DEVELOPMENT OF AUTOMATIC QUALITY CONTROL FOR RESISTANCE WELDS IN ALUMINUM ALLOYS

Phase I

A Study of the Change in Weld Zone Resistance in Spot Welding Aluminum Alloys

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PHILADELPHIA 32, PA.

PROJECT NO. OMS No. 5010.11.84300.51
(Formerly 5010.11.80800.51)

TITLE

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Resistance in Spot Welding Aluminum
Alloys

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Contract No.

DA 36-034-ORD 3217 RD

DATE February 20, 1962

A STUDY OF THE CHANGE IN WELD ZONE
RESISTANCE IN SPOT WELDING ALUMINUM ALLOYS

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ABSTRACT

The study of resistance spot welding of several commercial aluminum alloys using three phase power supply has shown a correlation between the weld zone resistances and the weld nugget development.

A three phase frequency converter spot welding machine with pulse counting timing was used for this study.

Spot weld tests on 0.020" 2024, 2014, 7075, 5052, and 0.025" 5086, and 0.050" 2024, 2014, 7075, 5086, and 5456 alloys with recognized welding schedules were made to study the resistance-time characteristics of each material. These tests were used to determine what signals should be measured to provide an accurate picture of weld development. The electrode tip voltage and weld current were selected and measured for each weld.

Weld tests showed the weld nugget was formed after one or two pulses of weld current. This was a desirable reference point. Also, the weld zone resistance-time graphs showed the resistances decreased continuously during weld time.

The effect of welding variables on the weld zone resistance and weld size was the main objective of this

study. The effect of weld current on the weld zone resistance was toward lower weld zone resistances as the weld current was increased for a given welding schedule. The increasing current, producing an increasing weld size correlated with an increasing percent change in weld zone resistance. The latter was calculated from the reference resistance (R_o) and the final resistance (R_f), excluding the initial contact resistance due to considerable inconsistency. The weld current produced the greatest reduction in the reference resistance (R_o) but reduced the final resistance (R_f) too.

The increasing electrode forces produced a similar effect on the weld zone resistances as the weld current, however, the magnitude of the changes were not as large.

The weld time affected the final resistance (R_f) to a greater extent than the reference resistance (R_o) for a given weld schedule. The longer weld times produced a lower final resistance.

The correlation of weld zone resistance changes with weld size or strength were less predictable in the 0.020" gage than in the 0.050" gage. The 5086 and 5456 alloys were more predictable in the resistance change vs. weld size than were the heat treatable alloys, 2024, 2014, and 7075.

Electrode tip shape produced a decreasing weld zone resistance with time for increasing tip radius and a given welding schedule. The resistance-time graphs showed a lesser magnitude of the instantaneous resistance with increasing radius for a given weld schedule.

Resistance spot welding of dissimilar alloys and gages indicated the weld zone resistances were more characteristic of the resistance-time graphs for the thinner material.

DEVELOPMENT OF AUTOMATIC QUALITY CONTROL
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INTRODUCTION

This contract, DA 36-034-ORD 3217 RD for Frankford Arsenal, Philadelphia, Pennsylvania was undertaken to determine the feasibility of using a weld zone feedback signal to control the weld development. Phase I of three phases of this contract was a study of the weld zone resistance during the resistance spot welding of several aluminum alloys in 0.020" and 0.050" gages.

The specific parts of Phase I are as follows:

Part I

An investigation of the welding of aluminum alloys according to recommended practices. The recommended practices were derived from current literature and the best combinations of machine settings were selected. The weld zone resistance will be measured for each weld made with these conditions.

Part II

The relationship of the weld zone resistance to weld strergth will be determined by the study of the following welding variaoles:

Section A

Effect of current magnitude and time on the relationship of weld zone resistance to weld strength.

Section B

Effect of electrode force on the relationship of weld zone resistance to weld strength.

Section C

Effect of electrode material, shape, and surface condition on the relationship of the weld zone resistance to weld strength.

Section D

The effect of dissimilar thickness and dissimilar materials on the weld zone resistance when welded with conditions for the thinner member of the pileup.

MATERIALS

The materials to be evaluated are shown in Table I with typical chemical analyses and mechanical properties of these materials.

CHEMICAL CLEANING

All materials were prepared for chemical cleaning by deburring the test coupons and degreasing with trichlorethane.

Figure 1 shows the chemical cleaning facilities. A metal rack with a 1" diameter spring served as a holder for the coupons during cleaning. Each alloy was immersed in an alkaline cleaner (Clepo 86P) at 165°F for 5 minutes. The rack was transferred to a rinse tank of cold running water. The rack was then transferred to a deoxidizer (Clepo 180S) at room temperature. Immersion times in the deoxidizer varied for each material to produce acceptable contact resistances.

A contact resistance of less than 150 microhms was permissible, however, resistance values around 50 microhms were more desirable and more easily maintained throughout the program. Figure 1A shows the instrumentation for checking the surface resistance. No attempts were made to evaluate welding conditions using aluminum alloys which were not chemically cleaned prior to welding.

The resistances shown in Table II indicate a range of surface resistances was common for a specific material.

Some of the alloys, especially 2024 and 7075 were more difficult to clean consistently as noted by the high and low values. An average surface resistance is shown for each alloy in Table II.

EQUIPMENT

The resistance spot welding tests were made on a 90 KVA three phase frequency converter machine using a pulse counting timing control. A dual force system for forge was available. The forging force and forge delay were used in Part I of the evaluation of recommended welding conditions.

Three signals, namely; the current, electrode tip voltage, and the electrode force were obtained from the welding machine. Figure 2 shows the welding machine and signal pickup leads.

All electrical signals representing weld current, weld zone voltages and electrode force were recorded on photographic paper by a 7 channel Westinghouse Type PA, Oscillograph. The galvanometers used had a frequency response of 1500-6000 cycles per second. The film speeds were as high as 300 inches per minute. The combination of high response of the galvanometer and fast film travel speed made it possible to produce accurate recordings of the electrical data.

A calibrated shunt as a section of the upper arm of the welding machine and a bucking coil were used to measure the weld current. Figure 3 shows the arrangement of the shunt and coil with leads. Appendix A shows the calibration of the shunt and method of calculating the current.

Another method of measuring secondary current was evaluated. This method did not give as satisfactory results as the calibrated shunt. This second method employed a pickup coil placed in the secondary loop of the welding machine. Since the induced voltage of a coil is the first differential of the welding current, it was necessary to integrate the output signal. The circuit evaluated did not produce a satisfactory current signal, hence it was agreed to use the more positive shunt and bucking coil technique throughout the program.

Calculation of the secondary weld current is given in Appendix A. Standard signals of 10 to 70 millivolts produced deflections of 0.16 to 1.07 inches. The average deflection factor was calculated as 64.9 millivolts per inch. By Ohm's Law ($I = \frac{E}{R}$) where R is the shunt resistance (Appendix A) and E is the volts/in., the calibration of the current trace was calculated to be 42.5 kiloamps per inch deflection.

The voltage across the electrodes was recorded for the purpose of calculating the weld zone resistance, therefore, this voltage signal must represent the true resistive voltage of the weld zone. . he lead wires from the electrodes to the oscillograph must pass through the strong magnetic field of the secondary circuit. If special precautions are not taken, there will be induced in these lead wires a voltage signal higher than the electrode voltage to be measured. Such an induced voltage is eliminated by twisting the leads together and placing them perpendicular to the axis of the electrodes as shown in Figure 4A. This arrangement produces an electrode voltage signal which is in-phase with the current signal and therefore, a purely resistive voltage.

Appendix B, galvanometer No. 6, gives the calibration of the tip voltage signal. A known signal of one volt DC on this galvanometer produced a deflection of 1.70 inches, therefore, the calibration factor "v" equals 0.59 volts per inch deflection.

The third signal, the electrode force, was obtained as the net result of the output of four strain gages mounted on a compression ring attached to a bar between the lower arm and the base of the machine (see Figure 2). The bar was preloaded in tension by adjusting the turnbuckle. Electrode forces were calibrated by applying several loads and measuring the deflection of the light beam galvanometer connected through a strain gage amplifier. Appendix B, galvanometer 3, gives the calibration loads and multiplication factors for the electrode forces. Since the 3000 ohm series resistance gave a deflection factor which covered the range of forces used, this factor was used throughout the program.

The primary or line currents were recorded to provide a record of the load balance on the three phase supply system. A current transformer was applied to each line (L_1, L_2, and L_3) leading to the three sets of ignitrons. A load resistor across the secondary of the current transformer provided a voltage signal which was recorded on the oscillograph Normally all three line currents were recorded. Later in the program it was established that the welding machine had consistently balanced firing, therefore, only one primary line current was recorded.

In Part I of the program the voltage across the inside or faying surfaces of the work pieces was recorded. This voltage signal was used to calculate the weld zone resistance without the influence of the electrode to work contact resistance and the base metal resistance. Figure 4A shows the method for measuring this faying surface voltage drop using snap-on contacts and flanged test specimens. Appendix B, galvanometer 5, gives the calibration data and the deflection factors for calculating the "inside surface voltage". For this galvanometer the deflection factor was 1.25 volts per inch.

WELD ZONE RESISTANCE MEASUREMENTS

A review of the welding literature was made to determine what work has been published on weld zone resistance measurements. Several authors have reported tests for the measurement of weld zone resistances for ferrous alloys[1,2] and specifically for aluminum alloys[5]. Each found a change in resistance occurred during the weld nugget development. The weld zone resistance studies for three phase spot welding of aluminum were quite limited and pertained to specific alloys and thickness of material.

Additional information was obtained from the literature survey pertaining to welding schedules and weld properties for several aluminum alloys and gages. The data compiled from this survey were helpful in selecting the recommended welding conditions reported in Part I of this investigation (Table IX).

A complete bibliography is included as part of this report.

SELECTION OF WELD ZONE SIGNALS

The study of the weld zone resistance change in aluminum spot welding was accomplished by oscillographic recording of the weld current and voltage drops at the weld zone. Several methods of obtaining the voltage across the weld were considered. The total resistive voltage between the electrodes and the welding current provide a means of calculating the weld zone resistance ($R = \frac{E}{I}$). This electrode voltage is a summation of seven voltages representing the seven series resistances. These resistances are shown schematically in Figure 4B. The resistances are: the electrode (2), the electrode to work surface contact (2), the base metal resistance (2), and the metal interface contact (1). It was the latter resistance which was required for evaluation of the weld nugget development. Voltage signals for calculating these several resistances were taken from across the inside surfaces, across the outer surfaces (interface plus metal resistance), and across the electrodes as shown in Figure 4C. With the multipoint adapter, it was possible to record three zone voltages during the making of a weld.

Resistances were calculated from these voltages and the secondary current recordings as shown in Appendix C.

INSTANTANEOUS WELD ZONE RESISTANCE

An analysis of the weld zone resistance for a standard welding schedule was made by considering the instantaneous weld zone resistances for 0.020" and 0.050" aluminum alloys. Although the weld zone resistance appeared to decrease continuously, it was necessary to know if any discontinuities in the weld zone resistance occurred during the time of each current pulse. It was for this reason, the instantaneous weld zone resistances were calculated.

The oscillographic traces of weld current and voltages were divided into 2/3 millisecond (.00066 sec.) intervals to provide an instantaneous measurement of the electrode tip to tip voltage drop (v) and the inside surface to inside surface voltage drop (v_1). These quantities were required for calculating the true instantaneous weld zone resistance. Figures 5, 6, and 7 show the plot of these calculated resistance values for 0.020" 2024T3, 0.050" 2024T3, and 0.050" 5086H34 respectively. Tables III, IV, and V show the test data for Figures 5, 6, and 7.

During each current pulse, particularly the first few, the resistances show considerable excursion from a high to a minimum and back to a high resistance. This is due to the effects of the initial cold contact resistance and resistance changed due to thermal effects. Each successive pulse diminishes the effect of the cold contact and the excursions are reduced considerably. Examination of the surfaces after successive pulses show the effective contact surface is progressively larger and smoother until fusion occurs.

A locus of points representing the apices of the resistance curves for each pulse follow the same general trend as the overall resistance curve. These points are the resistances calculated from measurements of voltage and current at the peaks of the weld current pulses. The resistance trend of the inside surface, which represents the resistance of the weld nugget, follows the same trend as the total weld zone resistance represented by the electrode to electrode measurements.

The resistance curves for the 2024T3 aluminum alloys show a similar decreasing resistance between the 0.020" and 0.050" thickness. The shape of the resistance curves for 0.050" 5086H34 are similar to the 0.050" 2024T3. Although the respective resistance curves, tip to tip and inside to inside surfaces, are not the same in magnitude, the overall trends of each curve are similar. The similarity of the two curves permit a selection of one location at the weld for the signal to be recorded. This reduced the voluminous data to be analyzed to only one source for the weld zone signal.

The effects of the cold worked material, such as the 5086H34, on the surface resistance is indicated by the differences in detail of the resistance curves between 5086 and 2024, the latt r being a heat treated material. Usually, the cold worked material produces a lower surface contact resistance than a heat treated and pickled surface. There are differences in the specific resistivity of materials also.

THE ANALYSIS OF WELD ZONE RESISTANCE

The basis for further studies of the change in weld zone resistance must consider the following items:

1. The trend of the weld zone resistance at the interface must be similar to the trend of resistance as measured across the electrode tips.
2. The measurements of the resistance must be made at the peaks of the current pulses to eliminate any induced voltage component, which will affect the calculated resistance values.
3. The selection of the reference resistance must be a common point for each weld. The preferable resistance value would be that which is measured at the start of fusion. This reference resistance permits the determination of percent change in weld zone resistance with weld development.

Conditions for Item 1 have been satisfactorily demonstrated by the resistance curves of Figures 5, 6, and 7. Item 2 above assures the truest weld zone resistance since no induced voltage components are introduced at this point of the current wave. Specifically, an induced voltage in addition to the electrode tip voltage would produce an erroneous resistance measurement.

Item 3 above was somewhat more difficult to determine precisely. The ability to observe the growth of a spot weld using unidirectional welding current has certain limitations since the termination of welding current can only be in intervals of three pulses. In the development of a spot weld, a mass of metal is heated nearly continuously until that mass has been raised to the melting temperature plus the latent heat of fusion.

It is difficult to produce small amounts of fusion consistently, hence welds are made with increasing pulses (1, 2, 3, 6, 9, etc.) of unidirectional three phase current. Suddenly a weld nugget is produced after an accumulation of sufficient heat is present. Increasing the weld time beyond this minimum time causes the weld nugget to grow until a desired size is reached.

A series of photomacrographs of resistance spot welds are shown for 1, 2, 3, 6, 9, 12, and 15 pulses of current and the weld zone resistances measured after each time interval. Figures 8, 9, and 10 illustrate the weld growth for 0.020" 2024, 0.050" 2024, and 0.050" 5086 respectively. Tables VI, VII, and VIII tabulate the data for Figures 8, 9, and 10.

A visible heat pattern occurs after 3 pulses in the 0.050" but no fusion, however, the zone is just below the melting point (approximately 1100°F) as shown in Figure 10. After 6 pulses, a weld nugget has formed and the heat affected zone has been enlarged. The weld zone resistance showed a large decrease during the prefusion interval, that is 1 to 3 pulses. The weld nugget continues to grow at 9, 12, and 15 pulses and the weld zone resistance continues to decrease. These graphic plates establish a correlation between the growth of the weld nugget and the decrease in weld zone resistance. Subsequent tests add further support to this correlation.

In order to compare the percentage weld zone resistance change with other weld zone properties, namely, weld diameter and weld strength, it was necessary to have a reference resistance. This resistance (R_o) was selected as the weld zone resistance calculated at the second pulse for 0.020" and at the third pulse for 0.050" thick aluminum alloys. Appendix C shows the calculation of this reference resistance. The reference resistance is nearest the times of initial fusion, however, the exact time will vary depending upon the contact resistance, the current magnitude, electrode force, and the type and gage of material being welded. All future calculations of the reference resistance for this phase of the project will be made as indicated in Appendix C.

It must be noted at this time that the arbitrary selection of the reference resistance (R_o), was necessary due to the limited information available. Further analysis of the existing data indicates the desirability of a more detailed investigation of the weld zone resistance, particularly the early stages of the welding heat period. Such detailed investigation is recommended as a part of a future program when quotient circuits will be available for recording the weld zone resistance during the welding operation.

The shapes of the resistance curves during the weld time indicate three major sections.

1. The initial cold contact weld zone resistances vary substantially for different materials.

Also, for a given material, this contact resistance varies from specimen to specimen.

2. A change in slope of the resistance curve was noted between the second and third pulses for both gages, 0.020" and 0.050". This inflection point is believed to be associated with the "seating" of the electrode tips into the aluminum surfaces. This seating of the electrodes is a prefusion effect and the extent was lesser for the materials having the higher annealed strength or hardness.
3. The final resistance (R_f) value was higher for the shorter weld times; other welding variables equal.

To summarize the procedure for selecting the weld zone signals and calculating the instantaneous weld zone resistance, it was necessary to make several assumptions regarding the signals to be recorded and the analysis of what occurs during the resistance spot welding.

Data have been introduced to support these assumptions. The specific studies as outlined in the Introduction will be presented with technical data to support the hypothesis and conclusions.

PART I

Weld Zone Resistance Studies for Recommended Welding Conditions

The literature survey and welding handbooks plus an interpretation of these data have produced a set of welding schedules for the 0.020" and 0.050" aluminum alloys. Welds were made for these conditions in order to evaluate a weld of known integrity.

Table IX lists the recommended welding conditions and the results of resistance spot welding tests. It should be noted that these schedules do not include a post weld forge force or any other post weld function. Since a forge force would not contribute to the heat generation in the weld zone during the weld heat time, this function was omitted from the schedule. Those functions which contribute to the weld heat and consequently influence the weld zone resistance, were considered in this study.

A typical example of the effect of applying the forge force before the end of the heat period is illustrated in Figure 11. These oscillograms show the effect of forge force on the weld zone resistance. It can be seen from these oscillograms, that as the forge force increases the weld zone voltage decreases, which would result in a substantial decrease in weld zone resistance.

Since this decrease in resistance due to the forge force is not an indication of weld nugget development, the use of forge force as a post weld function was not included in the welding schedule.

Figure 11, shows typical oscillograms and cross-sections for welding schedules with and without forging forces for the 0.050" 2014T6 and 0.050" 5456H343 alloys. The oscillograms, Figure 11, show the time at which forge force was introduced and show the effect of it on the electrode voltage. The current trace for the two alloys in 0.050" thickness material do not show any appreciable change at the time of application of the forge force.

For the 5456 alloy oscillogram, the forge force comes on at the ninth pulse and reaching final value at the last pulse. For the 2014, the forge force comes on at the eighth pulse, reaching the final value at the fourteenth pulse. Referring to Figure 13, the resistance-time graph, the application of force approximately midway through the time produced little drop in resistance.

In Figure 12, the cross-sections of spot welds for 0.050" 2014T6 and 0.050" 5456H343 show the effect on weld development by the application of forging force as recorded in the oscillograms of Figure 11; i.e. midway through the weld heat period. For both alloys, the weld nugget is substantially smaller with forge than that obtained without forge. As stated above the percent drop in resistance for these welds is approximately the same, which indicates a drop in weld zone resistance produced by the forge force approximately equal to that drop produced by nugget development. This phenomena was not apparent in the 0.020" gages since the weld nugget development and associated drop in resistance occurred before the application of forge, however, in the case of 0.050" material, the weld zone resistance was caused to drop below that produced by the weld nugget development.

Because of this omission of forge force from the standard welding schedule used in this program, the metallurgical quality of the weld nugget should not be used as a means of qualifying the welding schedule. For without the forge force, the metallurgical quality would be undesirable.

The weld cross-sections of 2014T6 and 7075T6 are shown in Figures 14 and 15 respectively. The effect of forge force on the metallurgical quality of the nuggets in the thin gage materials is not as pronounced as the 0.050" gage spot welds shown in Figure 12.

The weld zone resistances for 0.020" and 0.025" thickness materials are shown in Figure 16. The data for Figure 16 are shown in Table X.

Weld zone resistance-time plots for the four aluminum alloys listed in this range of thicknesses have the same order of magnitude and shape. The small differences in magnitude of resistance values at any given time are due to the small differences in the electrical resistivities of the base metals. The shape of these curves is essentially the same in that the weld zone resistances show a rapid decrease from the first to the third current pulse after which, the curves become more flat. The percent drop in resistance from the second to the sixth pulse is essentially the same for all four alloys.

The weld zone resistance versus time graphs show the general characteristics of the resistance change for a standard welding schedule which does not include a forge force.

Figure 17 shows the weld zone resistance-time plots of five aluminum alloys 0.050" thick. The welding schedule used for these alloys were the recommended conditions for 0.050" thicknesses, that is, all alloys were welded with weld times of 94 milliseconds, electrode force of 900 lbs, electrode tips of 5/8" diameter, RWMA Group A, Class 2, dressed to a 4" radius dome. The welding current was varied for the different alloys to produce a standard size weld nugget in each.

The resistance-time curves in Figure 17 show substantially the same general shape and order of magnitude from 10 to 40 microhms. The resistance value at any given time for the five materials is within 10 microhms, except for the first current pulse. The percent drop in resistance is in the range of 30 - 40 percent. Table XI shows data for Figure 17.

It is interesting to note in Figures 16 and 17, that during the weld heat period, the resistance-time plots are not affected appreciably by alloy type or material thickness. The curves show the same general characteristics as noted above and the resistance values are within a narrow range of magnitudes for all thicknesses and alloy types. These graphs prove there exists an electric signal from the weld zone and this signal has the characteristic which make it possible to use for control purposes.

To summarize Part I of this program, it was learned that:

1. For three phase spot welding of aluminum alloys

there exists an electric signal of sufficient magnitude and with the characteristic to serve as a process control feedback signal.

2. The signal for alloys and thicknesses studied are of the same general shape and magnitude which should greatly simplify its usage in a feedback control system.
3. The application of forge force before completion of the weld nugget will arrest further development of the weld nugget and cause the resistance signal to drop in value as would be produced by the further development of the nugget.
4. That the omission of the forge force from this study would be necessary to eliminate its masking effect on weld development and drop in weld zone resistance.
5. Weld quality related to weld zone resistance changes must be considered on weld size and not on metallurgical qualities since there will be no post weld forge effects.
6. For each metal thickness, a number of initial current pulses must be disregarded in calculating the weld zone resistance values due to the effects of the initial high contact resistance.

PART II

The Effect of Welding Variables on Weld Zone Resistance

The study of the effects of several welding variables was undertaken in Part II. In each welding test as shown in Table XII, one variable at a time was changed. Sufficiently large changes in each variable were made so that these changes would reflect the affects of each variable on the weld nugget size. Weld current was varied by the Percent Phase Shift Heat. The calculated weld currents were only slightly different for each alloy type due to the differences in electrical resistivity of the materials and due to some line voltage variations from day to day for identical phase shift heat settings. The electrode forces were set by using a calibrated strain gage and strain indicator system on a compression beam. Weld times were selected for testing purposes and machine limitations.

The study of the effects of welding conditions will be presented by considering the affect on weld zone resistance of spot welds in the alloys 2024, 2014, and 7075 in one group, representing the best treatable materials and 5086 and 5456 representing the strain hardened materials.

A comparison will be made for the affects of thickness on the weld zone resistance for each alloy except the 5456.

This study was conducted in four sections, namely,

A&B The effect of welding variables such as weld current, electrode force, and weld time on the weld zone resistance.

C The effect of several electrode tip shapes on the weld zone resistance.

D The effect of dissimilar materials and gages on the weld zone resistance. Pileup configurations and their effects on weld zone resistance.

In the study of the weld zone resistance, the percentage change in resistance will be compared with the weld size and strength for each alloy. Appendix D shows the calculation of the percent change in resistance as given by the formula,

$$\frac{R_o - R_f \times 100}{R_o}.$$

A presentation will be made regarding the affect of welding conditions on the reference resistance (R_o) and the final resistance (R_f). The resistances occurring before R_o, that is, for the first or second current pulses are of little concern since they are usually very high and very different from one material to another.

The reference resistance (R_o) will be the weld zone resistance after the second pulse of weld current for the 0.020" material and the third pulse for the 0.050" material. Depending upon the welding schedule this resistance value will represent a weld condition immediately before or after the initiation of fusion. In either instance, the R_o will serve as the most consistent value for comparison. The final resistance (R_f) is the value measured for the last pulse of the weld current.

Part II Section A & B 0.020" Aluminum Alloys

The Effect of Weld Current and Electrode Force on the Reference Resistance and the Final Resistance of Spot Welds in 0.020" 2024, 2014, 7075 and 0.025" 5086 Aluminum Alloys

The weld currents for 0.020" gages are shown in Table XII for each material. Each current change was made for a fixed electrode force and weld time. All test welds in this gage material were made with a weld time of 44 milliseconds (2 cycles or 6 current pulses). It is understood that this weld time is excessively long for 0.020" thick material, however, the six pulses were necessary to furnish enough test data to analyze the weld zone resistance.

The graphs shown in Figures 18, 19, 20, and 21 show the effects of electrode force on the reference resistance and final resistance for constant phase shift heat settings.

These curves show the reference resistance is dependent upon the electrode force for each heat setting. This is believed to be associated with the change in contact resistance and its affect on the reference resistance. Some alloys such as 7075 are most sensitive to the electrode force while the 2024 and 2014 are less sensitive. The strain hardened alloy 5086 was affected less than the 7075 but more than the 2024 or 2014. The final resistance was not affected appreciably by the electrode force. The variation of final resistance was between 13 and 17 microhms for all welds except those exhibiting metal expulsion.

If the electrode force is fixed, the variation of the reference resistance with increasing percent phase shift is toward a lower value. The final resistance does not change as markedly as the reference resistance for varying current at fixed electrode forces. Again, the 7075 alloy was most sensitive to weld currents. The graph of Figure 20 shows many points of metal expulsion.

The analysis of the reference resistance and final resistance are necessary to understand the relationship between the percent change in weld zone resistance and the weld size and strength.

The data for Figures 18 through 21 are shown in Tables XIII through XVI.

Part II Section A & B

The Effect of Weld Parameters on the Weld Zone Resistance Change

The indication of weld growth and development are shown by the weld nugget properties and the percent change in weld zone resistance. The relationship between weld size and percent change in weld zone resistance are shown in Figures 22, 23, 24, and 25. This relationship is based upon a weld zone resistance change for a given weld time. Percent change in weld zone resistance and weld size are shown in Table XVII.

Each material is presented with curves depicting weld nugget changes at fixed electrode forces and increasing percent phase shift heat settings. A family of curves shows the changes for electrode forces from 300 to 600 pounds.

In this gage material, the weld diameter was selected as the measure of weld development rather than the weld strength. The weld strength for thin materials was not directly related to the weld diameter due to the type of weld failure in the test specimens. For the four alloys presented, the weld diameter in the range of 0.110" to 0.130" corresponded to a change in weld zone resistance of approximately 16 to 24 percent. Also, larger weld diameters corresponded to a higher percent change in resistance.

A relatively large percent change was measured when no-fusion had occurred due to the effects of the "seating" of the electrodes by the higher electrode forces of 500 and 600 lbs. This was most pronounced in the 2024 alloy since changes of approximately 20 percent were measured for no-weld nugget diameter. The 5086 alloy showed the least effect of the "seating" and changes were 10-15% for no-weld nuggets. The acceptable weld diameter of 0.110" to 0.130" were produced by 15 to 17 percent resistance change, as illustrated in the Figure 25.

The 7075 showed the greatest variation in percent change in resistance. The weld size of 0.110" to 0.130" was produced at a change in weld zone resistance of 15 to 16 percent. Also, relatively small welds were produced at 25 percent.

The 2024 shows a poorer relationship than the 7075 because the weld zone may show a percent change of 25 without producing a weld nugget. At the same time, this percent change may represent a weld of adequate size with another welding schedule.

The relationship between weld size and percent change in resistance is not the same for all materials. It is good for the 5086 but poor for the 7075 and 2024 due to the narrow welding range of the latter materials. The "seating" effects produce serious affects on the weld size versus percent change relationship.

The 2014 shows a percent change in weld zone resistance of greater than 15 percent produces a desirable weld size. The welding force may be considerably lower for this material than any other. Also, the higher electrode forces used in the study of 2014 produced substantially larger welds at the same 15 percent change in resistance.

Figures 26, 27, 28, and 29 show typical oscillographic traces for the analysis of one material, 0.025" 5086H34. Each illustration shows the oscillographic traces for the current (i), electrode tip voltage (v), primary line voltage ($L_1L_2L_3$) and the electrode force (f). These traces are arranged for increasing weld currents at constant electrode forces of 300, 400, 500, and 600 lbs. and constant weld time of 44 milliseconds (2 cycles).

These oscillograms show the electrode tip voltage decreases beyond the third pulse. Calculating the weld zone resistance shows the resistance is decreasing after the second pulse due to a relatively rapidly increasing current during the first few pulses. The weld current continues to increase throughout the weld heat time. Examples of traces representing typically good welds are shown in Figures 28C and 29D.

As the electrode force increases with welding schedules of constant current and weld time, there is a smaller decrease in the electrode tip voltage than shown in 28C or 29D signifying a smaller weld has been produced and a lesser percent change in weld zone resistance.

The data for evaluating the percent change in weld zone resistances are shown in Tables XVIII, XIX, XX and XXI. Weld currents and weld zone resistances with the percent change in resistance and weld strength are shown in each table. The weld zone voltages may be obtained by multiplying the weld current and resistance for each pulse. This value is not reported in these tables.

The weld cross-sections for 0.020" 2014T6 are shown in Figure 30. The affect of welding schedules on the weld nugget size is illustrated. Several welds show evidence of considerable internal cavities resulting from these schedules producing metal expulsion. All welds made during Part II of the study are without the benefit of forge force which is required for metallurgically sound welds even in the thin gages. Although the appearance of the welds is relatively poor, the weld strengths have not suffered appreciably from the internal porosity. The common mode of failure is by pulling a plug from the parent metal which minimizes the effects of internal quality of the weld nugget. Also, this mode of failure makes it more difficult to compare weld strength with weld zone resistance change, therefore, weld diameters are better quantities for this comparison.

A detailed examination of the weld zones show the weld nugget to contain primary alpha aluminum and the eutectic. The grain boundaries adjacent to the weld nugget also contain eutectic due to partial melting. Considerable grain boundary melting has occurred through the heat affected zone. This is known as "incipient fusion". It may be troublesome where fatigue stresses are most important, but it does not appear to affect the static tension-shear weld strengths.

Part II   Section C

The Effect of Electrode Shape on the Weld Zone Resistance

It is well known that during the resistance spot welding of aluminum alloys electrode tip shape is very important. The changes in welding conditions as the electrodes wear, produces a flatter electrode face and a reduction in the contact resistance. This also produces a decrease in weld strength. The studies in Part II, Section C were made to examine the changes in weld zone resistances due to increasing electrode tip radius. A constant welding schedule was used, i.e., the electrode force (550 lbs.) and the weld time (44 milliseconds) were the same for all welds. Weld currents for each material were maintained nearly equal for the same percent phase shift (50 percent). The welding schedules were selected from the studies in Part II, Sections A & B such that the welding conditions would represent the most stable weld current, electrode force, and weld time. Only the electrode tip shape was changed to 1", 3", and 10" during the tests.

Four weld test specimens were made with each electrode tip shape and the weld strength, weld diameter, weld nugget penetration, and electrode indentation were measured. These properties were related to the percent weld zone resistance change and the weld strength. Figure 31 shows the effect of increasing electrode tip shape on the percent change in resistance and the weld strength for the four aluminum alloys. Figures 32 and 33 show the weld zone resistance change as the electrode tip shape changes for 0.020" 2014T6 and 0.025" 5086H34. Table XXII shows the data for Figures 31 to 33.

The strength decreases as the electrode tip radius increases due to a decreased current density. The percent change in resistance decreases although it may be high with the 1" radius due to some metal expulsion. The cross-sections and the oscillograms show evidence of metal expulsion with the relatively sharp radius (1"). The weld zone resistances as shown in Figures 32 and 33 show a decreasing magnitude with increasing electrode tip radius. The decreasing weld zone resistance is due to the larger contact area under the electrode for fixed heat input (current-force-time).

Part II   Section A, B, & C

Summary of 0.020" Spot Welding Study

The resistance spot welds show a correlation betweeen the weld zone resistance and the weld size. Weld strengths were highest in the 5086 alloy which produced the lowest percent change in resistance. Weld strengths were approximately the same for 7075 and 2014 but the latter showed a wider range of percent resistance change to produce this weld strength. The 2024 alloy required the highest percent weld zone resistance change to produce the same weld strength range (225-250 lbs.). Weld diameters were nearly the same for 2024, 7075, and 5086 but considerably larger for the 2014. In order to compare the weld properties of each alloy, it was necessary to select the same conditions such as weld time, weld size range, and weld strength range. In order to compare the weld zone properties, weld currents, electrode forces, and weld diameters were not exactly the same for each alloy for optimized welding schedules. The variations in conditions were necessary in order to compare the weld strength, weld size, and percent change in weld zone resistance.

The electrode tip radius had a pronounced affect on the weld zone resistance. As the radius increases (electrode tip flattens) the weld zone resistance decreases. Weld strength shows a slight decrease for most of the aluminum alloys with increased electrode tip radius.

Part II Section A 0.050" Aluminum Alloys

The Effect of Weld Current on the Reference Resistance and Final Resistance in 0.050" 2024, 2014, 7075, 5086, and 5456 Aluminum Alloys

An evaluation of the effects on the weld zone resistance by weld current at constant electrode force and weld time was made from the resistance-time graphs. Our original assumption for the selection of the reference resistance (R_o) proved to be valid for a narrow range of welding schedules. It was assumed, the resistance R_o, would not vary appreciably with changes in weld current. The resistance-time graphs of Figures 34 to 39 showed considerable shifting of the reference resistance, (R_o) especially for the 2024, 2014, and 7075 alloys. With a fixed reference resistance, (R_o), there is not a true correlation between percent change in resistance and weld size. With some welding schedules it was possible to produce small, medium, and large weld diameters for the same percent change in resistance. This method of calculating the percentage change in resistance could not serve as a means of determining the weld nugget development. A further look at the graphs of resistance-time showed two characteristics:

1. The inflection point or "knee" of the curve was shifted toward a lower resistance value as the weld current increased for constant electrode force and weld time.
2. The graph indicated a measurable decrease in resistance from the inflection point when a reasonable weld size was produced. Also, small resistance changes resulted when small welds were made.

The reference resistance (R_o) was very flexible with each alloy and welding schedule. It was necessary to consider another point as reference resistance in order to show the correlation between weld size and weld zone resistance change. The new reference resistance (R_o') was taken as the inflection point or "knee" in the resistance-time graphs. In this instance, the time of the reference resistance was not fixed. This R_o' permitted calculation of percent change in resistance of a more realistic value and generally a much lower value.

In studying each material, the 2024 alloy produced consistently higher R_o and R_o' which resulted in greater percent change. As the weld current was increased from 40% heat (27000A) to 65% (42000A) the R_o was lowered and approached R_o'. The values of R_o and R_o' for 7075 and 2014 were similar and considerably lower than 2024.

The 5086 and 5456 spot welds produced weld zone resistance-time graphs with R_o and R_o' almost identical. This made it easier to correlate the change in weld zone resistance with weld size. The effect of current was a decreasing weld zone resistance with increasing weld current at constant electrode force and weld time.

The medium to high currents (50% to 65%) at constant electrode forces produce decreasing weld zone resistances in the 5086 and 5456 alloys. There is less affect by the current on the reference resistance with higher currents and forces in the 5456 alloy than any other material. The range of reference resistance and final resistance seems to be less sensitive to changes in weld current in this combination of schedules for the 5000 series alloys. Again, the shorter weld time (3 cycles) produces weld zone resistances which were higher than those for the longer weld time (5 cycles).

As the weld time is increased from 3 cycles to 5 cycles, the respective weld zone resistances are decreased. The graphs of Figures 40 to 53 show the relationship between the electrode force, welding current, the reference resistance (R_o), and the final resistance (R_f) for each aluminum alloy. Weld times of 61 milliseconds (3 cycles) and 94 milliseconds

(5 cycles) were used to show the effect of time on this relationship.

As noted previously, the effect of increased weld time is to reduce the final resistance (R_f) without appreciably affecting the reference resistance (R_o). The latter does vary somewhat, but the beginning of the weld for a given current setting and force should be the same regardless of the final weld time.

As the weld time increases for constant current and electrode force so does the weld size. A decrease in final weld zone resistance (R_f) reflects the increasing weld size and strength. It is certain a weld must have a minimum weld time in which to develop the desired weld size properly. The high heat conductivity of aluminum requires the weld time to be short, however, the weld time must not be so short that the weld current must be exceedingly high in order to produce a satisfactory weld. The evaluation of Part I showed that 5 cycles is a practical weld time for the 0.050" material.

Part II Section B

The Effect of Electrode Force on the Weld Zone Resistances in 0.050" Aluminum Alloys

The abnormally low electrode force (600 lbs) produces metal expulsion or very small welds with the current ranges

(27000-29000) used in this part of the study. Reference resistances for these welding schedules were erratic, hence difficult to describe or correlate. The final resistances were usually very low, especially when metal expulsion occurred. If the welding schedules produced no-weld, the final resistance tended to be high or close to the reference resistance. Normally, as the electrode force was increased, the weld zone resistances decreased due to greater contact area and lesser contact resistance.

Referring to Figures 34, 35, 37, and 38 the effects of moderate electrode forces 800 and 1000 lbs. produce the greatest change in magnitude on the reference resistances, especially around 800 lbs. The final resistances are less affected as the electrode force is increased. A relatively high force (1200 lbs.)-low current (33,000A) weld schedule, producing no-weld, will produce a relatively high final resistance. The importance of this final resistance value will be seen when the percent change in resistance is discussed.

The increase in electrode force resulted in a greater affect on the reference resistance and made it necessary to seek a new reference resistance (R_o') as presented in the discussion of the effects of weld current. A comparison of the resistance-time curves of Figures 34 to 39 show the location of the R_o and R_o' for three alloys at two welding currents and one weld time.

Several graphs are shown in Figures 40 to 43 for the affect of electrode force on weld zone resistance for constant weld current and weld time in different aluminum alloys. In each curve, the weld zone resistances show a continual decrease in magnitude and a similarity of shape within one material. This decreasing resistance results in a shifting of the reference resistance to lower values and a decrease in the final resistance.

The weld zone resistance change as a percentage of the reference resistance reflects the degree of weld nugget growth. All of the aluminum alloy spot welds showed some correlation of the weld nugget size, strength, and percent resistance change. Table XXIII shows the ranges of percent change in weld zone resistances which produced acceptable weld properties, i.e., weld strengths of 400-700 pounds.

Table XXIV shows the correlation of weld size with percent change in resistance for spot welds made with several welding schedules. A comparison of both reference resistance R_o and R_o' are made with respective percentage resistance change. As the weld size increases the percent change increases for a given alloy. The same percentage change does not represent equal weld size for all materials. The 2024 produces the greatest change even when small welds are developed. The 5086 alloy produces the least change and the two reference resistances R_o and R_o' are nearly the same. The 7075 was between the two extremes of high and low percentage changes.

The spot welds for 2024, 2014, and 7075 are reported together. These three materials showed a higher range of resistance change to produce the same range in weld strengths as the 5000 series materials. The graphs in Figures 44 to 49 of the reference resistance and final resistance show the percent resistance changes would be high in these alloys. Generally, the reference resistance shows some variation with the particular welding schedule and the final resistances show variations but not as markedly as the reference resistance. The final resistances varied between 12 and 15 microhms for the welding schedules and a weld time of 94 milliseconds. A shorter weld time (61 milliseconds) produces final resistances of 14 to 19 microhms with reference resistances approximately the same for the welding schedules used. The higher the final resistance, the lower the percent resistance change and the smaller the weld size, all other conditions remaining the same.

As long as the reference resistance remains constant with the welding schedules, the final resistance is a direct correlation with the weld size. The reference resistance does not remain constant since it is influenced considerably by the electrode force which causes "seating" of the electrodes. This generally is toward a lower reference resistance which should produce a lower percent change in resistance, i.e., a lower resistance difference and a smaller ratio of final resistance to reference resistance. Table XXIV shows a comparison of the change in weld zone resistance for three alloys using the two reference resistances R_o and R_o'. The newer reference resistance produces better correlation of the weld nugget size with percent change in resistance, especially in the 2024 and 7075 alloys.

The graphs of Figures 54 and 55 show the affect of weld current, weld time, and electrode force on the percent change in resistance and weld strength for 0.050" 2014. These curves are typical for alloys of 2024 and 7075. The latter two alloys tend to shift the curves to the right toward greater percentages of resistance change. Table XXIII shows the data for percent resistance change taken from Figures 54 to 59.

Data are presented in Tables XXV to XXXIV for the welding schedules, weld zone resistances, percent resistance changes, and weld strengths for all aluminum alloy spot welds. These tables show data for Figures 54 to 59.

The weld zone resistance changes for the 5086 and 5456 aluminum alloys were considerably lower than those for the 2024, 2014, and 7075 alloys. Several factors enter the comparison of these two alloys (5086 and 5456) with the others. First, the lower resistance of the reference and final resistance (18-23 and 11-15 respectively) produced the smaller percent resistance changes. Second, considering the higher strength of the alloy, a smaller weld produces the same strength range and third, these materials appeared to be less sensitive to the variations of welding conditions particularly in the 0.050" gage. The graphs of Figures 50, 51, 52, and 53 show the relationship between the reference resistances and the final resistances for the two alloys. Also, Figures 56, 57, 58, and 59 show the effects of welding schedules on the weld zone resistance change and the weld strength. Tables XXXI to XXXIV show the data for the graphs of Figures 56 to 59.

Typical oscillograms for the 0.050" 5456H343 alloy for the variation of electrode force and weld current are shown in Figures 60 to 67. The oscillograms show a relatively flat curve for electrode tip voltage when no-weld has been produced as shown in Figure 60a. A tip voltage (v) showing successively greater voltage drop at the end of weld time was indicative of a larger, stronger weld. Those oscillograms showing an abrupt voltage drop or erratic voltage trace usually represented welds where metal expulsion occurred (Figure 62d). Even though these welds were relatively strong, they are produced by undesirable welding schedules.

Weld cross-sections showing the effects of welding schedules on weld properties are presented in Figures 68 and 69. The photomacrographs show mostly metallurgically sound welds for these welding schedules, however, some welds show internal defects of shrinkage and porosity. The data for Figures 68 and 69 are presented in Table XXXV.

Part II Section C

The Effect of Electrode Tip Shape on the Weld Zone Resistance

In order to study the effects of the electrode shape, a standard welding schedule was selected from Part II, Section A & B. This study was conducted as Part II, Section C of the work outline. The electrode shapes were 1", 4", 8", and 10" radii on 5/8" diameter RWMA Group A, Class 2 copper alloy electrodes.

The weld zone resistances were compared for each radius to see the effects of increasing radius on the weld zone resistance. All welds showed a decreasing resistance with increasing electrode tip radius. As the contact surface area increased, the contact resistance decreased. This is typical for all materials. The greatest differences were in the early period of weld times where the different radii produced a greater effect on the reference resistance. This was analagous to increased electrode force. The electrode shape produced considerable spread between the resistance-time curves for 2024, 2014, and 7075, especially the latter alloy. Greater spread was noted at the sharper radii, 1" and 4". Alloys 2024 and 2014 were similar. In the cold worked alloys, considerable spread was noted between 1" and 4" radii but a small spread between 4" and 10" radii. Each weld zone resistance-time curve was lower than the previous curve (sharper radius) which indicated the contact area was increasing and contact resistances were decreasing.

The percent change in weld zone resistance was calculated for each weld schedule. Graphs of the effect of electrode shape on percent change in weld zone resistance and weld strength are shown in Figures 70 and 71. These graphs are made from weld tests using the following welding schedule:

Weld current	34,000 - 38,000 amperes
Electrode Force	900 pounds
Weld Time	61 milliseconds (3 cycles)
Squeeze Time	5 cycles
Hold Time	5 cycles

Tables XXXVI to XL show the data for Figures 70 and 71.

A decreasing percent drop in weld zone resistance resulted in lower weld strength as the electrode tip shape became flatter. With the fixed heat input, the increasing contact area resulted in a lower current density and a smaller weld was produced.

Figure 72 shows a typical set of oscillograms for 0.050" 5456H343. The electrode tip voltage curve appears to be flat as the electrode tip radius increases. The effect on the weld nugget shape as shown in Figure 73, was to cause an appreciable reduction in nugget penetration and a lesser reduction in diameter. Table XL shows data for Figures 72 and 73.

Summary of Part II on 0.050" Aluminum Alloys

The effects of the various welding conditions show a more pronounced effect on the weld zone resistance in the 0.050" gage aluminum alloys than on the thinner materials such as 0.020". More predictable trends in the weld zone resistances, percent change in resistance, and weld strength are noted in the welds in the heavier gage. A range of percent resistance change produced a corresponding change in weld strength for all alloys. Two groups, one for the heat treatable alloys and one for the cold worked and stabilized alloys, showed some differences in the weld zone resistance changes. The first group showed a relatively narrow welding range where weld properties were acceptable. They also showed the highest resistance and resistance changes. The cold worked materials, although showing some higher initial contact resistances, produced weld zone resistance changes lower than the heat treatable group. The cold worked materials showed the highest as-welded strength. This is due to a higher annealed strength of the alloys over the heat treatable materials. Electrode tip shape influences the weld zone resistance since increasing electrode radius results in decreased weld zone resistance. The weld strength decreased greatly as the electrode tip radius increased. However, the percent drop in resistance showed a much smaller decrease with increasing electrode tip radius.

Part II Section D

The Effect of Dissimilar Thicknesses and Material on the Weld Zone Resistance of 0.020" 2014T6 and 0.020" 5052H34

This was a very limited study of the effect of changing the thickness combination and material composition but using a modified weld schedule for the thinner material. The two combinations were 0.020" 2014T6 to 0.050" 5456H343 and 0.020" 5052H34 to 0.050" 5456H343.

