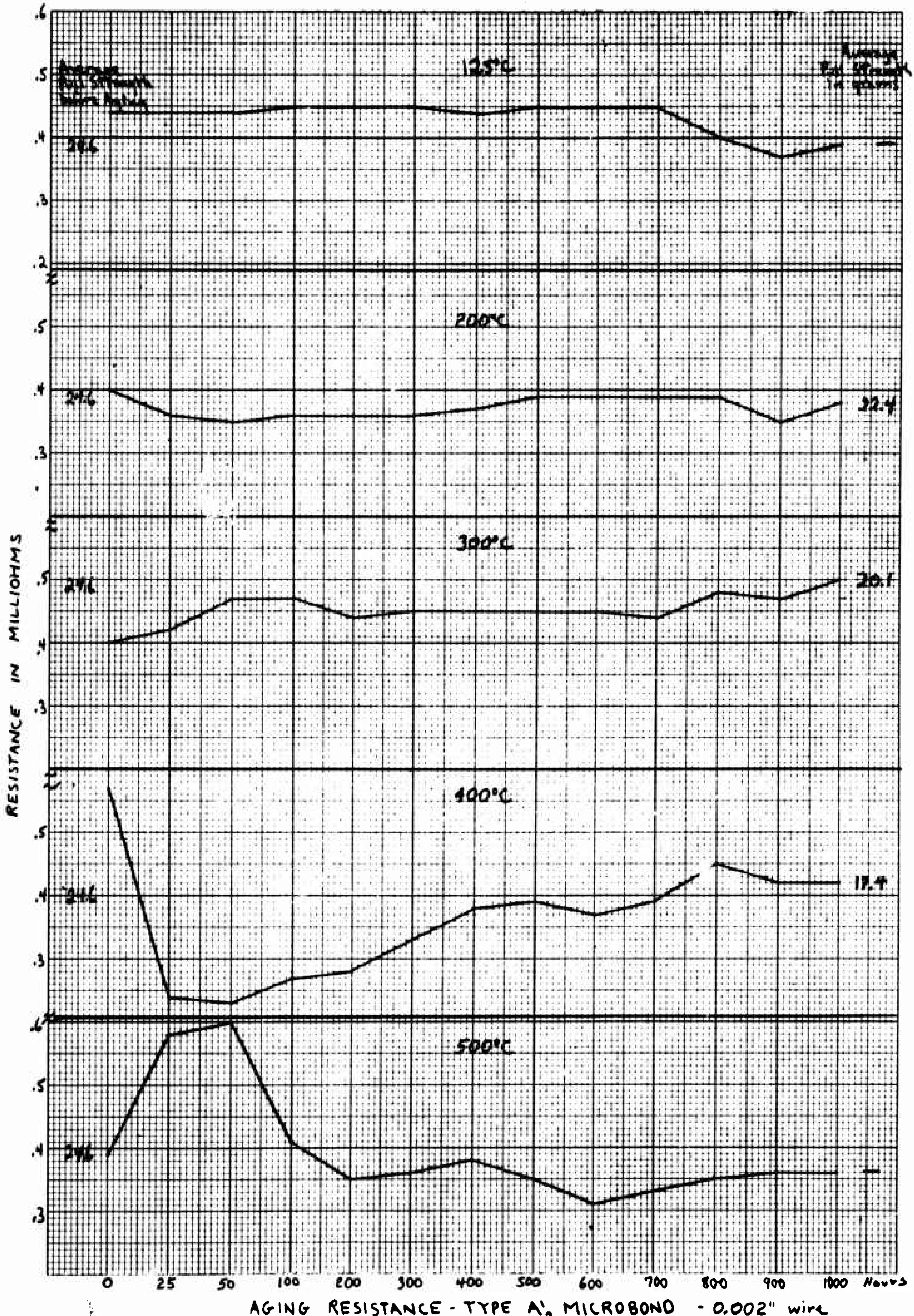


Figure 52 Resistance vs Thermal Aging Time - Type A'$_2$ Microbonds

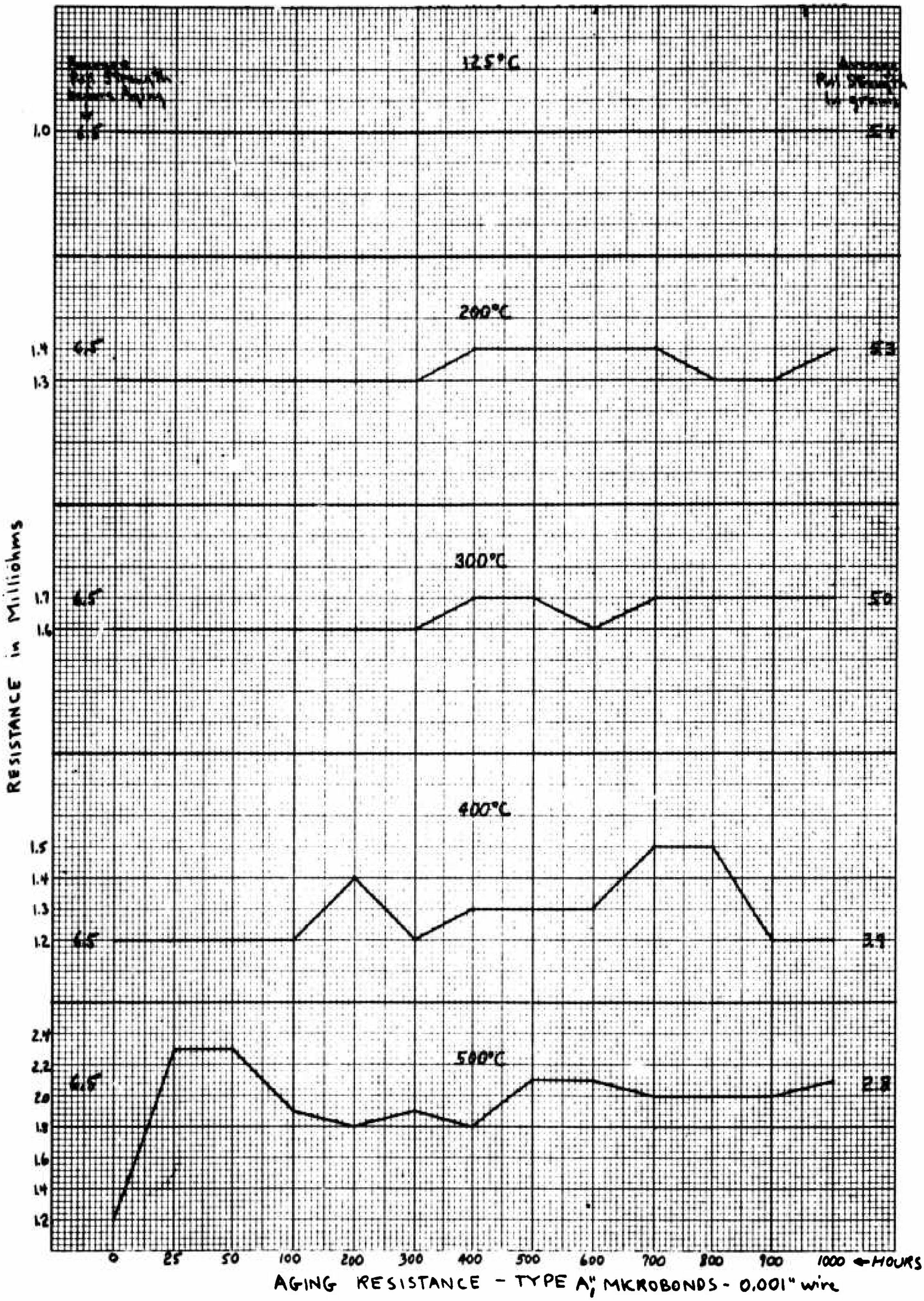


Figure 53 Resistance vs Thermal Aging - Type A^{*}_{1} Microbonds

Table III
Percent Change Of Resistance For Thermally Aged Microbonds - After 1000 Hours