Welds were prepared with each material and thickness combination and the weld zone resistance was calculated. A comparison was made of the weld zone resistances when welding two pieces of the thinner material using a similar welding schedule. Both combinations of dissimilar material resulted in a flattening of the weld zone resistance curve after the initial decrease from the contact resistance. The basic shape of the resistance-time curve was similar to that for the thinner material, but the resistance did not decrease as much with the dissimilar material combinations. Weld strengths and penetrations were acceptable. Welds pulled plugs from the thinner material at strengths satisfactory for the thinner material. Figure 74 shows typical weld zone resistance-time curves for the dissimilar materials. Also shown are the resistance-time curves for welds in two equal pieces of the thinner alloy of the combination. Table XLI shows the data for Figure 74. Typical oscillographic traces and weld zone cross-sections are shown in Figure 75. The penetration into the thinner sheet was adequate to produce a strong weld joint.

SUMMARY

The study of the welding of several commercial aluminum alloys using three phase power supply has shown a correlation between the weld zone resistance change and the weld nugget development.

Part I

Weld tests were made with recognized welding schedules for each alloy in Part I and the weld zone resistance was studied. These data were to be used for comparison later with studies on the welding variables and their influence on the weld zone resistances.

A standard three phase, frequency converter welding machine with pulse counting timing and dual force system was used for all welding tests.

Several methods were tried to produce the proper electrical signals for recording purposes which would assure pure weld zone resistances. The selection of the weld voltage signal, i.e. the electrode tip voltage, resulted from tests which demonstrated that the faying surface voltage and the electrode tip voltage were similar. Weld zone resistances calculated from these two voltage sources showed the weld zone resistance to be similar in shape but different in magnitude. The absolute resistance value was not of particular concern. The overall trend of the weld zone resistance during the heat time was of the utmost importance. Sufficient data were taken to assure the reliability of measurements at the electrode tips as representing the change of weld zone resistance.

In Part I, five aluminum alloys 2024, 2014, 7075, 5052, and 5086 of 0.020" - .025" thickness and five aluminum alloys 2024, 2014, 7075, 5086, and 5456 of 0.050" thick were evaluated.

The welding schedules used were those established for welds of a given size and strength. Several weld zone signals were studied to select the proper set of signals to be used for more extensive evaluation of the effect of welding schedules on the weld zone resistance.

These studies showed the first formation of the weld nugget began at the second current pulse for 0.020" thickness and at the third pulse for 0.050" thickness. The welds showed a decrease in weld zone resistance as the weld nugget continued to grow. This characteristic was utilized to study the effects of the welding variables, weld current, electrode force, and weld time on the change in weld zone resistance.

Part II Section A

The weld current was found to have the greatest influence on the weld zone resistance. As the weld current increased, the weld zone resistance was decreased for constant electrode force and weld time. The general shape of the weld zone resistance-time curve indicated the "knee" of the curve was shifted toward lower resistance and shorter time as the current increased. The latter two conditions of the resistance-time curve was influential on the reference resistances R_o and R'_o which were necessary to study the change in weld zone resistance. Percent change in resistance between the reference resistance and the final resistance was correlated with the weld size and strength.

A range of percent change in weld zone resistance was measured for each alloy spot weld in both gages. The 5086 and 5456 alloy produced the highest weld strengths with the lowest percent change. Also, the correlation of percent change with weld size was more reliable. The alloys 2014 and 7075 had the next highest range of weld zone resistances and were moderate in strength but lower than the 5000 series materials. The correlation of percent change in weld zone resistance with weld size was less reliable and was noted for a more narrow range of welding currents. The alloy 2024 had the highest values of percent change in resistance of all the alloys. It had the lowest as-welded strength and the poorest correlation of weld zone resistance change with weld size.

Part II Section B

The effect of electrode force at constant weld current and weld time on the weld zone resistance was to decrease the resistance as the force increased. An increase of force was most effective in changing the shape of the resistance-time plots toward lower resistance and shorter times. The electrode force had to increase substantially in order to produce a measurable change in the resistance values.

The weld time produced a decreasing final resistance with increasing time at constant weld current and electrode force. Weld time produced very little effect on the reference resistance since this value was measured at a preselected time. The percent weld zone resistance change increased with increasing weld time for all welding schedules.

Part II Section C

A study of the effects of electrode tip shapes showed the weld zone resistances were decreased as the electrode tip radius increased. The weld nugget penetrations were reduced as the tip radius increased, however, the reduction in weld strength or size was not as pronounced.

A decrease in percent weld zone resistance was measured as the electrode tip radius increased.

Part II Section D

A study was made to compare the weld zone resistance of dissimilar material and dissimilar thickness combinations with those for similar thin gage spot welds. In the similar material spot welds, such as 2014/2014, the weld zone resistance had a characteristic decrease with weld time whereas the dissimilar combinations 2014/5456 showed a more shallow resistance change. The weld strengths of both similar and dissimilar combinations were the same.

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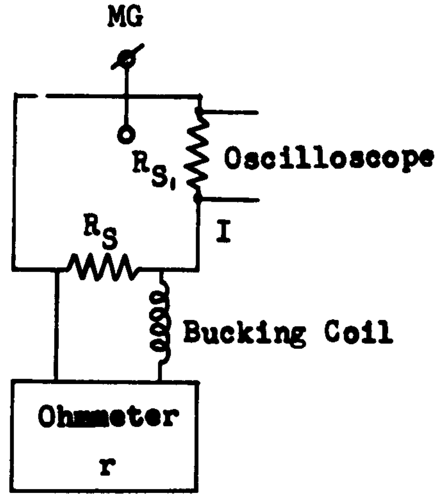
APPENDIX A

Calibration of Weld Current Shunt Resistance



$$R_s = \frac{I_1 \times R_1}{I_2}$$

I_1 = Standard current to produce 1 microhm on ohmmeter

R_1 = Relative Resistance measured to ohmmeter

I_2 = Applied Current to Measure R_s

R_s = Actual Resistance of Weld Current Shunt

Measurement No.	I_1 Amps.	I_2 Amps.	R_1	R_s microhms
1	2.25	50	34, 35	1.53, 1.57
2	2.25	100	67	1.50
3	2.25	150	105	1.57
			Av.	1.53

MG = Motorgenerator power source for DC current (150 Amp)

R_s = Shunt-section of upper arm of welding machine

Bucking Coil = Small wire wound coil to eliminate small induced voltage in leads

R_{s_1} = Shunt to measure DC current (150 Amp - 100 mv)

R_1 = Galvanometer type - Wheatstone Bridge

Calibration of Oscillograph Galvanometers

Galvanometer No. 2

Signal Recorded Weld Current

$$i = \frac{E}{R_{shunt}} = \frac{\text{millivolts per inch}}{\text{microhm}} = \text{Kilo Amps per inch}$$

$$= \frac{64.9}{1.53} = 42.5 \text{ Kilo amp per inch}$$

Measurement No.	Signal Millivolts	Deflection in.	Factor Millivolts per inch
1	10	0.16	62.0
2	20	0.31	64.5
3	30	0.45	66.5
4	40	0.62	64.5
5	50	0.78	64.2
6	60	0.90	66.8
7	70	1.07	65.6
		Av.	64.9

APPENDIX B

Calibration of Oscillograph Galvanometers

Galvanometer No. 6

Signal Recorded Tip Voltage

$V = v \cdot d$ = volts per inch x deflection

Measurement No.	Signal Volts	Deflection in.	Factor "v" volts per inch
1	1.0	1.7	0.59

Galvanometer No. 3

Signal Recorded Electrode Force

Measurement No.	Signal lbs.	Deflection inches	Series Resistance	Factor	lbs. per inch
1	500	1.75	1000	286)	
2	800	2.95	1000	272) Av.	275
3	1000	3.45	1000	290)	
4	1000	1.80	2000		550
5	1000	1.21	3000		825

Galvanometer No. 5

Signal Recorded Inside Surface Voltage

$V_1 = v_1 \times d_1$ = volts per inch x inches

Measurement No.	Signal Volts	Deflection in.	Factors v_1 Volts per inch
1	.15	.12	1.25

APPENDIX C

Calculation of Weld Zone Resistance

$$R_w = \frac{V_1}{I} = \frac{\text{Voltage at inside surface}}{\text{instantaneous secondary current}}$$

V_1	$= v_1 \times d_1$	v_1	= volts per inch
I	$= i \times d_i$	d_1	= deflection for voltage trace
R_w	= Weld Zone Resistance	d_i	= deflection for instantaneous current
		i	= Kilo amps per inch

$$R = \frac{V}{I} = \frac{\text{Tip Voltage}}{\text{instantaneous secondary current}}$$

V	$= v \times d$	v	= volts per inch
I	$= i \times d_i$	d	= deflection for voltage trace
R	= Total Resistance	d_i	= deflection for instantaneous current
		i	= Kilo amps per inch

Resistance for 0.020" and 0.050" thicknesses.

Initial Current Pulse	$R_A = \frac{V_A}{I_A}$	$V_A = v \times d_{va}$	$I_A = i \times d_{ia}$
Resistance at specified Weld Time	$R_o = \frac{V_o}{I_o}$	$V_o = v \times d_{vo}$	$I_o = i \times d_{io}$

Resistance at end of Weld Time $R_f = \frac{V_f}{I_f}$ $V_f = v \times d_{vf}$

$I_f = i \times d_{if}$

NOTE .020" 2nd pulse

.050" 3rd pulse

When the material thickness was 0.020", the resistance R_o is taken at the second pulse of current flow.

APPENDIX D

Calculation of Percentage Change in Weld Zone Resistance

$$\text{Pefcent Change in Resistance} = \frac{R_o - R_f}{R_o} \times 100$$

Where R_o = Resistance at first indication of fusion

R_f = Resistance at the end of weld time

The selection of R_o was a reference resistance to calculate a percent change. It is inferred that this resistance represents the weld zone resistance at the first signs of metal fusion.

TABLES

TABLE I

TYPICAL CHEMICAL ANALYSIS AND MECHANICAL PROPERTIES OF ALUMINUM ALLOYS FOR PHASE I

Alloy	Temper	Chemical Composition Limits Weight Percent								
		Si	Fe	Mn	Cu	Mg	Zn	Cr	Ti	Other
2024	T3	.50	.50	.30-.90	3.8-4.9	1.2-1.8	.25	.10		.15
2014	T6	.5-1.2	1.0	.40-1.20	3.9-5.0	.2-.8	.25	.10		.15
7075	T6	.50	.7	.30	1.2-2.0	2.1-2.9	5.1-6.1	.18-.40	.20	.15
5086	H34	.40		.2-.7	.10	3.5-4.5	.25	.05-.25	.15	.15
5456*	H343		.40	.5-1.0	.20	4.7-5.5	.25	.05-.20	.20	.15
5052	H34	0.45 Si+Fe		.10	.10	2.2-2.8	.10	.15-.35		.15

* .0005 weight Pct. Be.

TABLE I (CONTINUED)

TYPICAL CHEMICAL ANALYSIS AND MECHANICAL PROPERTIES OF ALUMINUM ALLOYS FOR PHASE I

Alloy	Temper	Mechanical Properties		
		Ultimate Tensile psi	Yield Stress psi	Elongation in 2" pct
2024	T3	64000	42000	12
2014	T6	67300	60200	8
7075	T6	82400	73000	9
5086	H34	47000	37000	10
5456	H343	56000	43000	9
5052	H34	38000	31000	10

TABLE II

SURFACE RESISTANCE OF ALUMINUM ALLOYS AFTER CHEMICAL CLEANING

Gage in	Alloy	Surface Resistance Range Microhms	
		Range	Average
0.020	2024T3	20 - 112	55
0.050	2024T3	10 - 140	55
0.020	2014T6	20 - 70	30
0.050	2014T6	20 - 45	30
0.020	7075T6	8 - 45	25
0.050	7075T6	18 - 30	25
0.025	5086H34	20 - 60	40
0.050	5086H34	8 - 75	40
0.050	5456H343	10 - 34	22
0.020	5052H34	24 - 40	32

Alloys 2024, 7075 and 5086 were cleaned using the same schedule.

Alloy 2014 used a shorter deoxidizing time (30 sec.) than the above alloys (105 sec.)

Alloy 5456 & 5052 used a 30 second deoxidizing time

TABLE III

INSTANTANEOUS WELD ZONE RESISTANCES FOR 0.020" 2024T3
PART I

SPECIMEN 24A68

Current	Weld Zone Resistance		Current	Weld Zone Resistance	
	Total	Inside Surface		Total	Inside Surface
Kiloamps	M.O.	M.O.	Kiloamps	M.O.	M.O.
5.5	120	111	23.8	20.5	8.C
9.3	69.8	54.8	26.3	19.7	8.0
12.3	47.1	38.2	27.2 4th	19.8	7.4
13.2	42.4	38.6	26.8	19.4	7.2
14.0 1st	36.4	30.0	25.1	18.7	6.4
12.7	34.6	28.3	21.2	19.8	7.2
10.6	34.9	29.2	18.3	19.1	5.9
7.2	38.8	34.7	15.7	20.4	7.7
5.5	40.0	34.5	15.7	28.0	9.0
5.1	60.7	50.9	25.9	18.5	6.2
14.9	30.8	22.8	27.6	18.8	5.8
16.1	33.5	24.2	29.3	18.8	5.8
18.3	30.6	20.7	29.7 5th	18.2	5.7
19.1	27.2	15.2	28.5	17.5	5.6
19.5 2nd	23.5	12.8	25.9	18.1	5.8
17.4	23.5	12.6	22.9	17.9	5.2
14.9	24.1	12.7	19.1	18.3	5.7
11.9	24.3	13.4	17.0	24.7	8.2
9.8	29.5	15.3	25.9	17.8	5.8
12.3	30.8	15.4	28.0	13.6	5.7
18.7	24.0	11.2	30.2	17.5	5.3
22.1	22.6	11.3	30.6	17.6	5.5

TABLE III (CONTINUED)

INSTANTANEOUS WELD ZONE RESISTANCES FOR 0.020" 2024T3
PART I

SPECIMEN 24A68

Current	Weld Zone Resistance		Current	Weld Zone Resistance	
	Total	Inside Surface		Total	Inside Surface
Kiloamps	M.o.	M.O.	Kiloamps	M.O.	M.O.
23.8 3rd	21.8	11.3	30.2 6th	17.9	4.6
23.4	21.7	10.2	28.5	17.5	6.6
22.5	21.3	9.3	25.1	18.3	5.5
20.0	21.5	8.5	22.5	16.9	6.7
18.3	20.2	8.2	18.7	13.5	5.3
13.6	22.7	8.1	13.6	16.9	5.9
11.5	33.0	7.6	10.6	19.8	5.7
20.4	21.0	7.5	9.8	15.3	4.5

ELECTRODE FORCE 550 WELD TIME 44 WELD DIA. 0.138" PENE. 52%

TABLE IV

INSTANTANEOUS WELD ZONE RESISTANCES FOR 0.050" 2024T3
PART I

SPECIMEN 24B53

CURRENT	RESISTANCE		CURRENT	RESISTANCE		CURRENT	RESISTANCE	
	Total	Inside Surface		Total	Inside Surface		Total	Inside Surface
Kiloamps	Microhms		Kiloamps	Microhms		Kiloamps	Microhms	
7.2	90.3	54.2	20.4	22.0	7.3	34.0	17.6	5.9
12.7	59.0	30.7	17.0	24.1	8.2	31.0	18.1	6.1
13.6	55.9	25.7	21.7	23.5	8.7	28.5	18.2	6.0
15.3	43.1	22.2	25.5	22.7	8.2	24.6	18.3	6.1
14.9	39.6	20.8	29.3	21.1	7.5	25.9	20.5	7.7
13.6	36.0	19.8	30.6	20.9	6.9	32.7	18.0	6.7
12.3	34.9	17.9	30.2	20.5	6.6	34.0	18.2	7.0
8.5	38.8	22.3	28.9	20.8	6.6	36.1	17.2	6.9
5.1	54.9	39.2	26.8	20.5	6.3	35.7	17.4	6.7
14.9	35.6	17.4	24.6	19.9	6.5	34.0	17.1	6.5
18.3	30.6	15.8	19.1	23.0	7.8	31.9	17	6
20.8	26.4	11.5	23.4	23.5	8.1	28.0	17	7
22.5	24.4	9.8	30.2	20.5	6.2	25.9	17	6
22.5	23.1	9.3	31.9	20.0	6.2	28.9	19	7
20.8	24.0	10.1	33.1	19.9	6.0	33.6	17	7
18.7	24.1	10.2	33.6	19.3	5.6	35.7	17	9
17.0	22.3	8.8	31.4	19.4	5.4	37.4	17	7
11.5	36.5	10.4	30.2	19.2	5.3	36.1	17	7
17.0	27.6	11.8	26.3	18.6	5.7	35.3	17	7
23.4	22.6	9.0	23.4	19.2	6.0	31.9	17	7
25.1	22.7	9.6	25.5	21.6	6.7	29.7	16	7
26.8	22.0	9.3	31.0	19.0	5.5	26.8	16	7
27.2	21.3	8.1	33.6	18.4	5.9	27.6	19	8
25.1	21.9	8.0	35.3	18.1	5.6	34.8	16	7
23.8	21.4	8.0	34.8	18.1	6.0	36.5	16	7

TABLE IV (CONTINUED)

INSTANTANEOUS WELD ZONE RESISTANCES FOR 0.050" 2024T3
PART I

SPECIMEN 24B53

CURRENT	RESISTANCE		CURRENT	RESISTANCE		CURRENT	RESISTANCE	
	Total	Inside Surface		Total	Inside Surface		Total	Inside Surface
Kiloamps	Microhms		Kiloamps	Microhms		Kiloamps	Microhms	
37.4	16	7	37.0	14	6	29.1	16	5
37.8	16	7	39.5	14	6	36.1	13	3
35.7	16	7	40.4	14	6	39.1	13	5
33.1	16	6	39.9	14	6	40.8	13	5
30.2	16	7	37.8	14	6	41.6	12	5
26.3	16	7	34.4	14	6	40.4	13	5
31.9	16	6	31.0	14	6	37.8	12	5
34.8	16	6	26.8	18	6	35.3	12	5
37.0	15	6	33.1	15	6	31.0	13	5
38.7	15	6	37.8	13	6	27.2	13	5
37.4	15	6	39.9	14	5	21.2	12	5
36.1	14	6	40.4	13	5	17.0	12	5
33.1	15	6	39.5	13	5	12.7	13	5
30.6	15	6	37.0	13	5			
26.3	18	6	34.0	14	6			
30.6	17	7	30.2	14	5			
36.1	15	6	27.6	17	5			
39.1	14	6	36.1	14	6			
40.4	14	6	38.7	13	5			
39.1	14	6	39.9	13	5			
37.8	14	6	40.8	12	5			
34.8	14	6	39.5	13	5			
31.0	14	6	37.4	13	5			
27.2	15	6	34.4	13	5			
33.1	15	6	31.0	13	5			

ELECTRODE FORCE 900 lbs. WELD TIME 94 M.S. WELD DIA. .246" PENE. 66%

TABLE V

INSTANTANEOUS WELD ZONE RESISTANCES FOR 0.050" 5086H34
PART I

SPECIMEN 86B19

CURRENT	RESISTANCE		CURRENT	RESISTANCE		CURRENT	RESISTANCE	
	Total	Inside Surface		Total	Inside Surface		Total	Inside Surface
Kiloamps	Microhms		Kiloamps	Microhms		Kiloamps	Microhms	
8.0	56.2	38.7	17.4	24.1	15.5	29.7	19.5	8.3
12.3	50.4	36.5	16.5	30.3	15.1	25.5	20.0	7.9
14.4	41.6	30.5	26.3	22.0	11.7	21.6	21.2	8.0
16.1	34.1	22.9	28.0	22.1	12.5	27.6	19.5	7.8
15.3	32.6	22.2	30.6	20.9	11.7	33.5	17.3	7.8
13.6	32.3	22.7	31.0	20.9	12.5	35.7	16.8	7.9
11.4	32.4	22.8	29.7	20.8	11.7	36.9	16.8	7.4
7.6	38.1	28.9	27.2	21.3	10.9	34.0	17.9	7.2
5.1	54.9	31.3	22.9	21.8	10.4	29.7	19.8	7.3
15.3	27.4	17.6	18.2	24.1	10.6	25.0	21.6	7.6
20.4	23.5	15.6	22.9	23.5	10.9	25.0	18.8	8.4
22.1	23.0	15.3	30.1	19.2	11.5	33.5	14.6	8.8
22.9	23.1	15.7	32.3	19.5	10.9	36.5	15.0	7.6
22.5	23.5	15.5	33.5	19.7	8.9	37.8	15.6	5.9
21.2	24.0	15.0	33.1	20.2	9.2	38.2	15.9	6.8
17.0	26.4	17.0	31.8	20.1	9.2	36.9	17.0	6.8
13.6	28.6	18.3	28.0	20.3	9.0	34.4	18.0	7.0
11.9	33.6	21.0	25.5	21.5	8.4	30.1	19.2	7.3
19.1	25.6	15.7	19.9	22.6	8.9	25.5	20.7	7.5
25.0	22.8	14.8	25.0	21.2	8.2	27.2	16.5	8.3
26.7	22.8	14.9	31.8	18.2	9.5	34.0	14.7	8.6
28.0	22.5	14.6	34.4	17.7	9.6	37.4	14.7	6.9
26.3	23.5	15.9	35.2	18.1	8.1	38.6	15.0	6.1
24.6	23.9	15.8	34.8	18.6	7.8	38.2	15.7	6.4
21.2	25.4	16.0	32.7	18.9	8.5	37.4	16.3	6.4

TABLE V (CONTINUED)

INSTANTANEOUS WELD ZONE RESISTANCES FOR 0.050" 5086H34
PART I

SPECIMEN 86B19

CURRENT	RESISTANCE		CURRENT	RESISTANCE		CURRENT	RESISTANCE	
	Total	Inside Surface		Total	Inside Surface		Total	Inside Surface
Kiloamps	Microhms		Kiloamps	Microhms		Kiloamps	Microhms	
34.0	17.0	6.8	39.9	14.5	6.3	42.5	12.9	5.0
30.6	18.6	6.9	37.4	15.2	6.6	41.6	13.7	5.3
25.0	23.6	7.3	34.0	15.8	6.2	39.1	14.3	5.8
29.3	15.0	7.8	28.4	17.9	6.4	25.2	15.3	6.0
36.1	14.4	8.0	29.7	14.4	6.4	31.0	16.4	6.1
38.2	14.1	6.4	36.9	13.0	7.3	27.6	15.9	6.2
39.9	14.2	6.0	39.5	13.1	5.7	19.9	19.0	6.7
39.5	14.9	6.2	41.6	12.9	5.4	14.8	19.5	6.8
37.8	15.6	6.2	40.8	13.9	5.5	11.4	21.9	8.5
33.5	17.0	6.5	39.9	14.2	6.0	9.3	20.4	9.4
28.0	18.9	6.8	36.9	14.9	6.3	8.9	16.8	9.6
25.9	18.5	6.5	32.2	16.0	6.2	8.5	14.1	7.5
33.1	12.6	7.5	28.0	17.1	6.5	8.0	13.7	6.7
37.8	13.7	7.7	34.0	12.0	6.8	7.6	10.5	5.8
39.9	13.7	5.7	38.2	13.3	7.1	7.2	9.7	2.5
40.8	14.2	5.8	41.6	12.7	5.5	6.8	7.3	
39.9	14.7	6.0	42.5	13.1	5.7	5.9	8.4	
37.4	15.5	6.1	42.0	13.5	5.7	5.5	7.2	
34.4	16.2	6.5	39.9	14.2	5.8			
30.1	17.2	6.6	35.7	15.4	6.1			
27.2	17.2	6.3	32.7	15.5	6.0			
34.0	13.2	6.9	28.4	15.4	6.1			
39.5	13.1	6.2	32.7	12.5	6.1			
40.8	13.4	4.7	39.9	12.7	6.6			
40.8	13.9	6.0	41.2	12.8	5.1			

ELECTRODE FORCE 900 lbs. WELD TIME 94 M.S. WELD DIA. .250" PENE. 61%

TABLE VI

WELD ZONE RESISTANCES FOR 0.020" 2024T3 FOR WELD GROWTH STUDY

Weld Current Kiloamps	Weld Time M.S.	Weld Zone Resistance Microhms
14.0		36.4
19.5		23.5
23.8	27	21.8
27.2		19.8
29.7		18.2
30.2	44	17.9

Weld Current Amps	Electrode Force lbs.	Weld Time M.S.
30,200	550	44

TABLE VII

WELD ZONE RESISTANCES FOR 0.050" 2024T3 FOR WELD GROWTH STUDY

Weld Current Kiloamps	Weld Time M.S.	Weld Zone Resistance Microhms
15.3		43.1
22.5		23.0
26.8	27	22.0
30.6		20.9
33.6		19.3
35.3	44	18.1
36.1		17.2
37.4		17.0
37.8	61	16.0
38.7		15.0
40.4		14.0
40.4	78	14.0
40.4		13.0
40.8		12.0
41.6	94	12.0

TABLE VIII

WELD ZONE RESISTANCES FOR 0.050" 5086H34 FOR WELD GROWTH STUDY

Weld Current Kiloamps	Weld Time M.S.	Weld Zone Resistance Microhms
15.3		32.6
22.9		23.1
28.0	27	22.5
31.0		20.9
33.5		19.7
35.2	44	18.1
35.7		16.8
38.2		15.9
38.6	61	15.0
39.9		14.2
40.8		14.2
40.8	78	13.9
41.6		12.9
42.5		13.1
42.5	94	12.9

TABLE IX

RECOMMENDED WELDING SCHEDULES AND TEST RESULTS
FOR RESISTANCE SPOT WELDING ALUMINUM ALLOYS

Gage	Alloy	Weld Current Recom.	Weld Current Actual*	Electrode Force	Weld Time**	Weld Diameter Recom.	Weld Diameter Actual	Pene.	Weld Strength Recom. Min.	Weld Strength Actual
in.		Amps	Amps	lbs.	M.S.	in.	in.	Pct.	lbs.	lbs.
0.020	2024T3	23000	29400	550	44	0.130	0.138	52	140	232
0.020	2014T6	23000	30500	550	44	0.130	0.140	80	140	242
0.020	7075T6	23000	30500	550	44	0.130	0.140	70	140	268
0.025	5086H34	20000	29000	550	44	0.130	0.130	38	140	315
0.050	2024T3	40000	38000	900	94	0.210	0.210	54	600	750
0.050	2014T6	40000	38000	900	94	0.210	0.206	53	600	760
0.050	7075T6	40000	39500	900	94	0.210	0.210	57	600	680
0.050	5086H34	35000	42500	900	94	0.210	0.220	61	600	880
0.050	5456H343	35000	38600	900	94	0.210	0.251	64	600	1040

* Maximum amplitude of current impulse

** - 44 milliseconds (M.S.) = 2 cycles (60 cps)
94 milliseconds (M.S.) = 5 cycles (60 cps)

M.S. = 16.66 x N + 11.4 where N = number of cycles primary current at 60 cps

Electrodes

0.020" 5/8" dia. RWMA Gr.A., Cl. 2, 3" radius dome
0.050" 5/8" dia. RWMA Gr.A., Cl. 2, 4" radius dome

TABLE X

WELD ZONE RESISTANCES FOR ALUMINUM SPOT WELDS FOR RECOMMENDED SCHEDULES

0.020" 2024T3		0.020" 2014T6		0.020" 7075T6		0.025" 5086H34	
Current	Resistance	Current	Resistance	Current	Resistance	Current	Resistance
Kiloamps	Microhms	Kiloamps	Microhms	Kiloamps	Microhms	Kiloamps	Microhms
15.7	33.2	16.2	29.2	14.9	55.6	14.1	36.5
22.5	20.0	21.2	21.7	20.0	28.3	19.5	25.0
26.7	15.4	24.7	21.4	23.4	23.5	23.4	22.7
29.8	13.8	26.8	21.0	26.4	20.0	24.7	20.0
33.1	13.6	29.0	19.0	27.2	19.2	27.6	19.3
33.5	13.8	29.8	16.8	29.3	16.5	28.5	18.0

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TABLE XI

WELD ZONE RESISTANCES FOR ALUMINUM SPOT WELDS FOR RECOMMENDED SCHEDULES

0.050" 2024T3		0.050" 2014T6		0.050" 5086H34		0.050" 5456H343	
Current	Resistance	Current	Resistance	Current	Resistance	Current	Resistance
Kiloamps	Microhms	Kiloamps	Microhms	Kiloamps	Microhms	Kiloamps	Microhms
15.3	43.1	17.0	41.0	16.2	33.0	16.1	23.6
22.5	23.0	23.2	26.8	23.8	21.5	22.1	19.9
26.8	22.0	29.0	21.0	29.0	20.4	26.4	18.1
30.6	20.9	32.3	21.6	31.0	20.2	28.5	17.8
33.6	19.3	34.8	22.1	36.6	17.8	31.0	17.0
35.3	18.1	35.7	20.0	37.4	17.6	32.8	15.5
36.1	17.2	37.0	18.2	38.3	16.2	33.6	14.5
37.4	17.0	39.5	16.9	39.5	15.5	34.0	13.8
37.8	16.0	40.4	15.7	40.3	15.0	35.3	13.0
38.7	15.0	40.8	14.4	40.8	14.4	35.7	12.3
40.4	14.0	42.1	13.9	42.1	13.5	36.1	11.9
40.4	14.0	43.4	13.1	42.5	13.1	36.9	11.3
40.4	13.0	43.7	12.7	43.0	12.4	36.9	11.1
40.8	12.0	45.0	12.1	43.4	12.4	37.8	10.5
41.6	12.0	45.4	12.0	43.8	12.1	38.2	8.9

TABLE XII

WELDING SCHEDULES FOR EVALUATION OF PART II

0.020" ALUMINUM ALLOYS

Phase Shift Pct.	Weld Currents Amperes Amps.	Electrode Force lbs.	Weld Time Milliseconds	Cycles
30	20000 - 23000	300, 400, 500, 600	44	2 (6 pulses)
40	23000 - 28000	300, 400, 500, 600	44	2 (6 pulses)
50	27000 - 32000	300, 400, 500, 600	44	2 (6 pulses)
65	32000 - 38000	300, 400, 500, 600	44	2 (6 pulses)

0.050" ALUMINUM ALLOYS

Phase Shift Pct.	Weld Currents Amperes Amps.	Electrode Force lbs.	Weld Time Milliseconds	Cycles
40	27000 - 29000	600, 800, 1000, 1200	61	3 (9 pulses)
50	33000 - 37000	600, 800, 1000, 1200	61	3 (9 pulses)
65	40000 - 42000	600, 800, 1000, 1200	61	3 (9 pulses)
80	59000 - 63000	600, 800, 1000, 1200	61	3 (9 pulses)
90	63000 - 70000	600, 800, 1000, 1200	61	3 (9 pulses)

0.050" ALUMINUM ALLOYS

Phase Shift Pct.	Weld Currents Amperes Amps.	Electrode Force lbs.	Weld Time Milliseconds	Cycles
40	27000 - 29000	600, 800, 1000, 1200	94	5 (15 pulses)
50	33000 - 37000	600, 800, 1000, 1200	94	5 (15 pulses)
65	40000 - 42000	600, 800, 1000, 1200	94	5 (15 pulses)
80	59000 - 63000	600, 800, 1000, 1200	94	5 (15 pulses)
90	63000 - 7000	600, 800, 1000, 1200	94	5 (15 pulses)

TABLE XIII

REFERENCE AND FINAL WELD ZONE RESISTANCES FOR 0.020" 2024T3

Electrode Force	Phase Shift 30%		Phase Shift 40%		Phase Shift 50%		Phase Shift 65%	
	Microhms							
lbs.	R_o	R_f	R_o	R_f	R_o	R_f	R_o	R_f
300	23	18	24	15	26	12		
400	22	19	22	16.5	27	12		
500	22	17	21	16	19	13	18	11
600	22	16	20	15	18	14	18	11

TABLE XIV

REFERENCE AND FINAL WELD ZONE RESISTANCES FOR 0.020" 2014T6

Electrode Force	Phase Shift 30%		Phase Shift 40%		Phase Shift 50%		Phase Shift 65%	
	Microhms							
lbs.	R_o	R_f	R_o	R_f	R_o	R_f	R_o	R_f
300	26	21	22	16	26	14		
400	21	17.5	19.7	16	20.2	14		
500	19	16.5	17.3	15.5	16.8	13.5		
600	18	15.5	15.5	14.5	16.0	13.8	16	12

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TABLE XV

REFERENCE AND FINAL WELD ZONE RESISTANCES FOR 0.020" 7075T6

Electrode Force	Phase Shift 30%		Phase Shift 40%		Phase Shift 50%		Phase Shift 65%	
	Microhms							
lbs.	R_o	R_f	R_o	R_f	R_o	R_f	R_o	R_f
300	30	17	30	14	31	11		
400	26.5	18	27	15.7	29.5	11		
500	17.5	15	18.5	15.0	20	12.8		
600	19.5	16	19.5	14.7	21.0	14.0	20	10.8

TABLE XVI

REFERENCE AND FINAL WELD ZONE RESISTANCE FOR 0.025" 5086H34

Electrode Force	Phase Shift 30%		Phase Shift 40%		Phase Shift 50%		Phase Shift 65%	
	Microhms							
lbs.	R_o	R_f	R_o	R_f	R_o	R_f	R_o	R_f
300	28	20	25.5	19	24	17		
400	20.5	17.5	20.0	17.5	21.0	15.5		
500	20.7	16.9	18.5	15.4	18.0	15.0		
600	20.0	16.7	18.7	16.0	19.0	15.0	19.0	14.3

TABLE XVII

WELD ZONE PERCENT CHANGE IN RESISTANCE VS. WELD SIZE

Gage	Material	Percent Weld Zone Resistance	Weld Diameter
in.		Pct.	in.
0.020	2024T3	20 - 26	0.138" - 0.144"
0.020	2014T6	15 - 20	0.143" - 0.150"
0.020	7075T6	15 - 16	0.130" - 0.131"
0.025	5086H34	15 - 17	0.115" - 0.132"

TABLE XVIII

DATA FOR WELD ZONE RESISTANCES FOR EFFECT OF WELDING SCHEDULES ON 0.020" 2024T3

Specimen No.	Weld Current Kiloamps	Electrode Force lbs.	Weld Time M.S.	Weld Zone Resistance 18MS M.O.	44MS M.O.	ΔR M.O.	Pct ΔR/R Pct	Av. Pct	Weld Strength Metal Exp.	lbs.	Av. lbs.
24A72	21.2	300	44	23.6	20.3	3.3	14.0	19.8	No	205	200
73	21.2			24.1	17.9	6.2	25.7		"	196	
76	25.0			23.5	15.6	7.9	33.6	37.0	"	251	259
77	25.5			25.7	15.3	10.4	40.5		"	266	
80	31.9			27.0	11.0	16.0	59.2	53.7	Yes	245	306
81	31.0			25.5	13.2	12.3	48.2		Yes	367	
84	37.4			25.8	11.0	14.8	57.4	53.5	Yes	327	361
85	36.5	300	44	24.4	12.3	12.1	49.6		Yes	395	
88	17.4	400	44	22.9	21.3	1.6	7.0	14.6	No		57
89	20.8			22.9	17.8	5.1	22.3		"	115	
92	23.8			23.6	16.0	7.6	32.3	26.6	"	222	226
93	23.8			21.8	17.2	4.6	21.1		"	230	
96	30.2			21.1	12.6	7.5	35.5	36.8	Yes	302	313
97	29.3			22.0	13.6	8.4	38.2		Yes	325	
100	34.8			21.3	10.0	11.3	53.0	51.4	Yes	335	343
101	33.6	400	44	23.1	11.6	11.5	49.8		Yes	352	
104	20.0	500	44	22.9	17.0	5.9	25.8	23.2	No		N.W.
105	19.6			21.8	17.3	4.5	20.6		"		
108	22.9			23.5	16.6	6.9	29.4	26.0	"	105	109
109	22.9			20.8	16.1	4.7	22.6		"	112	
112	28.1			19.4	13.9	5.5	28.3	26.5	"	272	266
113	28.1			19.4	14.6	4.8	24.7		"	261	
116	32.3			18.4	13.0	5.4	29.3	39.8	"	398	336
117	34.0	500	44	18.9	9.4	9.5	50.3		Yes	275	
120	20.8	600	44	23.6	16.3	7.3	30.9	29.5	No		N.W.
121	20.0			22.3	16.0	6.3	28.2		No		
124	23.4			21.3	16.7	4.6	21.6	25.2	No	140	137
125	22.9			20.8	14.8	6.0	28.8		No	134	
128	28.1			18.4	15.3	3.1	16.8	19.8	No	284	271
129	27.6			18.9	14.7	4.2	22.2		No	259	
132	34.0			18.4	11.5	6.9	37.5	36.4	Yes	380	349
24A133	33.6	600	44	18.4	11.9	6.5	35.3		Yes	319	

TABLE XIX

DATA FOR WELD ZONE RESISTANCES FOR EFFECT OF WELDING SCHEDULE ON
0.020" 2014T6

Specimen No.	Weld Current Kiloamps	Electrode Force lbs.	Weld Time M.S.	Weld Zone Resistance 18MS M.O.	44MS M.O.	ΔR M.O.	Pct R Pct	Av. Pct	Weld Metal Exp.	Weld Strength lbs.	Av. lbs.
14A22	20.0	300	44	28.6	24.5	4.1	14.3	17.9	No	175	135
23	20.0			23.6	18.5	5.1	21.6		"	95	
26	22.9			22.9	16.6	6.3	27.5	28.8	"	235	231
27	23.8			22.9	16.0	6.9	30.1		"	227	
30	28.9			26.0	14.5	11.5	44.2	46.1	Yes	315	292
31	29.3			27.0	14.0	13.0	48.1		Yes	270	
34	33.1			26.5	10.3	16.2	61.0	64.0	Yes	242	281
35	34.8	300	44	26.9	8.9	18.0	66.9		Yes	320	
38	20.0	400	44	22.3	18.5	3.8	17.0	17.6	No	-	N.W.
39	20.8			21.2	17.3	3.9	18.2		"	-	
42	22.1			19.7	18.5	1.2	6.0	23.3	"	184	190
43	23.8			19.7	15.1	4.6	23.3		"	197	
46	28.5			20.2	14.0	6.2	30.6	30.6	"	262	259
47	29.3			20.2	14.0	6.2	30.6		"	257	
50	34.0			23.5	10.9	12.6	53.6	49.5	Yes	340	321
51	35.3	400	44	21.8	11.9	9.9	45.4		Yes	302	
54	21.7	500	44	20.1	16.6	3.5	17.4	14.1	No	-	N.W.
55	21.2	500	44	18.5	16.5	2.0	10.8		"	-	
58	25.0			17.3	16.8	0.5	2.8	7.4	"	176	164
59	25.0			17.3	15.2	2.1	12.1		"	152	
62	30.2			16.6	14.2	2.4	14.4	19.4	"	257	258
63	31.4			17.2	13.0	4.2	24.4		"	260	
66	38.2			16.9	8.4	8.5	50.2	49.8	Yes	275	270
67	36.9	500	44	18.2	9.2	9.0	49.4		Yes	265	
70	21.7	600	44	19.1	16.1	3.0	15.7	15.9	No	-	N.W.
71	22.1			17.8	14.9	2.9	16.2		"	-	
74	25.5			15.1	14.1	1.0	6.6	7.5	"	130	115
75	25.5			16.3	14.9	1.4	8.5		"	100	
78	30.2			16.0	14.2	1.8	11.2	13.0	"	233	219
79	30.6			16.1	13.7	2.4	14.9		"	205	
82	31.4			16.1	13.4	2.7	16.7	21.1	Yes	243	234
14A83	34.8	600	44	16.0	11.9	4.1	25.6		No	225	

TABLE XX

DATA FOR WELD ZONE RESISTANCES FOR EFFECT OF WELDING SCHEDULE ON

0.020" 7075T6

Specimen No.	Weld Current Kiloamps	Electrode Force lbs.	Weld Time M.S.	Weld Zone Resistance 18MS M.O.	44MS M.O.	ΔR M.O.	Pct R Pct	Av. Pct	Weld Strength Metal Exp.	lbs.	Av. lbs.
75A22	22.5	300	44	34.7	18.2	16.5	47.6	41.6	Yes	230	230
23	22.5			26.4	16.9	9.5	36.0		Yes	230	
26	25.9			29.0	13.9	15.1	52.1	51.7	Yes	303	284
27	25.5			31.5	15.3	16.2	51.4		Yes	265	
30	31.4			32.1	10.8	21.3	66.4	63.6	Yes	228	241
31	31.4			30.1	11.8	18.3	60.8		Yes	255	
34	34.0			28.8	14.1	14.7	51.0	53.1	Yes	300	345
35	34.0	300	44	28.8	12.9	15.9	55.2		Yes	390	
38	21.2	400	44	26.5	18.4	8.1	30.6	32.2	No	190	192
39	21.2			27.1	17.9	9.2	33.9		"	195	
42	25.9			26.2	15.4	10.8	41.2	42.6	Yes	293	294
43	24.6			28.4	15.9	12.5	44.0		Yes	300	
46	31.0			30.0	11.9	18.1	60.3	62.0	Yes	250	262
47	30.6			29.0	10.5	18.5	63.8		Yes	275	
50	35.3			28.3	11.3	17.0	60.1	56.9	Yes	320	390
51	35.7	400	44	27.2	12.6	14.6	53.7		Yes	460	
54	23.4	500	44	17.2	15.0	2.2	12.8	15.2	No	-	60
55	22.9			18.6	15.3	3.3	17.7		"	120	
58	26.3			18.1	16.0	2.1	11.6	16.7	"	248	249
59	27.2			18.8	14.7	4.1	21.8		"	250	
62	31.9			21.2	13.2	8.0	37.7	37.2	Yes	340	335
63	32.3			20.1	12.7	7.4	36.8		Yes	330	
66	38.6			25.6	10.6	15.0	58.6	56.1	Yes	360	375
67	38.2	500	44	24.8	11.5	13.3	53.6		Yes	390	
70	20.0	600	44	20.0	16.0	4.0	20.0	16.5	No	-	N.W.
71	20.0			19.0	16.5	2.5	13.1		"	-	
74	24.6			19.3	15.0	4.3	22.3	24.5	"	140	135
75	24.2			19.8	14.5	5.3	26.8		"	130	
78	28.5			20.5	13.7	6.8	33.2	32.8	"	308	298
79	27.6			21.5	14.5	7.0	32.5		"	288	
82	35.7			19.9	10.4	9.5	47.7	45.8	Yes	340	350
75A83	34.0	600	44	20.0	11.2	8.8	44.0		Yes	360	

TABLE XXI

DATA FOR WELD ZONE RESISTANCES FOR EFFECT OF WELDING SCHEDULE ON
0.025" 5086H34

Specimen No.	Weld Current Kiloamps	Electrode Force lbs.	Weld Time M.S.	Weld Zone Resistance 18MS M.O.	44MS M.O.	ΔR M.O.	Pct $_R$ Pct	Av. Pct	Weld Strength Metal Exp.	lbs.	Av. lbs.
86A20	21.0	300	44	31.3	22.8	8.5	27.0	25.9	No	175	192
21	22.1	300		25.3	19.0	6.3	24.9		"	210	
24	24.2	300		26.2	19.0	7.2	27.5	25.3	"	305	324
25	24.5	300		25.0	19.2	5.8	23.2		"	343	
28	30.6	300		24.4	18.2	6.2	25.6	28.4	Yes	455	449
29	30.6	300		24.3	16.7	7.6	31.3		Yes	443	
32	34.0	300		26.3	13.5	12.8	48.6	47.8	Yes	505	491
33	35.5	300	44	25.3	13.4	11.9	47.0		Yes	477	
36	23.4	400	44	20.3	17.5	2.8	13.8	15.8	No	-	50
37	21.7			21.3	17.5	3.8	17.8		"	100	
40	26.8			21.0	17.9	3.1	14.8	13.8	"	299	279
41	25.9			19.5	17.0	2.5	12.8		"	260	
44	31.0			20.8	15.8	5.0	24.0	26.1	Yes	444	442
45	31.4			21.3	15.3	6.0	28.2		Yes	440	
48	36.1			24.4	13.3	11.1	45.5	48.2	Yes	538	513
49	36.9	400	44	24.9	12.5	12.4	51.0		Yes	490	
52	23.4	500	44	20.2	16.7	3.5	17.3	17.8	No	-	N.W.
53	22.9			20.8	17.0	3.8	18.3		"	-	
56	28.1			19.8	15.3	4.5	22.7	18.2	"	230	215
57	27.6			18.1	15.6	2.5	13.8		"	200	
60	32.3			17.9	14.9	3.0	16.7	18.1	Yes	446	443
61	31.4			19.0	15.3	3.7	19.5		Yes	440	
64	36.9			19.7	13.6	6.1	31.0	36.8	Yes	520	515
65	37.4	500	44	22.3	12.8	9.5	42.6		Yes	510	
68	20.0	600	44	20.5	17.0	3.5	17.1	17.6	No	-	N.W.
69	20.8			19.9	16.3	3.6	18.1		"	-	
72	23.4			18.6	15.8	2.8	15.0	15.1	"	100	107
73	23.4			19.1	16.2	2.9	15.2		"	115	
76	27.2			20.3	16.5	3.8	18.7	20.2	"	335	325
77	27.6			18.9	14.8	4.1	21.7		"	315	
80	32.8			18.0	14.6	3.4	18.9	24.9	Yes	463	454
86A81	32.8	600	44	20.3	14.0	6.3	31.0		Yes	445	

TABLE XXII

DATA FOR GRAPHS OF EFFECT OF ELECTRODE SHAPE ON WELD ZONE RESISTANCE FOR 0.020" ALUMINUM ALLOYS

0.020" 2024T3						0.020" 7075T6					
1"R 24A136		3"R 24A142		10"R 24A152		1"R 75A87		3"R 75A95		10"R 75A103	
Current K Amps	Res. M.O.	Current K Amps	Res. M.O.	Current K Amps	Res. M.O.	Current K Amps	Res. M.O.	Current K Amps	Res. M.O.	Current K Amps	Res. M.O.
16.1	30.4	15.3	35.9	15.7	29.9	16.1	25.4	15.7	26.1	16.6	19.8
20.0	22.5	20.8	21.6	20.8	19.2	20.8	21.6	21.2	19.3	21.2	17.4
24.2	22.7	24.2	18.5	25.0	15.6	25.0	18.0	25.0	17.6	25.5	16.8
25.5	19.6	26.4	16.2	27.2	13.9	27.2	15.0	27.2	16.1	27.6	15.9
28.1	17.4	28.5	14.3	29.3	13.3	29.8	10.7	28.9	14.1	29.3	14.6
28.9	16.2	29.3	12.9	30.6	13.3	31.9	10.0	31.0	12.2	31.4	11.7

0.020" 2014T6						0.025" 5086H34					
14A88		14A94		14A102		86A85		86A93		86A99	
17.0	20.0	16.6	19.2	16.1	22.3	14.4	28.4	14.4	28.4	14.4	25.6
22.1	19.0	22.1	17.6	21.7	16.5	20.0	24.0	20.0	19.0	19.6	18.8
25.5	17.6	25.5	17.6	25.5	16.4	22.9	19.2	22.9	17.9	22.1	18.5
28.1	15.3	28.1	16.3	27.6	15.2	25.0	17.6	24.6	16.2	24.6	16.2
30.2	13.2	29.8	14.7	29.3	13.9	26.8	16.4	27.2	15.4	26.8	15.2
31.4	11.7	31.4	12.7	31.4	12.4	28.1	14.5	28.1	15.3	27.2	15.0

TABLE XXIII

PERCENT CHANGE IN WELD ZONE RESISTANCE FOR SPOT WELDS IN 0.050" ALUMINUM ALLOYS

Material	Weld Time M.S.	Percent Resistance Change Pct	Weld Strength Lbs.
2024T3	61	30 - 37	450 - 700
2024T3	94	35 - 42	400 - 800
2014T6	61	22 - 26	450 - 700
2014T6	94	30 - 40	400 - 800
7075T6	61	19 - 35	450 - 700
7075T6	94	30 - 37	400 - 800
5086H34	61	20 - 26	450 - 700
5086H34	94	22 - 29	400 - 800
5456H343	61	13 - 21	450 - 700
5456H343	94	25 - 34	400 - 800

TABLE XXIV

COMPARISON OF WELD ZONE RESISTANCE CHANGE WITH WELD SIZE FOR THREE ALUMINUM ALLOYS

Alloy	Current Percent Heat	Electorde Force lbs.	Weld Time M.S.	R_o M.O.	R_o^1 M.O.	R_f M.O.	%R Pct.	%R^1 Pct.	Weld Dia. in.
2024T3	40	800	94	36.0	25	18.7	51.0	17.5	N.W.
2024T3	65	800	"	27.0	22	13.0	52.0	33.4	0.218
2024T3	40	1000	"	31	21	18.0	42.0	14.0	0.086
2024T3	65	1000	"	23.0	19.4	13.0	43.5	33.0	0.240
2024T3	40	1200	"	34.0	20	17.0	50.0	15.0	0.090
2024T3	65	1200	"	22.0	19.0	12.8	41.8	32.8	0.244
7075T6	40	800	"	27.7	24.5	17.7	36.0	27.8	0.100
7075T6	65	800	"	24.8	21.8	12.4	50.0	43.0	0.252
7075T6	40	1000	"	21.5	20.0	15.6	27.4	22.0	N.W.
7075T6	65	1000	"	21.8	20.0	12.4	43.0	38.0	0.263
7075T6	40	1200	"	24.6	20.0	17.0	31.0	15.0	N.W.
7075T6	65	1200	"	20.	17.5	12.7	36.5	27.4	0.229
5086H34	40	800	"	23.5	22	19	19.4	13.6	0.098
5086H34	65	800	"	22.0	21.0	13	41.0	38.0	0.220
5086H34	40	1000	"	23.2	21	18	21.5	14.3	N.W.
5086H34	65	1000	"	17.4	17.4	12.9	25.8	25.8	0.235
5086H34	40	1200	"	19.3	16.6	15.8	18.2	3.8	N.W.
5086H34	65	1200	"	18.3	17.2	12.4	32.1	28.0	0.226

TABLE XXV

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR 0.050" 2024T3
WELD TIME 61 M.S.

Specimen No.	Welding Schedule Current Kiloamps 27	End	Electrode Force lbs.	Weld Zone Resistance Start MO	27 MO	End MO	Weld Zone Resistance Change MO	Pct	Av.	Spit	Weld Strength lbs.	Av.
24B62	20.8	24.2	600	91.6	30.8	25.6	5.2	16.9	26.1	No	60	108
63	20.0	25.5	"	75.0	34.5	22.3	12.2	35.4		"	155	
66	22.2	31.5	"	77.9	28.9	19.7	9.2	31.8	24.5	"	370	352
67	28.5	31.0	"	80.7	23.8	19.7	4.1	17.2		"	335	
70	26.8	38.2	"	56.7	25.4	17.0	8.4	33.1	34.7	Yes	450	486
71	26.3	36.5	"	59.2	25.8	16.4	9.4	36.4		Yes	522	
74	32.7	53.1	"	58.0	26.9	12.8	14.1	52.4	52.4	Yes	885	945
75	33.1	52.7	600	58.4	25.4	12.1	13.3	52.4		Yes	1005	
94	20.4	26.3	800	68.9	27.0	20.9	6.1	22.6	28.1	No	160	142
95	20.4	25.9	"	70.9	31.4	20.8	10.6	33.7		"	125	
98	24.2	33.1	"	65.3	24.4	18.4	6.0	24.6	28.2	"	452	361
99	22.5	31.0	"	81.6	30.2	20.6	9.6	31.8		"	270	
102	25.9	38.7	"	68.0	24.7	16.3	8.4	34.0	40.8	"	742	741
103	26.3	37.0	"	57.3	25.1	17.0	8.1	47.6		"	740	
106	33.6	53.5	"	98.1	21.7	12.3	9.4	43.3	43.6	Yes	792	880
107	33.6	51.8	800	51.7	22.3	12.5	9.8	43.9		Yes	968	
126	19.1	26.8	1000	75.7	32.5	19.4	13.1	40.3	31.6	No	N.W.	N.W.
127	20.4	25.5	"	66.9	27.0	20.8	6.2	23.0		"	N.W.	
130	23.8	32.3	"	54.8	23.9	17.9	6.0	25.1	30.9	"	245	277
131	22.5	31.9	"	86.8	30.2	19.1	11.1	36.7		"	310	
134	27.2	38.7	"	63.4	22.8	16.0	6.8	29.8	27.5	"	632	657
135	27.6	38.2	"	49.7	22.1	16.5	5.6	25.3		"	683	
138	35.7	55.7	"	49.2	19.3	10.8	8.5	44.0	41.5	Yes	980	997
24B139	35.3	53.1	1000	46.0	19.8	11.9	7.9	39.9		Yes	1015	

TABLE XXV (CONTINUED)

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR 0.050" 2024T3
WELD TIME 61 M.S.

Specimen No.	Welding Schedule			Weld Zone Resistance			Weld Zone Resistance Change			Spit	Weld Strength	
	Current Kiloamps		Electrode Force									
	27	End	lbs.	Start MO	27 MO	End MO	MO	Pct	Av.		lbs.	Av.
24B142	38.7	62.5	1000	48.5	21.4	9.9	11.5	53.7	49.1	Yes	955	1015
143	37.4	60.3	1000	46.5	19.5	10.8	8.7	44.6		Yes	1075	
166	22.1	28.5	1200	42.9	22.6	17.9	4.7	20.8	23.6	No	N.W.	N.W.
167	21.2	27.2	"	43.4	26.0	19.1	6.9	26.5		"	N.W.	
170	26.3	35.7	"	32.3	19.4	15.4	4.0	20.6	21.0	"	70	150
171	25.5	34.4	"	34.2	20.0	15.7	4.3	21.5		"	230	
174	29.3	41.6	"	30.9	19.8	14.4	5.4	27.3	27.6	No	352	372
175	28.0	39.5	"	30.0	20.7	14.9	5.8	28.0		"	393	
178	37.4	57.4	"	29.9	18.4	12.4	6.0	32.6	37.4	Yes	703	612
179	36.1	54.0	"	29.0	18.0	10.4	7.6	42.2		Yes	521	
182	40.8	65.4	"	29.5	17.9	9.0	8.9	49.7	44.5	Yes	769	779
24B183	39.9	57.4	1200	26.9	17.5	10.6	6.9	39.4		Yes	789	

TABLE XXVI

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR 0.050" 2024T3
WELD TIME 94 M.S.

Specimen No.	Welding Schedule			Weld Zone Resistance			Weld Zone Resistance Change			Spit	Weld Strength	
	Current Kiloamps 27	End	Electrode Force lbs.	Start MO	27 MO	End MO	MO	Pct	Av.		lbs.	Av.
24B78	19.1	27.2	600	81.1	38.7	20.6	18.1	46.7	42.5	No	298	303
79	19.5	26.8	"	62.2	30.8	19.0	11.8	38.3		"	308	
82	22.9	36.1	"	67.4	31.4	13.6	17.8	56.7	52.2	"	540	571
83	22.1	34.0	"	71.4	30.8	15.9	14.9	48.4		"	602	
86	25.5	43.3	"	71.3	28.2	12.5	15.7	55.7	54.8	Yes	738	660
87	25.1	42.5	"	62.7	29.1	13.4	15.7	53.9		Yes	582	
90	34.0	61.6	"	58.0	25.0	9.4	15.6	62.4	61.9	Yes	1100	1137
91	32.3	58.2	600	57.0	25.4	9.8	15.6	61.4		Yes	1145	
110	19.1	27.6	800	69.7	37.2	19.2	18.0	48.4	48.1	No	95	157
111	18.7	27.2	"	65.2	35.3	18.4	16.9	47.9		"	220	
114	23.8	35.7	"	81.6	26.5	15.1	11.4	43.0	43.4	"	778	758
115	23.4	35.3	"	73.6	27.3	15.3	12.0	43.9		"	739	
118	25.9	43.3	"	68.4	25.1	12.9	12.2	48.6	51.6	"	1040	982
119	24.6	44.2	"	63.4	28.9	13.1	15.8	54.7		"	925	
122	33.6	61.6	"	67.8	25.3	10.1	15.2	60.1	56.8	Yes	1335	1290
123	34.0	58.6	800	43.8	20.9	9.7	11.2	53.6		Yes	1255	
146	20.4	27.6	1000	74.0	30.4	17.7	12.7	41.8	41.6	No	260	224
147	19.5	26.3	"	69.0	31.8	18.6	13.2	41.5		"	188	
150	21.7	34.8	"	77.2	33.2	15.3	17.9	53.3	45.4	"	618	609
153	23.8	34.8	"	54.4	73.9	14.9	9.0	37.6		"	600	
154	26.3	38.2	"	62.4	22.4	14.1	8.3	37.0	43.2	"	920	940
155	25.5	41.2	"	53.5	25.5	12.9	12.6	49.4		"	960	
158	34.0	62.0	"	59.0	20.6	7.7	12.9	62.6	61.9	Yes	918	938
24B159	34.0	57.8	1000	46.5	20.9	8.1	12.8	61.2		Yes	958	

TABLE XXVI (CONTINUED)

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR 0.050" 2024T3
WELD TIME 94 M.S.

Specimen No.	Welding Schedule			Weld Zone Resistance			Weld Zone Resistance Change			Spit	Weld Strength	
	Current		Electrode Force									
	Kiloamps 27	End	lbs.	Start MO	27 MO	End MO	MO	Pct	Av.		lbs.	Av.
24B186	19.1	30.2	1200	90.5	41.9	16.9	25.0	59.7	49.6	No	240	225
187	20.4	27.2	"	64.0	30.9	18.7	12.2	39.5		"	210	
190	25.5	37.0	"	31.8	22.3	14.0	8.3	37.2	36.0	"	475	453
191	25.1	37.0	"	35.0	20.7	13.5	7.2	34.8		"	432	
194	28.0	44.6	"	47.6	22.8	12.8	10.0	43.8	42.1	"	720	729
195	27.6	42.5	"	49.1	21.7	12.9	8.8	40.5		"	738	
198	36.1	61.2	"	41.5	20.8	10.6	10.6	49.0	55.1	Yes	1298	1158
24B199	35.3	60.8	1200	41.9	21.2	8.2	13.0	61.2		Yes	1018	

TABLE XXVII

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR 0.050" 2014T6
WELD TIME 61 M.S.

Specimen No.	Welding Schedule			Weld Zone Resistance			Weld Zone Resistance Change			Spit	Weld Strength	
	Current		Electrode Force									
	Kiloamps 27	End	lbs.	Start MO	27 MO	End MO	MO	Pct	Av.		lbs.	Av.
14B1	21.	24.2	600	52.8	26.7	23.6	3.1	11.6	16.3	No	196	219
2	21.	24.5	"	45.0	29.0	22.9	6.1	21.0		"	242	
5	23.8	33.1	"	46.3	28.1	19.3	8.8	31.3	36.5	"	678	591
6	24.6	33.1	"	41.0	26.4	15.4	11.0	41.7		"	504	
9	25.9	37.8	"	32.9	28.9	16.7	12.2	42.2	43.9	Yes	738	738
10	24.5	35.7	600	39.5	29.3	15.9	13.4	45.7		Yes	738	
33	21.0	26.4	800	50.0	27.1	19.7	7.4	27.3	19.6	No	0	57
34	21.0	23.8	"	36.7	24.3	21.4	2.9	12.0		"	114	
37	23.8	32.3	"	35.2	23.5	17.3	6.2	26.4	26.4	"	380	406
38	24.2	32.8	"	32.7	22.7	16.7	6.0	26.4		"	432	
41	26.8	38.6	"	31.8	22.8	15.5	7.3	32.0	33.7	"	700	707
42	26.8	37.8	"	34.9	24.2	15.6	8.6	35.5		"	714	
45	34.8	56.1	"	30.5	22.2	11.7	10.5	47.2	48.6	Yes	876	927
46	34.0	52.7	800	33.6	23.2	11.6	11.6	50.0		Yes	978	
65	21.2	28.1	1000	47.8	25.9	19.9	6.0	23.2	23.2	No	N.W.	N.W.
66	25.9	35.3	"	36.7	20.9	17.8	3.1	14.8	23.7	"	328	366
67	24.5	39.1	"	31.3	22.0	14.8	7.2	32.7		"	404	
70	29.8	42.0	"	29.2	18.4	14.2	4.2	22.2	24.4	"	746	745
71	27.6	40.3	"	32.9	20.3	14.9	5.4	26.6		"	744	
74	37.8	56.1	"	27.1	19.1	12.1	7.0	36.6	38.0	Yes	1080	1056
75	38.2	56.6	1000	27.3	18.3	11.1	7.2	39.4		Yes	1032	
94	21.2	27.5	1200	46.2	22.2	17.8	4.4	19.8	19.8	No	N.W.	N.W.
95	24.6	33.1	"	39.6	20.7	16.3	4.4	21.3	21.8	"	254	247
96	24.6	32.8	"	42.4	20.7	16.1	4.6	22.3		"	240	
99	28.1	39.1	"	40.7	18.2	14.1	4.1	22.5	22.1	"	612	589
100	28.8	40.3	"	28.7	18.0	14.1	3.9	21.7		"	566	
103	34.8	54.4	"	28.3	18.1	9.9	8.2	45.3	39.9	Yes	1218	1098
14B104	36.1	53.3	1200	37.9	17.4	11.4	6.0	34.5		Yes	978	

TABLE XXVIII

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR 0.050" 2014T6
WELD TIME 94 M.S.

Specimen No.	Welding Schedule Current Kiloamps 27	Welding Schedule Current Kiloamps End	Electrode Force lbs.	Weld Zone Resistance Start MO	Weld Zone Resistance 27 MO	Weld Zone Resistance End MO	Weld Zone Resistance Change MO	Weld Zone Resistance Change Pct	Weld Zone Resistance Change Av.	Spit	Weld Strength lbs.	Weld Strength Av.
14B17	21.0	27.6	600	42.1	27.1	17.7	9.4	34.6	33.7	No	404	402
18	21.0	27.6	"	29.5	27.6	18.5	9.1	32.9		"	400	
21	23.8	35.3	"	41.6	27.3	14.7	12.6	46.2	51.1	"	816	708
22	23.8	36.1	"	32.4	28.1	12.4	15.7	56.1		"	600	
25	26.8	44.2	"	37.4	28.3	10.6	17.7	62.7	60.1	Yes	752	875
26	24.5	41.6	600	35.0	29.8	12.7	17.1	57.5		Yes	998	
49	21.2	33.1	800	42.3	25.4	14.5	10.9	43.0	46.1	No	0	55
50	20.8	32.8	"	42.1	25.4	13.4	12.0	49.2		"	110	
53	24.6	36.1	"	33.7	21.5	13.8	7.7	35.8	34.8	"	672	676
54	24.6	36.1	"	38.2	22.4	13.6	8.8	33.9		"	680	
57	27.2	41.2	"	34.3	22.4	10.7	11.7	52.2	49.3	Yes	940	995
58	24.5	39.5	"	31.6	24.5	13.1	11.4	46.5		Yes	1050	
61	34.0	60.4	"	30.2	25.6	9.8	15.8	61.8	61.5	Yes	1260	1263
62	34.0	58.6	800	33.1	23.8	9.2	14.6	61.2		Yes	1266	
78	22.1	29.8	1000	28.0	23.1	16.4	6.7	29.0	27.8	No	282	296
79	22.9	28.8	"	29.5	22.2	16.3	5.9	26.6		"	310	
82	24.5	37.8	"	28.2	21.2	12.9	8.3	39.0	39.8	"	750	764
83	24.5	37.4	"	28.3	21.6	12.8	8.8	40.7		"	778	
86	28.8	45.9	"	29.9	20.1	11.5	8.6	42.7	44.2	Yes	990	1036
87	28.1	43.8	"	30.0	20.7	11.2	9.5	45.8		Yes	1082	
90	36.9	64.6	"	25.2	20.8	8.1	12.7	61.0	59.1	Yes	1148	1196
91	35.7	61.2	1000	29.0	22.2	9.3	12.9	57.2		Yes	1244	
111	21.2	26.4	1200	32.2	23.1	20.4	2.7	11.7	18.3	No	N.W.	N.W.
112	21.2	28.1	"	35.3	21.7	16.3	5.4	24.9		"	N.W.	
115	24.2	34.8	"	27.0	21.1	14.6	6.5	30.8	32.1	"	580	571
116	23.4	34.4	"	32.2	20.9	13.9	7.0	33.5		"	562	
119	28.1	41.6	"	18.4	18.8	13.0	5.8	30.9	33.0	"	788	824
120	27.2	41.2	"	27.7	18.7	12.1	6.6	35.2		"	860	
123	34.8	61.2	"	32.1	17.2	9.1	8.1	47.1	49.3	Yes	996	1093
14B124	35.3	59.6	1200	29.1	19.0	9.2	9.8	51.6		Yes	1190	

TABLE XXIX

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR 0.050" 7075T6
WELD TIME 61 M.S.

Specimen No.	Welding Schedule Current Kiloamps 27	End	Electrode Force lbs.	Weld Zone Resistance Start MO	27 MO	End MO	Weld Zone Resistance Change MO	Pct	Av.	Spit	Weld Strength lbs.	Av.
75B12	18.7	24.2	600	61.2	39.0	23.1	15.9	40.5	41.8	No	155	191
13	20.1	28.8	"	70.5	32.9	18.7	14.2	43.2		"	228	
16	22.1	31.0	"	59.6	32.0	19.3	12.7	39.8	40.0	"	320	340
17	22.1	30.6	"	60.0	31.6	18.9	12.7	40.2		"	360	
20	25.4	37.4	"	41.7	31.1	17.1	14.0	45.0	47.7	Yes	430	422
21	25.4	36.1	"	56.8	30.7	15.2	15.5	50.5		Yes	415	
24	31.9	53.5	"	47.2	29.1	12.3	16.8	57.8	60.2	Yes	599	638
25	32.3	51.5	600	43.7	30.6	11.4	19.2	62.7		Yes	678	
44	20.8	25.5	800	38.9	25.9	20.8	5.1	19.7	21.4	No	141	170
45	21.2	26.7	"	42.3	25.4	19.5	5.9	23.1		"	200	
48	24.8	32.7	"	56.3	24.6	17.1	7.5	30.5	29.4	"	392	423
49	23.8	32.3	"	40.7	25.0	17.9	7.1	28.4		"	455	
52	26.8	39.1	"	45.2	25.0	15.6	7.4	37.5	36.6	"	560	562
53	27.2	37.4	"	32.3	24.2	15.5	8.7	35.8		"	565	
56	34.0	54.8	"	42.1	23.8	12.4	11.4	48.0	49.5	Yes	632	692
57	33.5	51.8	800	38.0	25.1	12.3	12.8	51.0		Yes	753	
76	21.2	26.4	1000	47.2	26.4	19.7	6.7	25.3	18.3	No	216	214
77	22.5	26.8	"	38.1	21.8	19.3	2.5	11.4		"	213	
80	28.5	31.9	"	48.7	21.4	18.8	2.6	12.1	18.5	"	429	472
81	24.2	33.6	"	42.0	22.3	16.7	5.6	25.0		"	515	
84	27.6	39.1	"	40.0	23.5	15.1	8.4	35.7	35.1	"	681	690
85	27.6	39.5	"	38.8	23.5	15.4	8.1	34.5		"	698	
88	34.8	53.9	"	34.7	22.4	12.8	9.6	41.8	42.4	Yes	785	822
75B89	34.8	56.1	1000	36.8	22.4	12.6	9.8	43.0		Yes	860	

TABLE XXIX (CONTINUED)

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR 0.050" 7075T6
WELD TIME 61 M.S.

Specimen No.	Welding Schedule: Current, Kiloamps 27	Welding Schedule: Current, Kiloamps End	Welding Schedule: Electrode Force, lbs.	Weld Zone Resistance: Start MO	Weld Zone Resistance: 27 MO	Weld Zone Resistance: End MO	Weld Zone Resistance Change: MO	Weld Zone Resistance Change: Pct.	Weld Zone Resistance Change: Av.	Spit	Weld Strength: lbs.	Weld Strength: Av.
75B116	21.2	25.9	1200	46.5	20.8	18.8	2.0	10.4	10.7	No	-	N.W.
117	21.2	26.4	"	46.4	20.8	18.5	2.3	11.1		"	-	
120	24.2	31.9	"	27.6	21.1	17.5	3.6	17.1	14.8	"	335	353
121	24.6	32.3	"	21.8	19.1	16.7	2.4	12.5		"	371	
124	26.8	36.9	"	31.7	20.5	15.4	5.1	24.8	26.4	"	698	689
125	28.1	38.6	"	24.7	20.6	14.8	5.8	28.0		"	680	
128	34.8	51.8	"	28.1	19.0	12.1	6.9	36.4	42.1	Yes	1155	1130
75B129	29.8	55.3	1200	29.1	22.8	11.9	10.9	47.8		Yes	1105	

TABLE XXX

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR 0.050" 7075T6
WELD TIME 94 M.S.

Specimen No.	Welding Schedule: Current Kiloamps 27	Current Kiloamps End	Electrode Force lbs.	Weld Zone Resistance Start MO	Weld Zone Resistance 27 MO	Weld Zone Resistance End MO	Weld Zone Resistance Change MO	Change Pct	Change Av.	Spit	Weld Strength lbs.	Weld Strength Av.
75B28	18.7	24.6	600	68.0	36.3	21.5	14.8	40.7	40.1	No	272	342
29	20.1	26.4	"	45.0	31.3	18.9	12.4	39.6		"	413	
32	22.1	29.8	"	73.5	28.5	14.2	14.3	50.2	43.8	"	474	522
33	24.6	34.8	"	40.7	26.0	16.2	9.8	37.5		"	570	
36	24.6	40.0	"	59.6	29.6	14.5	15.1	51.0	58.6	Yes	505	444
37	24.6	43.3	"	51.9	30.8	10.4	20.4	66.2		Yes	383	
40	30.6	57.0	"	51.0	32.3	10.2	22.1	68.5	64.6	Yes	827	848
41	32.7	58.1	600	43.8	26.3	10.3	16.0	60.8		Yes	868	
60	20.1	27.6	800	54.5	29.3	17.7	11.6	39.6	36.0	No	165	257
61	20.2	26.4	"	45.7	26.2	17.7	8.5	32.4		"	350	
64	22.9	35.3	"	52.7	27.1	14.4	12.7	46.8	47.2	"	751	757
65	22.1	33.2	"	49.2	28.9	15.1	13.8	47.7		"	764	
68	26.4	41.6	"	35.3	25.0	12.5	12.5	50.0	49.3	"	798	846
69	26.8	41.2	"	39.8	24.2	12.4	11.8	48.7		"	895	
72	33.2	52.5	"	41.2	22.9	9.2	13.7	59.8	59.5	Yes	938	975
73	34.8	61.7	800	40.6	22.4	9.1	13.3	59.3		Yes	1012	
96	22.5	28.5	1000	50.0	21.3	15.8	5.5	25.8	26.0	No	243	214
97	22.9	29.8	"	37.1	20.9	15.4	5.5	26.3		"	185	
100	24.6	35.7	"	41.0	21.9	14.0	7.9	36.1	36.0	"	614	618
101	26.4	36.9	"	31.9	20.8	13.3	7.5	36.0		"	625	
104	27.6	42.5	"	37.6	21.7	12.4	9.3	42.7	42.1	"	943	958
105	28.5	44.2	"	38.8	21.2	12.4	8.8	41.5		"	974	
108	34.0	62.1	"	53.0	21.2	8.4	12.8	60.5	58.2	Yes	864	1041
75B109	34.8	64.2	1000	43.8	22.1	9.5	12.6	56.0		Yes	1218	

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TABLE XXX (CONTINUED)

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR 0.050" 7075T6
WELD TIME 94 M.S.

Specimen No.	Welding Schedule			Weld Zone Resistance			Weld Zone Resistance Change			Spit	Weld Strength	
	Current Kiloamps 27	End	Electrode Force lbs.	Start MO	27 MO	End MO	MO	Pct	Av.		lbs.	Av.
75B136	20.8	26.4	1200	62.5	24.5	17.4	7.1	28.0	26.8	No	180	210
137	20.8	26.8	"	40.2	22.6	16.8	5.8	25.6		"	240	
140	23.4	33.1	"	28.9	20.9	14.2	6.7	32.0	31.1	"	575	565
141	25.0	35.7	"	28.3	19.2	13.4	5.8	30.2		"	555	
144	28.1	41.2	"	30.7	19.6	12.7	6.9	35.2	35.7	"	915	890
145	26.8	40.7	"	29.9	20.1	12.8	7.3	36.2		"	864	
148	34.0	60.4	"	33.2	19.4	7.9	11.5	59.2	55.9	Yes	917	1060
149	36.1	61.7	1200	31.1	18.8	8.9	9.9	52.6		Yes	1204	

TABLE XXXI

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR 0.050" 5086H34
WELD TIME 61 M.S.

Specimen No.	Welding Schedule Current Kiloamps 27	Welding Schedule Current Kiloamps End	Electrode Force lbs.	Weld Zone Resistance 27 MO	Weld Zone Resistance End MO	Weld Zone Resistance Change MO	Weld Zone Resistance Change Pct	Weld Zone Resistance Change Av.	Spit	Weld Strength lbs.	Weld Strength Av.
86B23	22.1	25.5	600	22.4	22.6	- .2	-	9.1	No	196	200
24	20.2	25.5	"	26.2	23.8	2.4	9.1		"	204	
27	24.2	31.9	"	24.6	20.4	4.2	17.0	14.7	"	568	566
28	26.4	33.2	"	21.7	19.0	2.7	12.5		"	564	
31	24.2	31.9	"	28.5	21.4	7.1	25.0	31.0	"	750	788
32	28.0	38.2	"	27.4	17.0	10.4	37.0		"	816	
35	34.0	55.6	"	27.2	12.5	14.7	54.0	57.0	Yes	1280	1280
36	34.9	56.6	600	30.6	12.0	18.6	60.5		Yes	1280	
51	20.7	26.4	800	19.5	22.6	- 3.1		0	No	138	151
52	23.4	28.1	"	20.1	20.4	- .3			"	164	
55	24.2	32.7	"	23.1	19.8	3.3	14.7	14.4	"	498	491
56	26.4	34.4	"	21.3	18.3	3.0	14.2		"	484	
59	27.2	38.3	"	22.3	17.0	5.3	23.8	25.4	"	816	796
60	28.5	40.0	800	21.5	15.7	5.8	27.0		"	776	
83	19.6	25.5	1000	33.5	23.1	10.4	31.0	21.7	"	186	147
84	22.1	27.2	"	23.3	20.4	2.9	12.5		"	108	
87	24.2	33.2	"	20.7	17.8	2.9	14.0	18.2	"	330	332
88	25.1	35.7	"	21.1	16.2	4.9	23.2		"	334	
91	28.0	39.0	"	21.4	15.8	5.6	26.1	26.3	"	664	649
92	28.0	39.5	"	21.0	15.4	5.6	26.6		"	634	
95	35.3	55.8	"	20.5	11.8	8.7	42.5	42.5	Yes	1126	1071
96	35.7	55.2	1000	20.7	11.9	8.8	42.5		Yes	1016	
115	21.7	27.2	1200	22.0	19.5	2.5	11.3	11.3	No	N.W.	0
116	25.0	33.2	"	20.5	18.2	2.3	11.2	10.7	"	304	284
117	25.5	33.2	"	19.4	17.4	2.0	10.3		"	264	
120	27.6	38.2	"	20.0	16.4	3.6	18.0	21.3	"	528	518
121	27.6	38.7	"	19.0	14.7	4.3	22.6		"	508	
124	36.2	54.4	"	19.2	13.6	5.6	29.2	31.4	Yes	1060	1180
86B125	36.2	54.4	1200	17.6	11.7	5.9	33.4		Yes	1202	

TABLE XXXII

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR 0.050" 5086H34
WELD TIME 94 M.S.

Specimen No.	Welding Schedule: Current, Kiloamps 27	Current, Kiloamps End	Electorde Force lbs.	Weld Zone Resistance 27 MO	Weld Zone Resistance End MO	Weld Zone Resistance Change MO	Pct.	Av.	Spit	Weld Strength lbs.	Av.
86B67	21.6	26.4	800	32.2	22.4	9.8	30.2	26.7	No	290	237
68	21.2	28.0	"	23.2	17.8	5.4	23.2		"	184	
71	25.5	34.8	"	22.0	16.8	5.2	23.7	25.5	"	788	759
72	26.7	37.4	"	20.6	14.7	5.9	27.3		"	730	
75	28.5	42.5	"	20.4	13.4	7.0	32.6	39.0	"	1092	986
76	26.7	43.4	"	24.0	13.1	10.9	45.4		"	880	
79	34.8	62.4	"	22.4	9.2	13.2	58.0	62.5	Yes	1470	1484
80	35.6	62.8	800	22.6	9.5	13.1	67.0		Yes	1498	
99	21.2	27.6	1000	23.2	18.0	5.2	22.4	20.0	No	N.W.	N.W.
100	22.1	28.0	"	22.0	18.1	3.9	17.6		"	118	
103	27.2	38.2	"	17.0	13.8	3.2	18.7	20.1	"	740	776
104	26.4	37.6	"	17.2	13.5	3.7	21.5		"	818	
107	29.3	42.8	"	17.5	13.3	4.2	24.0	26.0	"	1150	1165
108	29.8	42.8	"	17.2	12.4	4.8	28.0		"	1214	
111	36.1	61.1	"	18.8	8.9	9.9	22.5	35.0	Yes	1482	1490
112	40.4	65.0	1000	16.8	8.5	8.3	49.5		Yes	1500	
132	22.5	29.3	1200	18.6	15.3	3.3	17.6	19.2	No	N.W.	N.W.
133	21.6	28.4	"	20.2	16.0	4.2	20.8		"	N.W.	
136	26.4	37.0	"	19.0	14.8	4.2	22.0	22.7	"	572	539
137	26.4	36.5	"	18.0	13.6	4.4	23.4		"	506	
140	28.0	42	"	19.3	12.5	6.8	35.0	32.0	"	966	955
141	28.9	42.5	"	17.3	12.3	5.0	29.0		"	944	
144	39.4	62.0	"	17.4	8.5	8.9	51.0	52.7	Yes	1274	1338
145	37.0	62.0	"	17.8	8.7	9.1	54.5		Yes	1402	
148	40.0	69.0	"	19.6	8.8	10.8	55.0	55.5	Yes	1352	1411
86B149	40.0	69.0	1200	18.4	8.1	10.3	56.0		Yes	1470	

TABLE XXXIII

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR 0.050" 5456H343
WELD TIME 61 M.S.

Specimen No.	Welding Schedule Current Kiloamps 27	Welding Schedule Current Kiloamps End	Electrode Force lbs.	Weld Zone Resistance 27 MO	Weld Zone Resistance End MO	Weld Zone Resistance Change ΔR MO	Weld Zone Resistance Change Pct R Pct	Weld Zone Resistance Change Av. Pct.	Spit	Weld Strength lbs.	Weld Strength Av. lbs.
56B15	18.3	24.2	600	23.4	19.4	4.0	17.0	15.2	No	360	322
16	20.0	24.6	"	21.5	18.6	2.9	13.4		"	285	
19	22.5	28.9	"	20.8	16.2	4.6	22.1	22.7	"	635	640
20	22.9	29.8	"	20.5	15.7	4.8	23.4		"	645	
23	25.5	34.8	"	20.7	13.5	7.2	34.7	37.6	Yes	830	872
24	25.5	36.9	"	21.9	13.0	8.9	40.6		Yes	915	
27	32.3	49.3	"	58.9	10.1	48.8	82.8	83.0	Yes	1420	1470
28	32.8	51.8	600	59.1	9.8	49.3	83.4		Yes	1520	
47	21.7	25.5	800	20.7	19.2	1.5	7.2	14.2	No	325	292
48	21.7	26.8	"	19.3	15.2	4.1	21.2		"	260	
51	25.0	32.3	"	19.6	14.2	5.4	27.5	28.6	"	735	722
52	24.6	32.8	"	19.5	13.7	5.8	29.7		"	710	
55	26.8	38.2	"	19.4	12.8	6.6	34.0	39.2	Yes	940	900
56	27.2	39.5	"	19.1	10.6	8.5	44.5		Yes	860	
59	36.9	54.8	"	17.3	10.0	7.3	42.1	49.2	Yes	1520	1467
60	36.1	57.0	800	18.8	8.2	10.6	56.3		Yes	1415	
79	20.8	25.0	1000	19.2	19.2	0	0	4.3	No	250	255
80	20.0	24.2	"	18.5	16.9	1.6	8.6		"	260	
83	22.9	29.3	"	19.2	16.3	2.9	15.1	17.7	"	580	570
84	22.5	30.2	"	18.2	14.5	3.7	20.3		"	560	
87	25.5	34.8	"	18.4	13.7	4.7	25.5	26.4	"	860	870
88	26.8	36.9	"	17.5	12.7	4.8	27.4		"	880	
91	32.3	48.7	"	17.3	9.4	7.9	45.6	47.3	Yes	1230	1295
56B92	33.1	51.5	1000	17.5	8.9	8.6	49.7		Yes	1360	

TABLE XXXIII (CONTINUED)

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR 0.050" 5456H343
WELD TIME 61 M.S.

Specimen No.	Welding Schedule			Weld Zone Resistance		Weld Zone Resistance Change			Spit	Weld Strength	
	Current Kiloamps		Electrode Force								
	27	End	lbs.	27 MO	End MO	ΔR MO	Pct[R] Pct	Av. Pct		lbs.	Av. lbs.
56B111	21.2	25.5	1200	21.2	17.6	3.6	16.9	17.2	No	-	0
112	22.1	26.8	"	17.6	14.5	3.1	17.6		"	-	
115	23.8	31.9	"	19.3	14.4	4.9	25.3	24.7	"	500	480
116	24.6	34.0	"	17.0	12.9	4.1	24.1		"	460	
119	27.6	37.8	"	17.7	12.6	5.1	28.8	27.8	"	860	852
120	28.5	39.0	"	16.8	12.3	4.5	26.8		"	845	
123	35.3	53.9	"	16.1	9.8	6.3	39.1	40.2	Yes	1330	1325
124	34.8	55.3	"	16.9	9.9	7.0	41.4		Yes	1320	
127	38.6	61.2	"	16.3	8.1	8.2	50.3	48.9	Yes	1205	1357
56B128	39.1	62.9	1200	16.6	8.7	7.9	47.5		Yes	1510	

TABLE XXXIV

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR 0.050" 5456H343
WELD TIME 94 M.S.

Specimen No.	Welding Schedule: Current Kiloamps 27	Current Kiloamps End	Electrode Force lbs.	Weld Zone Resistance 27 MO	Weld Zone Resistance End MO	Weld Zone Resistance Change ΔR MO	$\frac{\Delta R}{R}$ Pct	Av. Pct.	Spit	Weld Strength lbs.	Weld Strength Av. lbs.
56B31	20.0	25.5	600	22.0	16.5	5.5	25.0	27.1	No	580	585
32	20.8	25.5	"	21.1	14.9	6.2	29.3		"	590	
35	23.4	34.4	"	21.8	12.2	9.6	44.0	40.4	Yes	880	890
36	23.4	30.6	"	20.1	12.7	7.4	36.8		Yes	900	
39	25.0	41.2	"	22.4	9.2	13.2	58.9	57.4	Yes	960	1055
40	24.6	40.3	"	23.2	10.2	13.0	56.0		Yes	1150	
43	31.9	57.8	"	21.0	7.4	13.6	64.7	64.2	Yes	1490	1425
44	31.9	55.3	600	21.0	7.6	13.4	63.8		Yes	1360	
63	19.6	25.9	800	19.9	14.3	5.6	28.1	23.5	No	310	295
64	21.2	25.5	"	17.4	14.1	3.3	18.9		"	280	
67	22.5	32.8	"	18.7	11.9	6.8	36.3	35.1	"	850	850
68	23.8	32.8	"	17.6	11.6	6.0	34.0		"	850	
71	25.9	40.3	"	18.1	8.4	9.7	53.5	56.2	Yes	1070	987
72	23.8	40.7	"	20.2	8.3	11.9	58.9		Yes	905	
75	33.6	60.4	"	18.1	6.4	11.7	64.6	61.2	Yes	1240	1455
76	34.0	57.0	800	18.8	7.9	10.9	57.9		Yes	1670	
95	20.8	28.5	1000	19.2	14.4	4.8	25.0	24.7	No	490	480
96	21.2	28.1	"	17.9	13.5	4.4	24.5		"	470	
99	23.8	36.5	"	18.9	11.2	7.7	40.7	39.1	"	930	947
100	25.0	35.3	"	17.6	11.0	6.6	37.5		"	965	
103	27.2	45.5	"	18.0	8.1	9.9	55.0	56.1	Yes	1030	962
104	27.6	44.2	"	18.5	7.9	10.6	57.2		Yes	895	
107	35.3	62.9	"	17.6	6.2	11.4	64.7	62.7	Yes	1350	1277
56B108	36.9	61.2	1000	17.1	6.7	10.4	60.8		Yes	1205	

TABLE XXXIV

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR 0.050" 5456H343
WELD TIME 94 M.S.

Specimen No.	Welding Schedule			Weld Zone Resistance		Weld Zone Resistance Change			Spit	Weld Strength	
	Current		Electrode Force								
	Kiloamps 27	End	lbs.	27 MO	End MO	ΔR MO	Pct R Pct	Av. Pct.		lbs.	Av. lbs.
56B131	21.7	29.8	1200	17.0	12.1	4.9	28.8	26.6	No	215	227
132	22.1	28.5	"	16.3	12.3	4.0	24.5		"	240	
135	25.0	36.1	"	17.6	11.3	6.3	35.7	29.4	"	890	852
136	26.0	45.5	"	11.2	8.6	2.6	23.2		"	815	
139	28.1	43.4	"	16.7	10.1	6.6	39.5	40.4	"	1240	1243
140	28.1	42.0	"	16.7	9.8	6.9	41.3		"	1245	
143	34.8	62.5	"	16.1	6.9	9.2	57.1	55.4	Yes	1275	1330
144	34.4	59.6	"	17.1	7.9	9.2	53.8		Yes	1385	
147	38.2	68.4	"	17.0	7.0	10.0	58.8	58.4	Yes	1565	1612
56B148	37.8	65.0	1200	17.2	7.2	10.0	58.1		Yes	1660	

TABLE XXXV

WELDING SCHEDULES AND WELD PROPERTIES FOR SATISFACTORY WELD SIZES

Material	Weld Currents	Electrode Forces	Weld Times	Weld Dia.	Weld Nugget Pene.	Weld Strength
	Kiloamps	lbs.	M.S.	in.	Pct	lbs.
2024	38500	1000	61	0.185	51	657
2024	34800	1000	94	0.175	51	609
2014	41000	1000	61	0.209	58	745
2014	37600	1000	94	0.207	53	764
7075	39400	1000	61	0.202	65	690
7075	36000	1000	94	0.205	50	618
5086	39000	1000	61	0.183	49	649
5086	37900	1000	94	0.175	43	776
5456	36900	1000	61	0.210	60	870
5456	35900	1000	94	0.225	59	940

TABLE XXXVI

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR EFFECT OF ELECTRODE SHAPE
0.050" 2024T3

Current				Weld Zone Resistance							
24B206	24B210	24B214	24B218	24B206		24B210		24B214		24B218	
Kiloamps				Res MO	%R pct	Res MO	%R pct	Res MO	%R pct	Res MO	%R pct
16.3	16.6	16.3	17.0	43.5		34.9		43.5		35.2	
22.9	22.5	23.4	23.4	27.5		27.1		25.2		23.5	
26.8	26.8	28.1	27.6	26.1		23.9		22.1		20.7	
29.3	30.2	30.6	31.0	25.6		21.5		21.2		19.0	
31.9	32.3	33.1	34.0	23.9		21.7		21.4		17.9	
33.6	34.0	34.0	34.8	21.1		20.0		20.0		18.3	
34.8	35.3	35.3	35.7	19.5		19.0		18.7		17.3	
36.5	36.5	36.5	37.4	17.8		18.1		18.1		17.1	
38.2	37.8	37.4	38.2	12.8	51.0	17.0	28.9	16.8	24.0	16.0	22.7
				W.S.	840 lbs	W.S.	756 lbs	W.S.	756 lbs	W.S.	676 lbs

Weld Time 61 M.S.
Electrode Force 900 lbs.

Specimen 24B206 1" rad.)
" 24B210 4" rad.)
" 24B214 8" rad.) RWMA Gr. A, Class 2
" 24B218 10" rad.)

TABLE XXXVII

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR EFFECT OF ELECTRODE SHAPE
0.050" 2014T6

Current				Weld Zone Resistance							
14B152	14B156	14B160	14B164	14B152		14B156		14B160		14B164	
Kiloamps				Res MO	%R pct	Res MO	%R pct	Res MO	%R pct	Res MO	%R pct
16.6	16.3	15.7	16.3	24.7		28.8		35		36.1	
22.1	21.2	22.1	22.5	26.2		22.6		22.2		21.3	
25.9	24.5	26.4	27.2	25.8		20.8		19.3		18.0	
27.6	28.5	29.3	29.3	27.9		18.6		18.1		17.4	
29.8	30.6	31.9	32.3	24.2		18.9		18.5		17.9	
31.0	31.9	33.1	33.6	22.2		19.4		19.6		19.1	
32.3	32.8	33.1	32.3	20.1		19.2		20.0		24.1	
33.6	33.6	34.0	34.0	19.1		18.7		19.7		19.7	
34.4	34.0	34.0	34.4	17.8	31.0	18.5	11.0	19.1	1.0	18.3	-2.0
				W.S.	782 lbs	W.S.	524 lbs	W.S.	550 lbs	W.S.	508 lbs

Weld Time	61 M.S.
Electrode Force	900 lbs.

Specimen	14B152	1" rad.)	
"	14B156	4" rad.)	
"	14B160	8" rad.)	RWMA Gr. A, Class 2
"	14B164	10" rad.)	

TABLE XXXVIII

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR EFFECT OF ELECTRODE SHAPE
0.050" 7075T6

Current				Weld Zone Resistance							
75B156	75B160	75B164	75B168	75B156		75B160		75B164		75B168	
Kiloamps				Res MO	%R pct	Res MO	%R pct	Res MO	%R pct	Res MO	%R pct
17.5	15.7	17.0	17.0	18.6		33.2		29.5		27.0	
24.2	21.3	22.1	22.1	18.8		23.5		19.0		19.3	
26.8	25.5	25.5	26.8	18.0		20.5		18.0		17.5	
28.5	29.3	29.4	29.0	18.0		18.0		16.4		17.5	
30.6	30.6	31.9	31.9	16.3		17.5		16.0		16.1	
32.3	31.8	33.2	33.2	15.0		17.4		14.9		14.5	
33.2	32.3	33.6	34.4	13.7		16.1		14.2		13.5	
35.3	33.5	34.6	34.8	12.5		15.1		13.5		12.5	
35.7	34.0	34.9	36.1	12.0	33.0	14.7	28.4	13.0	27.8	12.0	31.0
				W.S.	780 lbs	W.S.	700 lbs	W.S.	700 lbs	W.S.	709 lbs

Weld Time 61 M.S.
Electrode Force 900 lbs.

Specimen 75B156 1" rad.)
" 75B160 4" rad.)
" 75B164 8" rad.) RWMA Gr. A, Class 2
" 75B168 10" rad.)