Bond Type	°C	Resistance In Milliohms			Pull Strength - Grams		
		Initial Resist.	Final Resistance	Percent Change	Before Aging	After Aging*	Percent Change
E	125	.92	.96	4.3	6.6	5.0	24
	200	1.05	1.11	5.7		3.7	44
	300	.90	1.59	76.6		4.8	27
	400	.94	4.68	398		4.4	33
	500	1.10	1.82	64.6		.65	90
F	125	1.3	1.3	0	6.5	5.8	11
	200	1.3	1.3	0		5.1	22
	300	.80	1.1	37.5		4.9	25
	400	1.2	6.5	441		4.4	33
	500	1.1	1.7	54.6		---	---
G	125	.94	.96	2.1	6.3	5.9	6
	200	.93	1.06	14		5.3	16
	300	.82	1.6	95		4.9	22
	400	1.4	7.3	420		4.2	33
	500	1.4	105.2	7400		---	---
H	125	1.4	1.5	7.1	6.6	5.2	21
	200	1.6	1.7	6.2		5.3	20
	300	1.8	2.4	33.3		5.2	21
	400	1.7	4.4	159		4.4	33
	500	1.6	---	---		---	---
A'_1 0.001" Wire	125	1.1	1.2	9.1	6.5	5.1	22
	200	.71	.78	9.9		5.6	14
	300	1.1	1.2	9.1		4.5	31
	400	1.2	1.7	41.6		---	---
	500	1.1	1.5	36.4		---	---
A''_1 0.001" Wire	125	1.0	1.0	0	6.5	5.4	17
	200	1.3	1.4	7.7		5.3	18
	300	1.6	1.7	6.2		5.0	23
	400	1.2	1.2	0		3.9	40
	500	1.2	2.1	75		2.8	57
A'_2 0.002" Wire	125	.44	.39	-11.4	24.6	---	---
	200	.40	.38	-5.0		22.4	9
	300	.40	.50	25		20.1	18
	400	.57	.42	-26.3		17.4	29
	500	.39	.36	7.7		---	---

10 Microbonds of Each Type Aged at Each Temperature

* Pull Strengths After Aging Were Also Weaker Due to Handling During Resistance Measurements

develop bonds whose resistance did not change by more than 10% following 1000 hours of thermal aging. Table IV lists the bonds that met the requirement. It is important to note that all bond types met the goal at 125° C and all but Type G bonds met the goal at 200° C. These are the most important temperatures since the hybrid microcircuits that require these bonds would normally be operated below 125° C and stored at temperatures below 200° C. It is also of interest to note that even when the bond resistance increased by more than 10%, it was in all cases less than the maximum allowable resistance.

Table III shows that the microbond pull strength was degraded by thermal aging, particularly at the higher temperatures. This was mainly due to film weakening caused by gold-chromium diffusion. Figure 54 illustrates the bonds and film separation for Type H microbonds after 1000 hours at 500° C.

4.4 Summary of Work on Task I and Task IA

Tables V, VI and VII give a summary of the pull strength results of all microbonds completed at this time. Table V indicates the maximum number of expected failures based on the Poisson sampling plan for a 90% confidence level. Table VI indicates the failure bond strength as a precentage of the minimum expected strength, and Table VII shows a comparison of the mean bond pull strength to the mean tensile strength of the base wire. All bond types met the requirement that the mean pull strength be larger than 30% of the base wire tensile strength. Three bond types, H, A^{*}_{2} and A^{*}_{5}, met the goal that the maximum expected number of bond failures be 3 per thousand at the 90% confidence level. However, the failure expectation has not been calculated for the aluminum wire to gold film microbonds. Also, it is again emphasized that over 90% of the failures have been film-to-substrate failures rather than wire or wire-to-film failures. This indicates that with better film adhesion, more bond types would meet the pull strength goal.

Table VIII summarizes the average bond resistance for all completed microbond types. All bonds easily met the contractual goal but there was no correlation between bond resistance and bond pull strength.

4.5 Task II - Microcircuit Module Stack Welding

Table IX shows the design plan for stack welding. All bonds will be formed by, the Hughes Model MCW-550 power supply and variable gap weld head, Model VTA-66. This resistance welder and the fixturing required were described in Quarterly Report No. 7. (2)

4.5.1 Materials

4.5.1.1 Riser Wires

Gold-plated nickel riser wire matrices were chemically etched to Hamilton Standard tolerances. However, undercutting proved to be a problem as evidenced by Figures 55 and 56. Therefore, even though the Type V bonds were completed

Table IV

Thermally Aged Microbonds For Which $\Delta R < 10\%$ After 1000 Hours (SCL 7746A Goal)

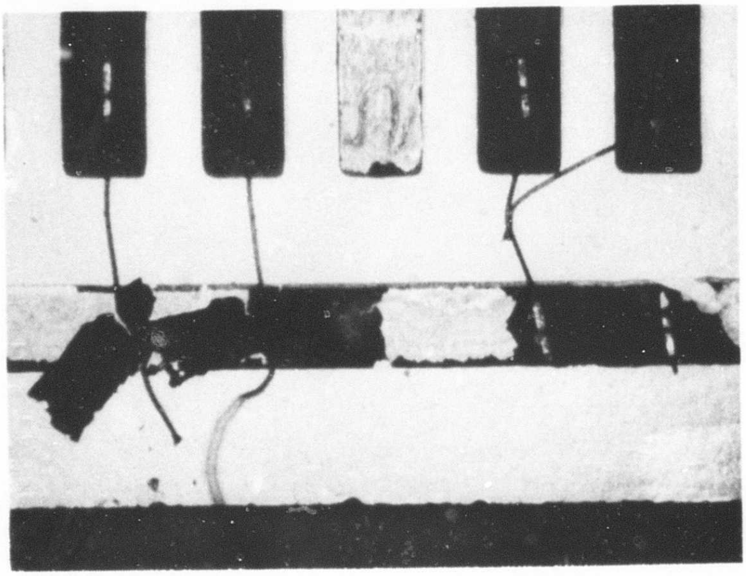
Microbond Type	Temperature °C 125	200	300	400	
E	9	7			
F	9	10 M			
G	7				
H	9	8			
$A'_1$0.001" wire	8	10 M			
$A''_1$0.001" Wire	10 M	10 M	9	8	
$A'_2$0.002" Wire	6	10 M			

KEY

○ Number Circled = Numbers of bonds remaining after 1000 hours

M = Bond Types For Which The Mean Time Between Failures $\geq$ 4330 Hours assuming Poisson Distribution and Using 90% one-sided Tolerance Figure lower limit

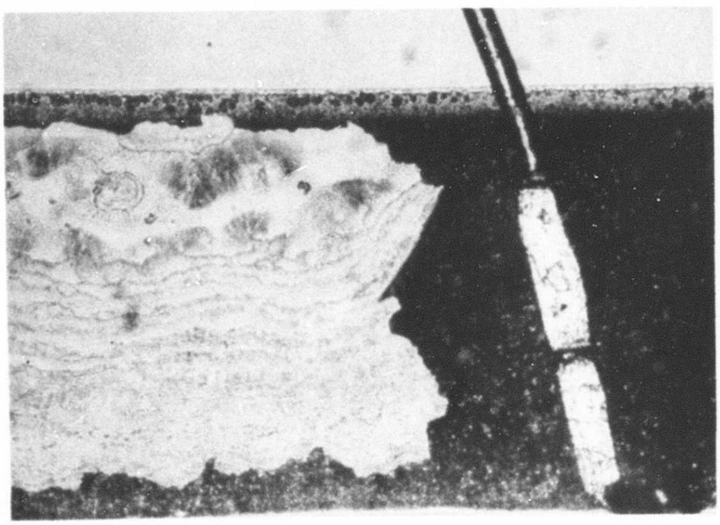
Calculation = .433 x 1000 x 10 bonds = 4330



0.001" Gold Wire on Gold/
Chromium over Oxidized Silicon

After 1000 hours at 500 °C

Magnification ~ 30X



Enlargement of Above
Subatrate Illustrating
Film-Substrate Separation
And Gold-Chromium Diffusion

Magnification ~ 128X
Scale → 0.1mm ←
→ ~.004" ←

Figure 54 Thermally Aged Type H Microbonds

Table V
Maximum Expected Number Of Bond Failures - Based on Poisson Sampling Plan (Distribution Free)
for 90% Confidence Level - Per Mil Std 19500D, Appendix C

Micro-bond Type	Wire	Film	Substrate	Sample Size	Number of bonds Below Failure Criteria*	Maximum Expected Number of Failures Per Thousand Bonds**
E	0.001" Gold	Au/Cr	Polished Vycor	783	6	15
F			Alumina	790	1	5
G			Glazed Alumina	789	7	15
H			Oxidized Silicon	776	0	3
K	0.001" Al.		Alumina	100	0	***
A'_1	0.001" Gold		Polished Sapphire	779	5	15
A'_2	0.002" Gold			783	12	30
A'_5	0.005" Gold			782	1	5
A''_1	0.001" Gold		Beryllia	785	6	15
A''_2	0.002" Gold			788	0	3
A''_5	0.005" Gold			782	0	3
B'_1	0.001" Al.		Polished Sapphire	100	0	***
B'_2	0.002" Al.			100	1	***
B''_2	0.002" Al		Beryllia	100	1	***