H

TABLE XXXIX

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR EFFECT OF ELECTRODE SHAPE
0.050" 5086H34

Current				Weld Zone Resistance							
86B156	86B160	86B164	86B169	86B156		86B160		86B164		86B169	
Kiloamps				Res MO	%R pct	Res MO	%R pct	Res MO	%R pct	Res MO	%R pct
15.7	16.3	16.3	15.7	40.0		53.2		41.7		31.0	
21.2	22.5	22.5	22.1	32.0		27.1		25.8		19.2	
25.0	26.8	27.2	26.8	29.2		24.6		23.5		18.7	
28.1	29.8	29.3	28.0	26.0		22.4		22.8		20.0	
30.2	32.3	32.3	30.6	25.5		24.8		20.7		17.2	
31.9	33.6	33.6	32.3	21.3		24.4		21.7		17.2	
33.6	34.0	33.6	33.1	20.0		21.4		25.0		16.4	
34.8	35.3	34.4	34.4	19.2		20.4		22.7		15.6	
35.2	36.1	35.3	36.2	17.9	38.6	19.1	22.2	21.5	8.5	14.7	21.2
				W.S.	772 lbs	W.S.	724 lbs	W.S.	738 lbs	W.S.	664 lbs

Weld Time 61 M.S.
Electrode Force 900 lbs.

Specimen 86B156 1" rad.)
" 86B160 4" rad.)
" 86B164 8" rad.) RWMA Gr. A, Class 2
" 86B169 10" rad.)

TABLE XL

DATA FOR PERCENT CHANGE IN WELD ZONE RESISTANCE FOR EFFECT OF ELECTRODE SHAPE
0.050" 5456H343

Current				Weld Zone Resistance							
56B151	56B155	56B159	56B163	56B151		56B155		56B159		56B163	
Kiloamps				Res MO	%R pct	Res MO	%R pct	Res MO	%R pct	Res MO	%R pct
16.1	15.3	15.3	15.7	27.3		37.9		46.4		41.4	
21.2	23.4	23.4	23.4	25.0		20.0		20.0		17.9	
24.6	25.9	26.8	28.1	23.9		19.6		19.4		16.7	
26.4	28.5	28.5	30.6	25.3		18.9		18.9		16.0	
28.1	29.3	31.0	32.8	21.3		19.1		18.3		16.1	
30.6	32.3	33.6	34.0	17.6		16.4		16.0		15.0	
31.4	33.1	33.6	34.0	16.2		14.8		15.4		14.1	
33.0	34.0	34.4	35.7	15.4		14.1		15.1		13.1	
34.0	35.3	35.3	36.5	12.3	48.5	13.3	32.1	14.4	25.7	12.6	24.5
				W.S.	865 lbs	W.S.	910 lbs	W.S.	850 lbs	W.S.	877 lbs

Weld Time 61 M.S.
Electrode Force 900 lbs

Specimen	56B151	1" rad.)	
"	56B155	4" rad.)	
"	56B159	8" rad.)	RWMA Gr. A, Class 2
"	56B163	10" rad.)	

TABLE XLI

DATA FOR WELD ZONE RESISTANCE VS. TIME FOR DISSIMILAR WELD PILEUP CONFIGURATIONS

0.020" 2014T6/0.050" 5456H343 14A56B39		0.020" 5052H34/0.050" 5456H343 52A56B1	
Current Kiloamps	Resistance M.O.	Current Kiloamps	Resistance M.O.
17.0	16.4	16.1	22.3
21.2	16.5	22.1	13.5
24.6	15.8	26.4	13.2
27.2	16.1	28.5	13.6
28.5	16.1	30.6	14.0
29.8	14.7	31.4	13.0

Weld Time 44 M.S.
Electrode Force 550 lbs.

FIGURES

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CHEMICAL CLEANING SET-UP FOR ALUMINUM ALLOYS

CHEMICAL CLEANING TANKS

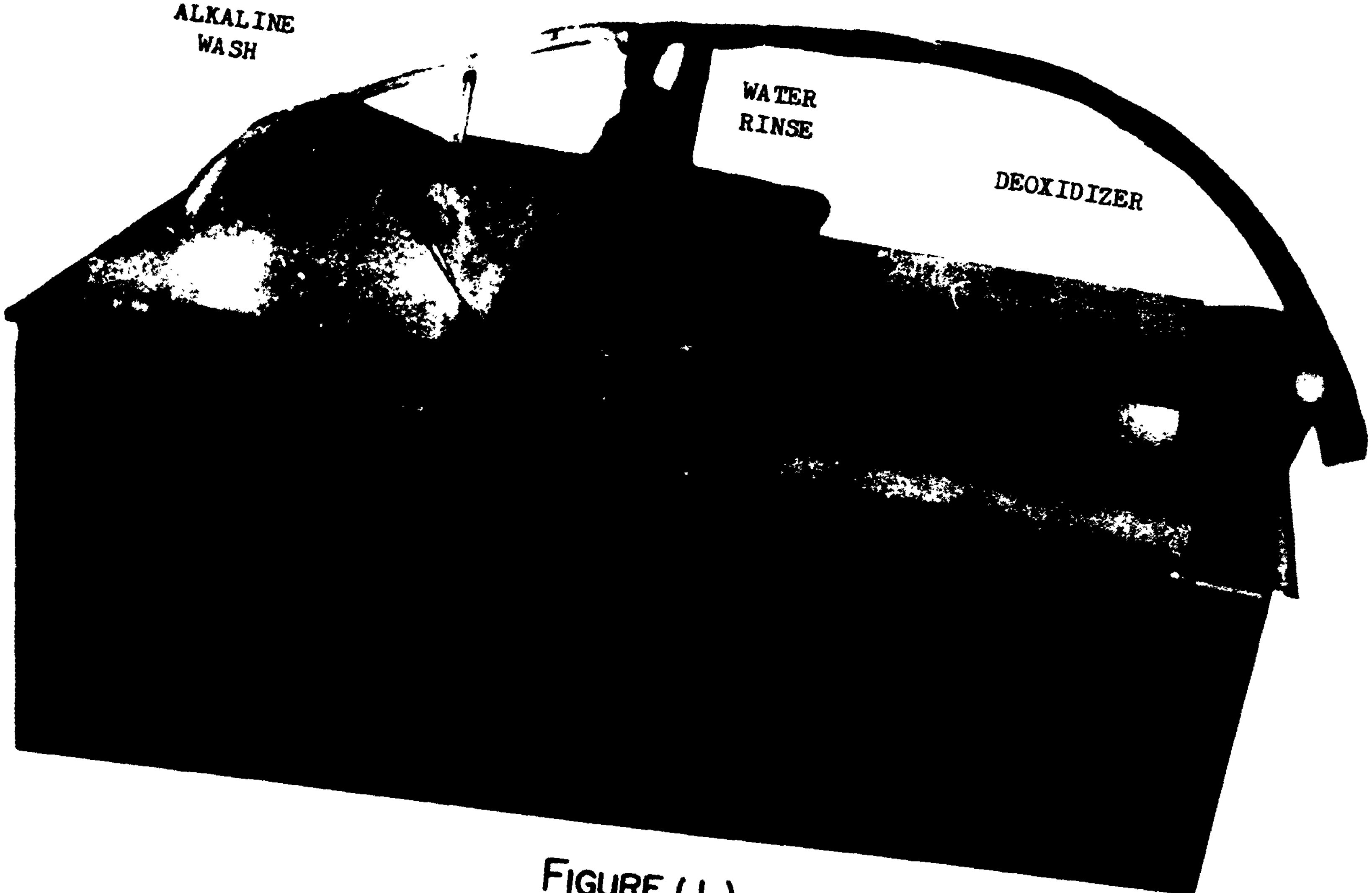
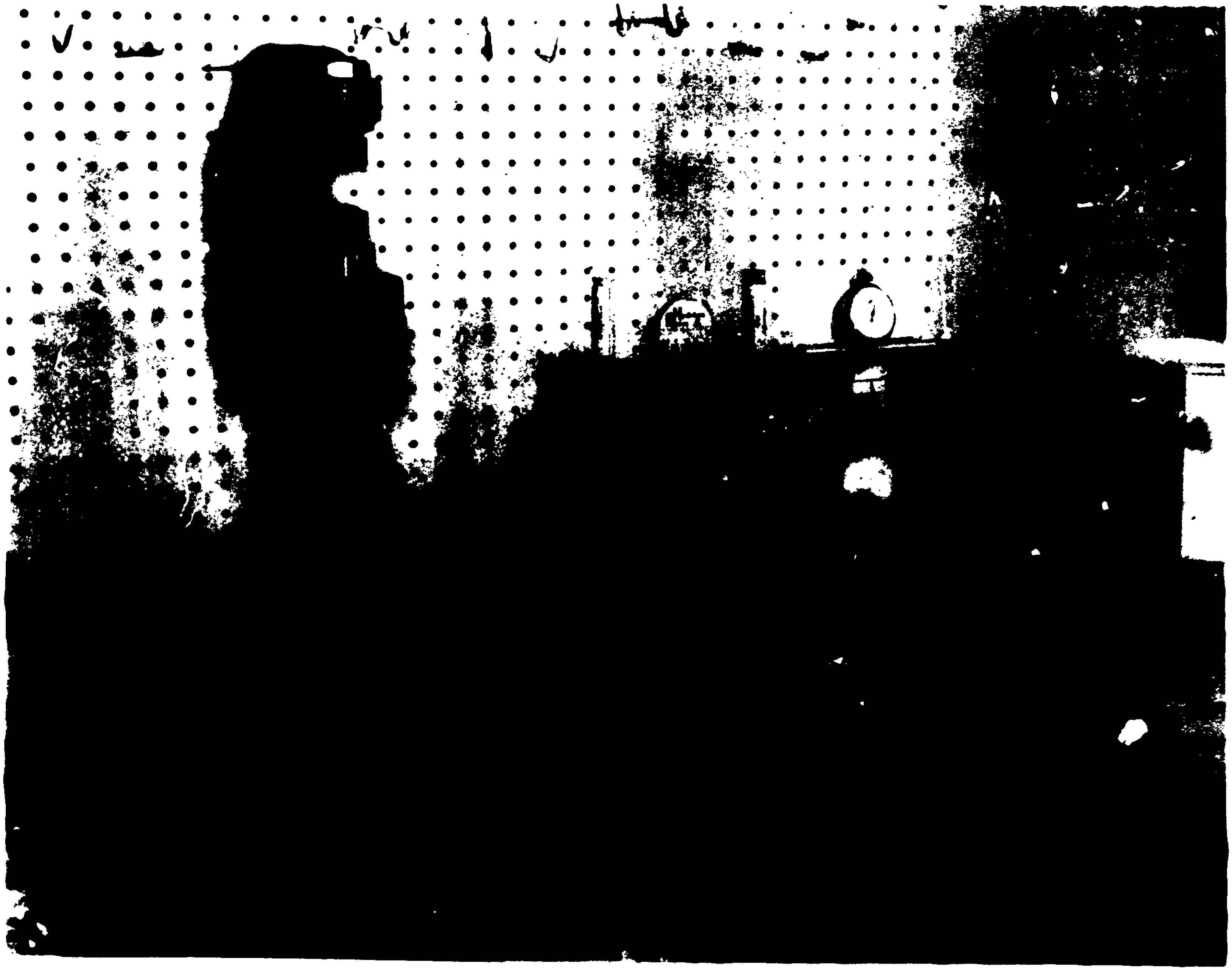
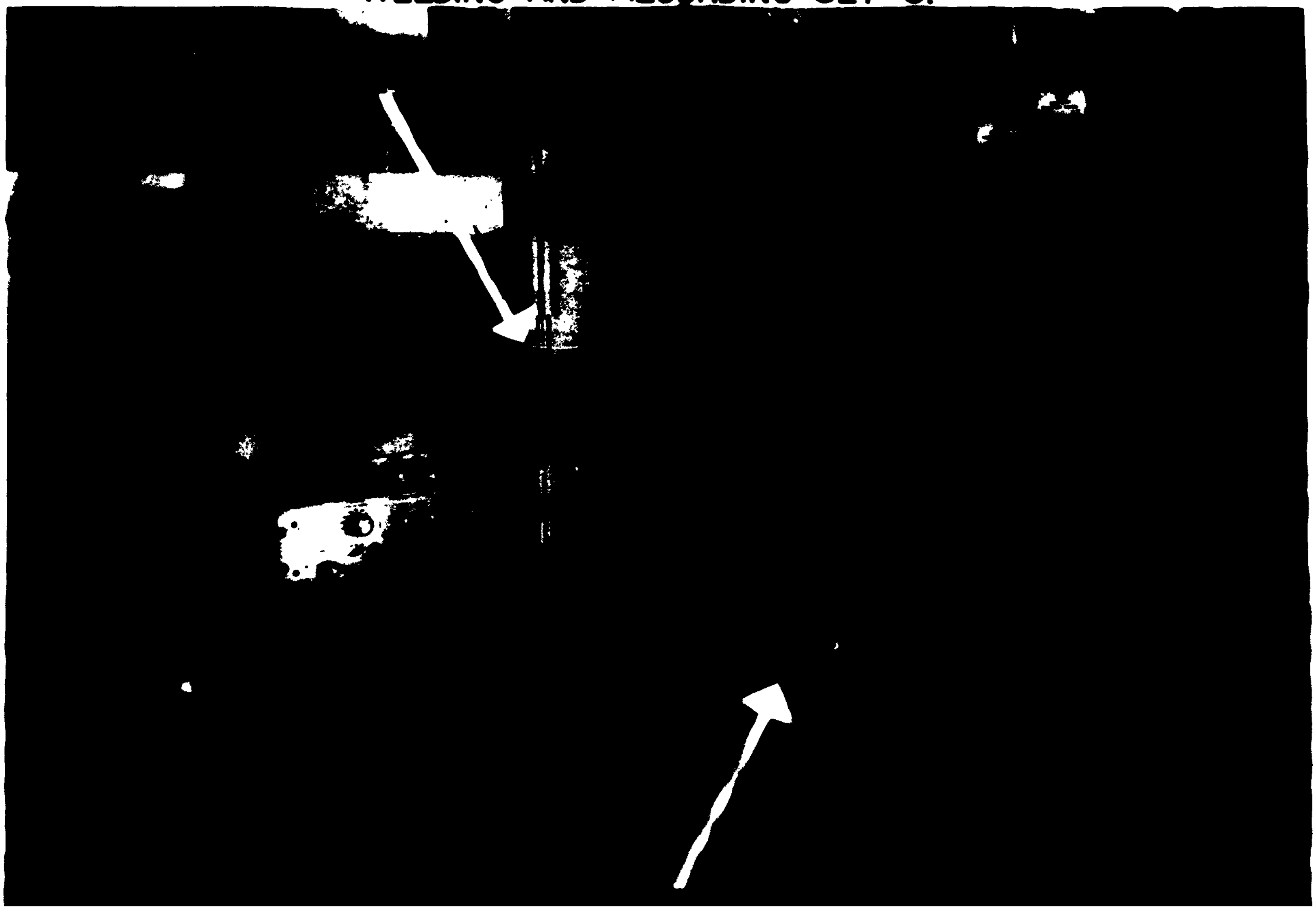


FIGURE (1)

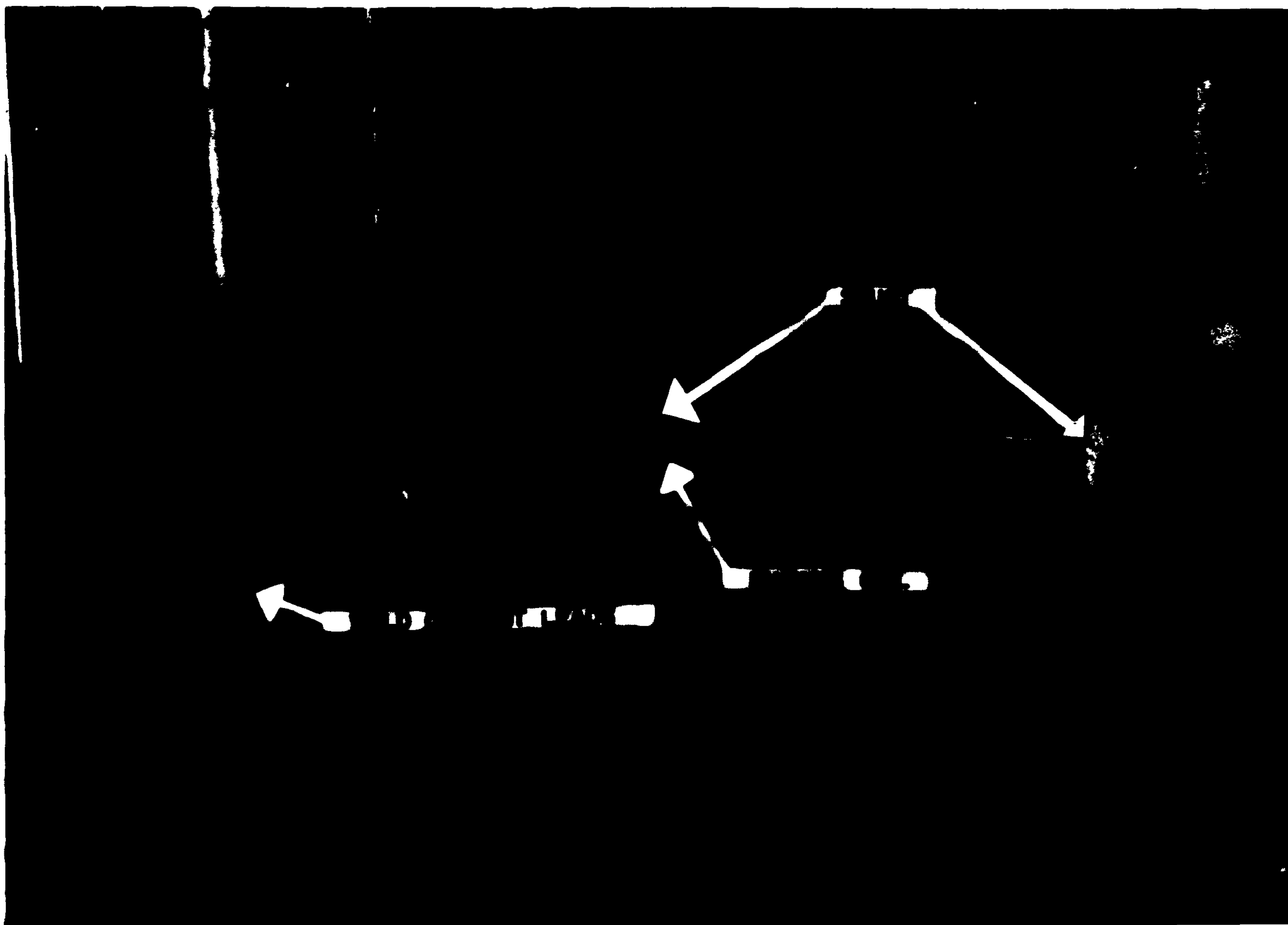
SURFACE RESISTANCE MICRO OHMMETER



Welding and Recording Set-Up



WELD CURRENT MEASURING SHUNT



WELD ZONE SIGNAL PICK-UP

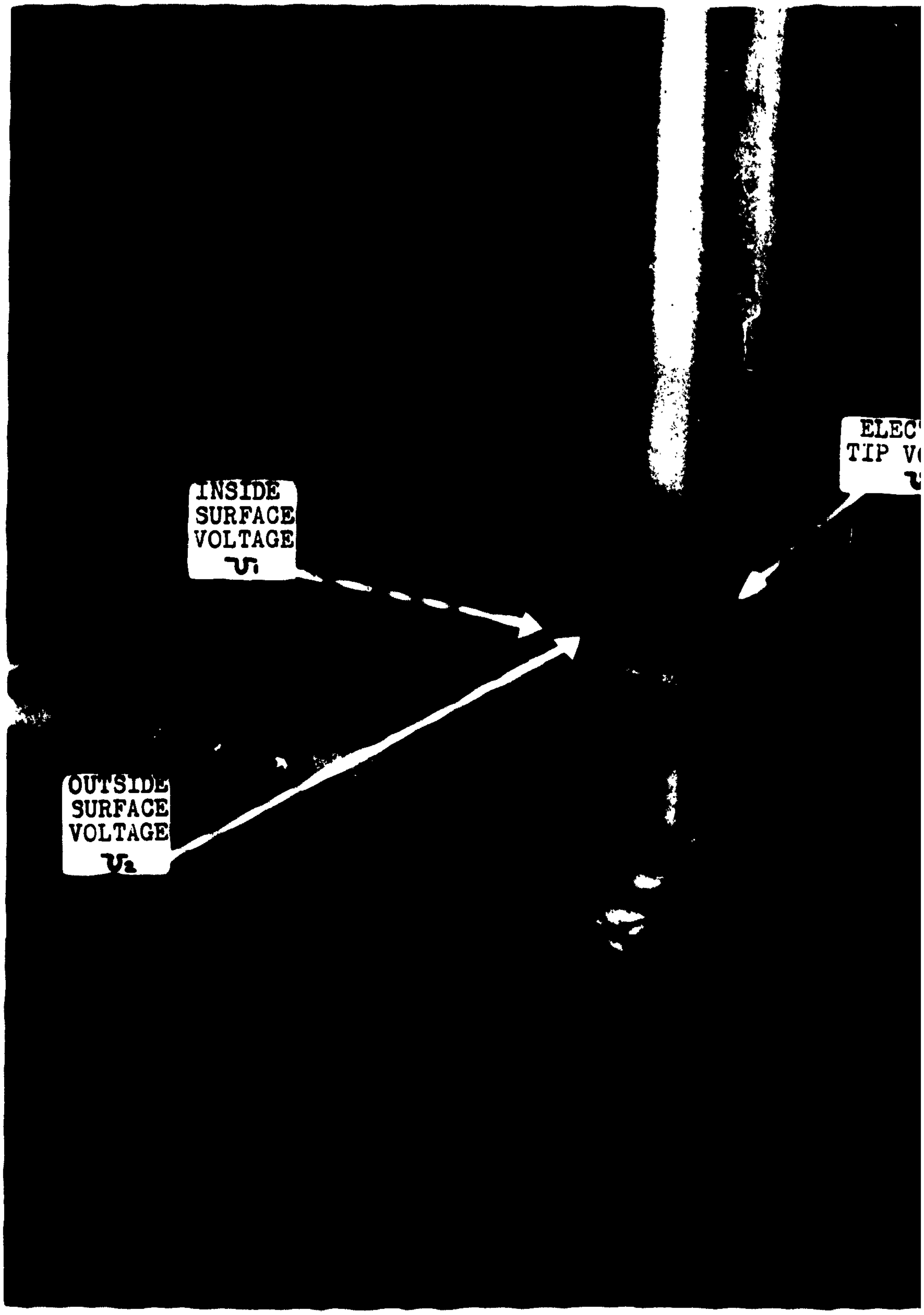
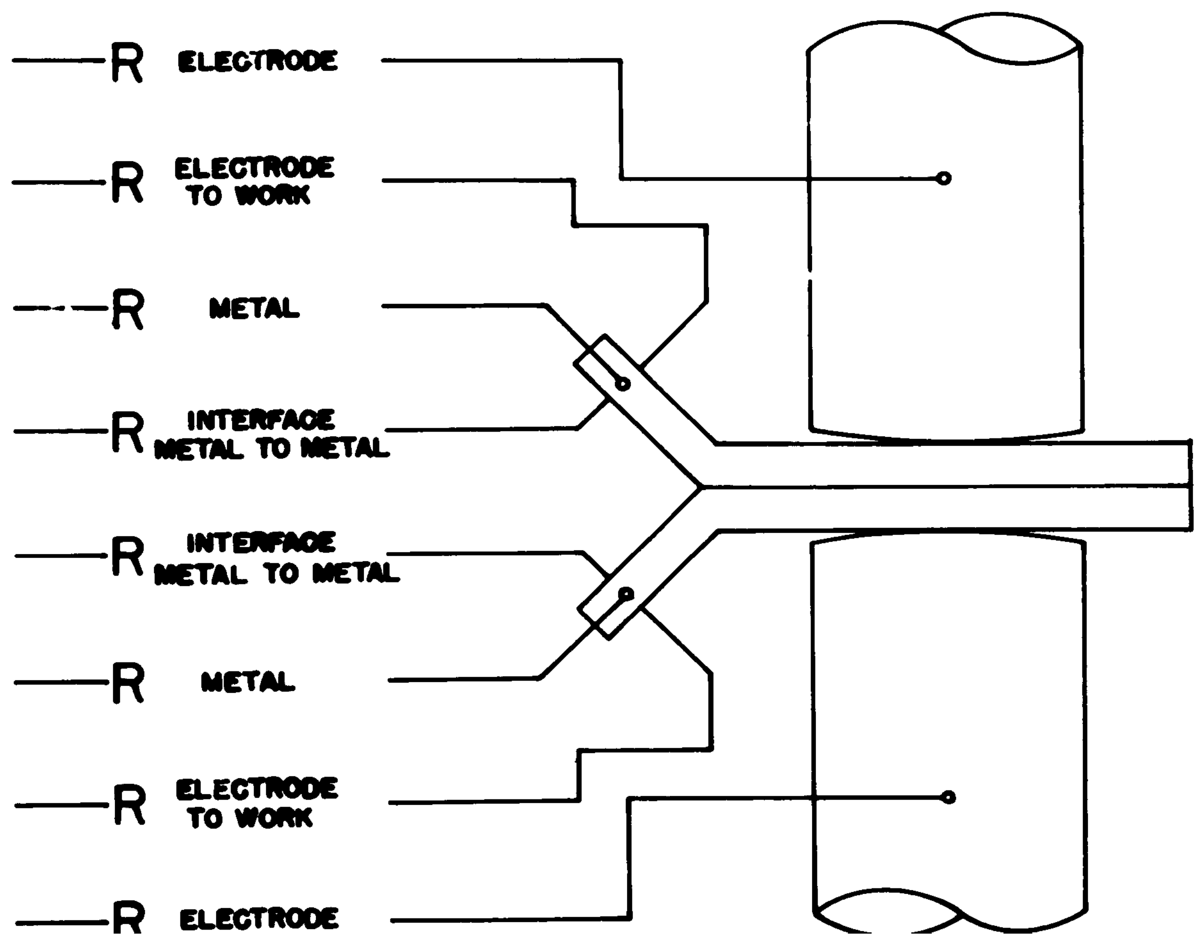


FIGURE (4A)

Schematic of Seven Series Resistance Encountered During Resistance Spot Welding



EFFECT OF SEVEN SERIES RESISTANCE OF WELD ZONE RESISTANCE

AS THE WELD DEVELOPES

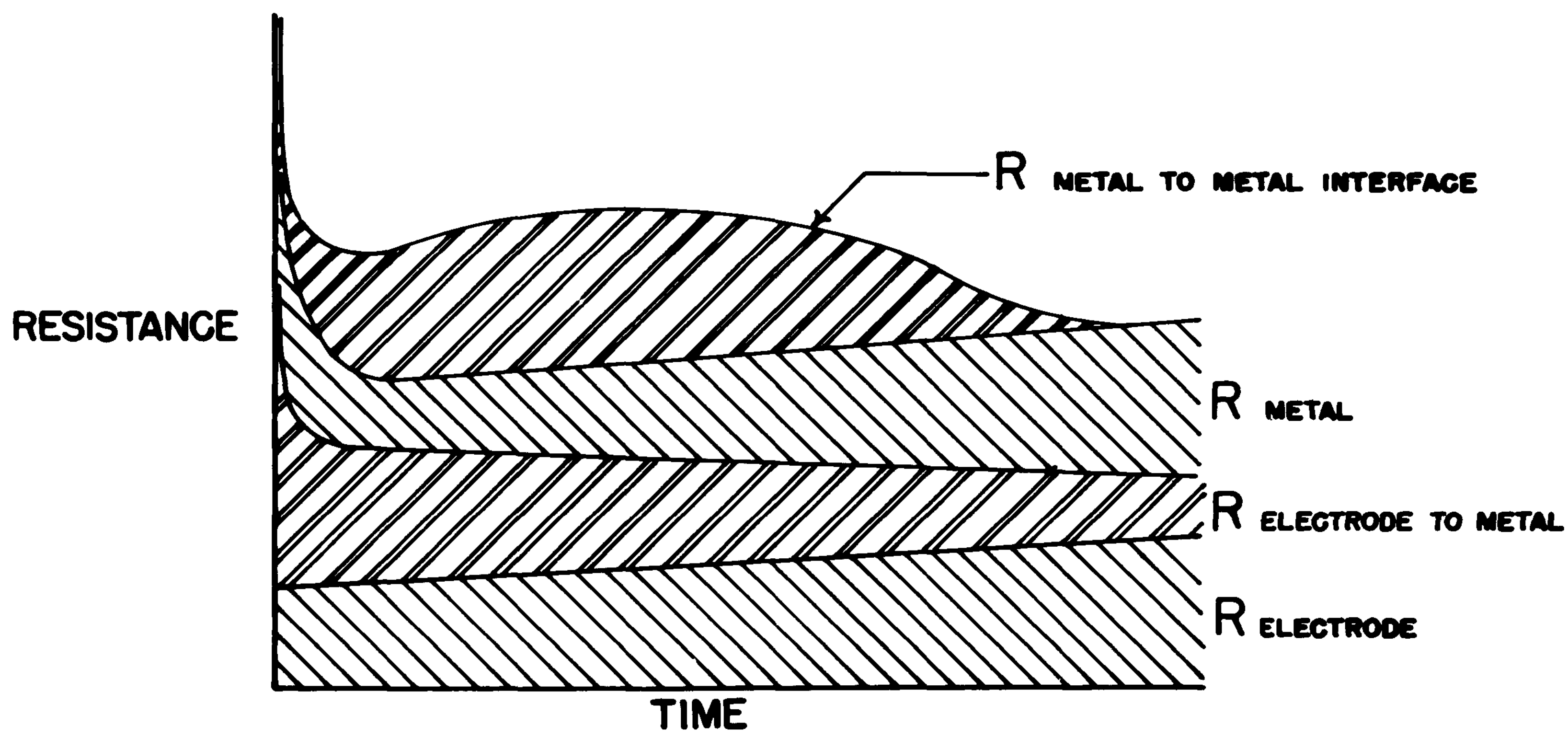


FIGURE (4C)

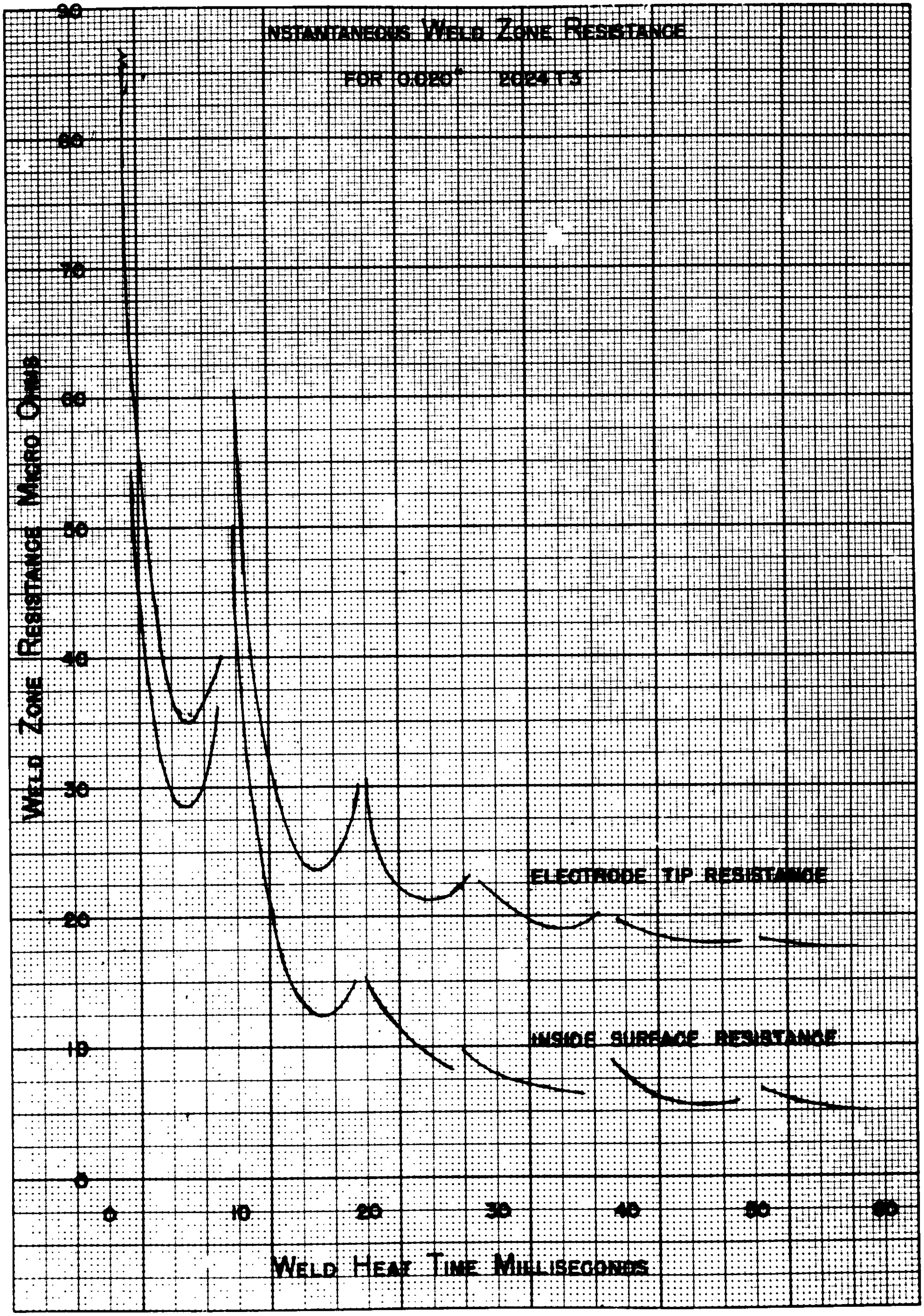
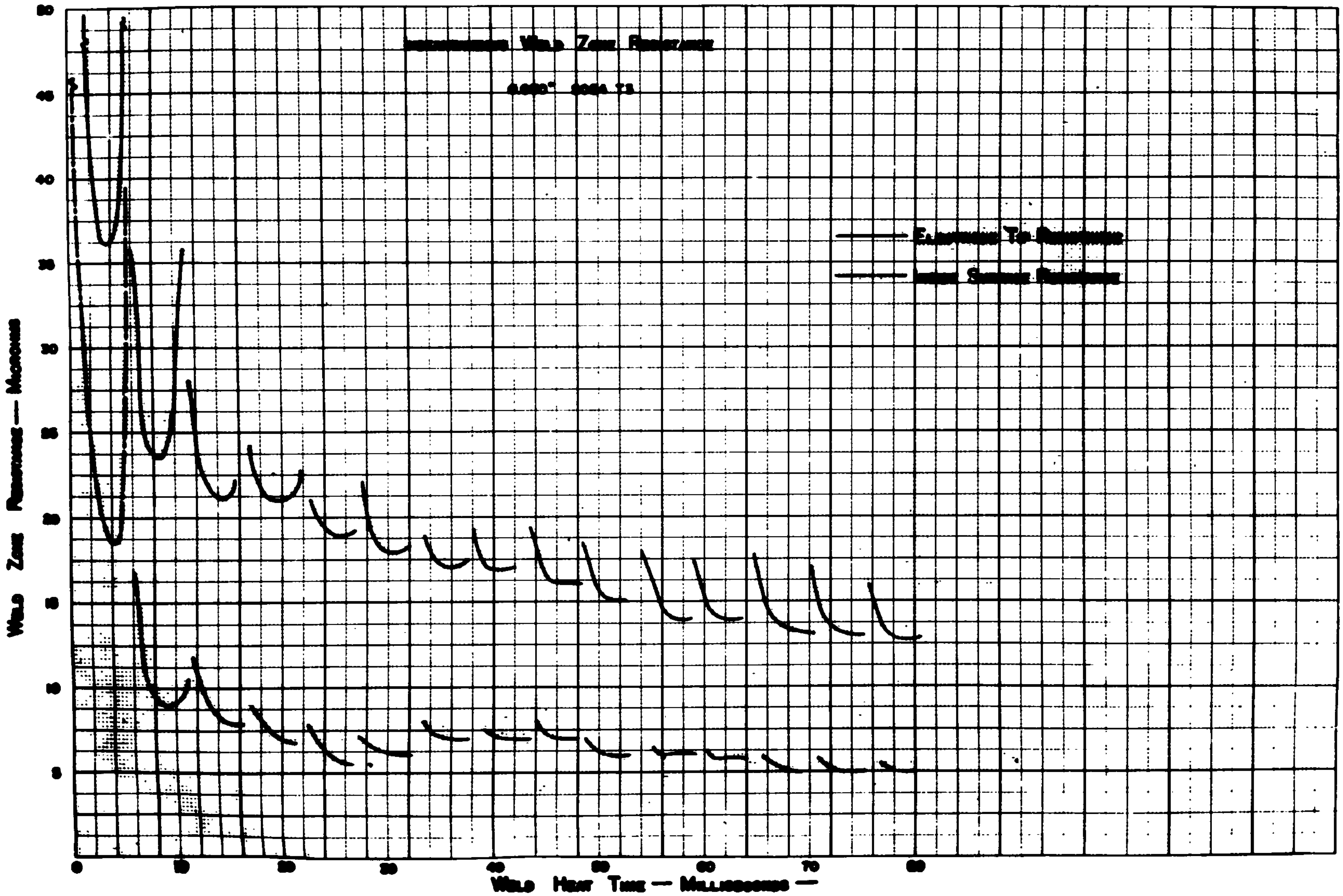
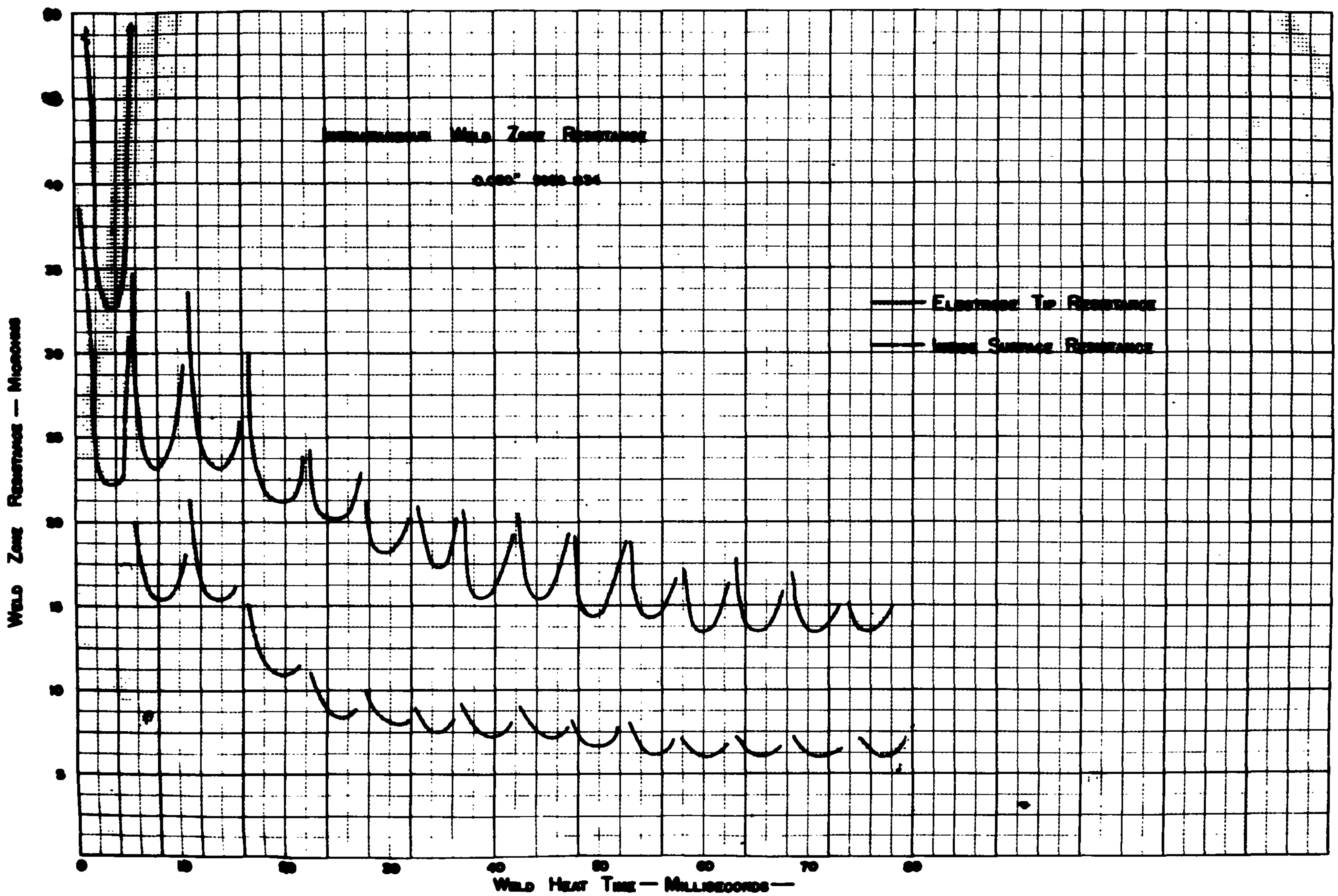

INSTANTANEOUS WELD ZONE RESISTANCE
FOR 0.020" 2024 T 3
WELD ZONE RESISTANCE MICRO OHMS
ELECTRODE TIP RESISTANCE
INSIDE SURFACE RESISTANCE
WELD HEAT TIME MILLISECONDS

FIGURE (5)



Weld Zone
Weld Zone
0
10
20
30
40
50
60
70
80
Weld Heat Time — Milliseconds —
5
10
15
20
25
30
35
40
45
50

Figure (6)



Instantaneous Weld Zone Resistance
Electrode Tip Resistance
Inside Surface Resistance
Weld Zone Resistance — Microhms
Weld Heat Time — Milliseconds —
0
10
20
30
40
50
60
70
80
5
10
15
20
25
30
35
40

Figure 175

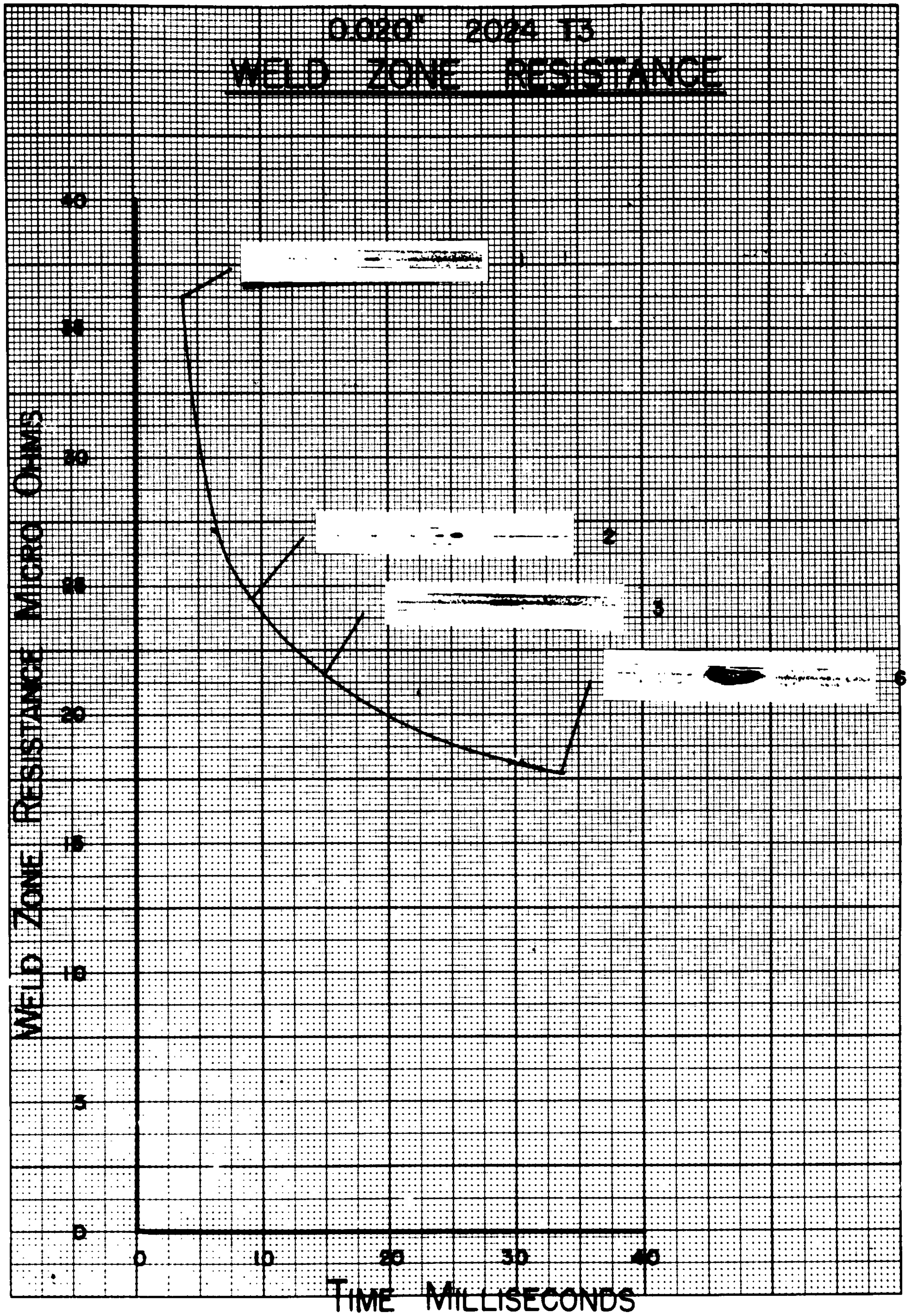
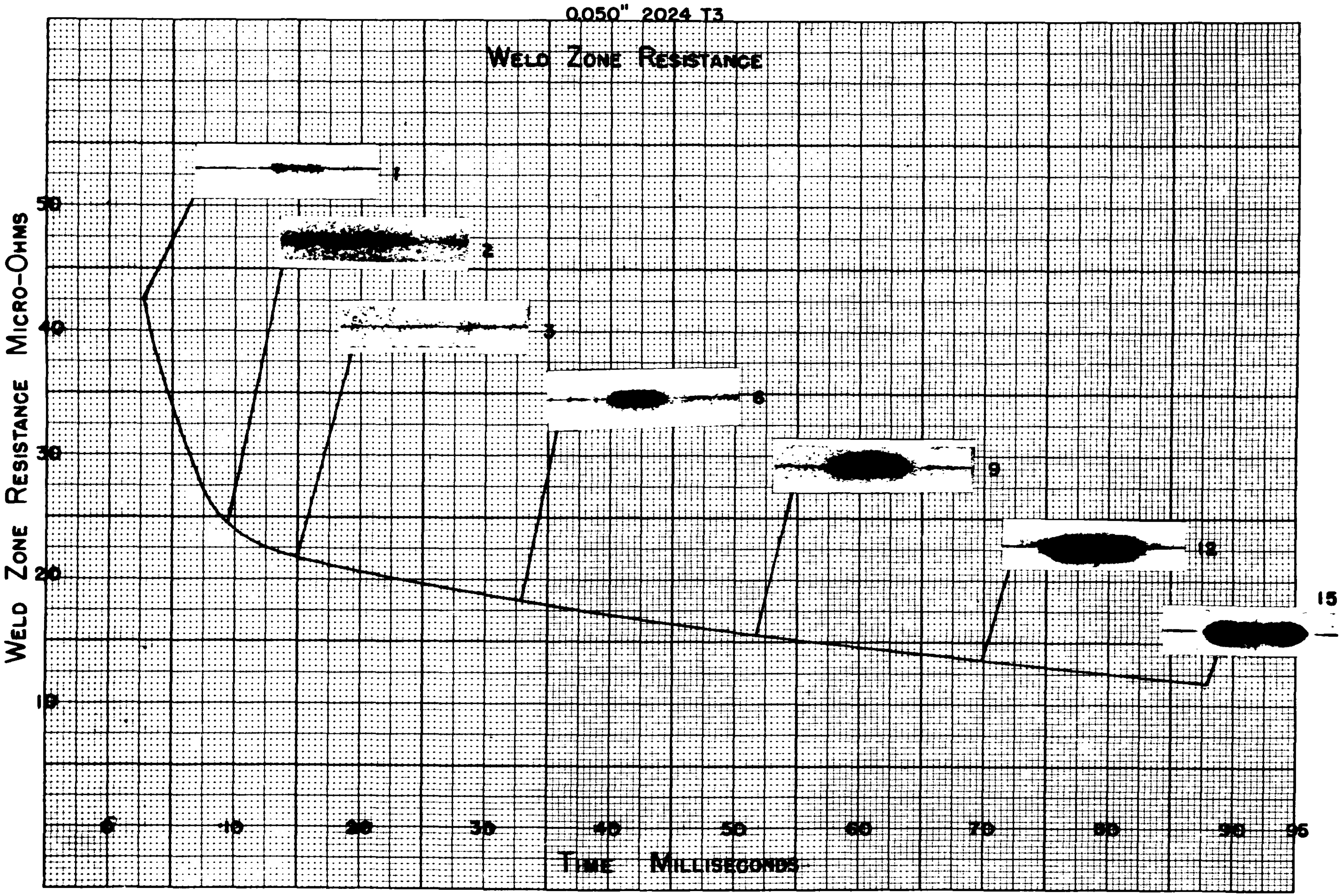
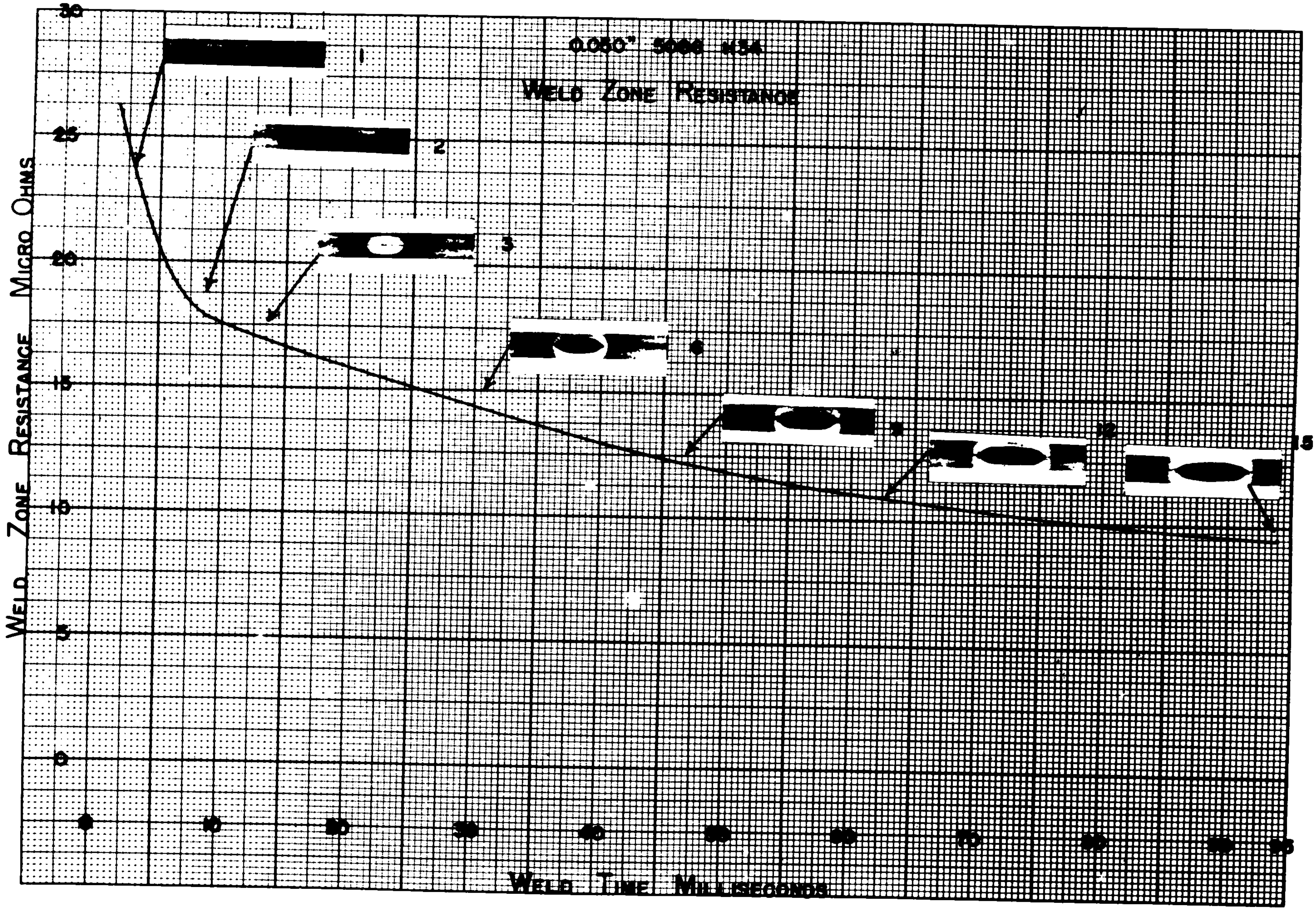

0.020" 2024 T3
WELD ZONE RESISTANCE
WELD ZONE RESISTANCE MICRO OHMS
40
35
30
25
20
15
10
5
0
2
3
6
0
10
20
30
40
TIME MILLISECONDS

FIGURE (8)



0.050" 2024 T3
WELD ZONE RESISTANCE
WELD ZONE RESISTANCE MICRO-OHMS
50
40
30
20
10
1
2
3
6
9
12
15
0
10
20
30
40
50
60
70
80
90
95
TIME MILLISECONDS

FIG. 9



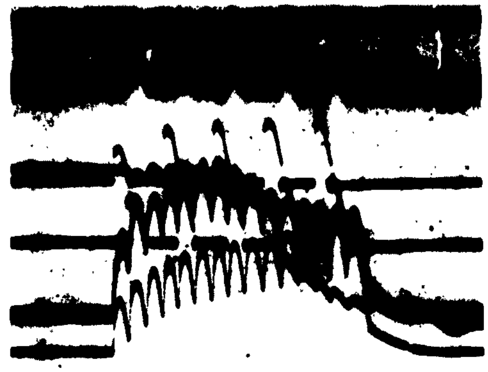
Weld Zone Resistance
Weld Zone Resistance Micro Ohms
Weld Time Milliseconds
30
25
20
15
10
5
0
10
20
30
40
50
60
70
80
90
95
1
2
3
12
15

The Effect of Weld Force and Forge Force on the Weld Zone Signals

0.050" 2014 T6

Time→

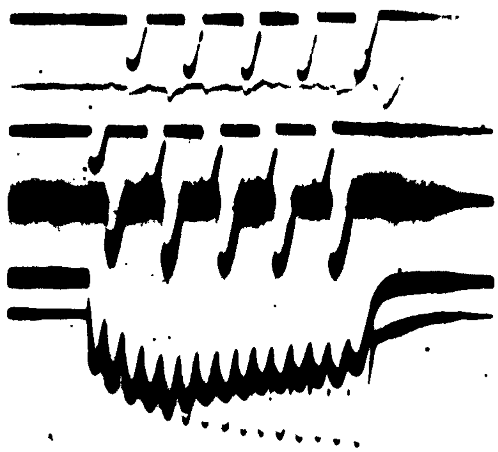
Weld Current - 45,000 Amps.
Weld Force - 900 lbs.
Weld Time - 94 M.S.



Time→

Weld Current - 42,500 Amps.
Weld Force - 900 lbs.
Forge Force - 2,000 lbs.
Weld Time - 94 M.S.
Forge Delay Time - 66 M.S.

0.050" 5456 H343



Time→

Weld Current - 38,200 Amps.
Weld Force - 90 lbs.
Weld Time - 94 M.S.

Time→

Weld Current - 38,600 Amps.
Weld Force - 900 lbs.
Forge Force - 2,000 lbs.
Weld Time - 94 M.S.
Forge Delay Time - 66 M.S.

FIG. (11)

The Effect of Weld Force and Forge Force on the Weld Nugget

0.050" 2014 T6

Weld Current - 45,000 Amps.
Weld Force - 900 lbs.
Weld Time - 94 M.S.
Weld Diameter - 0.260 in.
Weld Nugget Penetration - 66 pct.

Weld Current - 42,500 Amps.
Weld Force - 900 lbs.
Forge Force - 2,000 lbs.
Weld Time - 94 M.S.
Forge Delay Time - 66 M.S.
Weld Diameter - 0.200 in.
Weld Nugget Penetration - 64 pct.

0.050" 5456 H343

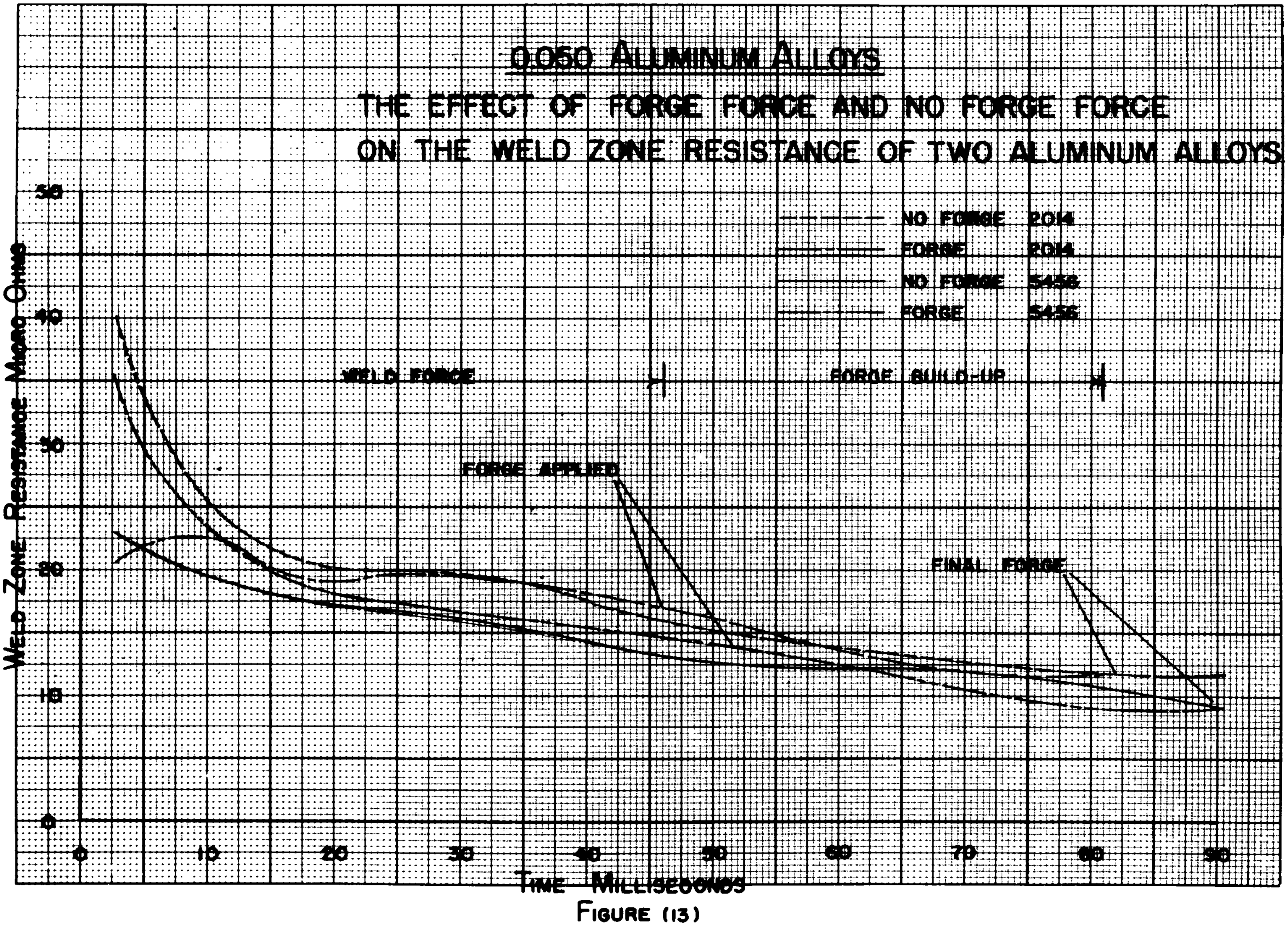
WITH OUT FORGE

Weld Current - 38,200 Amps.
Weld Force - 900 lbs.
Weld Time - 94 M.S.
Weld Diameter - 1.251 in.
Weld Nugget Penetration - 64 pct.

WITH FORGE

Weld Current - 38,600 Amps.
Weld Force - 900 lbs.
Forge Force - 2,000 lbs.
Weld Time - 94 M.S.
Forge Delay Time - 66 M.S.
Weld Diameter - 0.212 in.
Weld Nugget Penetration - 69 pct.

FIGURE (12)



0.050 Aluminum Alloys
The Effect of Forge Force and No Forge Force on the Weld Zone Resistance of Two Aluminum Alloys
No Forge 2014
Forge 2014
No Forge 5456
Forge 5456
Weld Force
Forge Build-Up
Forge Applied
Final Forge
Weld Zone Resistance Micro Ohms
Time Milliseconds
0
10
20
30
40
50
60
70
80
90

Figure (13)

0.020" 2014 T6

PART I

14A6

WELD CURRENT 29300 (50% HEAT)
ELECTRODE FORCE 550 LBS.
WELD TIME 44 MS
WELD DIAMETER .146"
PENETRATION 80%

FIGURE (14)

14A21

WELD CURRENT 29700 (50%)
WELD CURRENT 29700 (50% HEAT)
ELECTRODE FORCE 550 LBS.
FORGE 1000 LBS.
WELD TIME 44 MS
FORGE DELAY 13 MS
WELD DIAMETER .144 IN.
PENETRATION 73 PCT.

0.020" 7075 T6

PART I

75A7

WELD CURRENT	29300 (50% HEAT)
ELECTRODE FORCE	550 LBS.
WELD TIME	44 MS
WELD DIAMETER	.146 IN.
PENETRATION	64 PCT.

FIGURE (15)

75A21

WELD CURRENT	29700 (50% HEAT)
ELECTRODE FORCE	550 LBS.
FORGE	1000 LBS.
WELD TIME	44 MS
FORGE DELAY	13 MS
WELD DIAMETER	.150 IN.
PENETRATION	70 PCT.

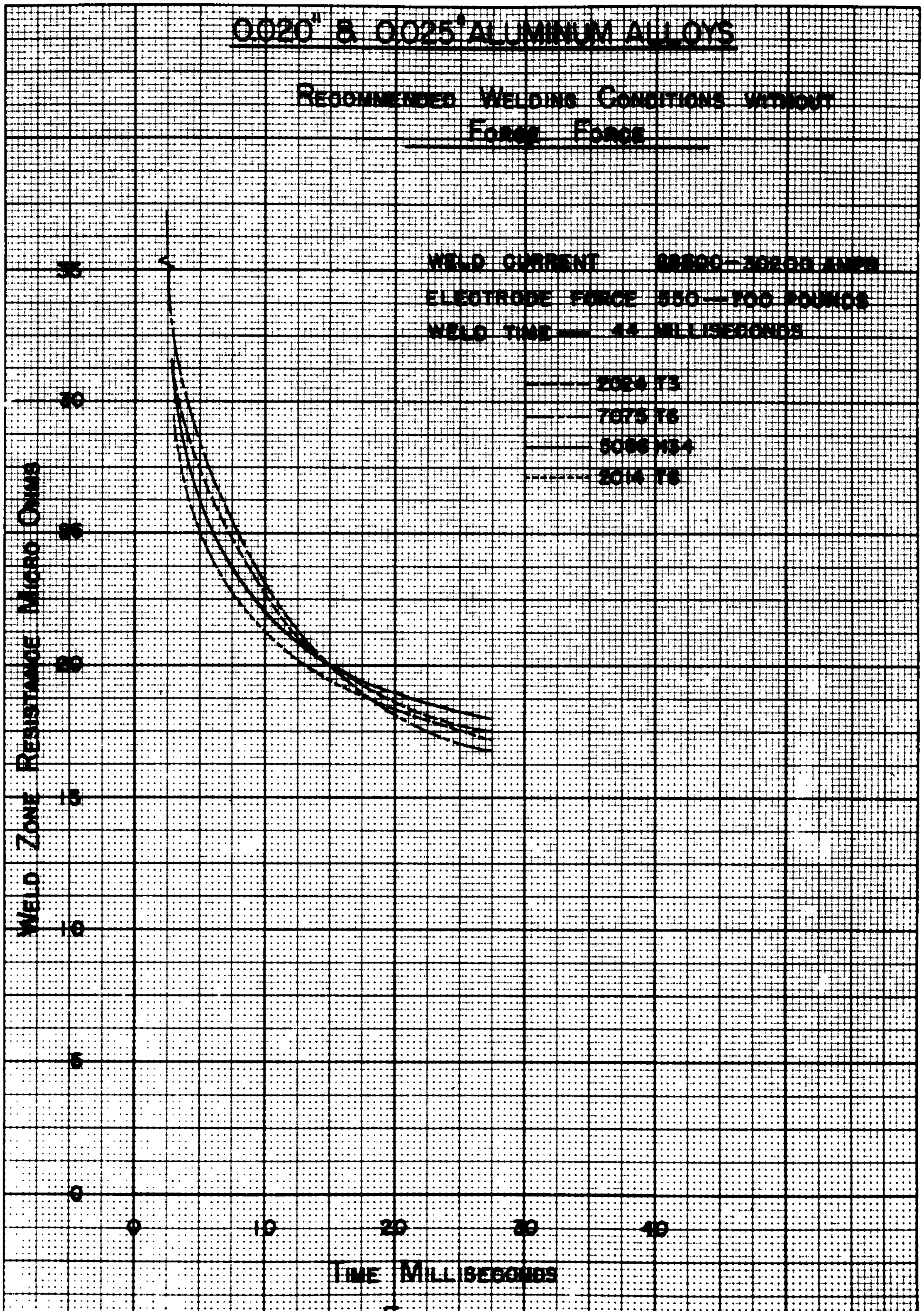
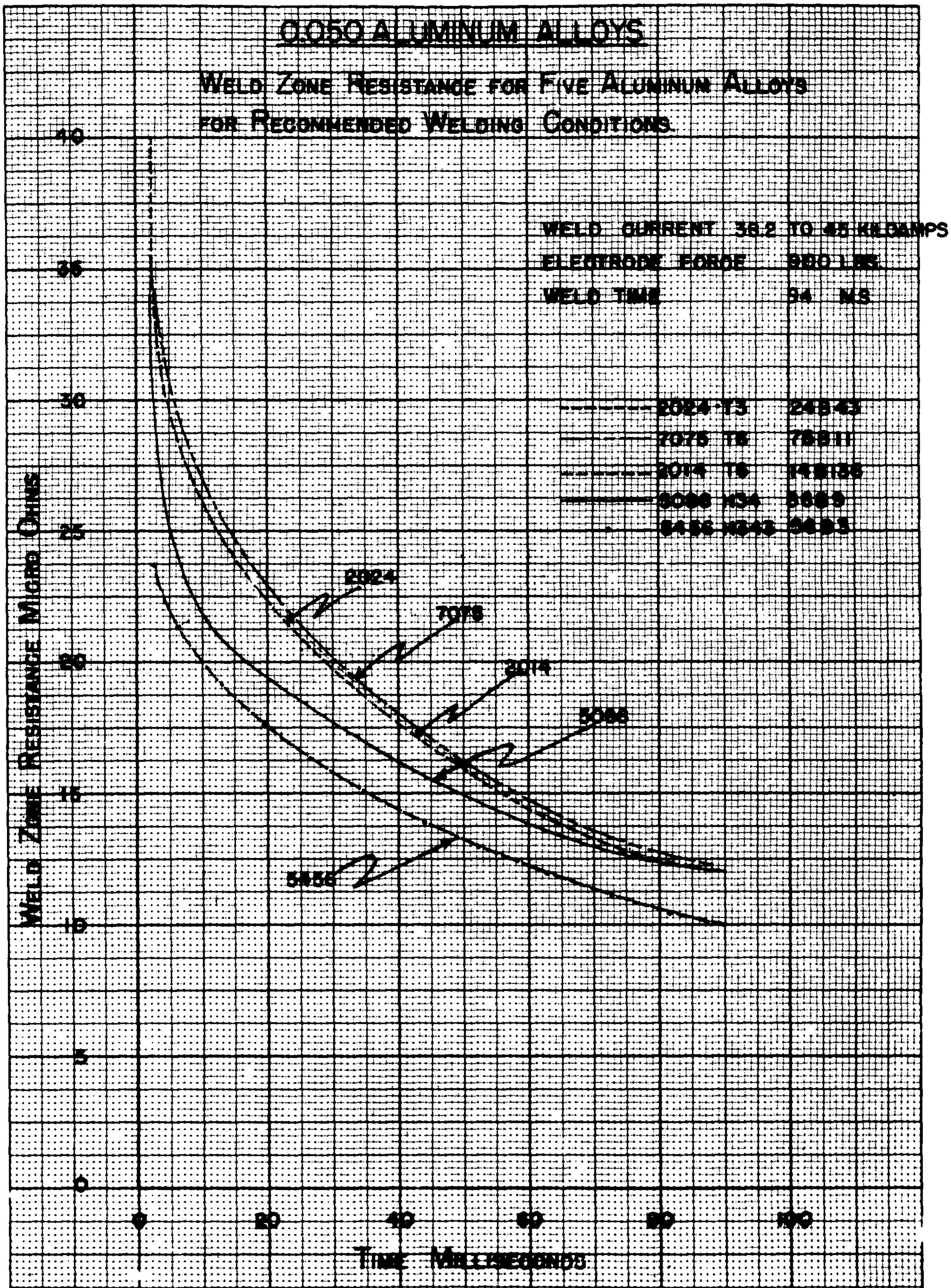
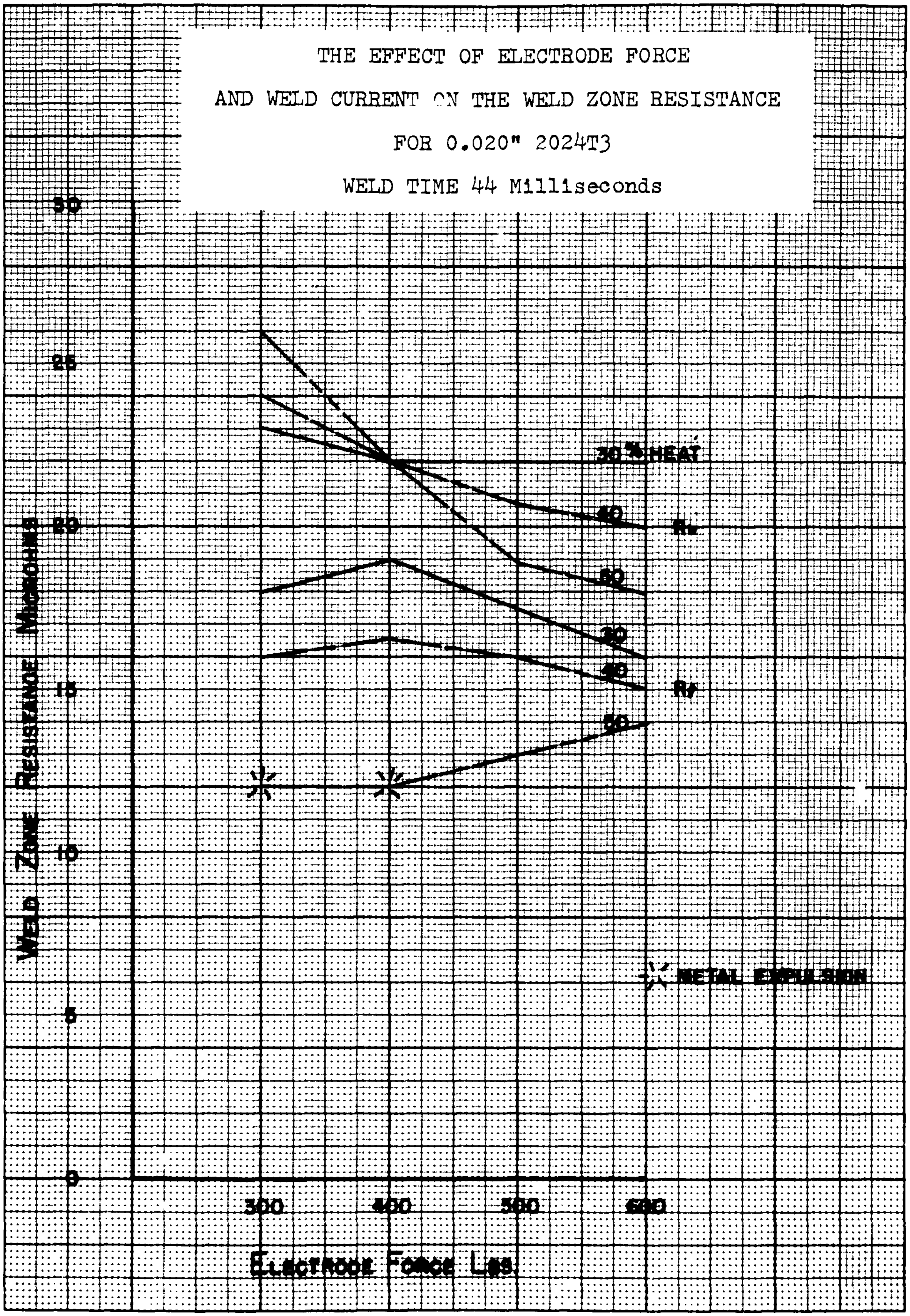

0.020" & 0.025" ALUMINUM ALLOYS
Recommended Welding Conditions without Forge Force
WELD CURRENT
WELD TIME — 44 MILLISECONDS
2024 T3
7075 T6
5086 H34
2014 T6
Weld Zone Resistance Micro Ohms
35
30
25
20
15
10
5
0
0
10
20
30
40
Time Milliseconds

Figure (16)



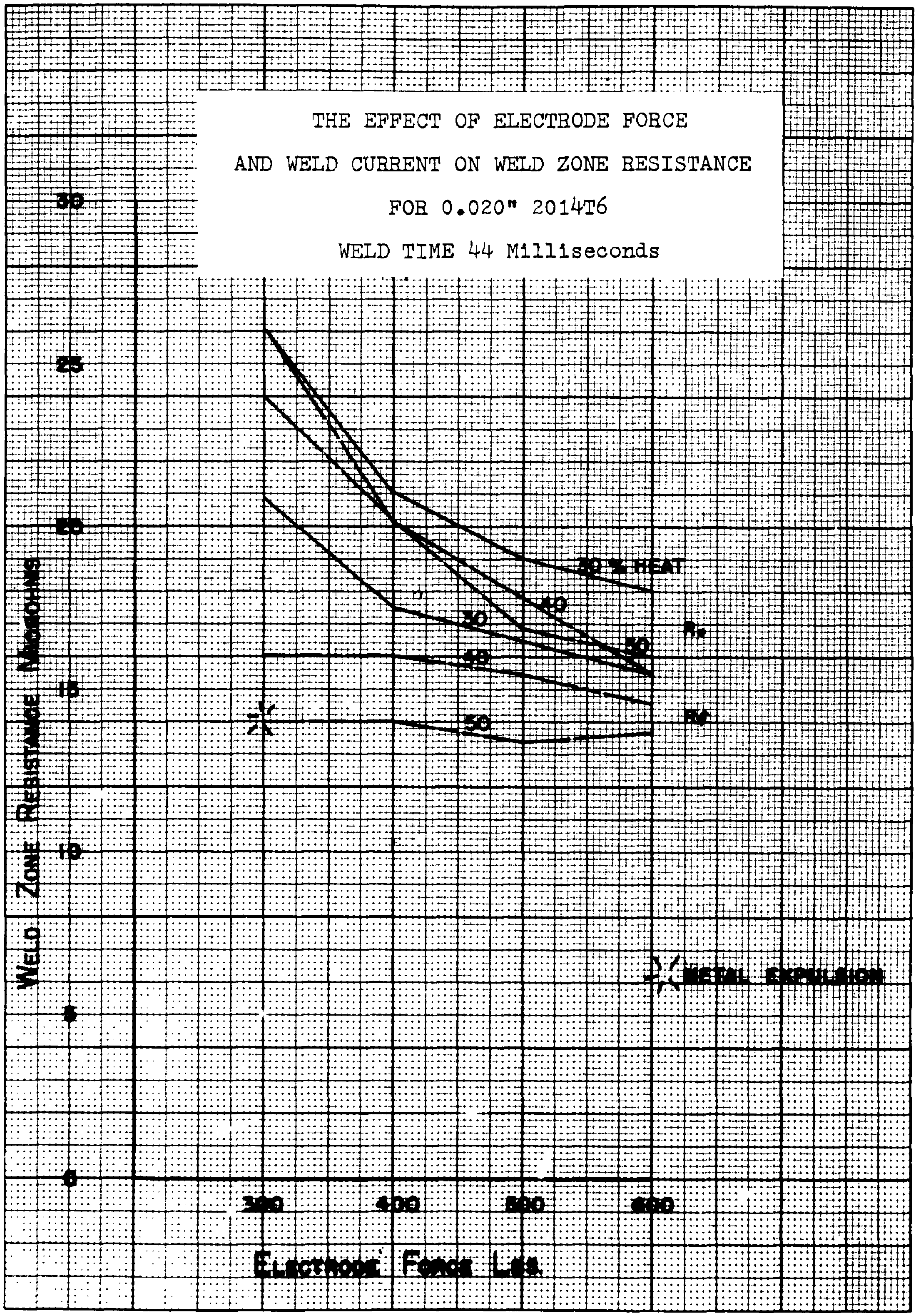
0.050 ALUMINUM ALLOYS
WELD ZONE RESISTANCE FOR FIVE ALUMINUN ALLOYS FOR RECOMMENDED WELDING CONDITIONS.
WELD CURRENT 36.2 TO 45 KILOAMPS
ELECTRODE FORCE 900 LBS.
WELD TIME 94 MS
2024-T3
7075 T6
2014 T6
5086 H34
5456 H343
2024
7075
2014
5086
5456
WELD ZONE RESISTANCE MICRO OHMS
40
35
30
25
20
15
10
5
0
0
20
40
60
80
100
TIME MILLISECONDS

FIGURE 117



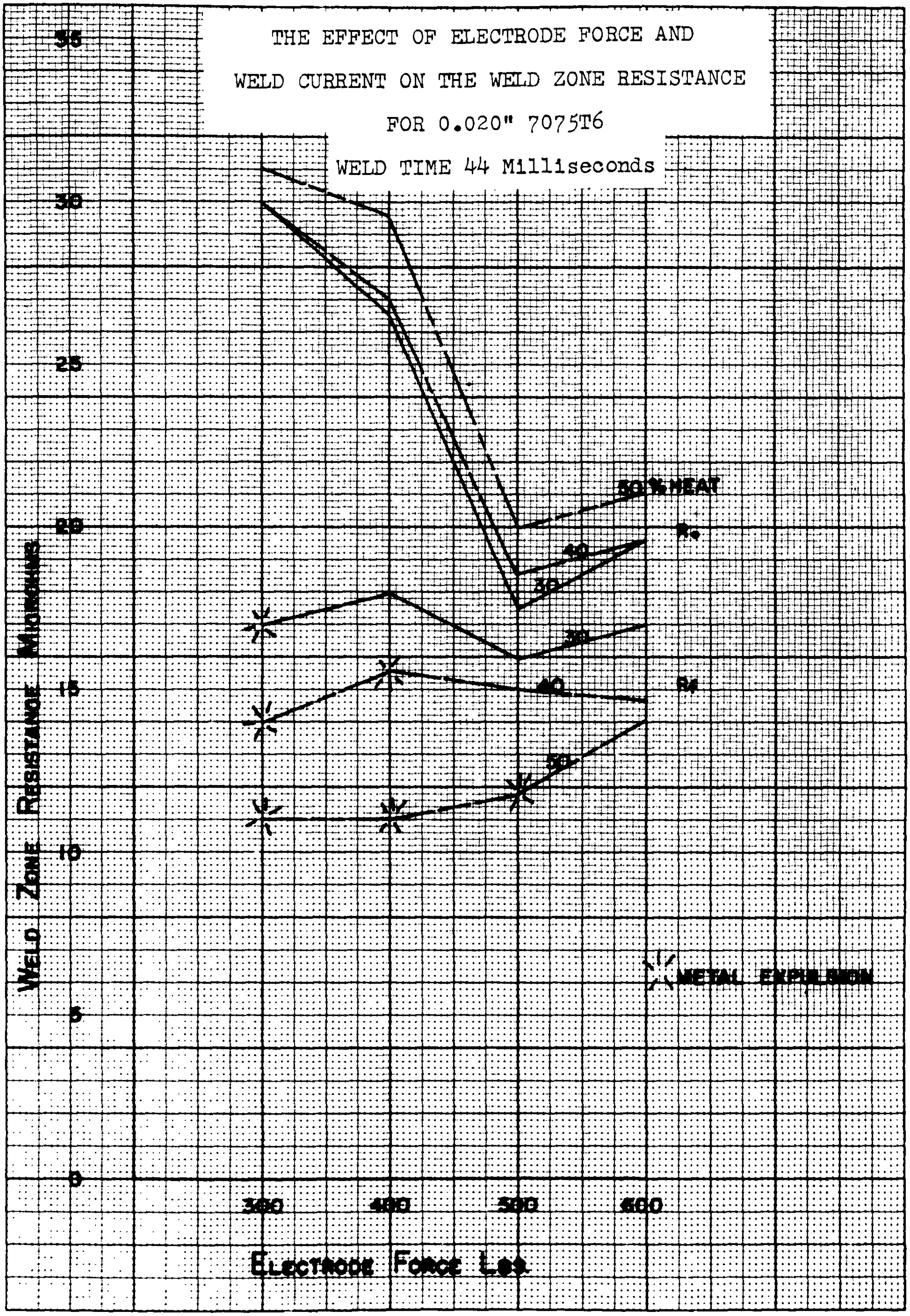
THE EFFECT OF ELECTRODE FORCE
AND WELD CURRENT ON THE WELD ZONE RESISTANCE
FOR 0.020" 2024T3
WELD TIME 44 Milliseconds
30
25
20
15
10
5
0
30 % HEAT
40
50
30
40
50
Rw
Rf
METAL EXPULSION
300
400
500
600
WELD ZONE RESISTANCE MICROHMS
ELECTRODE FORCE LBS.

FIG. (18)



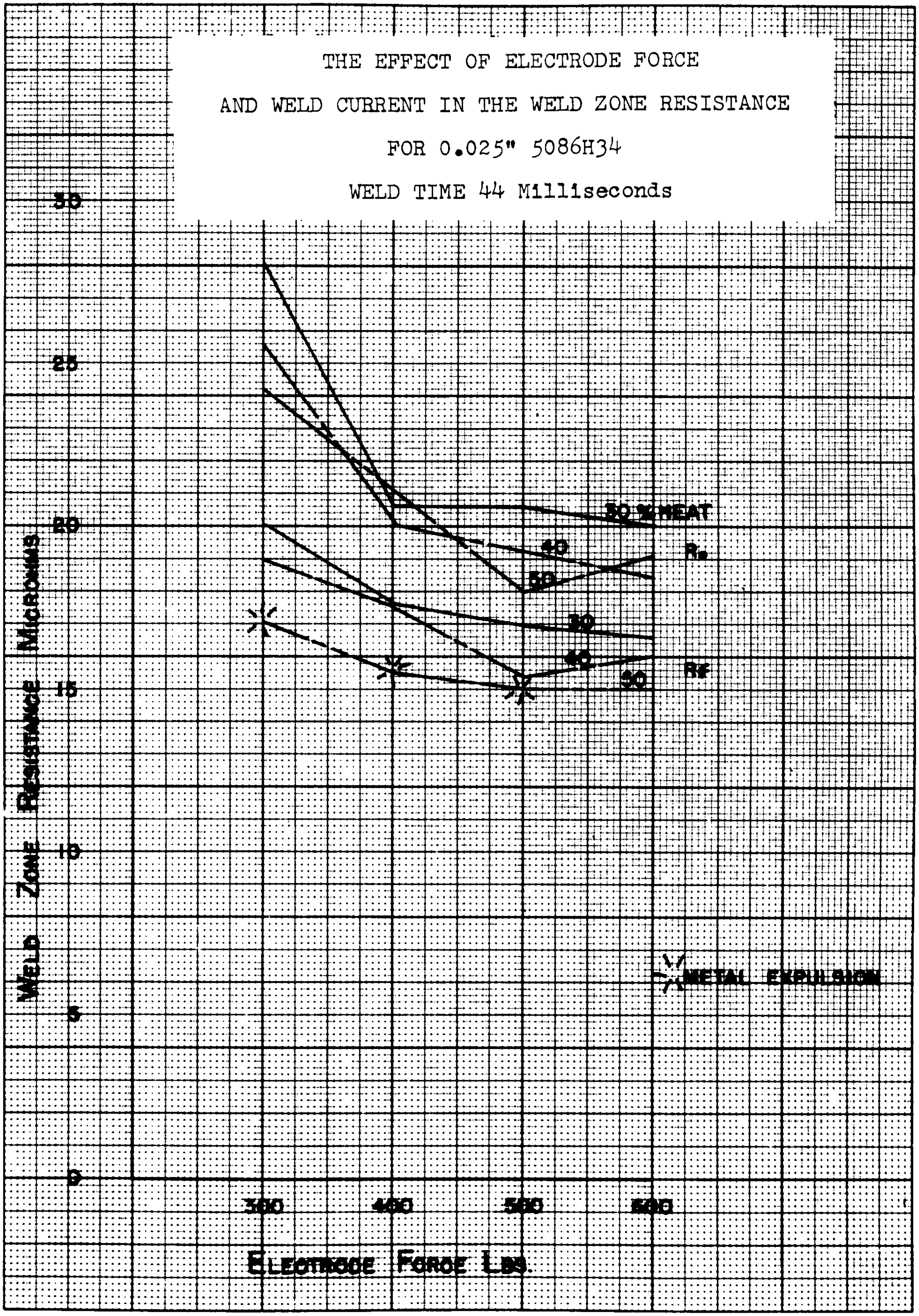
THE EFFECT OF ELECTRODE FORCE
AND WELD CURRENT ON WELD ZONE RESISTANCE
FOR 0.020" 2014T6
WELD TIME 44 Milliseconds
WELD ZONE RESISTANCE MICROHMS
30
25
20
15
10
5
0
300
400
500
600
ELECTRODE FORCE LBS.
30 % HEAT
40
50
30
40
50
METAL EXPULSION

FIG. (19)



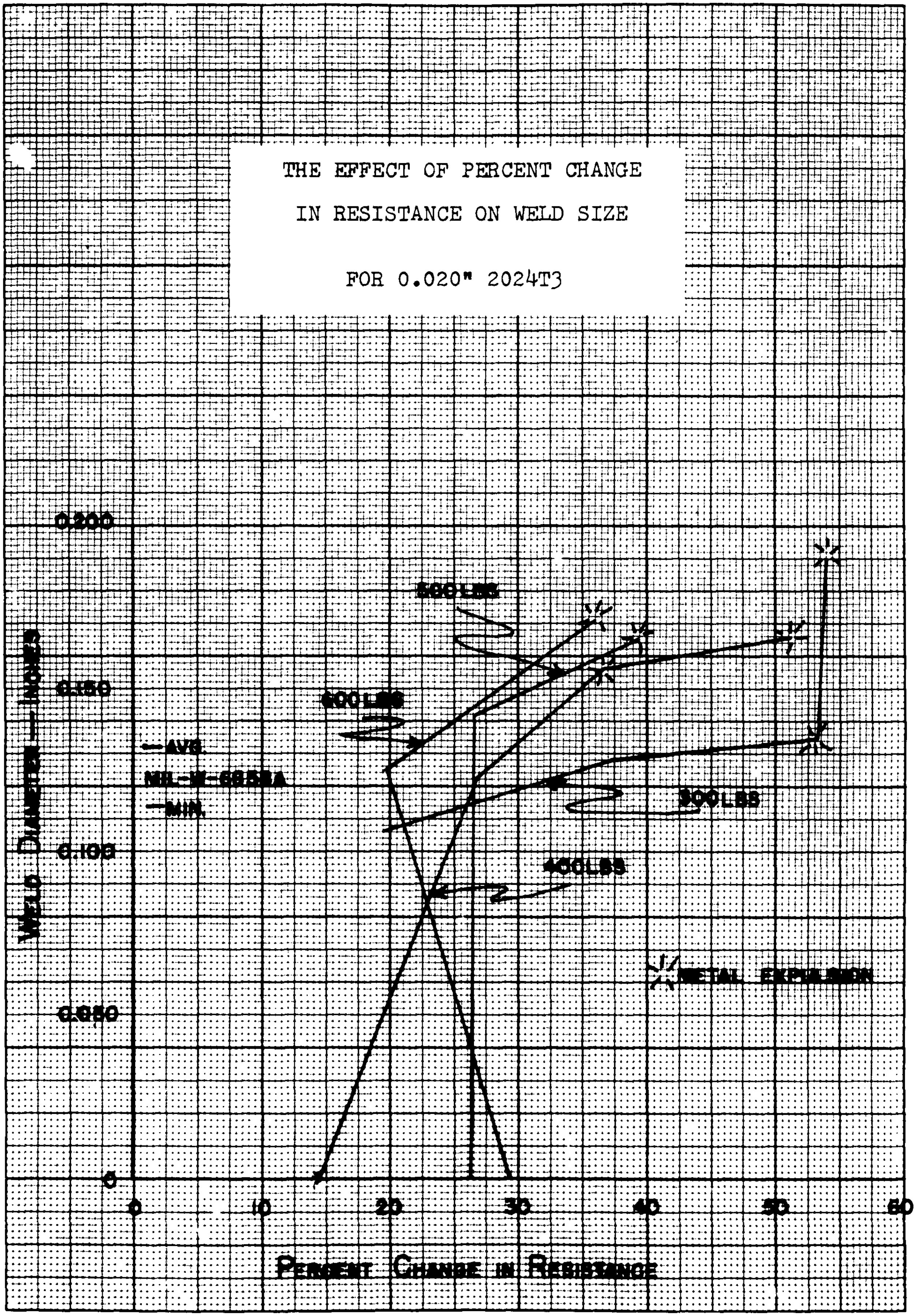
THE EFFECT OF ELECTRODE FORCE AND
WELD CURRENT ON THE WELD ZONE RESISTANCE
FOR 0.020" 7075T6
WELD TIME 44 Milliseconds
WELD ZONE RESISTANCE MICROHMS
ELECTRODE FORCE LBS.
0
5
10
15
20
25
30
35
300
400
500
600
50 % HEAT
40
30
30
40
50
METAL EXPULSION

FIG. (20)