* Failure Criteria: Bond Strength $\geq$ 50% of mean pull strength

** Maximum expected Failure Rate Goal Per SCL 7746A, 3 bonds per Thousand

*** Failure rates will be calculated on the basis of normal statistics and reported at a later date.

Table VI
Microbond Failures Expressed As Percentage of Minimum Pull Strength Expected

Micro-bond Type	Wire	Film	Substrate	Pull Strength in Grams		Percentage of Minimum %
				50% of mean (Minimum Expected)	Failures	
A'_5	0.005" Gold	Au/Cr	Sapphire	79.5	25	31
A''_2	0.002" Gold	Au/Cr	Beryllia	12.5	None	—
A''_5	0.005" Gold	Au/Cr	Beryllia	70.5	None	—
K	0.001" Al.	Au/Cr	Alumina	3.4	None	—
B'_1	0.001" Al.	Au/Cr	Sapphire	4.6	None	—
B'_2	0.002" Al.	Au/Cr	Sapphire	15.8	7.5	47
B''_2	0.002" Al.	Au/Cr	Beryllia	8.7	8	92

All Gold Wire bonds have minimum sample size of 770

All Aluminum wire bonds have minimum size of 100

Table VII
Base Wire Strength vs Average Microbond Pull Strength

Microbond Type	Wire	Film	Substrate	Wire Strength (Grams)	Bond Strength (Grams)	% Bond Strength/ Wire Strength
E	0.001" Gold Bar 509	Au/Cr	Vycor	7.0	6.6	94
F	0.001" Gold Bar 509*	Au/Cr	Alumina	6.7	6.5	97
G	0.001" Gold Bar 509	Au/Cr	Glazed Alumina	7.0	6.3	90
H	0.001" Gold Bar 509*	Au/Cr	Oxidized Silicon	6.7	6.6	98
K	0.001" Si-Aluminum Spool 1-G-30	Au/Cr	Alumina	14.5	6.8	47
A'_1	0.001" Gold Bar 509*	Au/Cr	Sapphire	6.7	6.5	97
A'_2	0.002" Gold Bar 434	Au/Cr	Sapphire	26.5	24.6	93
A'_5	0.005" Gold Bar 434	Au/Cr	Sapphire	200	159	79
A''_1	0.001" Gold Bar 509*	Au/Cr	Beryllia	6.7	6.5	97
A''_2	0.002" Gold Bar 434	Au/Cr	Beryllia	26.5	25	94
A''_5	0.005" Gold Bar 434	Au/Cr	Beryllia	200	141	71
B'_1	0.001" Si-Aluminum Spool 1-G-30	Au/Cr	Sapphire	14.5	9.2	63
B'_2	0.002" Si-Aluminum Spool 1-J-13	Au/Cr	Sapphire	54.2	31.6	58
B''_2	0.002" Ai-Aluminum Spool 1-J-13	Au/Cr	Beryllia	54.2	17.4	32

* Wire Strength variation for Bar 509, 0.001" Gold due to Tensile Tester recalibration

Table VIII

Microbond Resistance Values

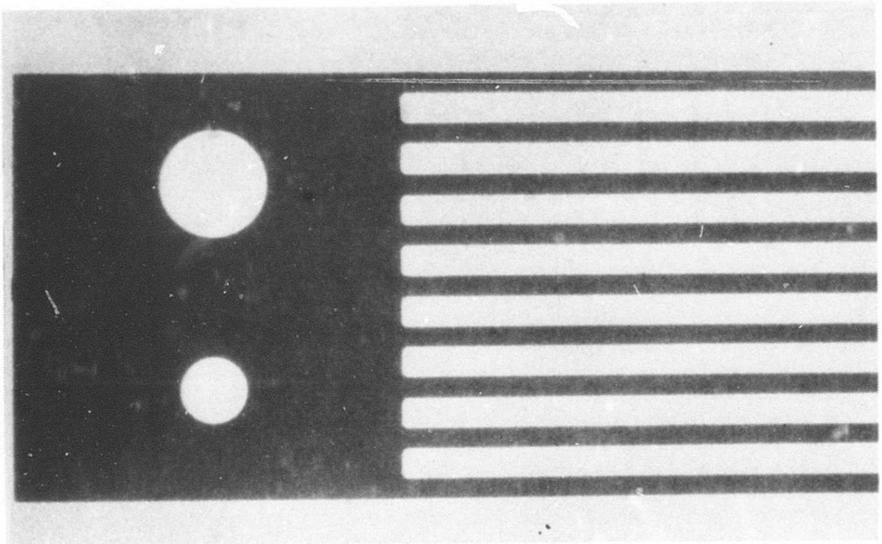
Microbond Type	Wire	Film	Substrate	Mean Value In Milliohms	Maximum Observed (Milliohms)	Maximum Allowable* (Milliohms)
E	0.001"Gold	Au/Cr	Vycor	1.2	1.5	~180
F			Alumina	1.1	1.7	
G			Glazed Alumina	1.1	1.5	
H			Oxidized Silicon	1.3	1.8	
K	0.001" Al.		Alumina	5.7	16	~ 240
A'_1	0.001"Gold	Au/Cr	Sapphire	.73	.9	~ 180
A'_2	0.002"Gold			.45	.5	~ 56
A'_5	0.005"Gold			.16	.18	~ 21
A''_1	0.001"Gold		Beryllia	1.5	2.7	~ 180
A''_2	0.002"Gold			.54	.75	~ 56
A''_5	0.005"Gold			.14	.18	~ 21
B'_1	0.001" Al.		Sapphire	1.1	2.0	~ 240
B'_2	0.002" Al.			.53	1.9	~ 75
B''_2	0.002" Al.		Beryllia	2.6	6.2	~ 75

* Maximum allowable = 150% of (F_s + W) where F_s = film sheet resistance in ohms/sq., (0.1 ohms/sq. max)
W = resistance of 0.1" of wire

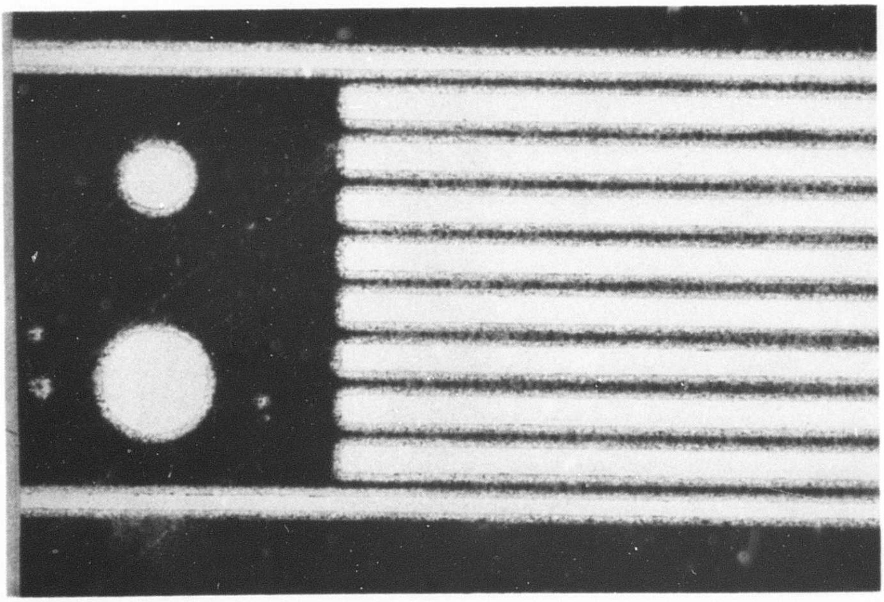
TABLE IX

BOND REQUIREMENTS FOR TASK II - STACK WELDING

Bond Type	Riser Wire	Riser Wire Size	Termination	Substrate
V	Gold-plated Nickel	0.002" x 0.010"	Ni/Au/Cr	Alumina (as-fired)
W	↓	↓	↓	Glazed Alumina
X	↓	↓	↓	Sapphire
Y	↓	↓	↓	Beryllia



Etched at Buckbee Mears



Etched at Hamilton Standard

Figure 55 Photoetched Gold Plated Nickel Riser Wire Matrix

Magnification ~ 570X
Scale: |←0.002"→|
Hamilton Standard

|←0.106"→|

Magnification ~ 285X
Scale 0.002" →| |←
Buckbee Mears
(b)

Figure 56 Cross-section Through Gold Plated Nickel Riser Wire with riser wires etched at Hamilton Standard, new nickel riser wires were ordered from the Buckbee Mears Company since they were able to obtain more uniform etching. The new riser wires also shown in Figures 55 and 56 will be used to complete this task.

The tensile strength distribution for the riser wires used to make the Type V microbonds is illustrated in Figure 57. The average strength is 760 grams.

4.5.1.2 Terminations

Although originally the terminations were electroplated nickel on gold/chromium films, it was decided to add a 50 microinch layer of electroplated gold over the nickel. This was done in order to eliminate any resistance variations due to nickel oxides.

4.5.2 Weld Schedule Development

Figure 58 illustrates the preliminary Type V microbonds made to gold/nickel/gold/chromium films on alumina substrates. These bonds were made at exploratory weld parameters as familiarity with the equipment and bond characteristics was gained. The welds shown in Figure 58 a and b were pulled in the 90° pull test. Due to the termination construction it was decided to use the more sensitive 90° pull test for the weld schedule development. However, since the ultimate pull strength of the 90° pull test was found to be the termination adhesion, it was decided to use the 0° or straight (weld in shear) pull test for the reliability data. This also eliminated bending of the nickel riser wire which tended to weaken the weld.

The weld profiles for the Type V Microbonds using half-hard temper nickel riser wires etched at Hamilton Standard are shown in Figure 59. The parameters chosen for the Hughes MCW/EL resistance welder to obtain optimum bond strength were:

Electrode Force	2 pounds
Pulse Width	20 msec
Pulse Voltage	0.55 volts
Electrodes	ESQ 1525-02-RWMA #2 (0.015" x 0.025")

This parameter setting is not the one which gave the highest pull strength on the weld profile, but was chosen since the electrode gap was slightly smaller and caused less wafer cracking. Control of the electrode spacing was only approximate.

4.5.3 Type V Microbonds - Gold-plated Nickel Riser Wires Welded to Gold/Nickel Gold/Chromium Films on As-fired Alumina Substrates

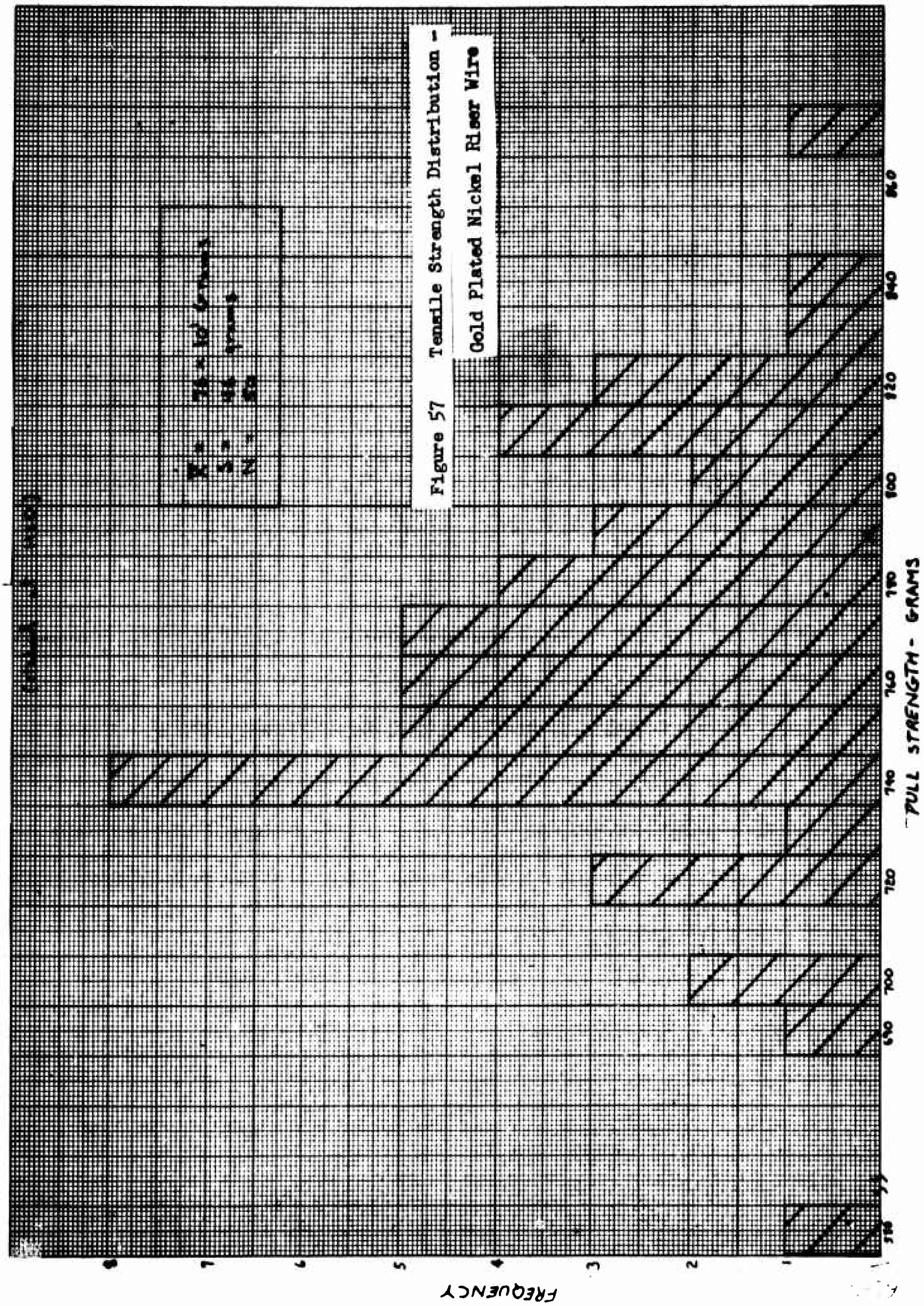


Figure 57 Tensile Strength Distribution - Gold Plated Nickel Riser Wire

This end to be pulled

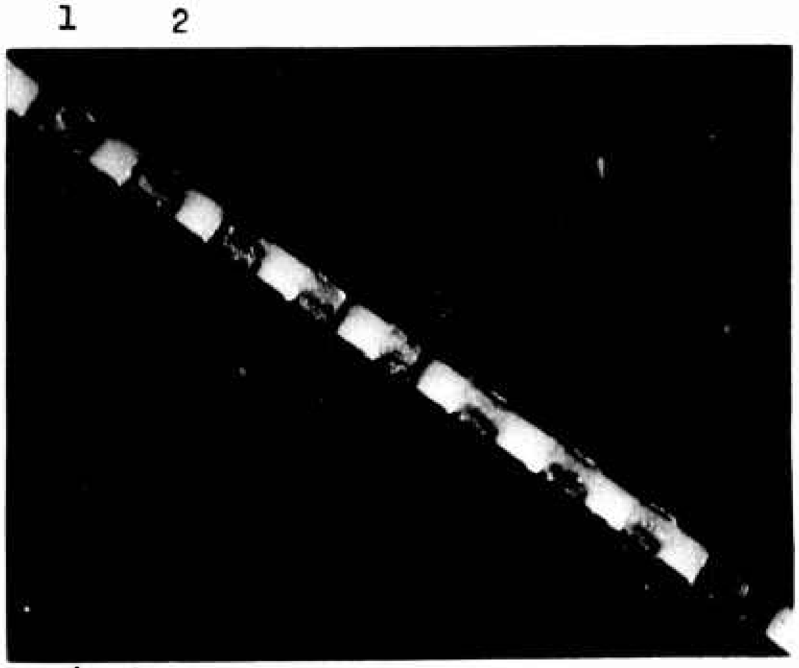
Welds Before 90 Peel Test
(a)

Gold Plated Nickel Riser Wire Welds to Ni/Au/Cr terminals

Scale: 8 mils

Riser Wire $\bar{x}$ = 765 grams
u = 16

Welds:
1 2



Pull Strength Grams

190 350 350 340 370 410 430 300 360

Grams

Welds after 90° Peel Test
(b)

Welds: 1 2

Magnification ~ 69X
(c)

Weld Schedule:
Electrodes: ESQ 1525-02
Gap: ~ 4 mils
Force: ~ 3 pounds
Pulse Duration: 10 msec
Weld Voltage: .4 volts