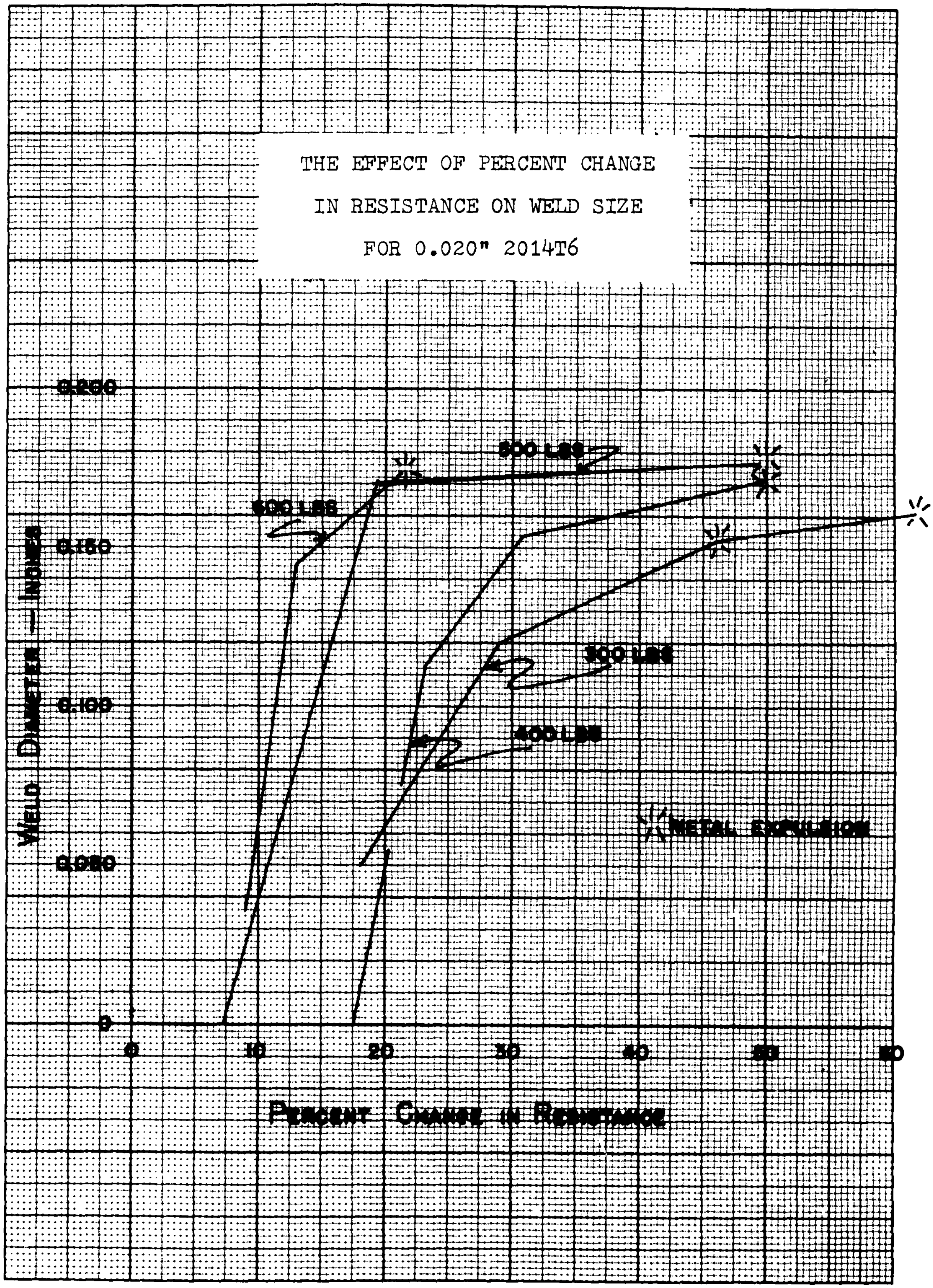
THE EFFECT OF ELECTRODE FORCE
AND WELD CURRENT IN THE WELD ZONE RESISTANCE
FOR 0.025" 5086H34
WELD TIME 44 Milliseconds
30
25
20
15
10
5
0
WELD ZONE RESISTANCE MICROHMS
300
400
500
600
ELECTRODE FORCE LBS.
30 % HEAT
40
50
Ro
30
40
50
Rf
METAL EXPULSION

FIG. (21)



THE EFFECT OF PERCENT CHANGE
IN RESISTANCE ON WELD SIZE
FOR 0.020" 2024T3
0.200
0.150
0.100
0.050
0
0
10
20
30
40
50
60
500LBS
600LBS
—AVG.
MIL-W-6858A
—MIN.
300LBS
400LBS
METAL EXPULSION
WELD DIAMETER — INCHES
PERCENT CHANGE IN RESISTANCE

FIG.(22)



THE EFFECT OF PERCENT CHANGE
IN RESISTANCE ON WELD SIZE
FOR 0.020" 2014T6
WELD DIAMETER — INCHES
0.200
0.150
0.100
0.050
0
0
10
20
30
40
50
60
PERCENT CHANGE IN RESISTANCE
500 LBS
600 LBS
300 LBS
400 LBS
METAL EXPULSION

Fig.(23)

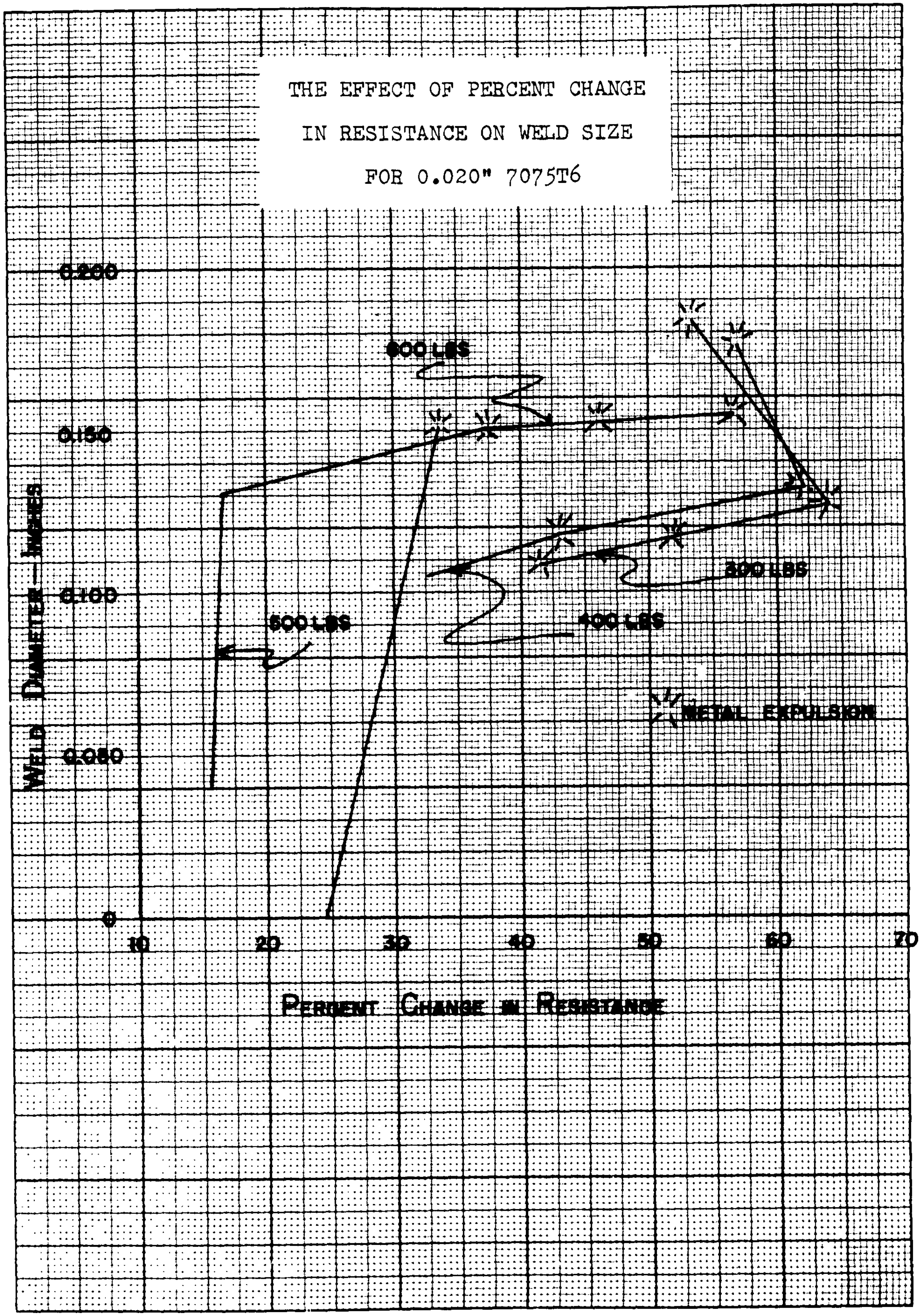

THE EFFECT OF PERCENT CHANGE
IN RESISTANCE ON WELD SIZE
FOR 0.020" 7075T6
0.200
0.150
0.100
0.050
0
10
20
30
40
50
60
70
600 LBS
500 LBS
400 LBS
300 LBS
METAL EXPULSION
WELD DIAMETER — INCHES
PERCENT CHANGE IN RESISTANCE

FIG. (24)

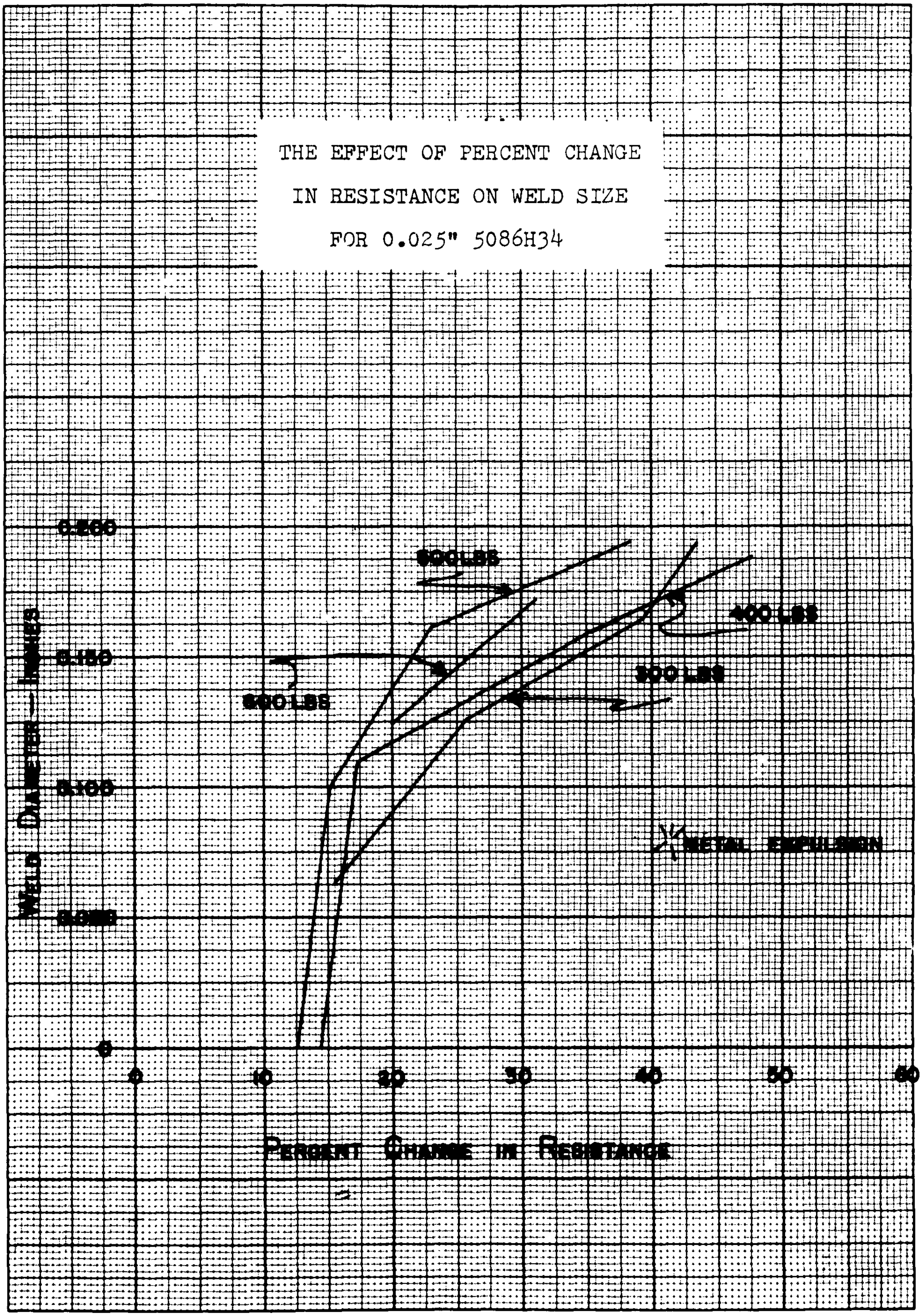

THE EFFECT OF PERCENT CHANGE
IN RESISTANCE ON WELD SIZE
FOR 0.025" 5086H34
WELD DIAMETER — INCHES
0.200
0.150
0.100
0.050
0
0
10
20
30
40
50
60
PERCENT CHANGE IN RESISTANCE
600 LBS
500 LBS
400 LBS
300 LBS
METAL EXPULSION

FIG. (25)

0.025" 5086 H34

OSCILLOGRAPHIC TRACES OF RESISTANCE SPOT WELDS

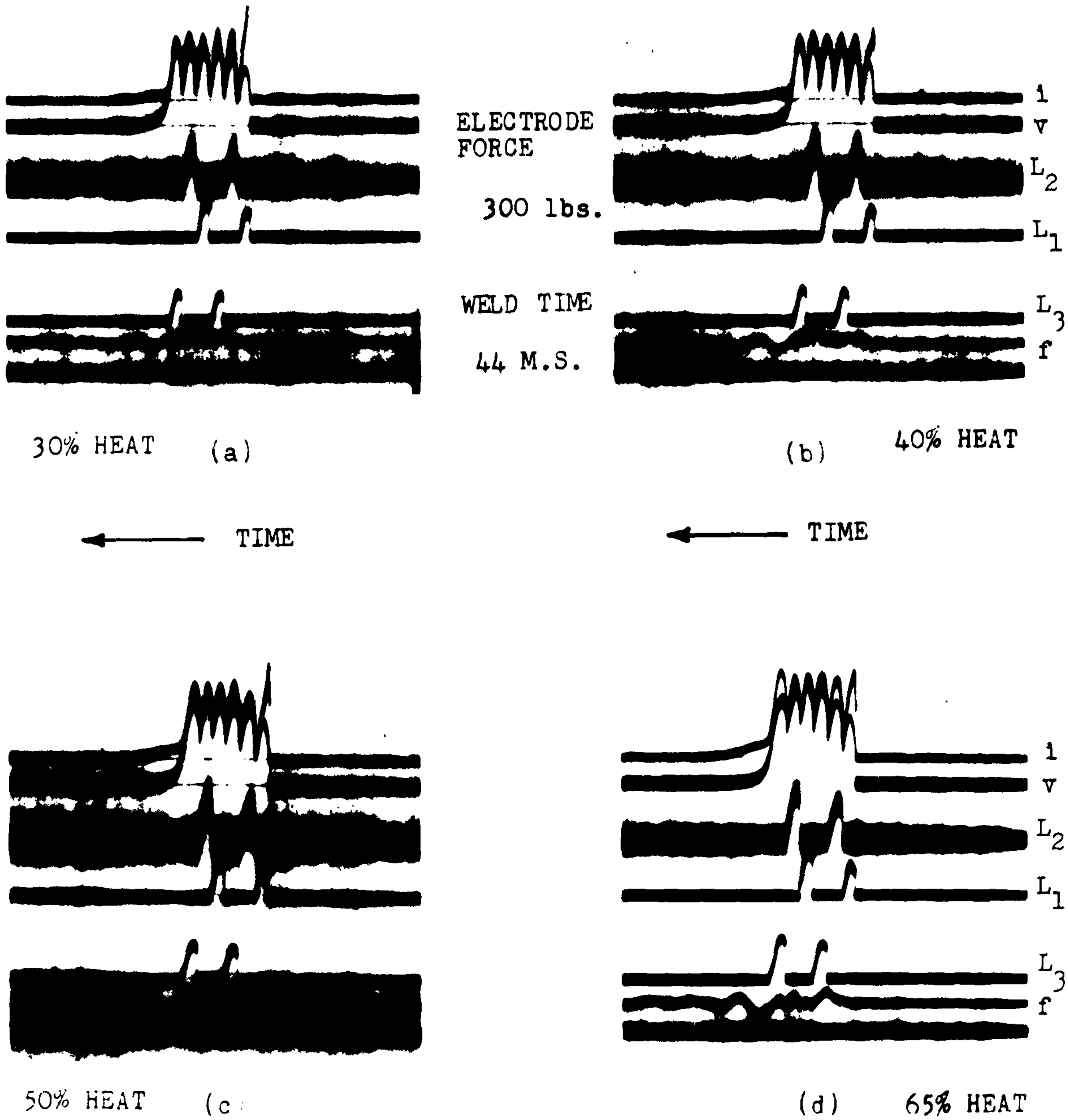


FIGURE (26)

0.025" 5086 H34

Oscillographic Traces of Resistance Spot Welds

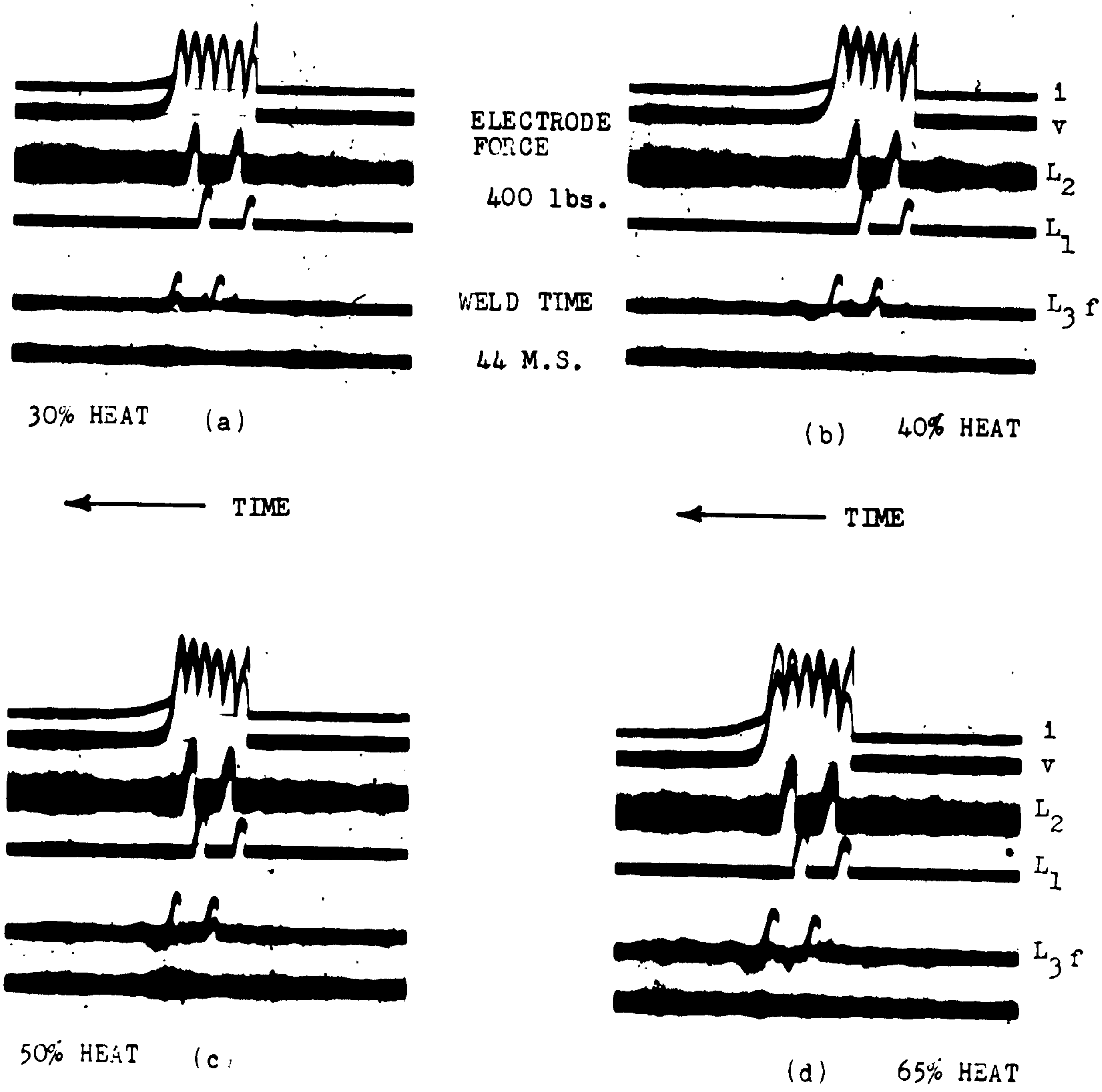


FIGURE (27)

0.025" 5086 H34

OSCILLOGRAPHIC TRACES OF RESISTANCE SPOT WELDS

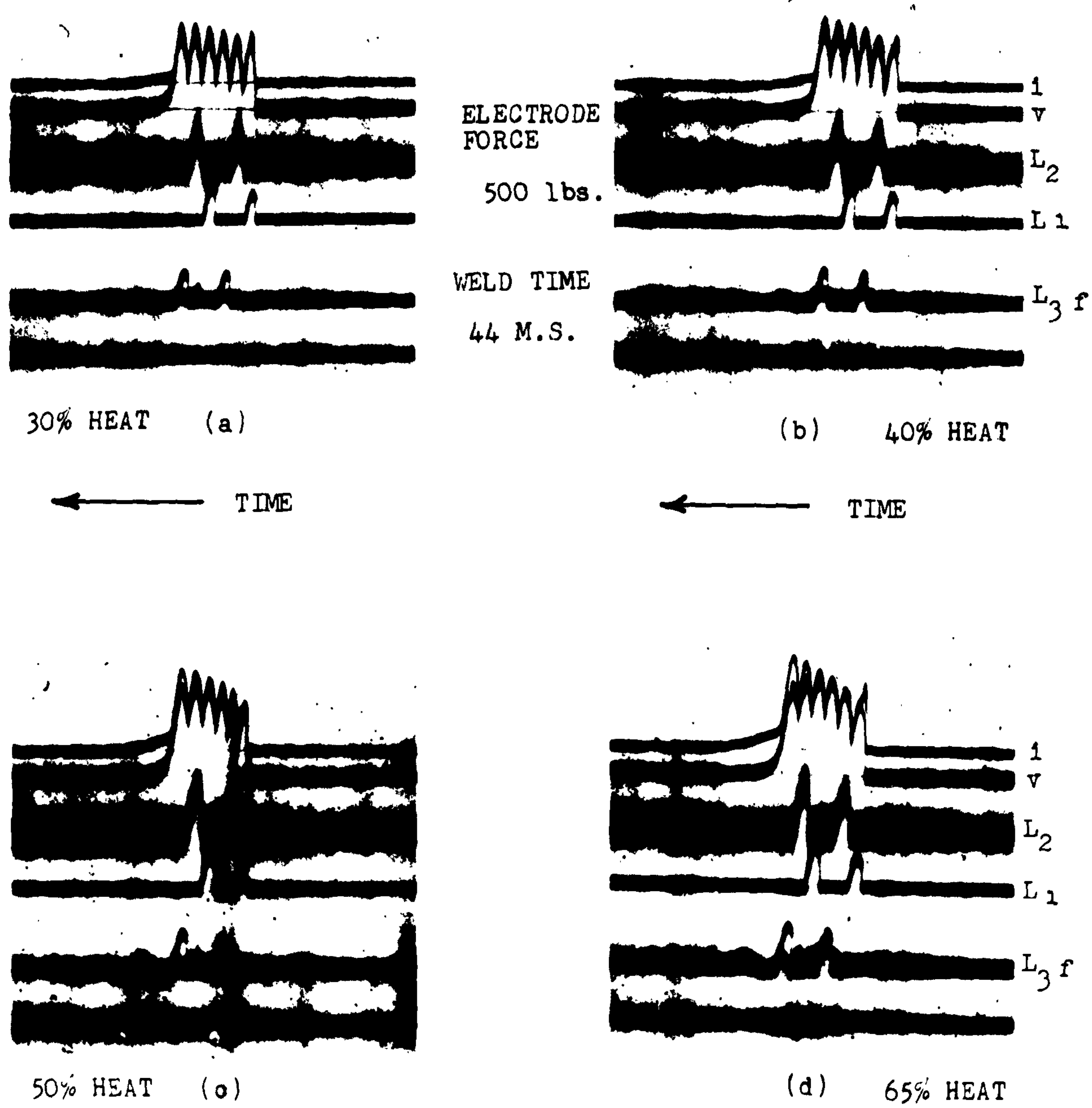


FIGURE (28)

0.025" 5086 H34

Oscillographic Traces of Resistance Spot Welds

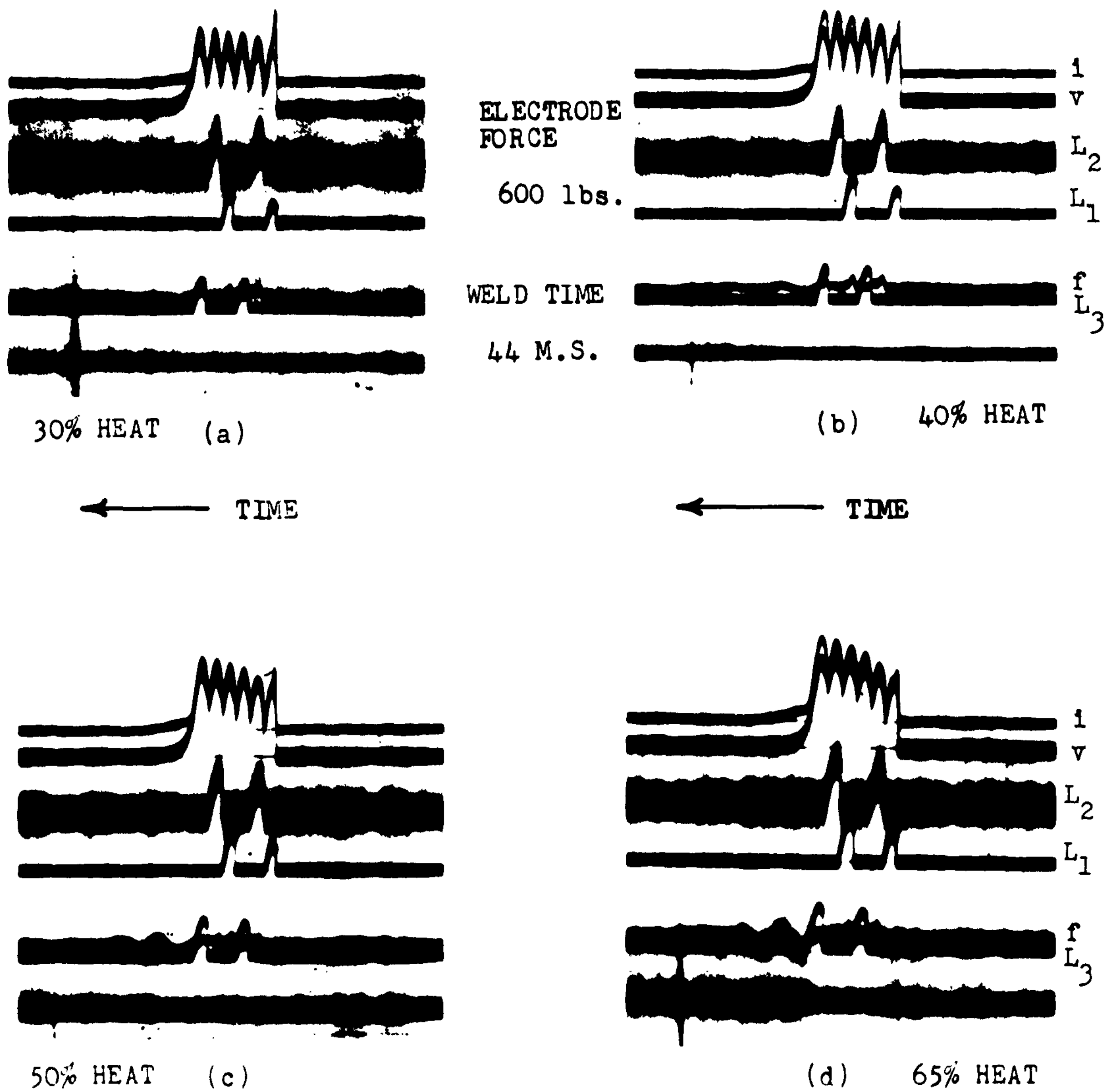


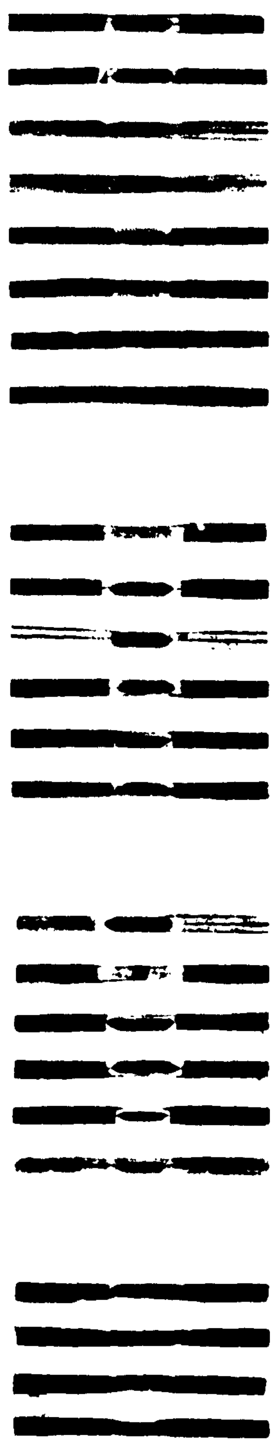
FIGURE (29)

THE EFFECT OF WELDING SCHEDULES

ON THE WELD SIZE AND SHAPE

FOR 0.020" 2014T6

WELD TIME 44 MILLISECONDS (2 CYCLES)



WELD CURRENT PERCENT HEAT	ELECTRODE FORCE	WELD DIA.	PENETRATION
65	300	0.161	35/100
65	300	0.160	91/100
50	300	0.154	100
50	300	0.152	85/100
40	300	0.120	73
40	300	0.120	72
30	300	0.068	52
30	300	0.043	47
65	400	0.171	100
65	400	0.170	81/100
50	400	0.149	84
50	400	0.159	83
40	400	0.120	60
40	400	0.110	60
65	500	0.175	100
65	500	0.180	90/100
50	500	0.175	75
50	500	0.165	75
40	500	0.112	52
40	500	0.090	26
65	600	0.175	85
65	600	0.174	74
50	600	0.150	59
50	600	0.143	59

FIGURE 30

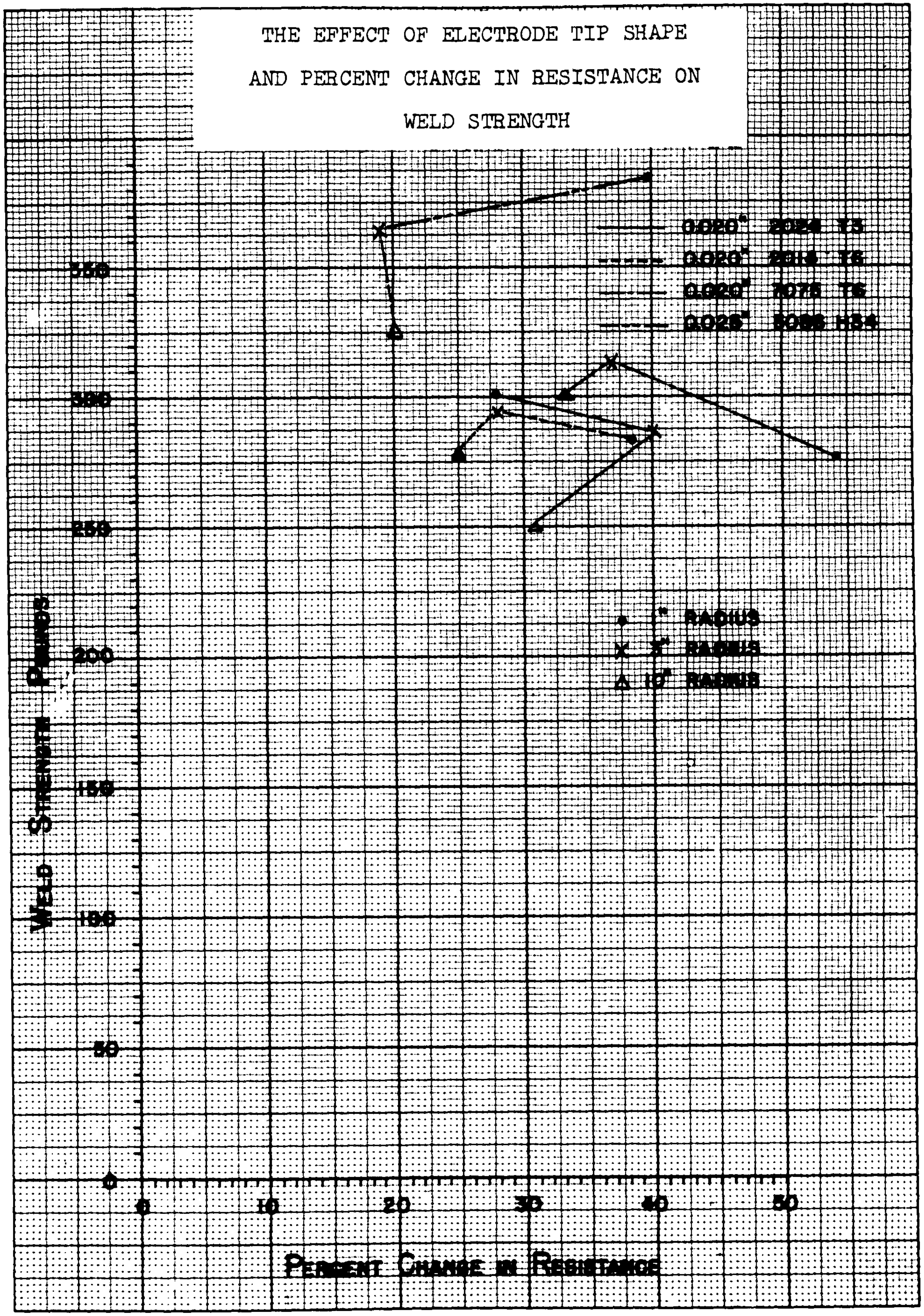

THE EFFECT OF ELECTRODE TIP SHAPE
AND PERCENT CHANGE IN RESISTANCE ON
WELD STRENGTH
0.020" 2024 T
0.020"
0.020" 7075 T6
0.025"
RADIUS
RADIUS
10" RADIUS
WELD STRENGTH POUNDS
350
300
250
200
150
100
50
0
0
10
20
30
40
50
PERCENT CHANGE IN RESISTANCE

FIG. (31)

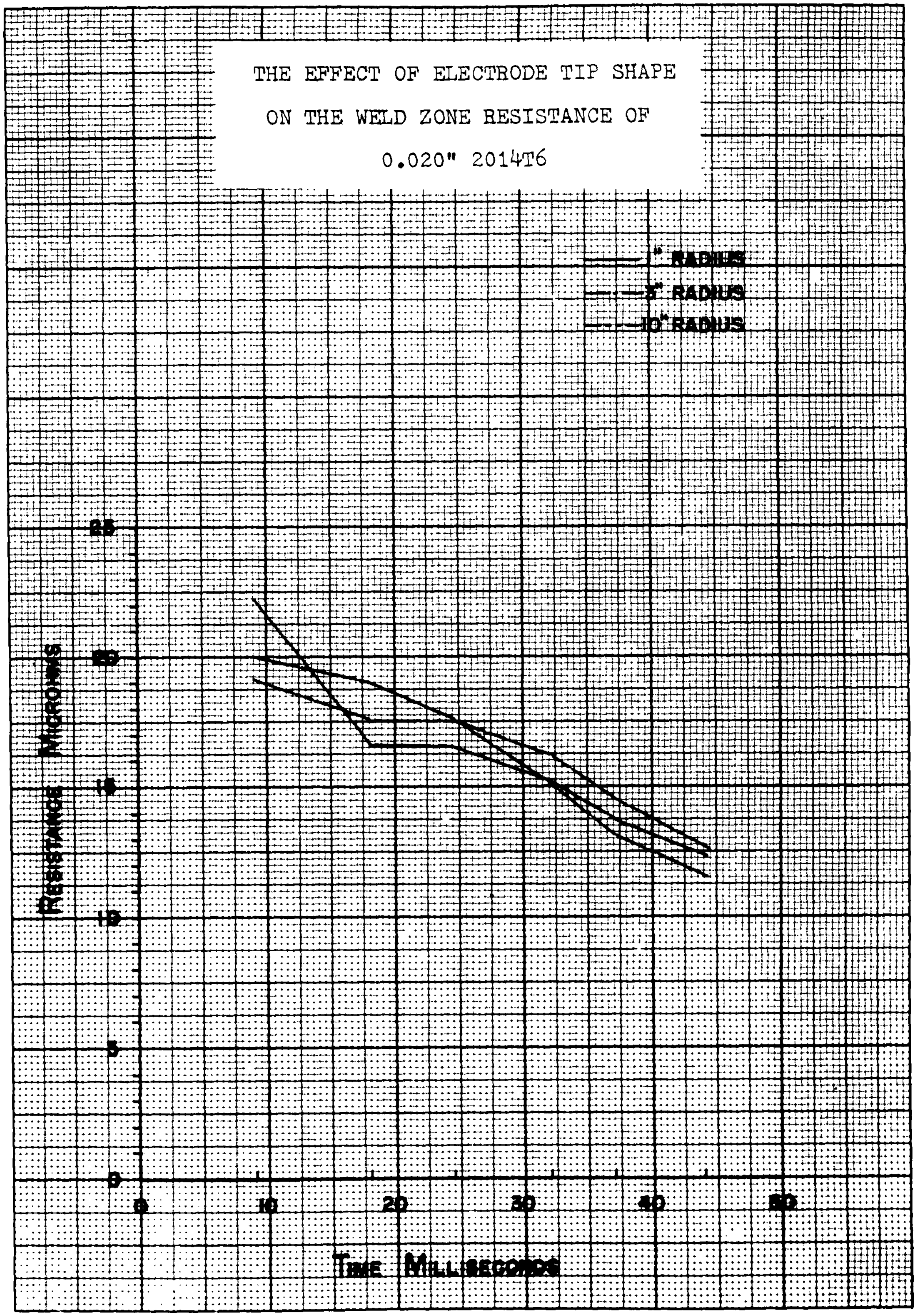

THE EFFECT OF ELECTRODE TIP SHAPE
ON THE WELD ZONE RESISTANCE OF
0.020" 2014T6
1" RADIUS
5" RADIUS
10" RADIUS
RESISTANCE MICROHMS
25
20
15
10
5
0
0
10
20
30
40
50
TIME MILLISECONDS

FIG. (32)

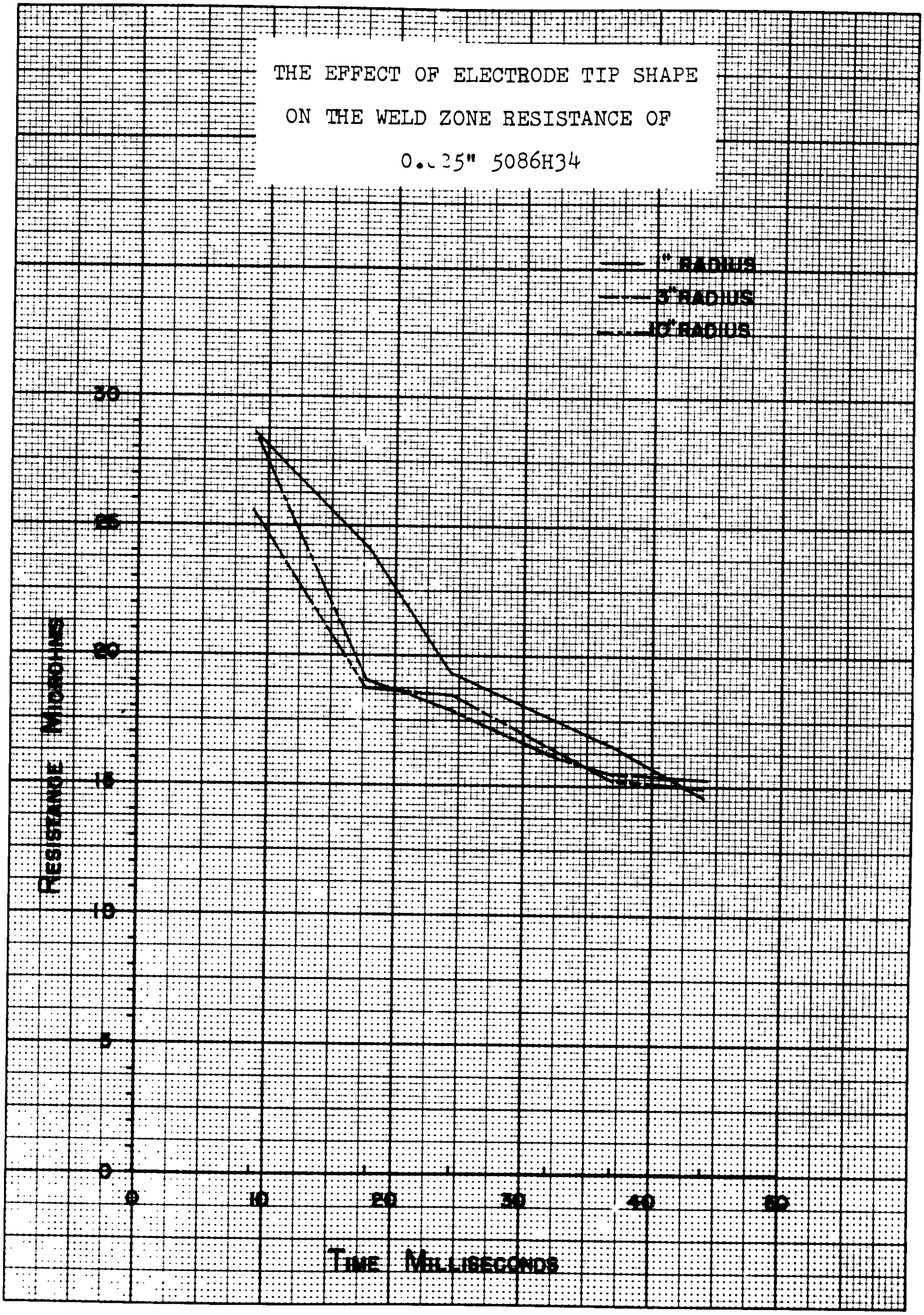

THE EFFECT OF ELECTRODE TIP SHAPE
ON THE WELD ZONE RESISTANCE OF
5086H34
" RADIUS
3" RADIUS
10" RADIUS
RESISTANCE MICROHMS
30
25
20
15
10
5
0
0
10
20
30
40
50
TIME MILLISECONDS

FIG. (33)