Figure 58 Typical Type V Microbonds

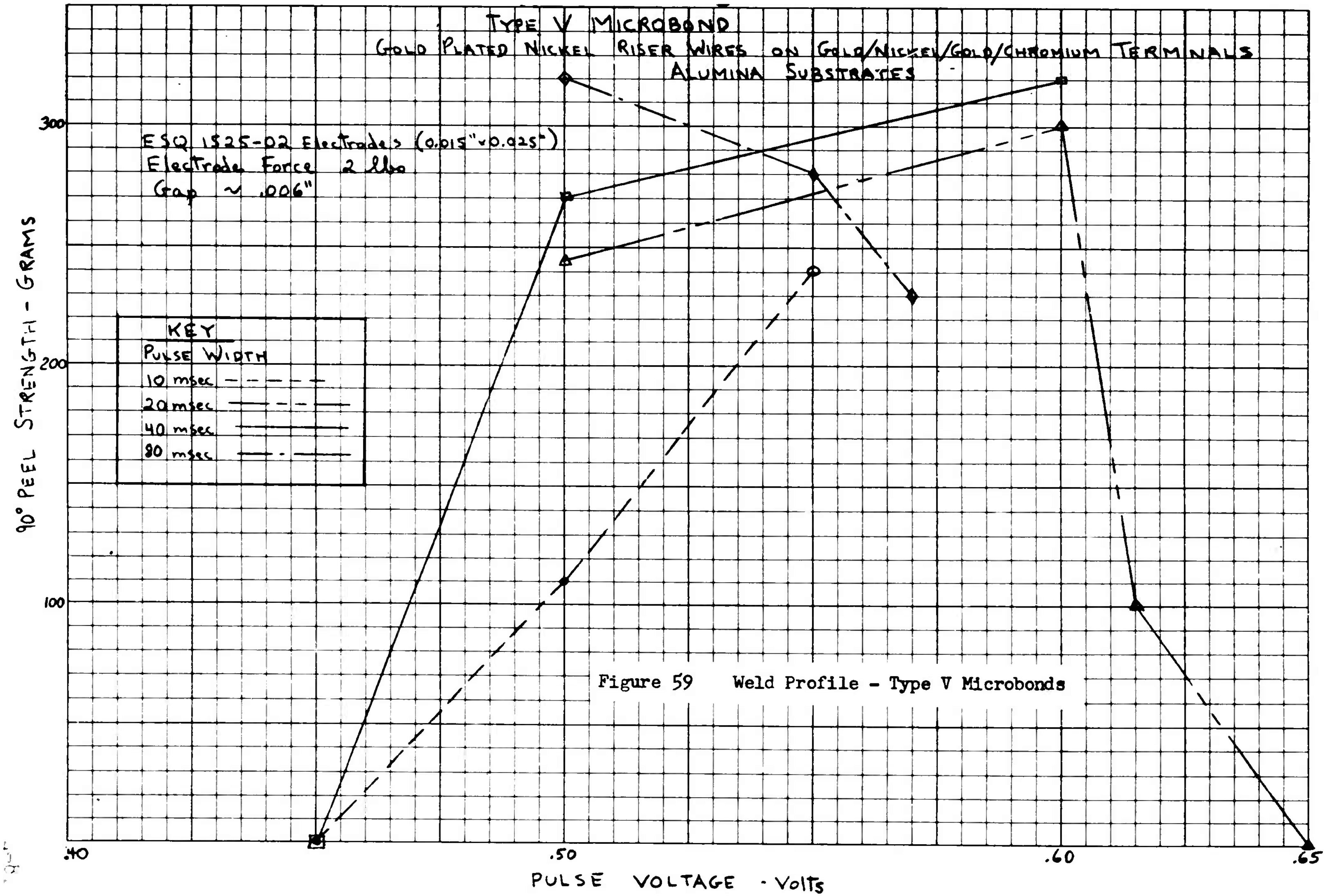


Figure 59 Weld Profile - Type V Microbonds

4.5.3.1 Evaluation of Mechanical Strength by Straight Shear Pull Test

Figure 60 shows the weldments made on an alumina wafer stack using the above weld schedule.

The pull strength distribution for 800 Type V microbonds is illustrated in Figure 61. The average pull strength was 727 grams, which is 96% of the riser wire tensile strength. There was one failure below 50% of the mean, which again was a film-to-substrate adhesion failure. The maximum number of expected failures at the 90% confidence level was 5 per thousand Type V microbonds.

4.5.4 Summary of Work on Task II

The Hughes MCW/EL system has been successfully used as an alternate method for stack welding substrates in the Hamilton Standard Microcircuit Module. Although even with more fixturing, the technique cannot compete on a time basis with the electron beam welding method, it could be used for prototype development.

The primary problems encountered in the development of the Task II microbonds were:

1. Precise positioning of the electrode over the weld area was difficult due to the use of manual positioning. It is expected that the employment of an X-Y stage will eliminate this problem.

2. The electrodes wear on the inside edge of each electrode and electrode dressing was required after approximately 25 microbonds.

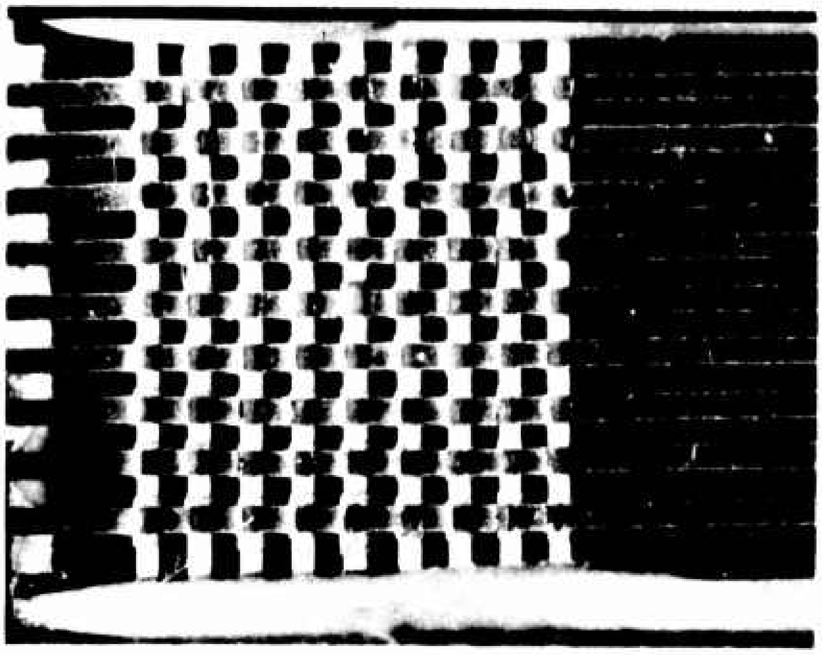
3. There was excessive substrate breakage during pull testing due to the nature of the pull test fixture and the high strength of the welds.

4.6 Task III - Flat Pack Welding

This task requires welding of flat-pack lead combinations to multilayer printed circuit board combinations with weldable external layers. The welds are to be pull tested and results discussed at the 60% confidence level which requires 300 welds of each combination. Three lead types will be welded to three multilayer board types for a total sample population of 2700 welds. The leads must meet the requirements of MIL-STD-1276A - Military Standard Weldable Leads for Electronic Component Parts.

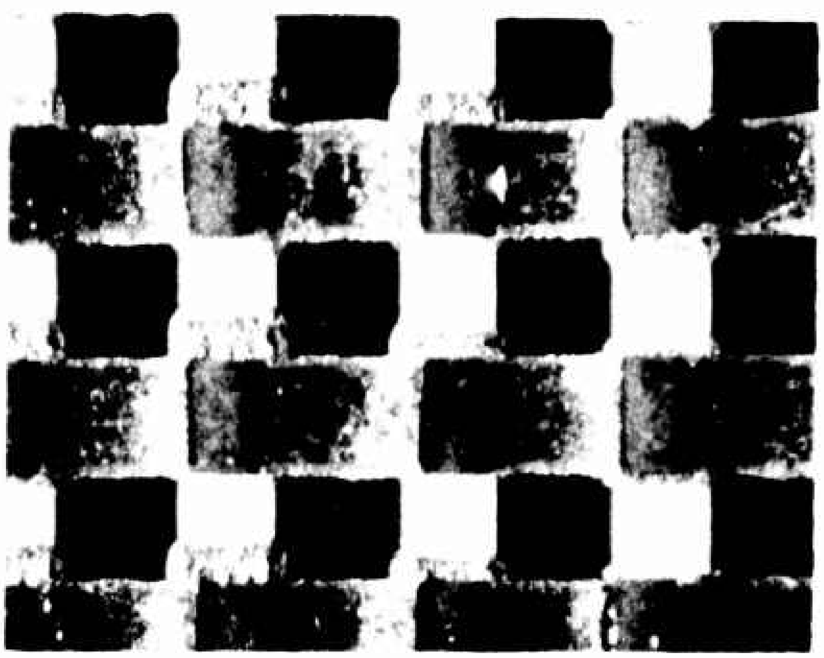
The work will be performed on the Hughes MCW/EL system which was designed for miniature printed circuit board welding. Use of this equipment for printed circuit boards has been extensively reported.[5,6]