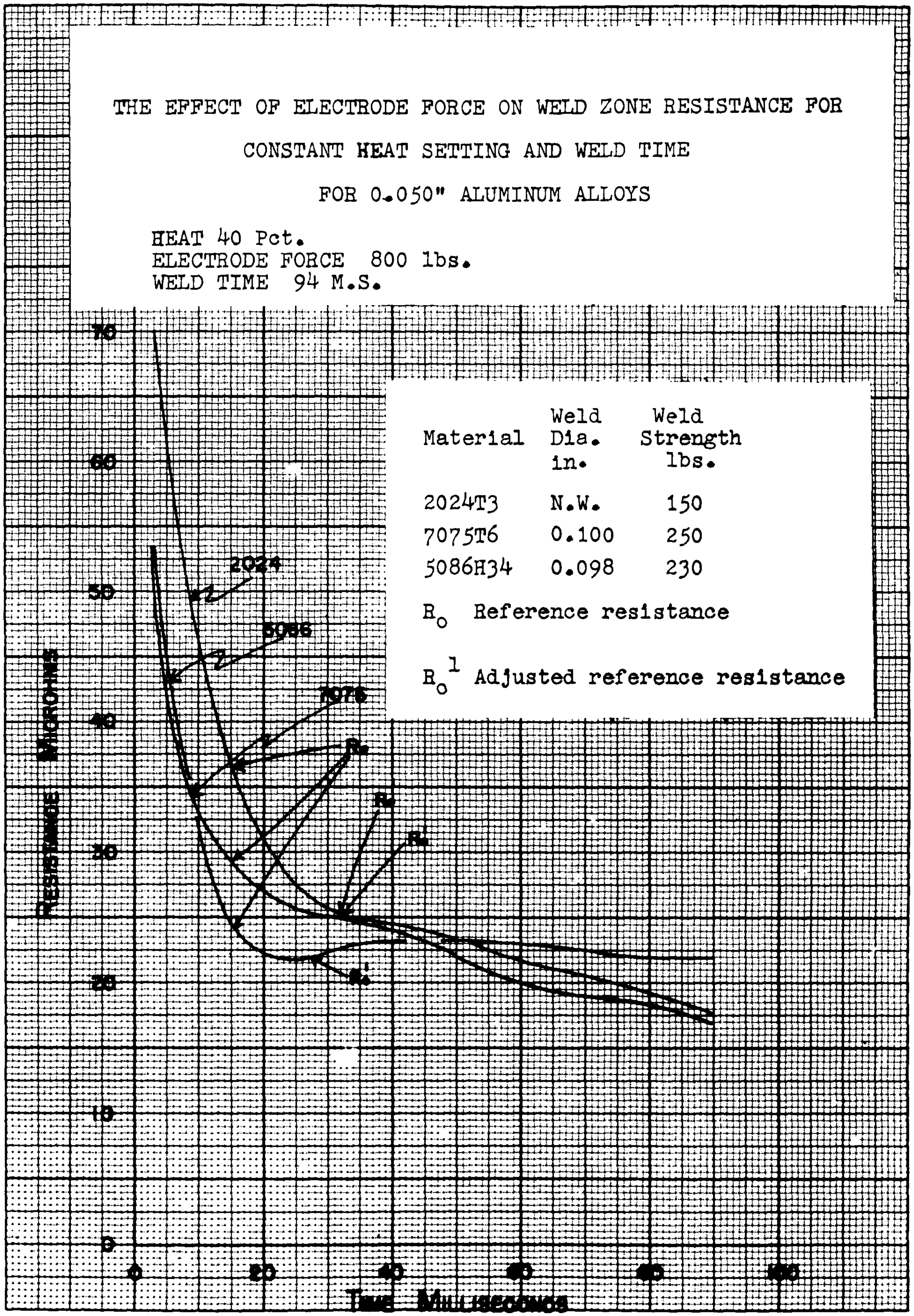
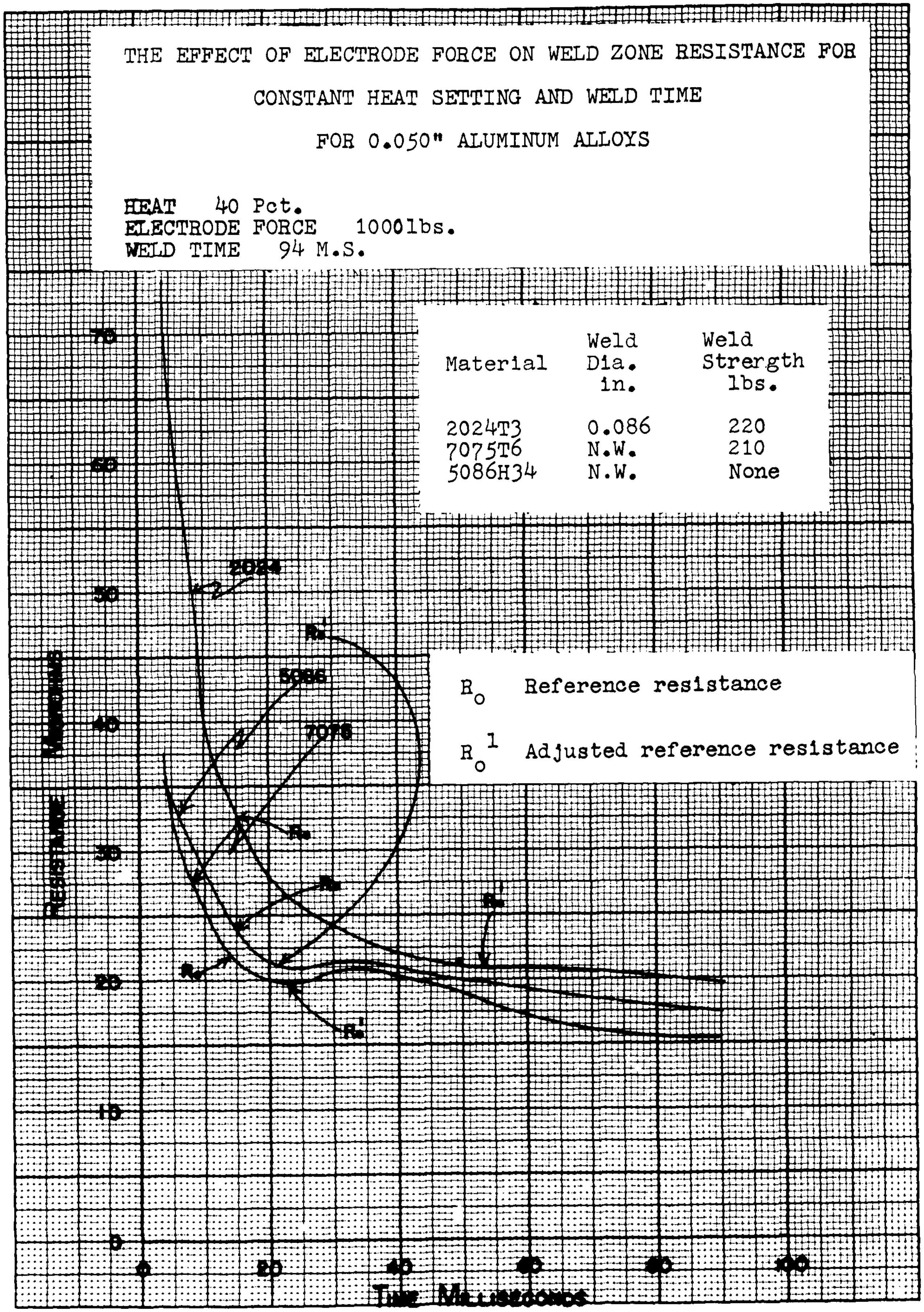
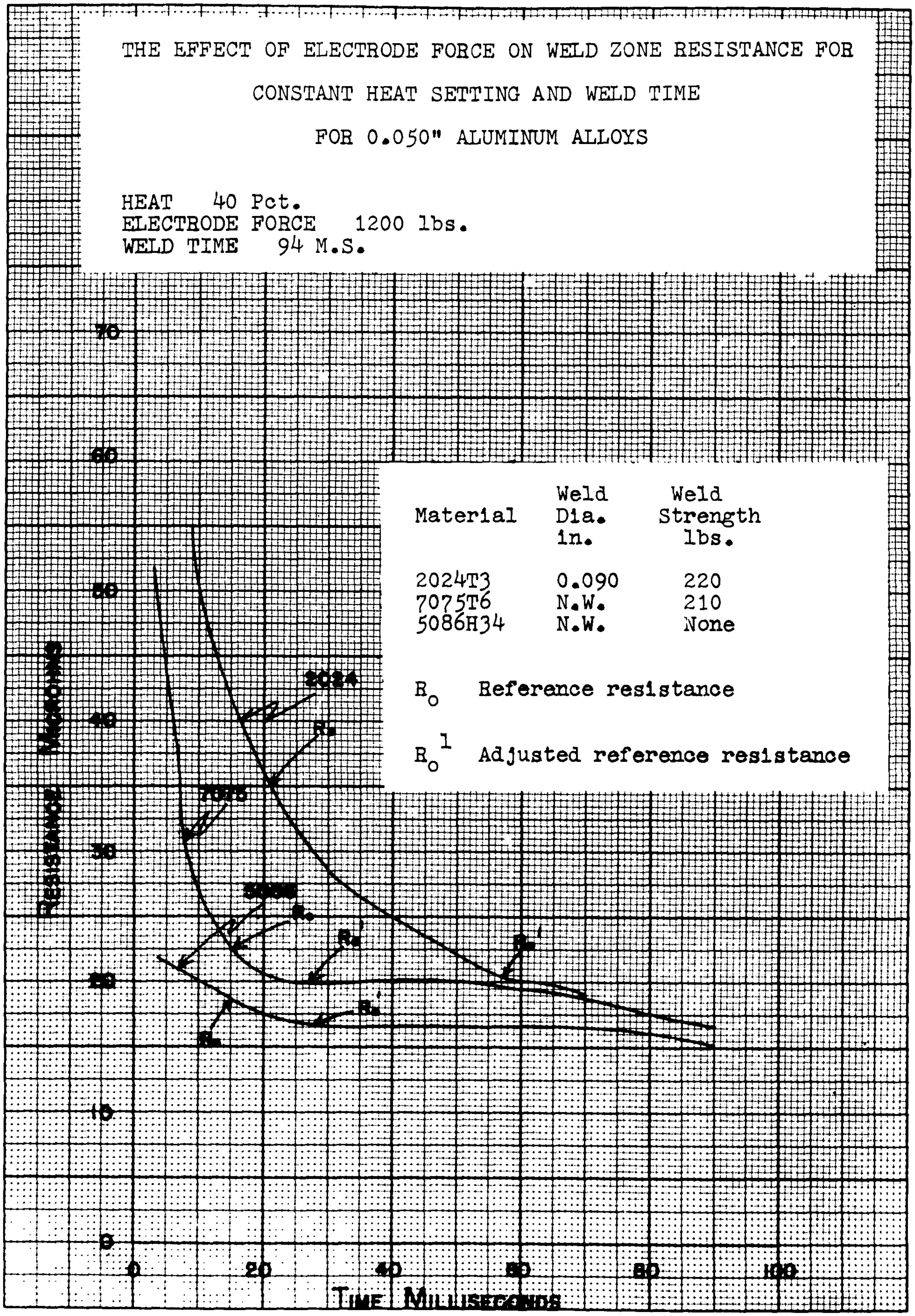

THE EFFECT OF ELECTRODE FORCE ON WELD ZONE RESISTANCE FOR
CONSTANT HEAT SETTING AND WELD TIME
FOR 0.050" ALUMINUM ALLOYS
HEAT 40 Pct.
ELECTRODE FORCE 800 lbs.
WELD TIME 94 M.S.
Material
Weld Dia. in.
Weld Strength lbs.
2024T3 N.W. 150
7075T6 0.100 250
5086H34 0.098 230
R_o Reference resistance
$R_o{}^1$ Adjusted reference resistance
2024
5086
7075
RESISTANCE MICROHMS
TIME MILLISECONDS
0
10
20
30
40
50
60
70
0
20
40
60
80
100

FIG. (34)



Material	Weld Dia. in.	Weld Strergth lbs.
2024T3	0.086	220
7075T6	N.W.	210
5086H34	N.W.	None

FIG. (35)



THE EFFECT OF ELECTRODE FORCE ON WELD ZONE RESISTANCE FOR
CONSTANT HEAT SETTING AND WELD TIME
FOR 0.050" ALUMINUM ALLOYS
HEAT 40 Pct.
ELECTRODE FORCE 1200 lbs.
WELD TIME 94 M.S.
Material | Weld Dia. in. | Weld Strength lbs.
2024T3 | 0.090 | 220
7075T6 | N.W. | 210
5086H34 | N.W. | None
R_o Reference resistance
R_o^1 Adjusted reference resistance
2024
7075
5086
RESISTANCE MICROHMS
TIME MILLISECONDS
70
60
50
40
30
20
10
0
0
20
40
60
80
100

FIG. (36)

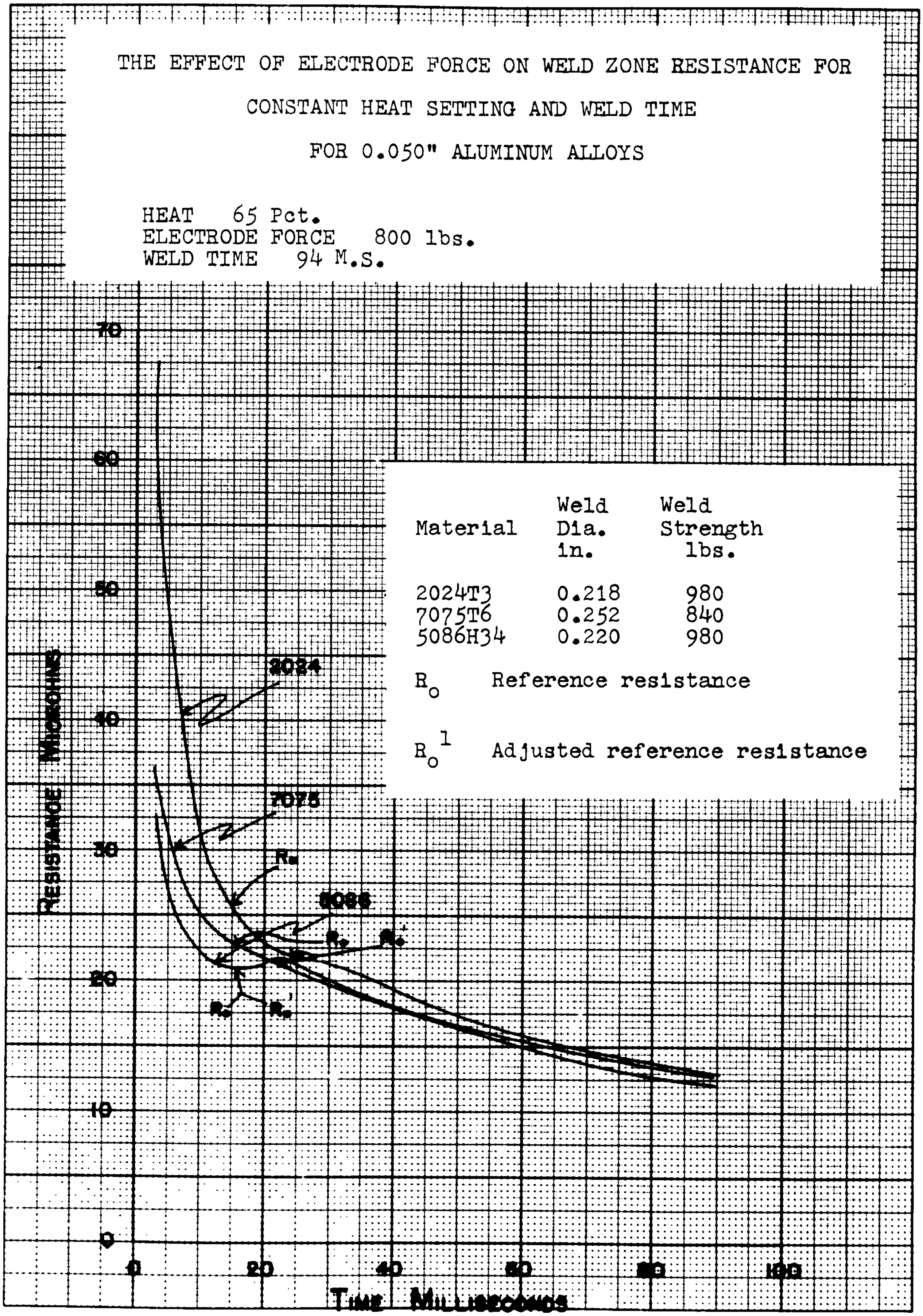

THE EFFECT OF ELECTRODE FORCE ON WELD ZONE RESISTANCE FOR
CONSTANT HEAT SETTING AND WELD TIME
FOR 0.050" ALUMINUM ALLOYS
HEAT 65 Pct.
ELECTRODE FORCE 800 lbs.
WELD TIME 94 M.S.
Material
Weld Dia. in.
Weld Strength lbs.
2024T3 0.218 980
7075T6 0.252 840
5086H34 0.220 980
Ro Reference resistance
Ro1 Adjusted reference resistance
2024
7075
5086
70
60
50
40
30
20
10
0
0
20
40
60
80
100
RESISTANCE MICROHMS
TIME MILLISECONDS

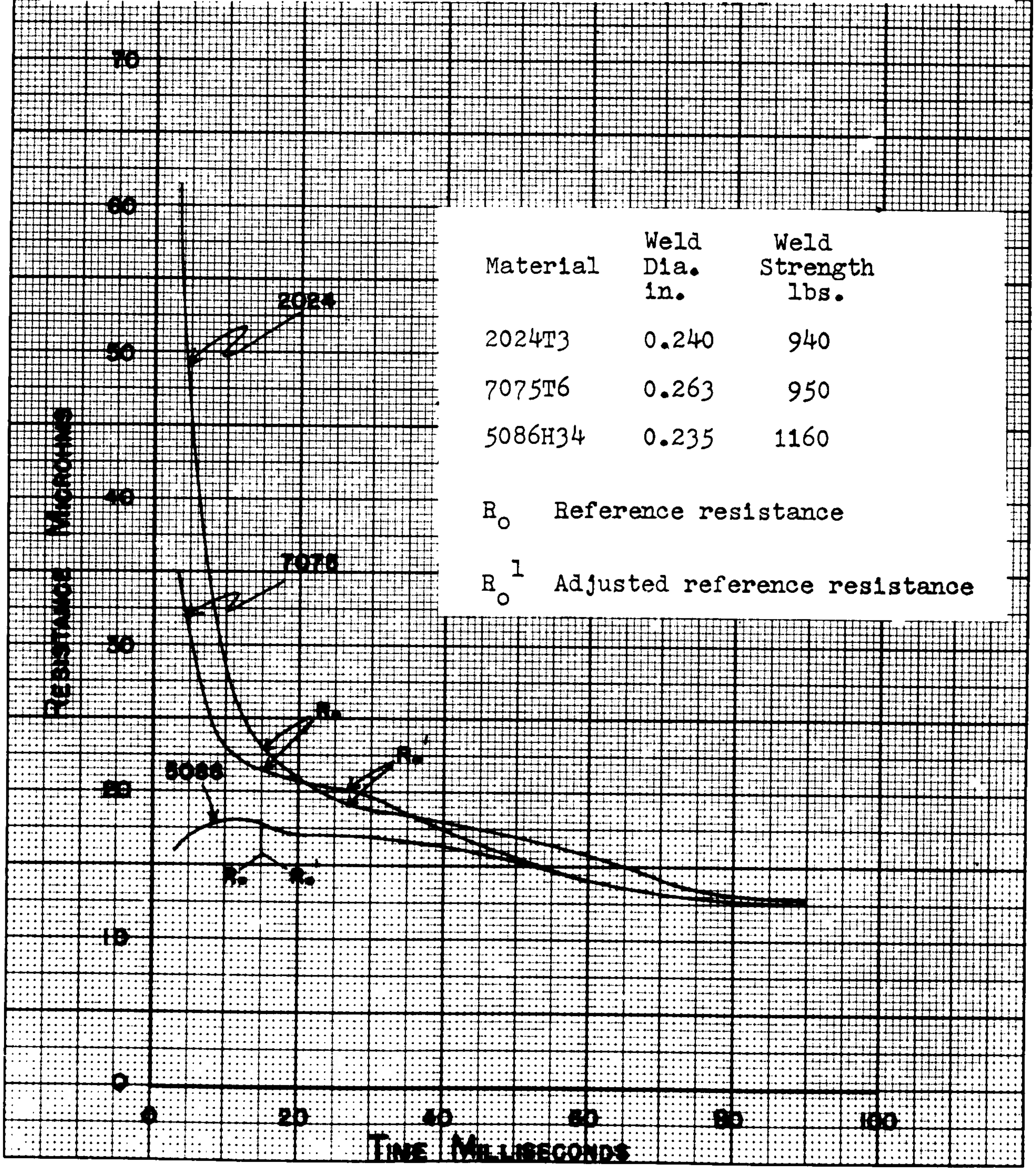
Fig. (37)

THE EFFECT OF ELECTRODE FORCE ON WELD ZONE RESISTANCE FOR

CONSTANT HEAT SETTING AND WELD TIME

FOR 0.050" ALUMINUM ALLOYS

HEAT 65 Pct.
ELECTRODE FORCE 1000 lbs.
WELD TIME 94 M.S.



Material	Weld Dia. in.	Weld Strength lbs.
2024T3	0.240	940
7075T6	0.263	950
5086H34	0.235	1160

R_o Reference resistance

R_o^1 Adjusted reference resistance

FIG. (38)

THE EFFECT OF ELECTRODE FORCE ON WELD ZONE RESISTANCE FOR CONSTANT HEAT SETTING AND WELD TIME FOR 0.050" ALUMINUM ALLOYS

HEAT 65 Pct.
ELECTRODE FORCE 1200 lbs.
WELD TIME 94 M.S.

Material	Weld Dia. in.	Weld Strength lbs.
2024T3	0.244	730
7075T6	0.229	890
5086H34	0.226	950

R_o Reference resistance

R_o^1 Adjusted reference resistance

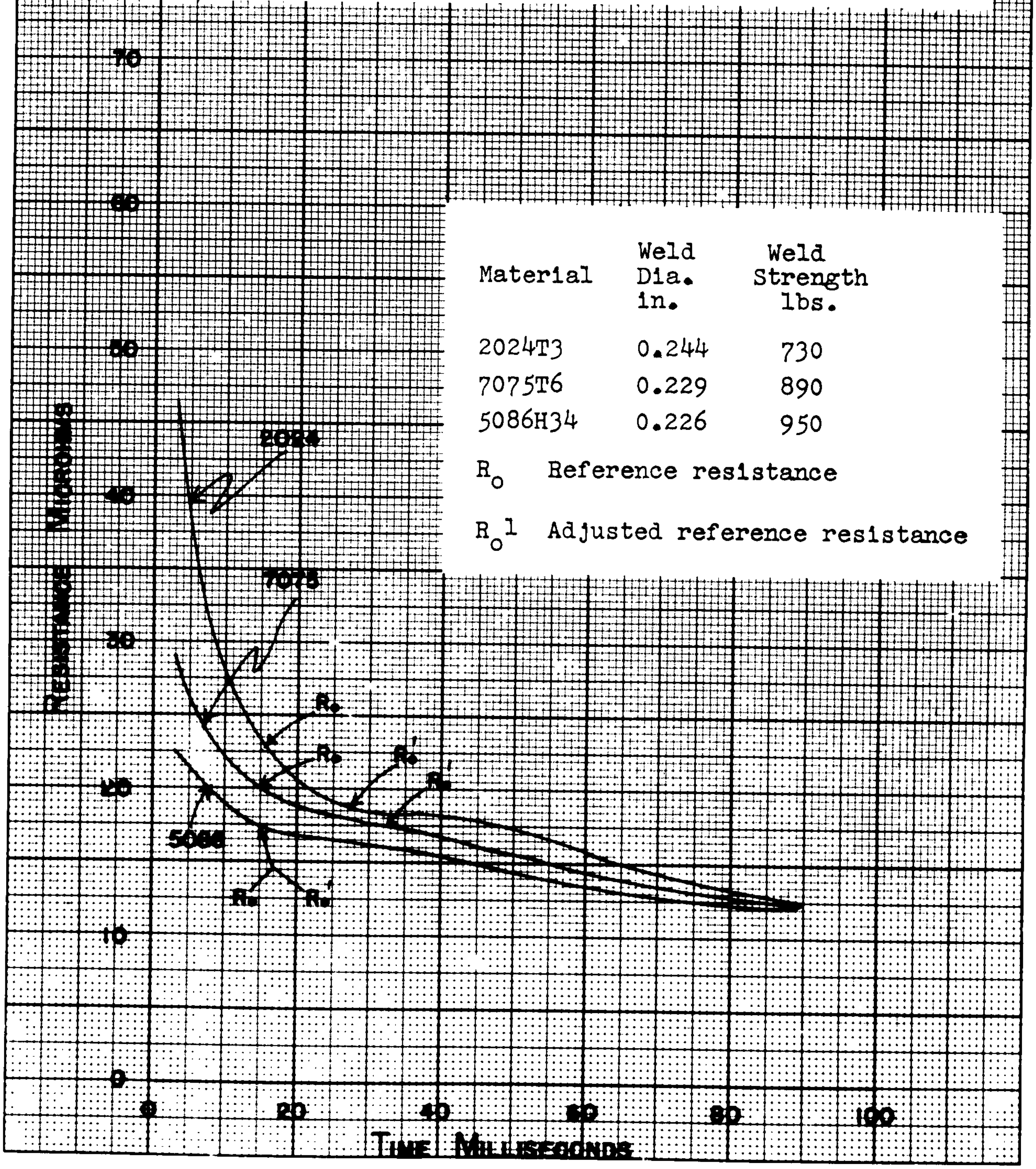


Fig.(39)

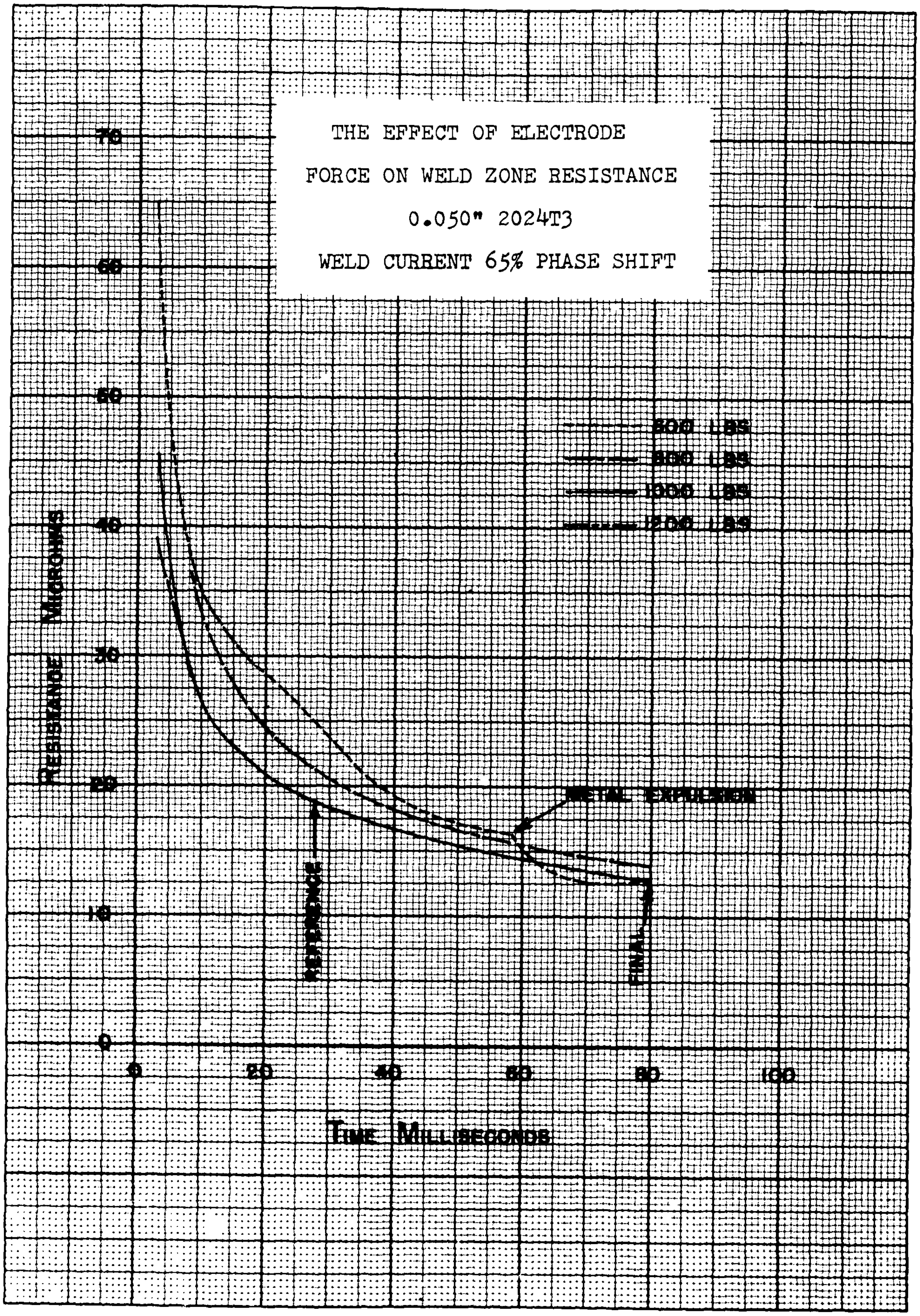
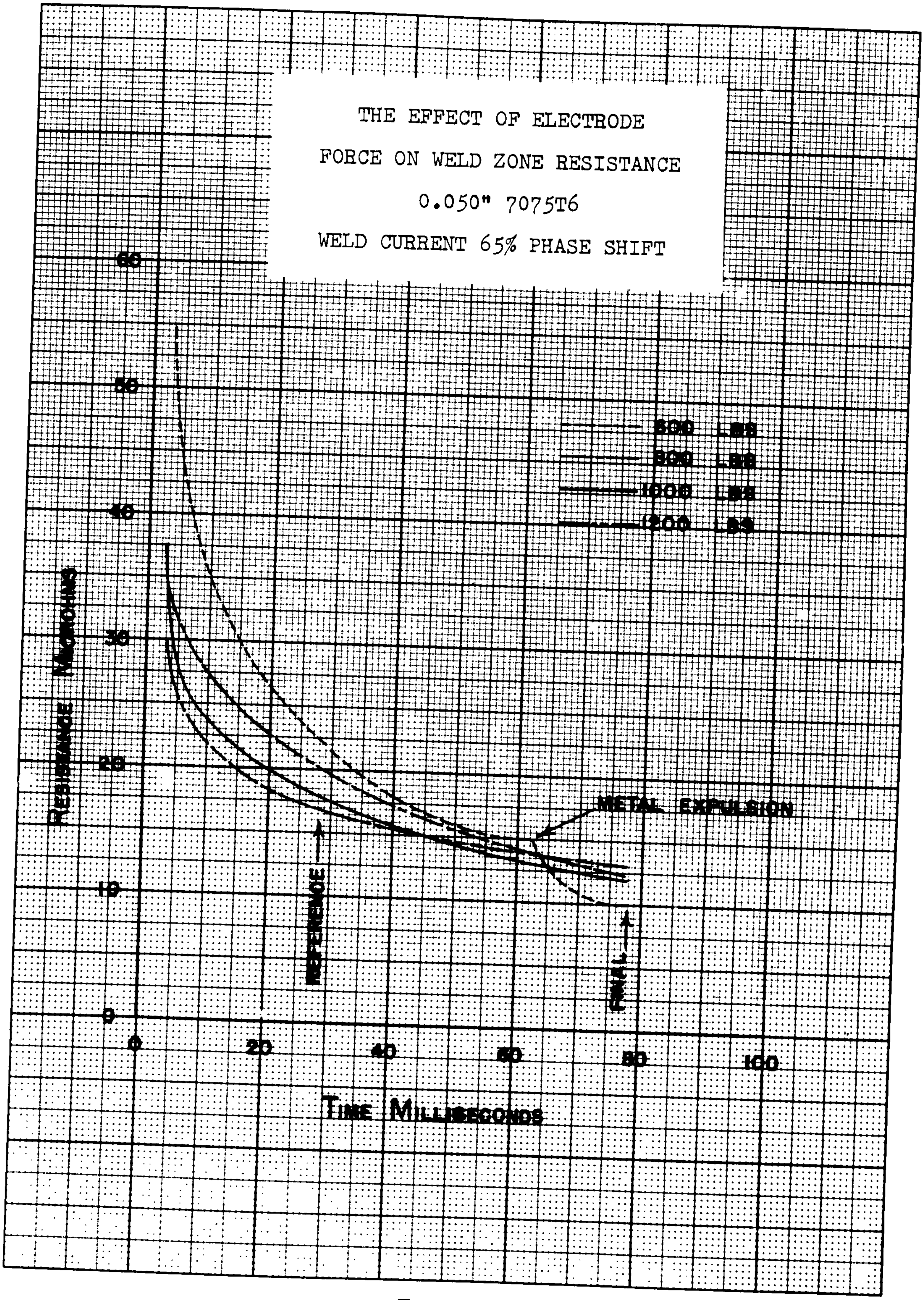

THE EFFECT OF ELECTRODE
FORCE ON WELD ZONE RESISTANCE
0.050" 2024T3
WELD CURRENT 65% PHASE SHIFT
600 LBS
800 LBS
1000 LBS
1200 LBS
METAL EXPULSION
REFERENCE
FINAL
RESISTANCE MICROHMS
TIME MILLISECONDS
0
10
20
30
40
50
60
70
0
20
40
60
80
100

Fig.(40)



THE EFFECT OF ELECTRODE
FORCE ON WELD ZONE RESISTANCE
0.050" 7075T6
WELD CURRENT 65% PHASE SHIFT
1000 LBS
1200 LBS
RESISTANCE MICROHMS
60
50
40
30
20
10
0
METAL EXPULSION
REFERENCE
FINAL
0
20
40
60
80
100
TIME MILLISECONDS

FIG.(41)

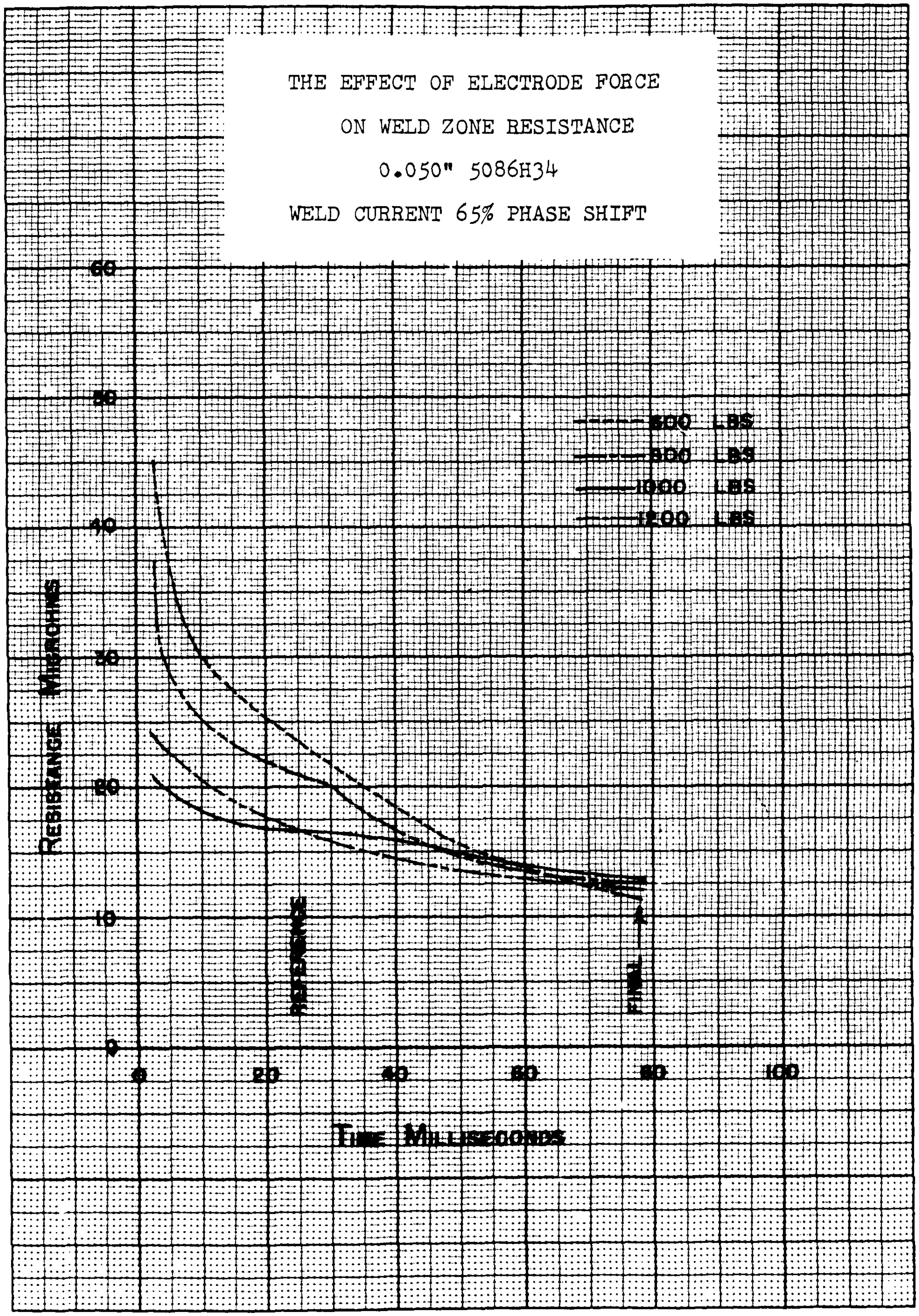

THE EFFECT OF ELECTRODE FORCE
ON WELD ZONE RESISTANCE
0.050" 5086H34
WELD CURRENT 65% PHASE SHIFT
600 LBS
800 LBS
1000 LBS
1200 LBS
RESISTANCE MICROHMS
60
50
40
30
20
10
0
REFERENCE
FINAL
0
20
40
60
80
100
TIME MILLISECONDS

FIG.(42)

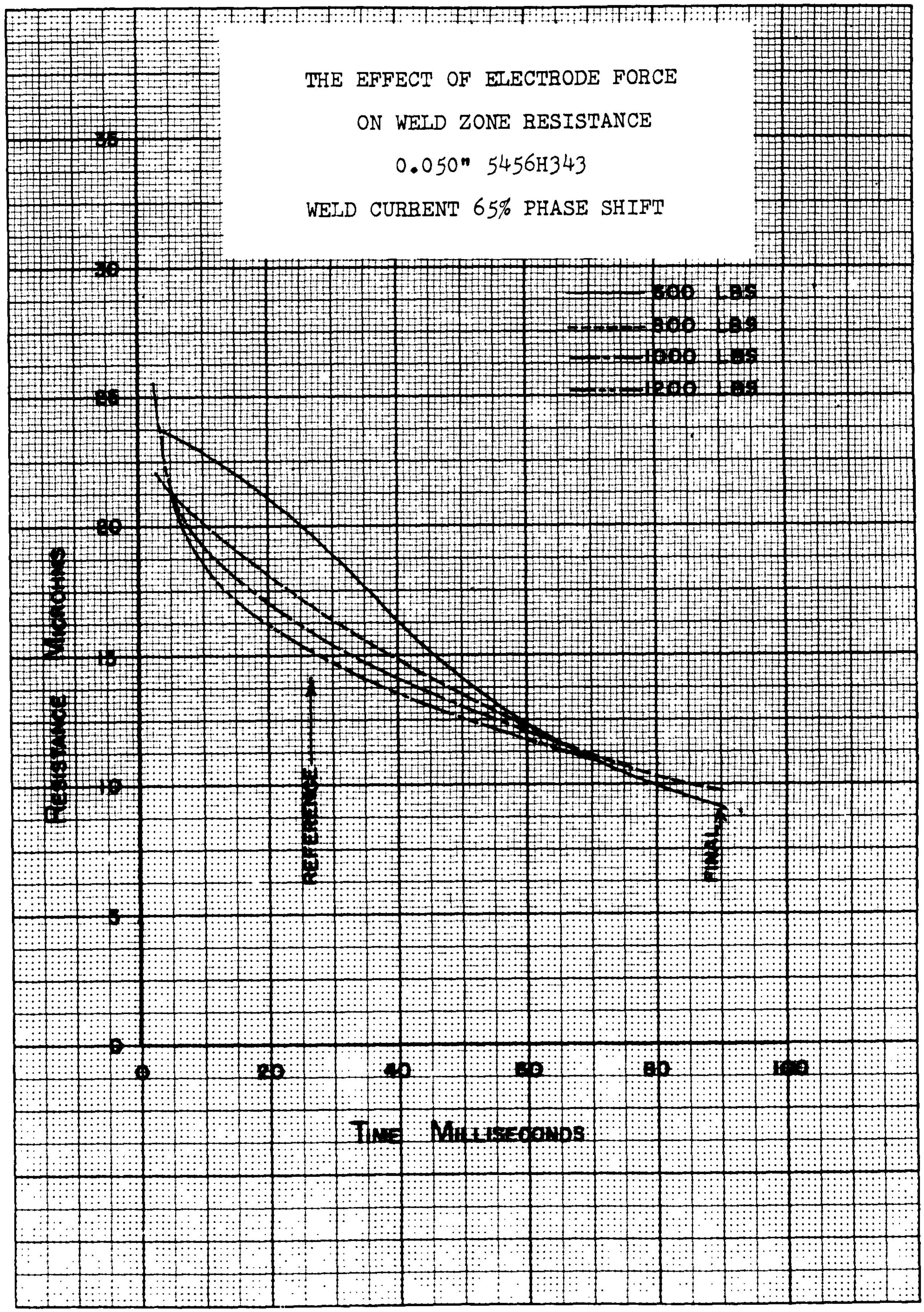

THE EFFECT OF ELECTRODE FORCE
ON WELD ZONE RESISTANCE
0.050" 5456H343
WELD CURRENT 65% PHASE SHIFT
500 LBS
800 LBS
1000 LBS
1200 LBS
35
30
25
20
15
10
5
0
RESISTANCE MICROHMS
REFERENCE
FINAL
0
20
40
60
80
100
TIME MILLISECONDS

FIG. (43)

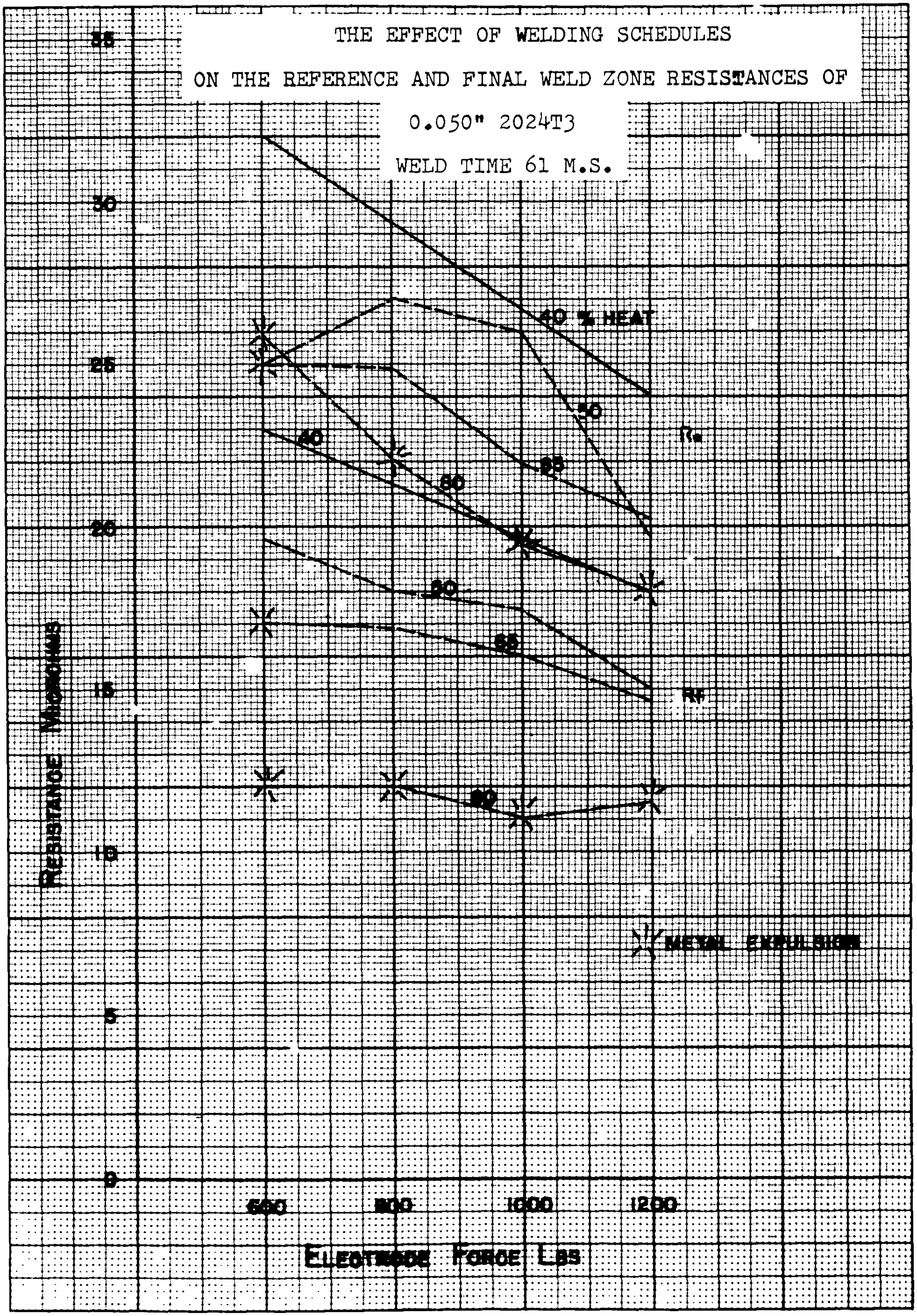

THE EFFECT OF WELDING SCHEDULES
ON THE REFERENCE AND FINAL WELD ZONE RESISTANCES OF
0.050" 2024T3
WELD TIME 61 M.S.
40 % HEAT
50
40
55
60
50
65
60
METAL EXPULSION
RESISTANCE MICROHMS
35
30
25
20
15
10
5
0
600
1000
1200
ELECTRODE FORCE LBS

FIG.(44)

THE EFFECT OF WELDING SCHEDULES

ON THE REFERENCE RESISTANCE AND FINAL WELD ZONE RESISTANCE FOR

0.050" 2024T3

WELD TIME 94 M.S.

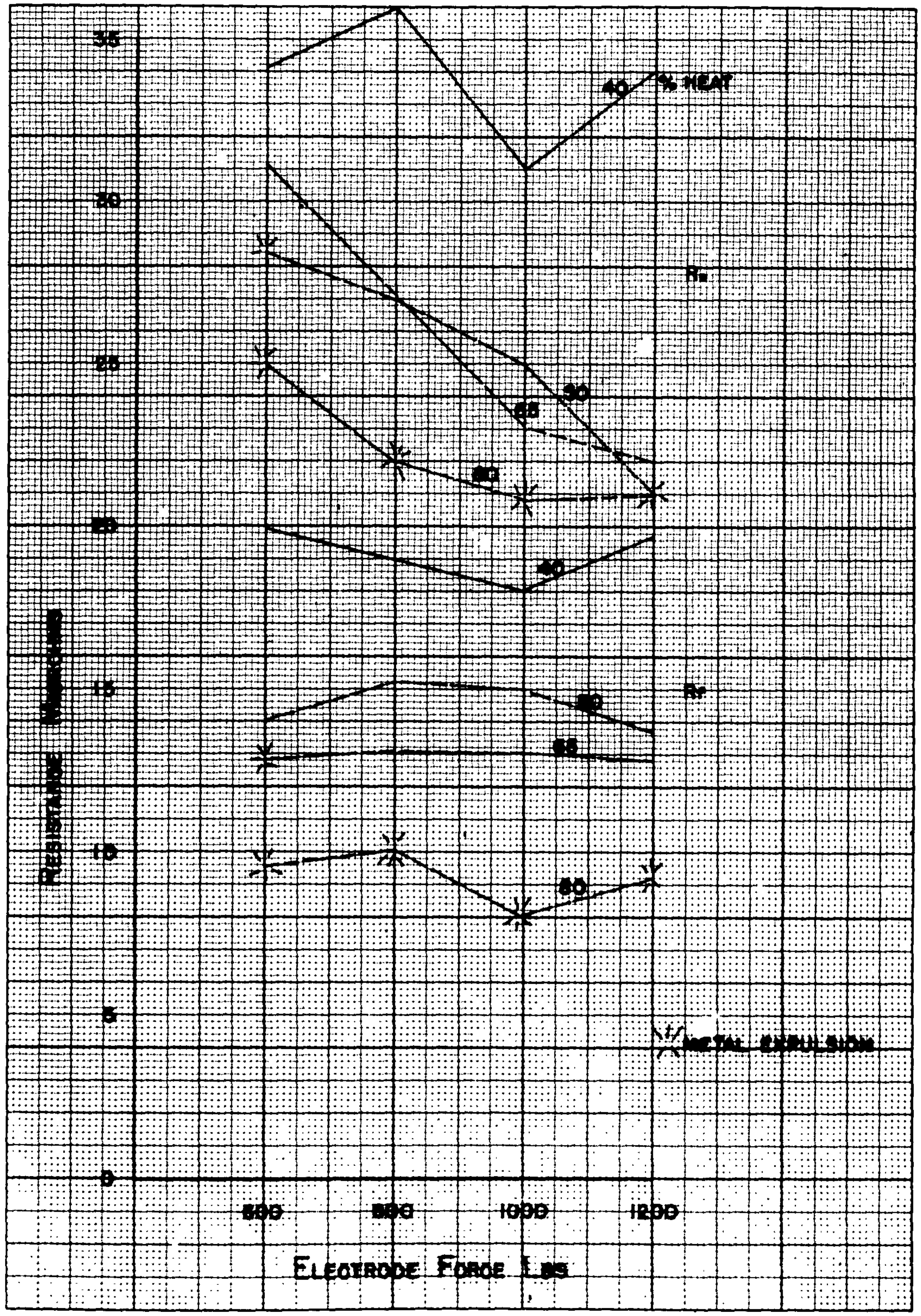


FIG.(45)

THE EFFECT OF WELDING SCHEDULES

ON THE REFERENCE AND FINAL WELD ZONE RESISTANCES FOR

0.050" 2014T6

WELD TIME 61 M.S.