(Parallel Gap Weldments)



Magnification ~ 10X

Welded Stack



Magnification ~ 42X

Figure 60 Resistance Welded Stack - Type V Microbonds

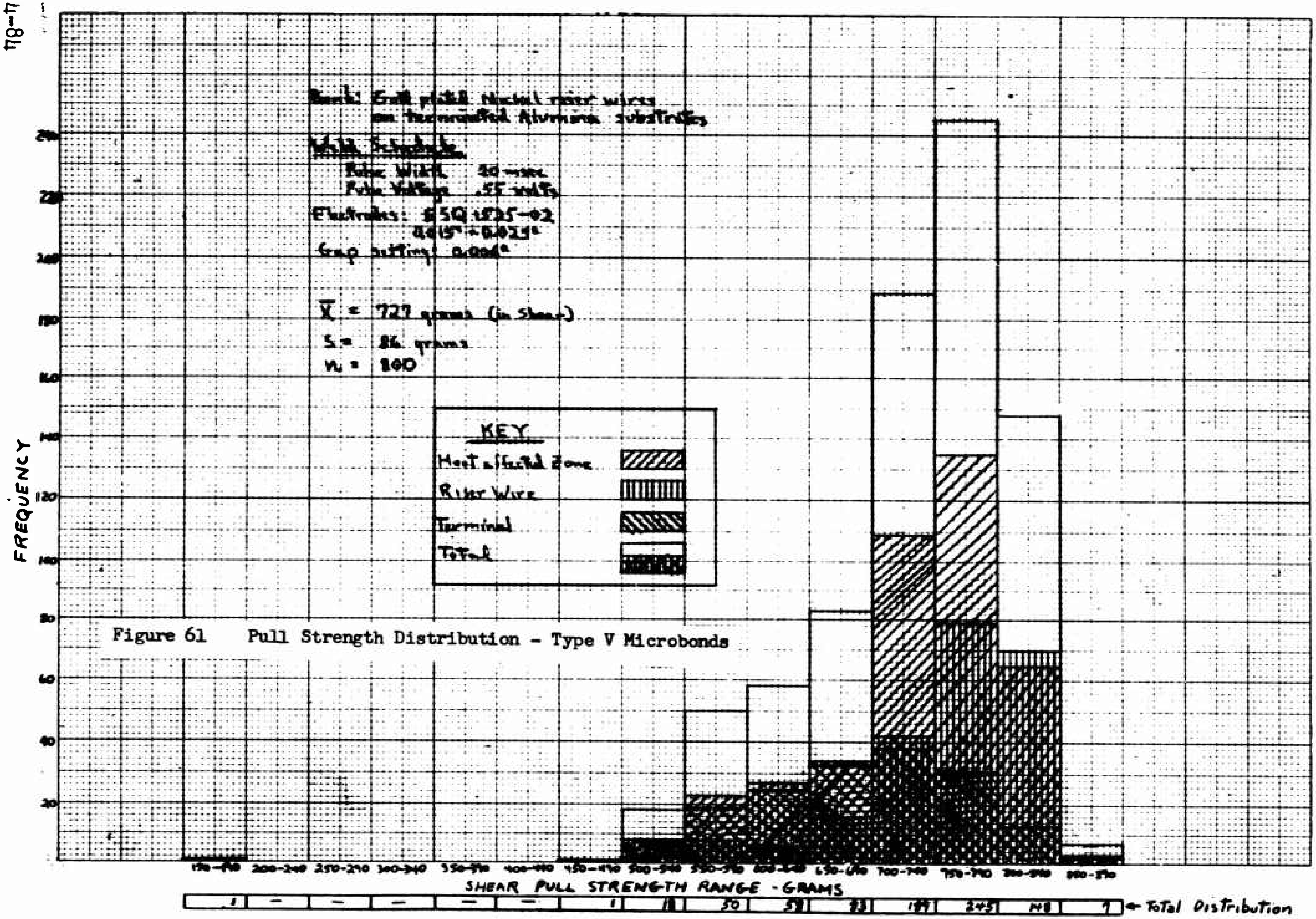


Figure 61 Pull Strength Distribution - Type V Microbonds

4.6.1 Multilayer Printed Circuit Boards

The multilayer printed circuit boards were ordered during the current quarterly period. In the interest of cost, the boards were ordered without plated-through holes. The boards will be composed of four conductor layers and G-10 laminates. The inner layers will be two ounce copper while the outer weldable layer will be:

1. Gold-plated nickel - 0.003 inch thick

2. Gold-plated - nickel-plated copper - 0.001 inch nickel plate on 2 ounce copper

3. Gold-plated ALNIFER (Texas Instruments laminate)

All layers will be photoetched to the pattern shown in Figure 62, aligned and laminated.

4.6.2 Flat-Packs

Flat-packs of the two combinations with kovar leads were illustrated in Quarterly Report No. 6 (1) The lead frames made of nickel (the third lead type) were supplied by the Coors Porcelain Company and are illustrated in Figure 63. Cross-sections of the three lead types are shown in Figure 64. The cross-sectional dimensions of the three lead types are approximately:

Type	Width (Inches)	Thickness (Inches)	Material
Coors	0.012	0.0045	Nickel
General Electric	0.012	0.004	Kovar
Philco	0.017	0.005	Kovar

The nickel lead frames have a tapered cross-section resulting in non-uniform area. This will possibly result in a large standard deviation when the pull strength distribution is evaluated.

4.6.3 Summary of Work on Task III

The printed circuit boards should be received during the next report period. Completion of the flat-pack welding will follow Task II, which also requires use of the Hughes Microwelder.

4.7 Task IV Flip-Chip Bonding

This task calls for the development and evaluation of flip-chip bonding

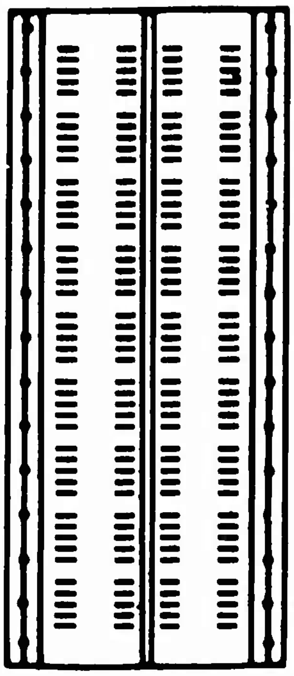


Figure 62 Multilayer Printed Circuit Board Pattern

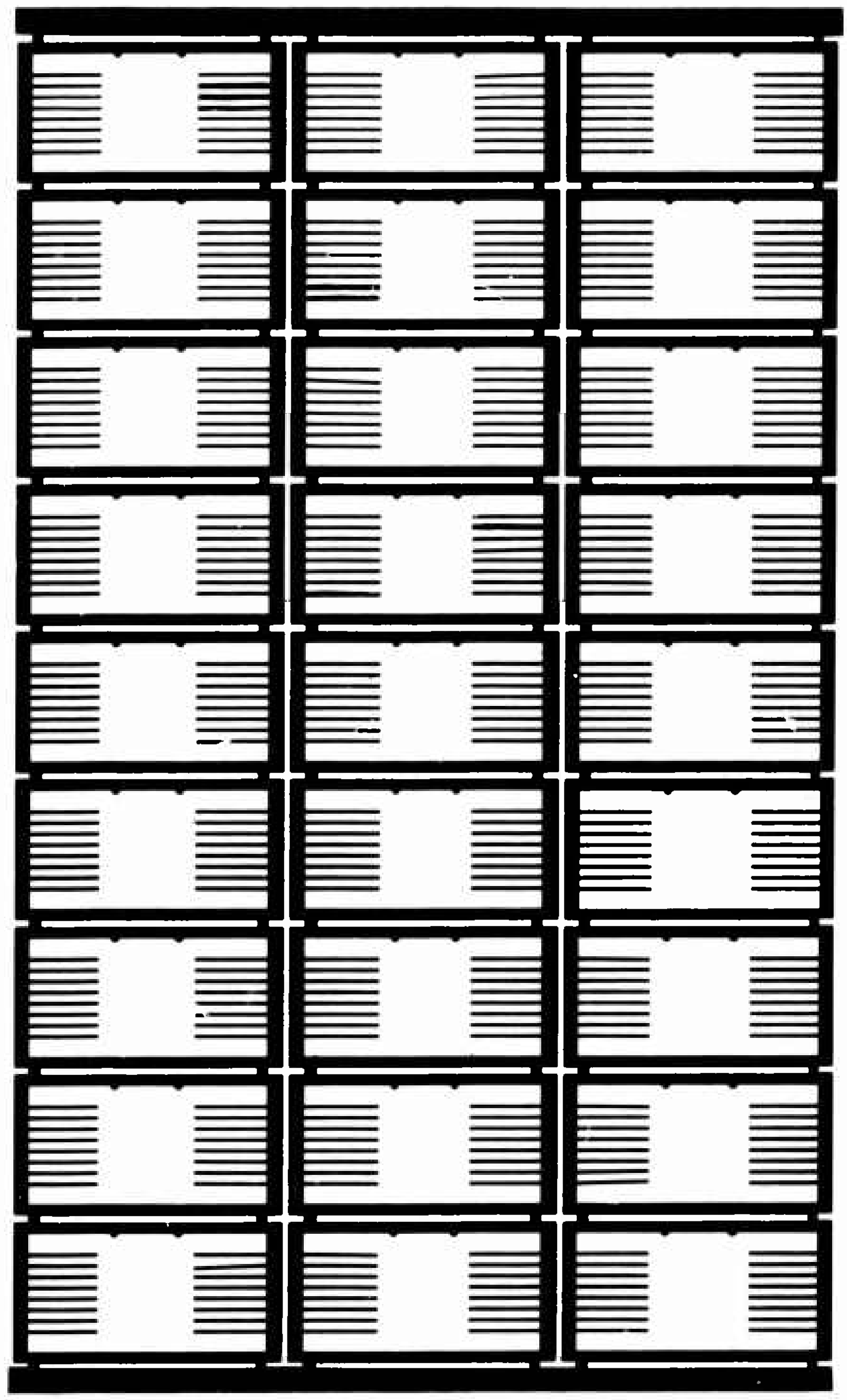
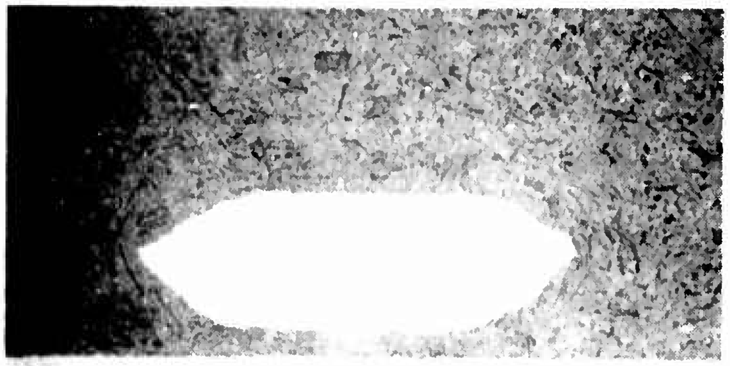


Figure 63 Nickel Lead Frames



Coors - Lead, Gold Plated Nickel
Magnification ~ 128X
Scale 0.1mm ~.004"

GE - Lead, Gold Plated Kovar
Magnification ~ 128X

Philco - Lead, Gold Plated Kovar
Magnification ~ 128X

Figure 64 Cross-sections of Flat-Pack Leads techniques using devices equivalent to the 2N706 transistor. Electrical and mechanical testing will be carried out at the 70% confidence level. Arrangements have been made with the Hughes Microelectronics Division to have a sufficient quantity of Hughes GAT 1002-1 transistors ultrasonically bonded to gold/copper chromium films on alumina substrates. Figure 65 illustrates a typical substrate pattern with five flip-chips ultrasonically bonded.

4.7.1 Mechanical Testing

Evaluation of the mechanical strength will be a shear test as shown in Figure 66. The test gauge is a dynamometer with a range of 15 to 150 grams.

4.7.2 Summary of Work on Task IV

Ultrasonically bonded flip-chips have been ordered from the Hughes Microelectronics Division. These devices should be received during the next report period and the testing will be completed.

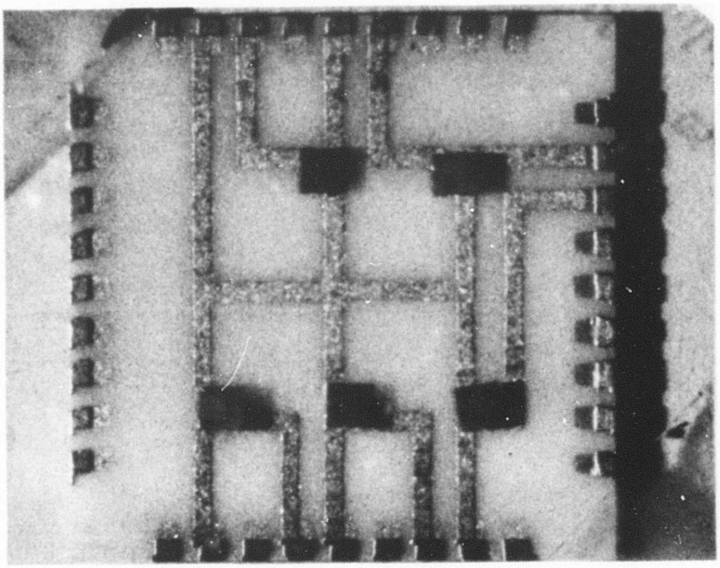
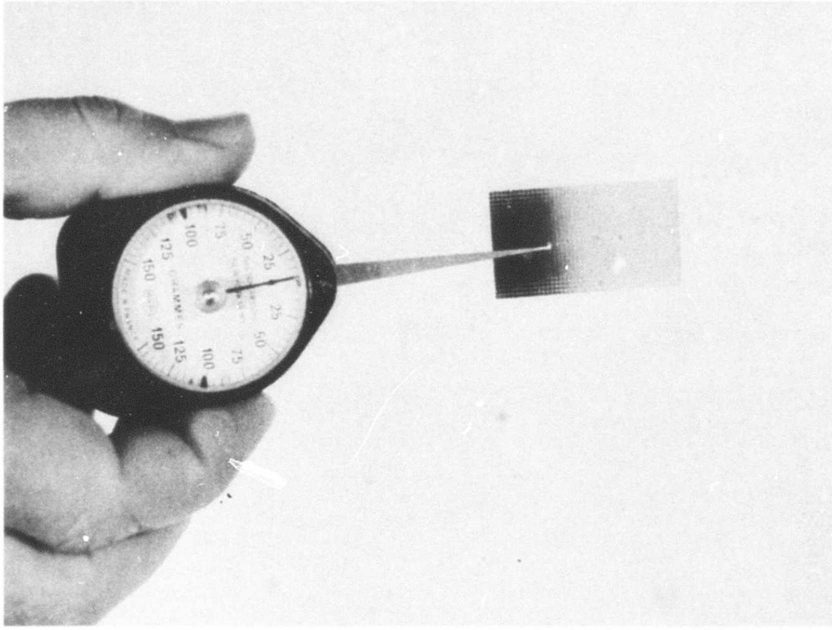


Figure 65 Ultrasonically Bonded Flip-Chip Transistors



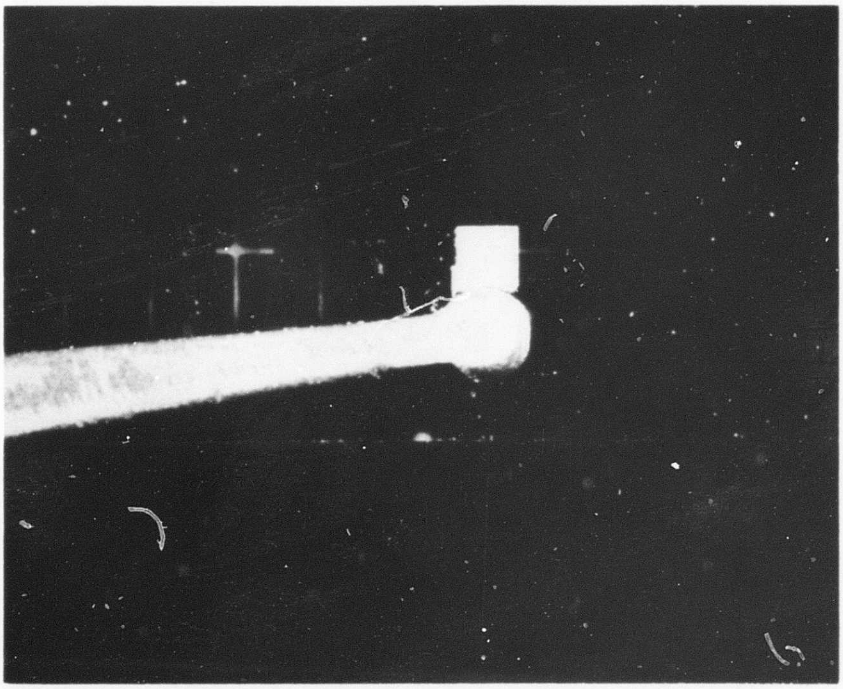


Figure 66 Dynamometer for Shear Testing Flip-Chip Bonds

5.0 CONCLUSIONS

The investigation of Task I and Task IA microbonds for gold-gold and aluminum-gold type bonds was continued during the 8th Quarter. Types A'$_5$, A"$_2$ and A"$_5$ microbonds were completed to complete bond types formed with the split tip resistance welder. Also completed in this Quarter were the Types K, B'$_1$, B'$_2$ and B"$_2$ microbonds which are aluminum wire ultrasonically bonded to gold/chromium films on various substrates.

At this time, the Type H, Type A"$_2$ and Type A"$_5$ microbonds have met the reliability goal of a maximum expected number of failures of three bonds per thousand at the 90% confidence level. However, over 90% of the failures of other bond types have been film-to-substrate adhesion failures. The aluminum wire bonds have not yet been analyzed for failure expectation.

Thermal aging studies of bond Types E, F, G, H, A'$_1$, A'$_2$ and A"$_2$ have shown that the reliability goal that no bond type increase in resistance by more than 10% following 1000-hour bakeout was met for all bond types at 125° C, and for all but Type G at 200° C. This is significant from the standpoint of practical storage and operating device temperatures in use today.

Type V microbonds of gold-plated nickel riser wires to gold/nickel/gold/chromium films on alumina substrates were completed. The work showed that resistance welding could be used as an alternate method to fabricate MicroCircuit Module stacks and that the maximum number of expected failures is 5 per thousand Type V microbonds.

Little work was done on the flat-pack welding and flip-chip bonding tasks since the necessary materials have not yet been received.

6.0 REFERENCES

1. P. R. Amlinger and S. L. Sherman, "Microbonds for Hybrid Microcircuits", 6th Quarterly Report, Contract No. DA-36-039 AMC-03742(E), Hamilton Standard Division, United Aircraft Corporation, 1 May 1965 to 31 July, 1965.

2. P. R. Amlinger and S. L. Sherman, "Microcircuits for Hybrid Microcircuits", 7th Quarterly Report, Contract No. DA 36-039-AMC-03742(E), Hamilton Standard Division, United Aircraft Corporation, 1 August 1965 to 31 October 1965.

3. P. R. Amlinger and S. Rogers, "Microbonds for Hybrid Microcircuits," 5th Quarterly Report, Contract No. DA 36-039 AMC-03742(E), Hamilton Standard Division, United Aircraft Corporation, 1 February 1965 to 30 April 1965.

4. A. J. Avila and G. E. Klienedler,"Lead Attachment to Thin Film Circuits", Advances in Electronic Circuit Packaging, Vol. 6

5. W. H. Hill "Parallel Gap Welding Kovar Leads to Copper P. C. Boards ", Hughes Welding Notes, Bulletin #106

6. G. A. Dreyer, "Environmental Testing of Kovar-to-Copper and Kovar-to-Nickel Parallel Gap Weldments," Hughes Report No. Rs-333

7.0 PLANS FOR NEXT QUARTER

It is expected that all work on Task I and Task IA, including thermal shock, thermal aging, resistance measurements and pull strength measurements will be completed during the next Quarter.

The stack welding task is scheduled to be completed, followed by completion of the flat-pack welding task. These tasks cannot be done simulteneously since the same welding equipment is required for both tasks.

The flip-chip bonding evaluation will be initiated upon receipt of the bonded flip-chips and this should also be completed during the 9th Quarter.

At the end of the 9th Quarter, a Final Report on this Program and a Weld Handbook which includes a summary of the knowledge and experience gained in this work will be written and published.

8.0 IDENTIFICATION AND QUALIFICATION OF KEY PERSONNEL

Name	Title	Assignment
A. R. Riben	Program Manager	50%
P. R. Amlinger	Program Manager	Part Time
S. L. Sherman	Project Engineer	Full Time

The resume of A. R. Riben is contained on the following page.

Arthur R. Riben
Program Manager

Dr. Riben joined the Electronics Department in February 1965. Since that time he has been responsible for development and correlation of the laser induced modulation of infra-red radiation in silicon as applied to minority carrier life-time, and in the correlation of lead and header bonding integrity to birefringence effects in silicon. He was also partially responsible for the development of a multilayer ceramic circuit board for the interconnection of functional electronic blocks and MicroCircuit Modules. In addition, he has acted as part-time consultant on development techniques used on the Hamilton Standard MicroCircuit Module.

Prior to this, Dr. Riben completed the requirements for the Ph.D degree in Electrical Engineering at the Carnegie Institute of Technology. His thesis subject was "nGa-PGaAs Heterojunctions", and involved the fabrication and evaluation of semiconductor heterojunction devices. Dr. Riben also received a B. S. in Electrical Engineering from the University of Connecticut and a M. S. in Electrical Engineering from the Carnegie Institute of Technology.

He is a member of Tau Beta Pi, Eta Kappa Nu, Sigma Pi Sigma, Phi Kappa Phi and Sigma Xi honor societies.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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3. REPORT TITLE

Microbonds for Hybrid Microcircuits

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5. AUTHOR(S) (Last name, first name, initial)

Riben, A.R., and Sherman, S.L.

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10. AVAILABILITY/LIMITATION NOTICES

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U.S. Army Electronics Command Fort Monmouth, New Jersey (AMSEL-KL-IB)

13. ABSTRACT

The overall objective of this program is the development of reliable high yield processes for bonding fine wires of gold and aluminum to gold-chromium and aluminum films on various substrates such as alumina, sapphire, and oxidized silicon. Furthermore, techniques are to be developed and evaluated for fabricating MCM stacks and joining standard flat-packs to multilayer circuit boards by means of resistance welding and for ultrasonic bonding of flip-chip transistors to gold-chromium films on as-fired alumina.

During this quarter, the mechanical strengths of Type K (0.001 inch Al wire ultrasonically bonded to Au/Cr films on as-fired alumina), Type A' (0.005 inch Au wire resistance welded to Au/Cr films on sapphire, Type A_2'' (0.002 inch Au wire resistance welded to Au/Cr films on beryllia), Type A_5'' (0.005 inch wire resistance welded to Au/Cr films on beryllia), Type B_1' (0.001 inch Al wire ultrasonically bonded to Au/Cr films on sapphire), Type B_2' (0.002 inch Al wire ultrasonically bonded to Au/Cr films on sapphire), and Type B_2'' (0.002 inch Al wire ultrasonically bonded to Au/Cr films on beryllia) were evaluated. The reliability goal of an expected failure of no more than 3 bonds per thousand at the 90% confidence level was met for the Types A_2'' and A_5'' microbonds.

Electrical resistance measurements have shown that all bonds completed to date met the contractual goal of SCL-7746A. Thermal aging tests indicated that bond Types E, F, G, H, A_1', A_2', and A_1'' all met the contractual goal for a temperature of 125°C, and all but Type G met the goal of 200°C. (Please see attached sheet.)

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8.0 IDENTIFICATION AND QUALIFICATION OF KEY PERSONNEL

Name	Title	Assignment
A. R. Riben	Program Manager	50%
P. R. Amlinger	Program Manager	Part Time
S. L. Sherman	Project Engineer	Full Time

The resume of A. R. Riben is contained on the following page.

ABSTRACT (Cont'd)

Type V stack welded microbonds were completed and the maximum number of expected bond failures was 5 per thousand, The Type V average pull strength was 96% of the nickel riser wire tensile strength.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Microbonds						
Split-Tip Resistance Welder						
Substrates						
Thin Films						
Hybrid Microcircuits						
Pull Tests						
Mechanical Joint Strength						
Flip-Chip Bonding						
Micro-Circuit Modules						
Flat-Pack Welding						
Weldable Multilayer Printed Wiring						
Parallel Gap Welding						
Ultrasonic Bonding						
Microwafer Stack Welding						

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