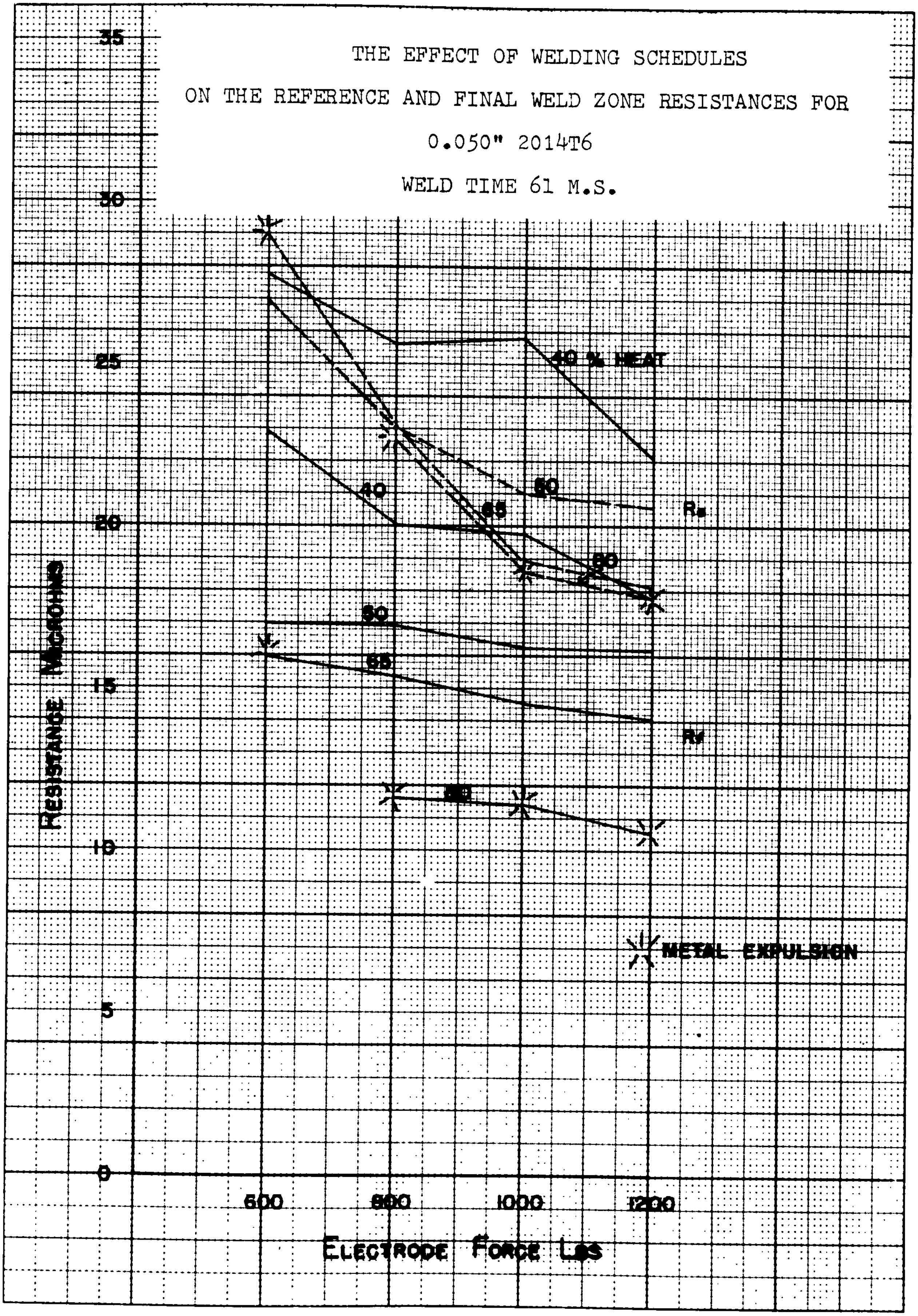
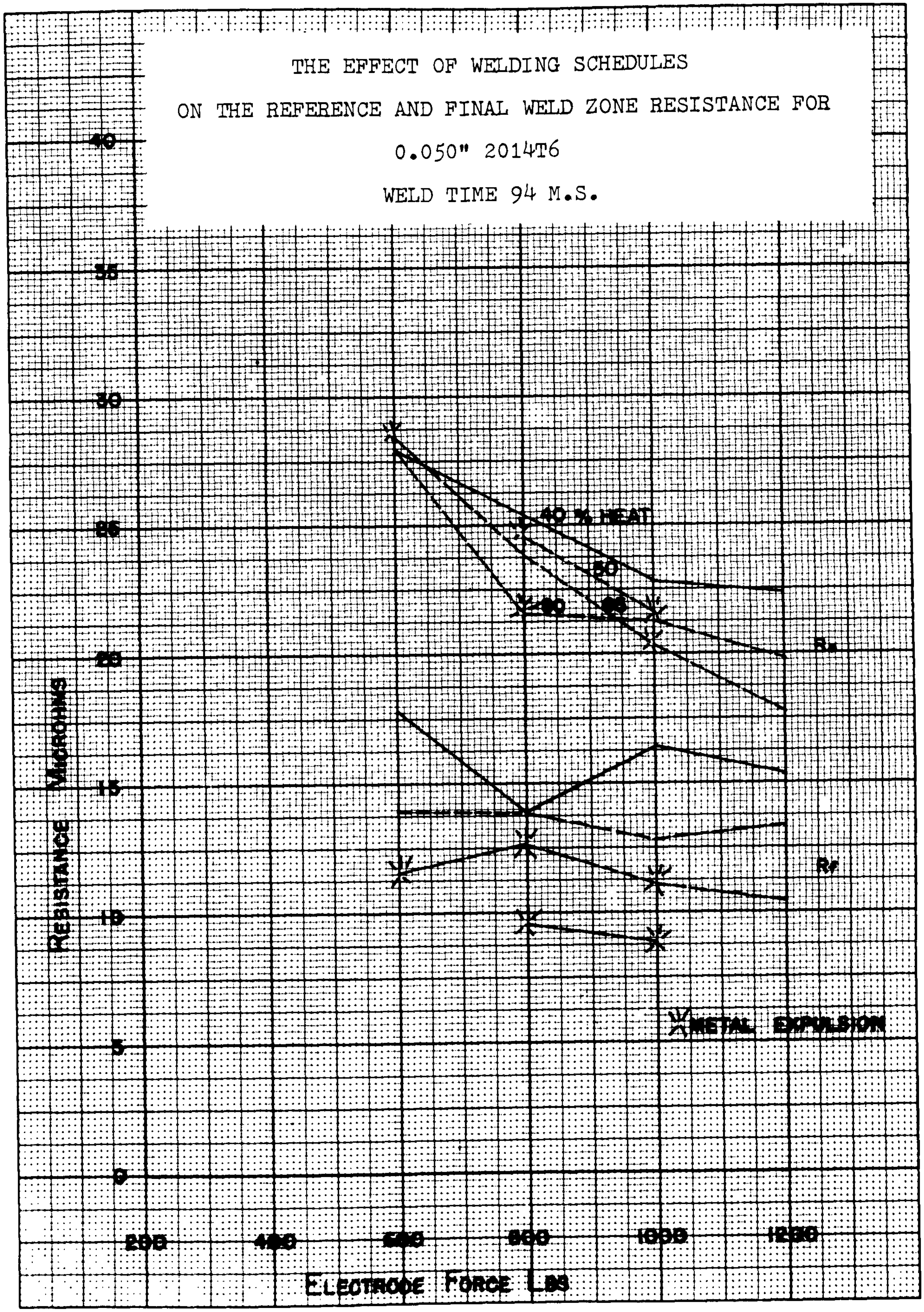


FIG.(46)



THE EFFECT OF WELDING SCHEDULES
ON THE REFERENCE AND FINAL WELD ZONE RESISTANCE FOR
0.050" 2014T6
WELD TIME 94 M.S.
40
35
30
25
20
15
10
5
0
40 % HEAT
50
60
65
Ro
Rf
METAL EXPULSION
RESISTANCE MICROHMS
200
400
600
800
1000
1200
ELECTRODE FORCE LBS

FIG. (47)

THE EFFECT OF WELDING SCHEDULES

ON THE REFERENCE AND FINAL WELD ZONE RESISTANCE FOR

0.050" 7075T6

WELD TIME 61 M.S.

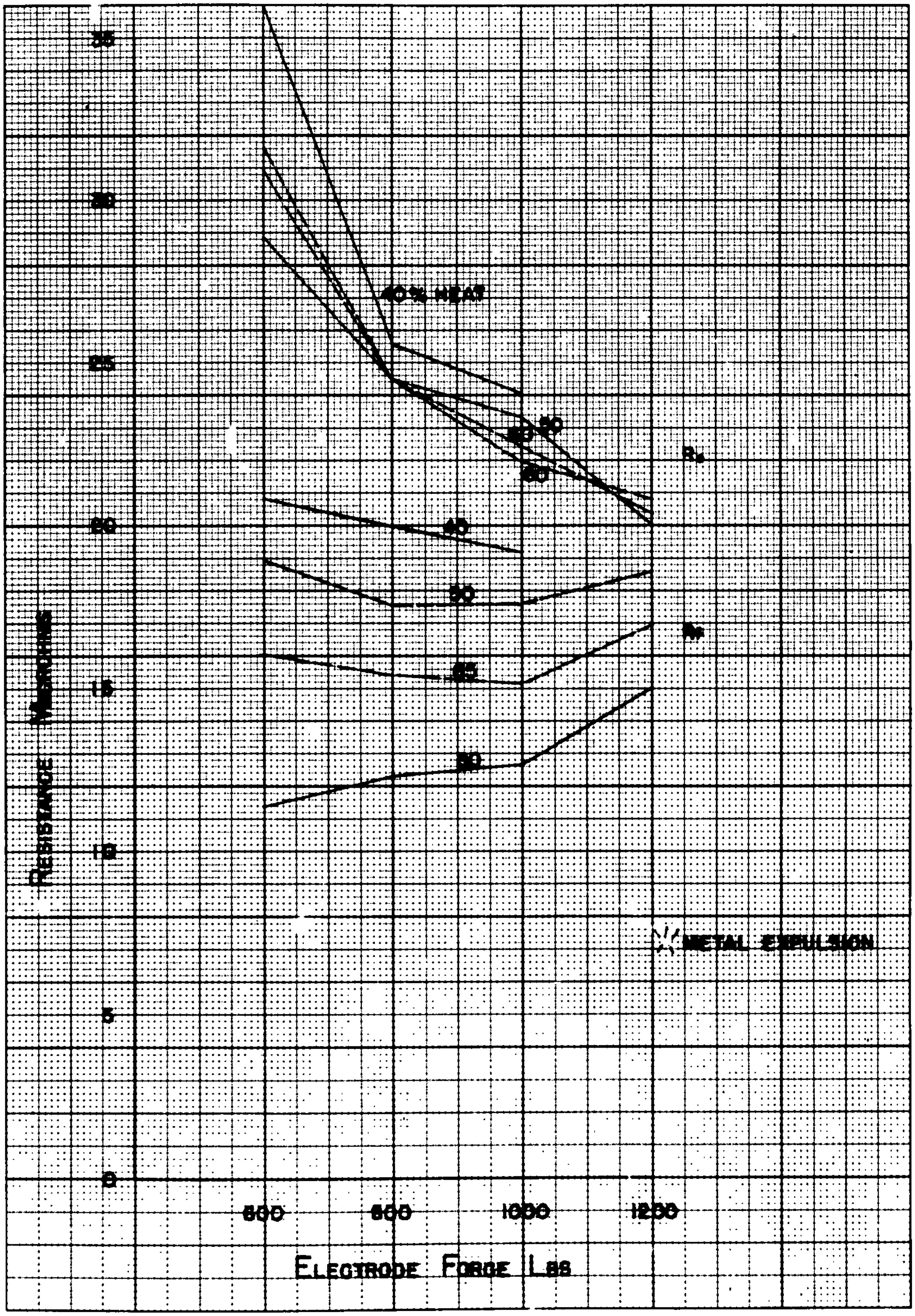
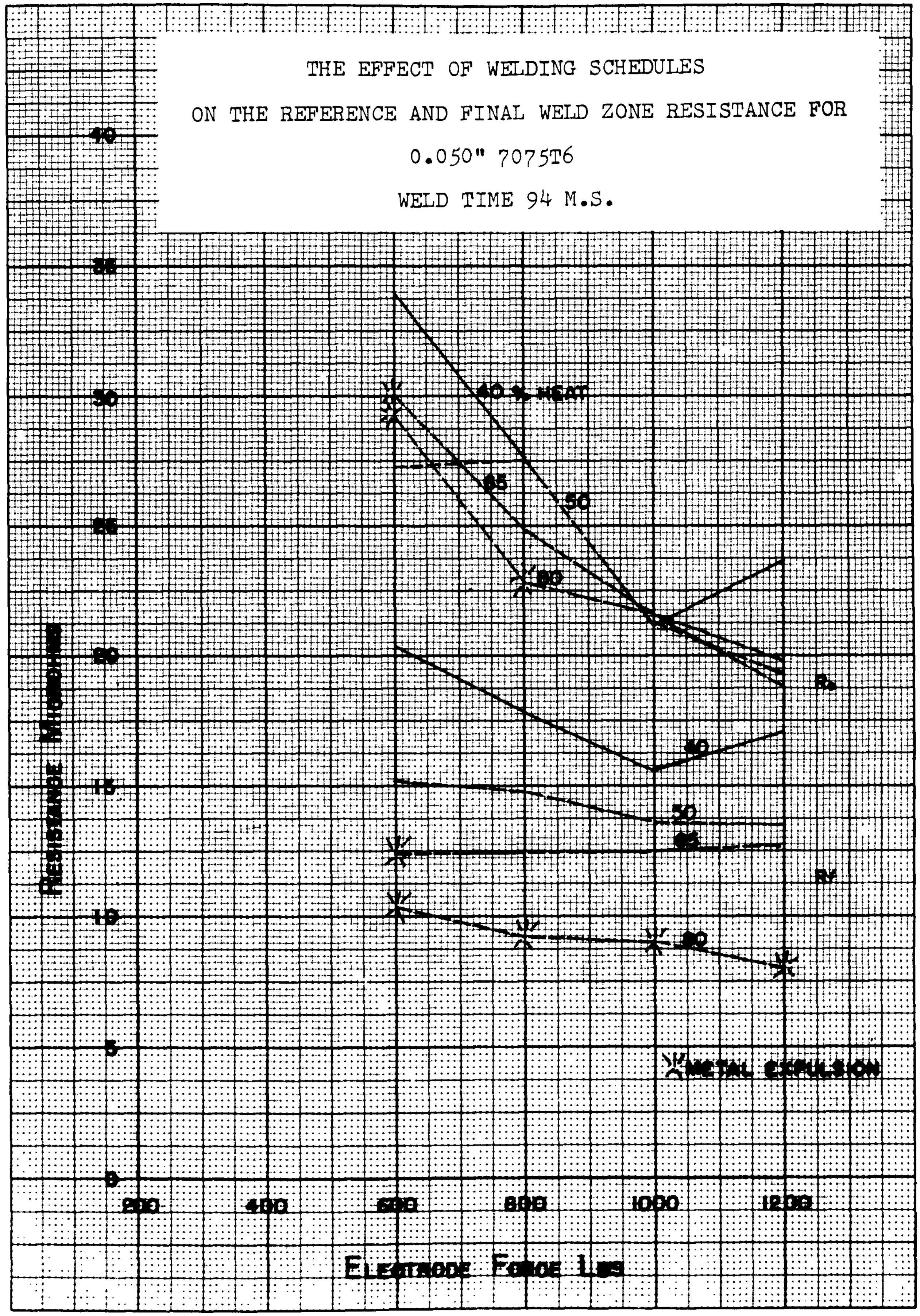


FIG. (48)



THE EFFECT OF WELDING SCHEDULES
ON THE REFERENCE AND FINAL WELD ZONE RESISTANCE FOR
0.050" 7075T6
WELD TIME 94 M.S.
RESISTANCE MICROHMS
ELECTRODE FORCE LBS
40 % HEAT
METAL EXPULSION

Fig.(49)

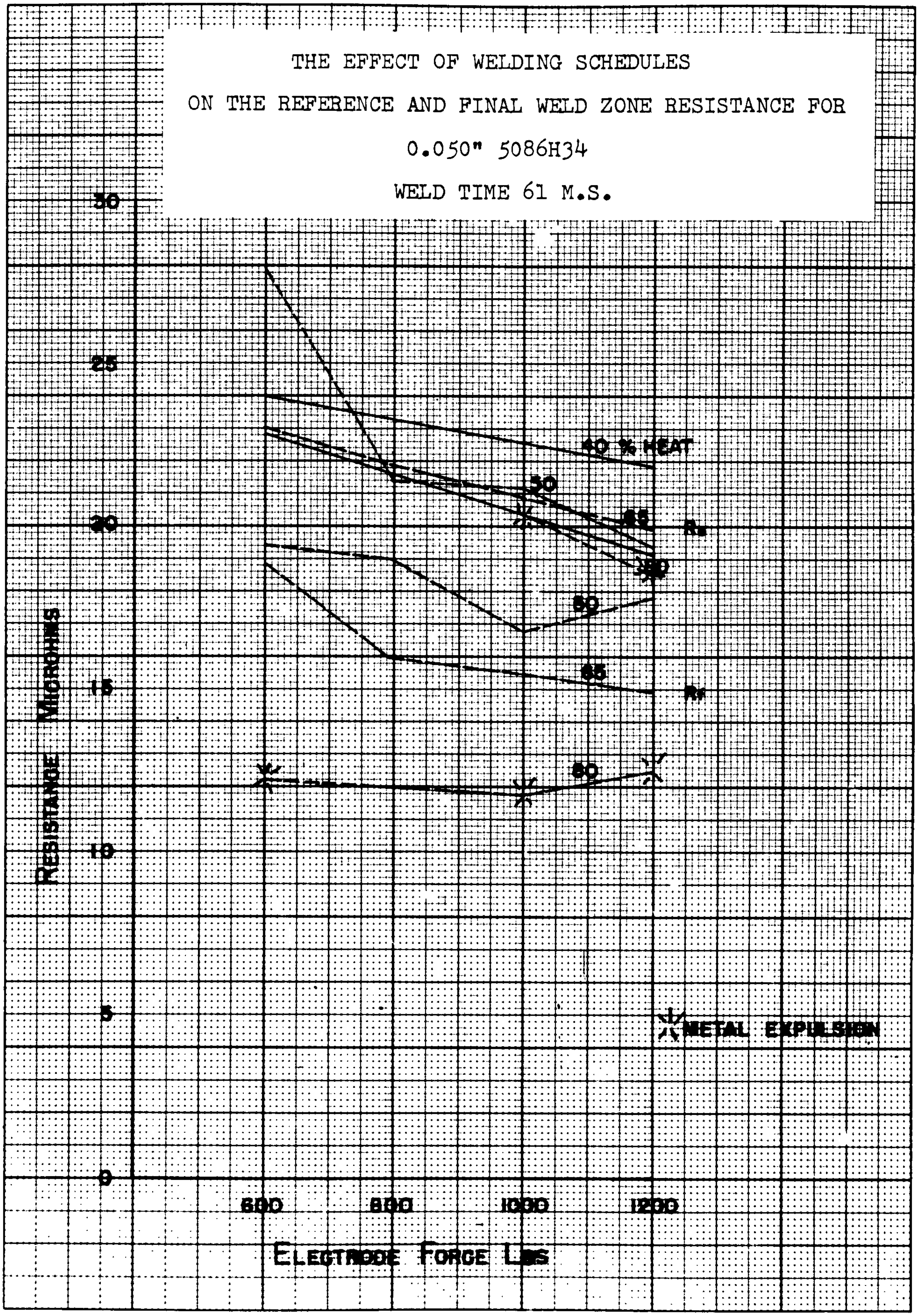

THE EFFECT OF WELDING SCHEDULES
ON THE REFERENCE AND FINAL WELD ZONE RESISTANCE FOR
0.050" 5086H34
WELD TIME 61 M.S.
30
25
20
15
10
5
0
40 % HEAT
50
65
80
Rs
80
65
Rf
80
METAL EXPULSION
600
800
1000
1200
RESISTANCE MICROHMS
ELECTRODE FORCE LBS

FIG. (50)

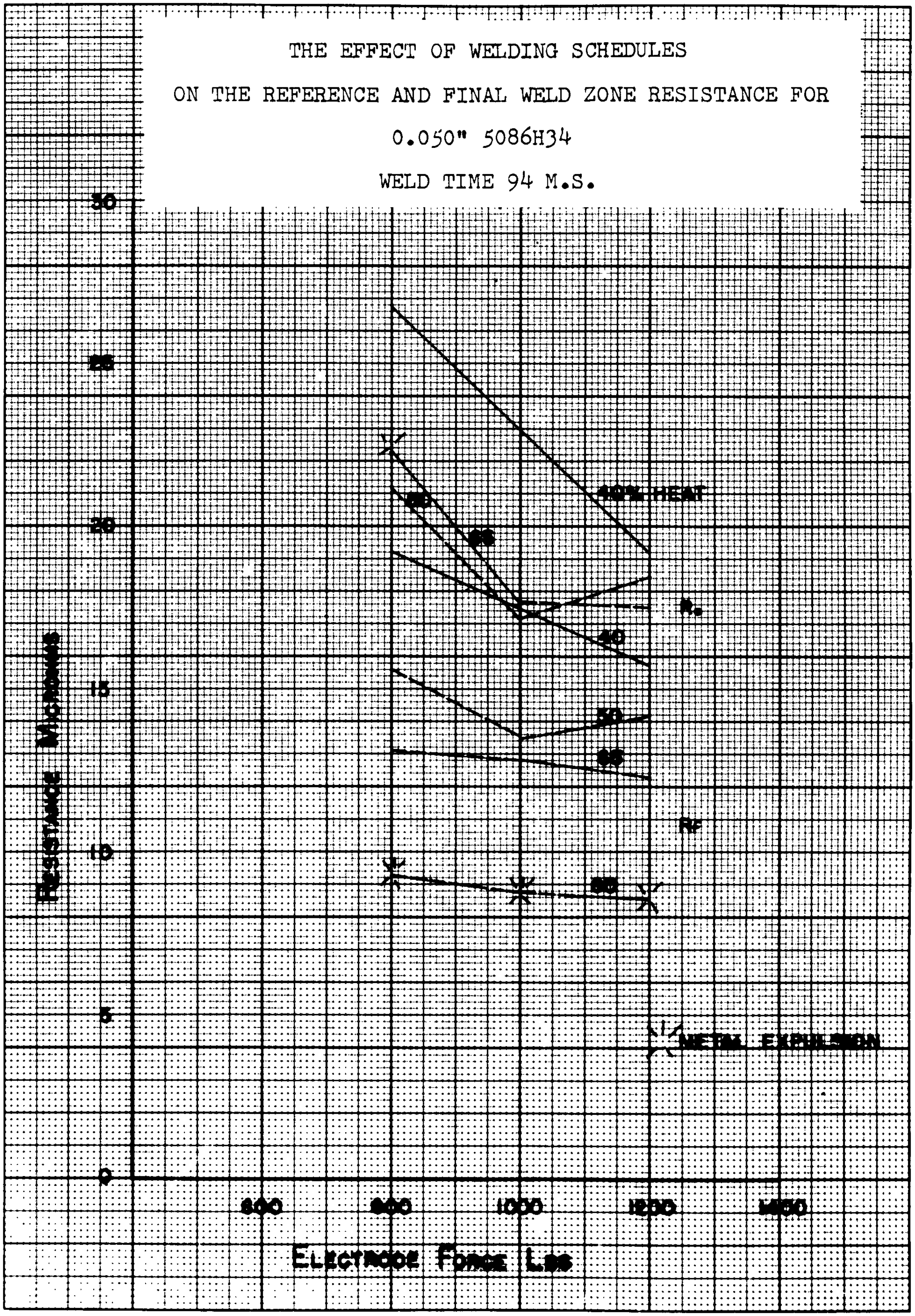

THE EFFECT OF WELDING SCHEDULES
ON THE REFERENCE AND FINAL WELD ZONE RESISTANCE FOR
0.050" 5086H34
WELD TIME 94 M.S.
RESISTANCE MICROHMS
30
25
20
15
10
5
0
40% HEAT
40
50
METAL EXPULSION
600
800
1000
1200
1400
ELECTRODE FORCE LBS

FIG.(51)

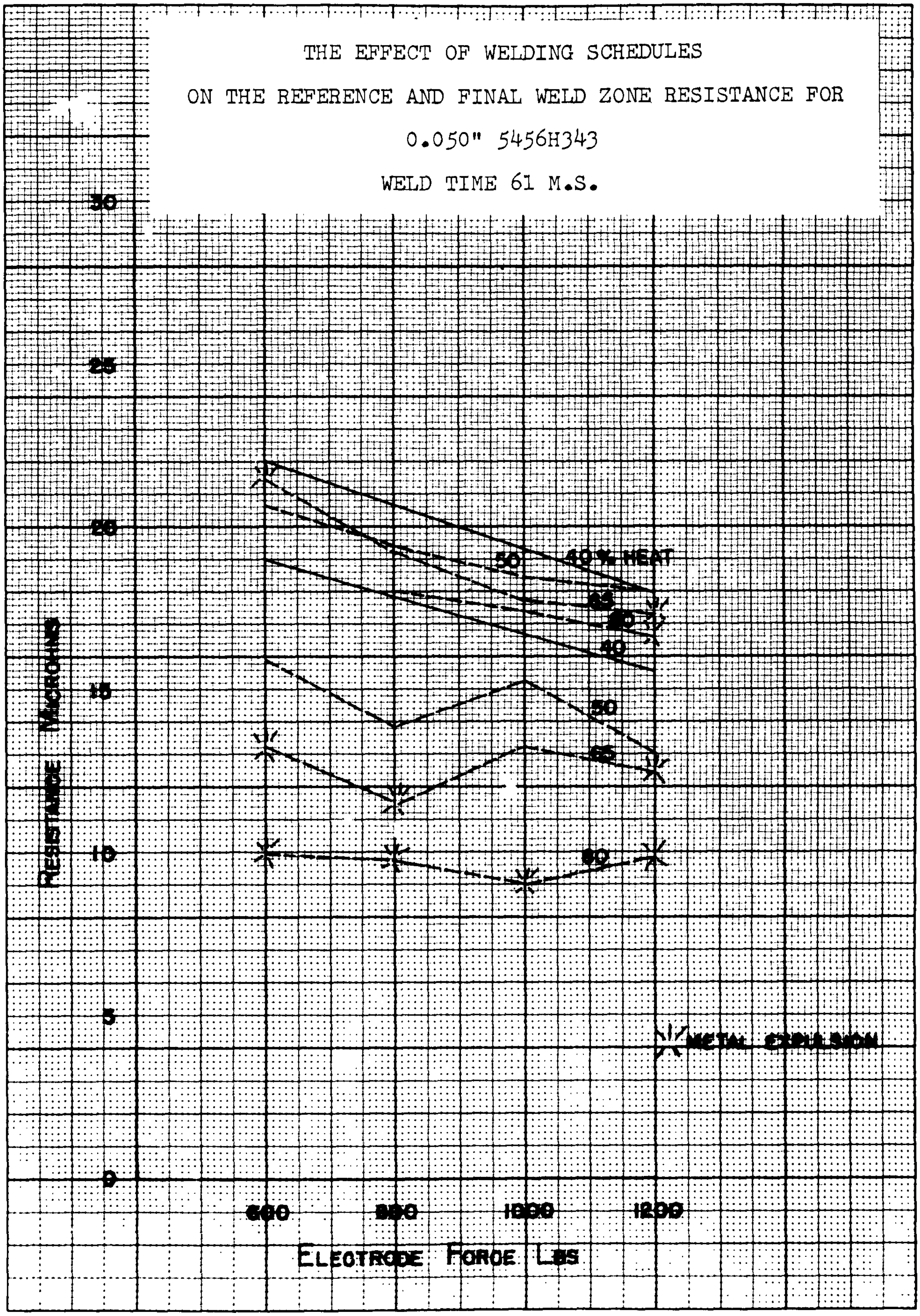

THE EFFECT OF WELDING SCHEDULES
ON THE REFERENCE AND FINAL WELD ZONE RESISTANCE FOR
0.050" 5456H343
WELD TIME 61 M.S.
30
25
20
15
10
5
0
RESISTANCE MICROHMS
50
40% HEAT
65
80
40
50
65
80
METAL EXPULSION
600
800
1000
1200
ELECTRODE FORCE LBS

FIG. (52)

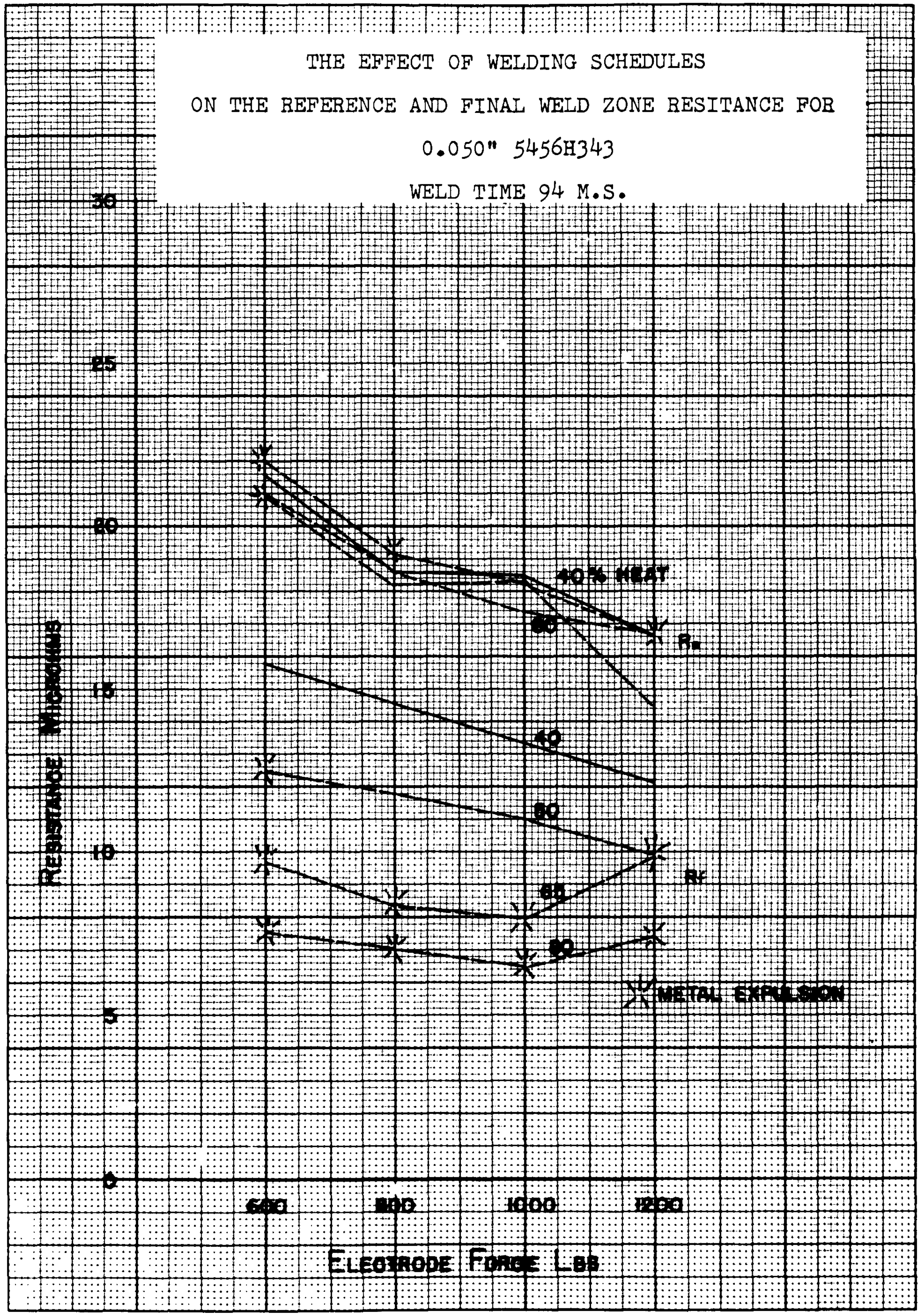
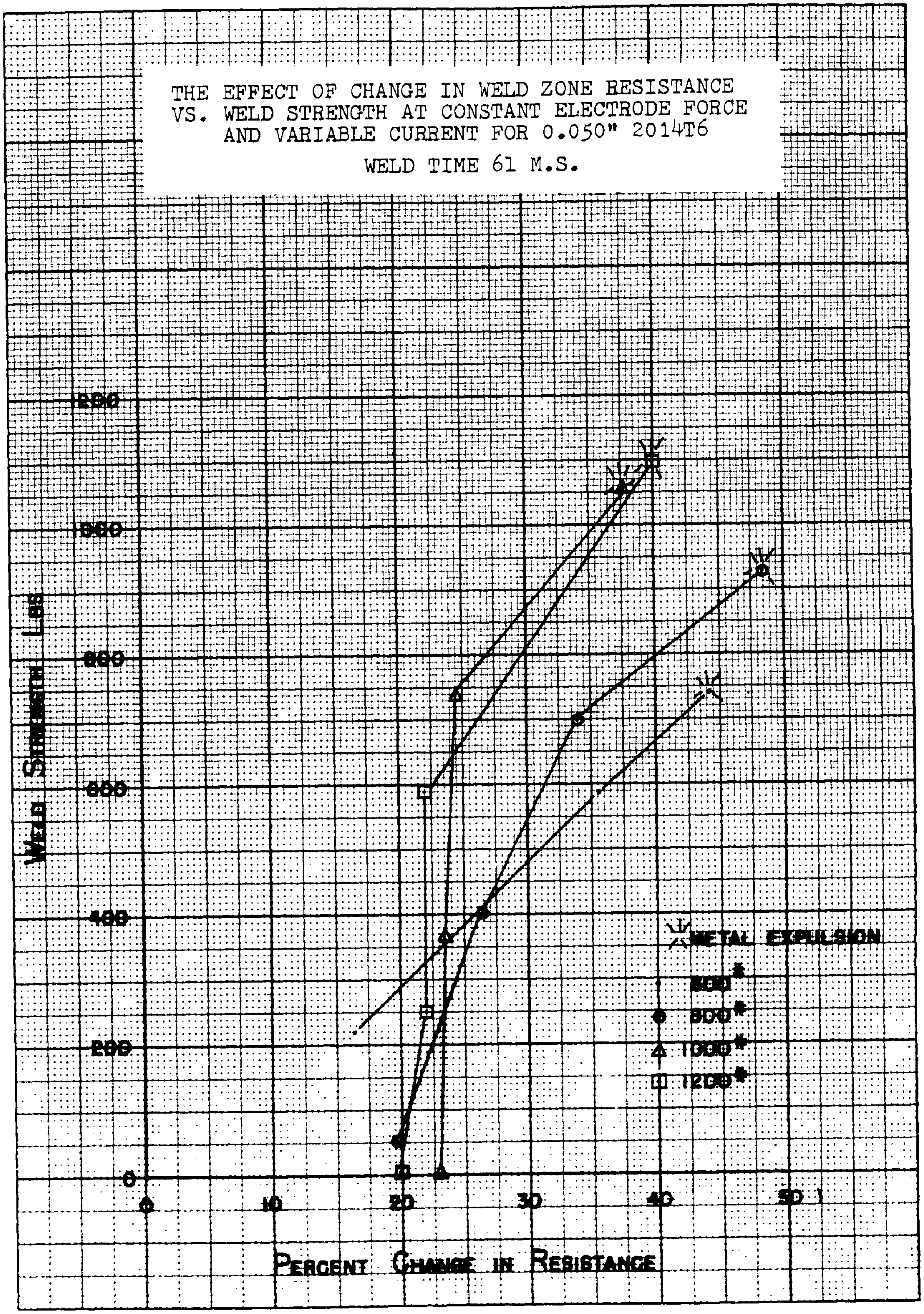

THE EFFECT OF WELDING SCHEDULES
ON THE REFERENCE AND FINAL WELD ZONE RESITANCE FOR
0.050" 5456H343
WELD TIME 94 M.S.
30
25
20
15
10
5
0
40% HEAT
50
40
50
65
80
Ro
Rf
METAL EXPULSION
600
800
1000
1200
RESISTANCE MICROHMS
ELECTRODE FORCE LBS

FIG.(53)



THE EFFECT OF CHANGE IN WELD ZONE RESISTANCE
VS. WELD STRENGTH AT CONSTANT ELECTRODE FORCE
AND VARIABLE CURRENT FOR 0.050" 2014T6
WELD TIME 61 M.S.
WELD STRENGTH LBS
1200
1000
800
600
400
200
0
0
10
20
30
40
50
PERCENT CHANGE IN RESISTANCE
METAL EXPULSION
600#
800#
1000#
1200#

FIG. (54)

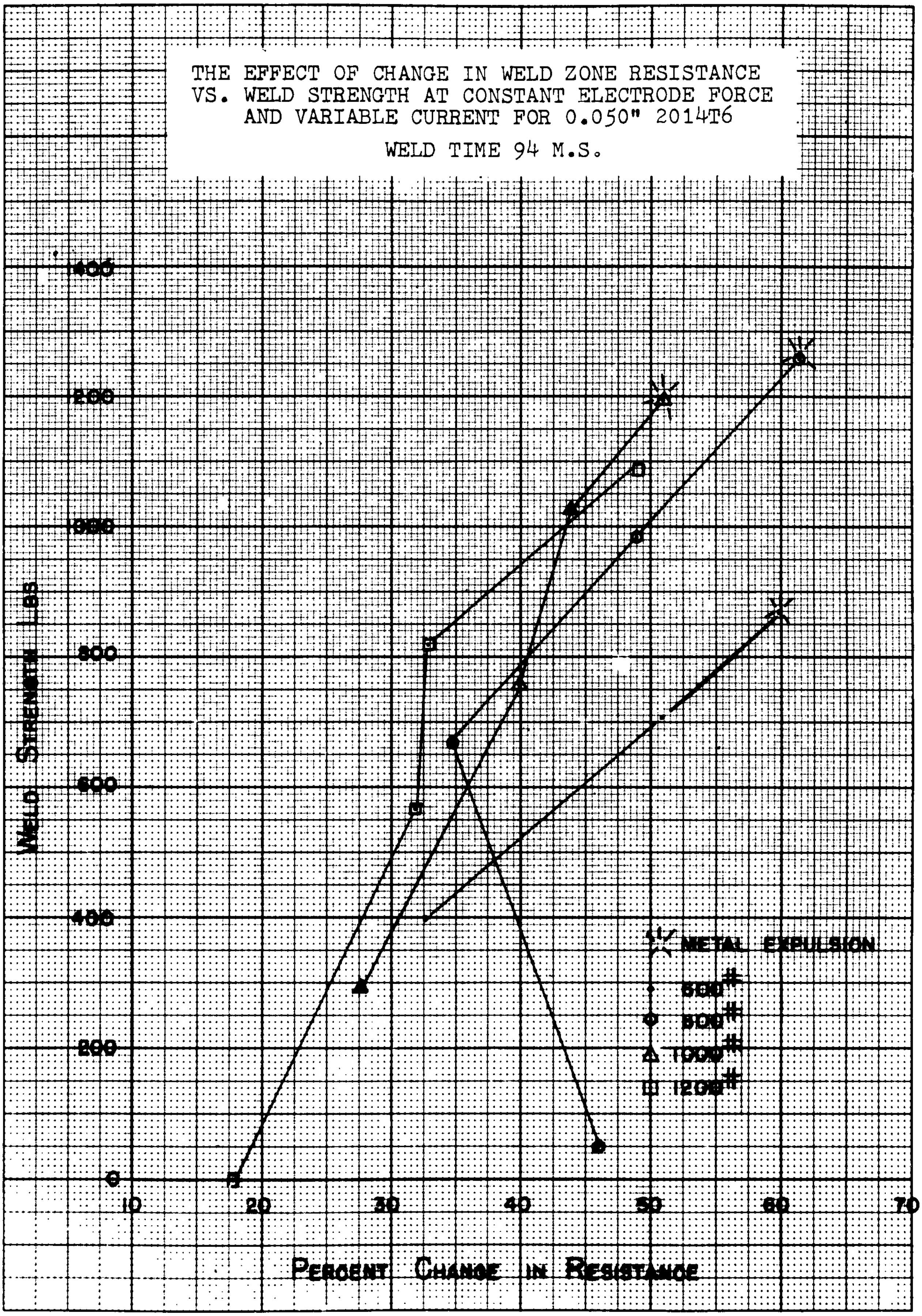
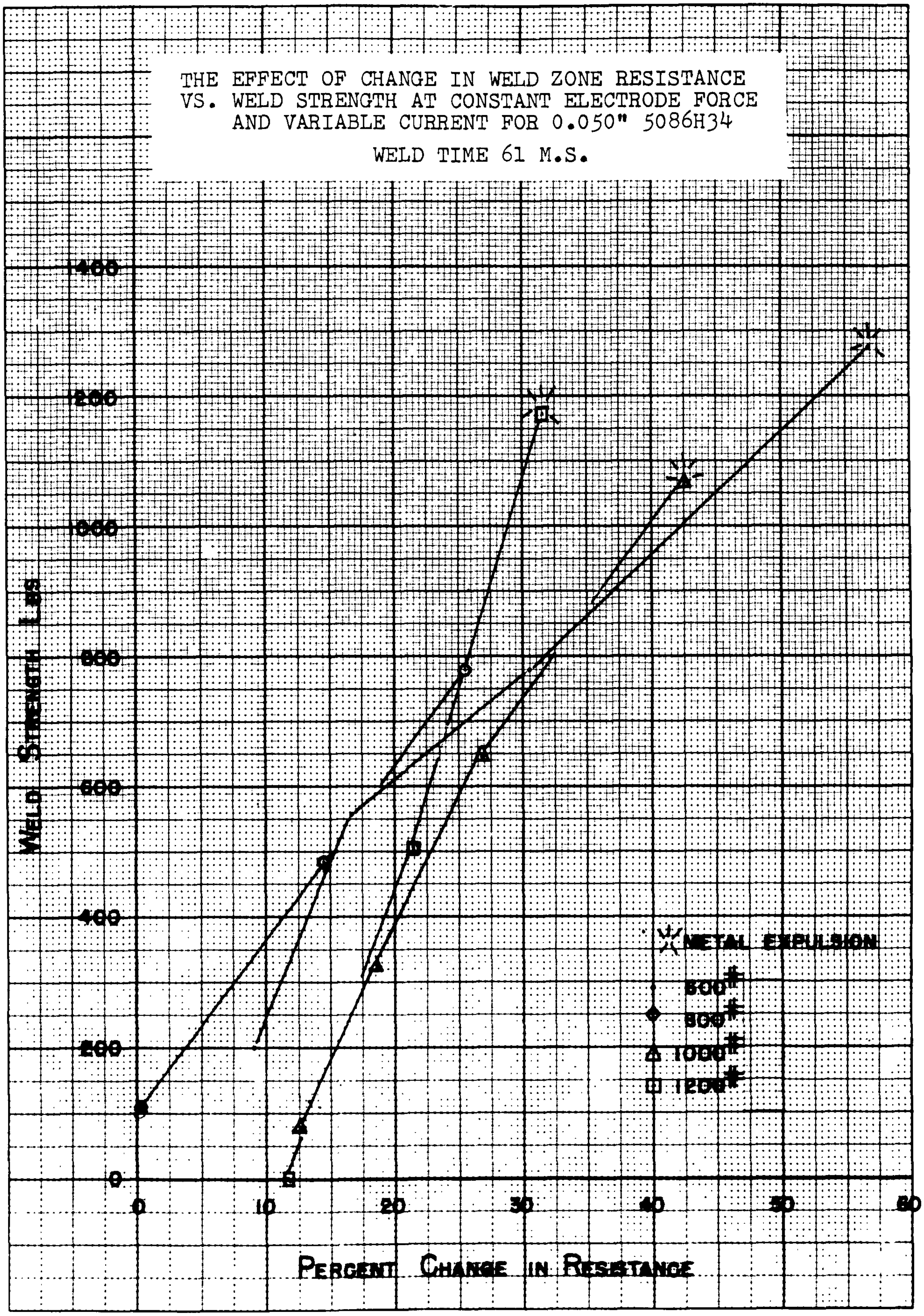

THE EFFECT OF CHANGE IN WELD ZONE RESISTANCE
VS. WELD STRENGTH AT CONSTANT ELECTRODE FORCE
AND VARIABLE CURRENT FOR 0.050" 2014T6
WELD TIME 94 M.S.
WELD STRENGTH LBS
1400
1200
1000
800
600
400
200
0
10
20
30
40
50
60
70
PERCENT CHANGE IN RESISTANCE
METAL EXPULSION
500#
800#
1000#
1200#

FIG.(55)



THE EFFECT OF CHANGE IN WELD ZONE RESISTANCE
VS. WELD STRENGTH AT CONSTANT ELECTRODE FORCE
AND VARIABLE CURRENT FOR 0.050" 5086H34
WELD TIME 61 M.S.
WELD STRENGTH LBS
1400
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
PERCENT CHANGE IN RESISTANCE
METAL EXPULSION
600#
800#
1000#
1200#

FIG.(56)

THE EFFECT OF CHANGE IN WELD ZONE RESISTANCE VS. WELD STRENGTH AT CONSTANT ELECTRODE FORCE AND VARIABLE CURRENT FOR 0.050" 5086H34

WELD TIME 94 M.S.

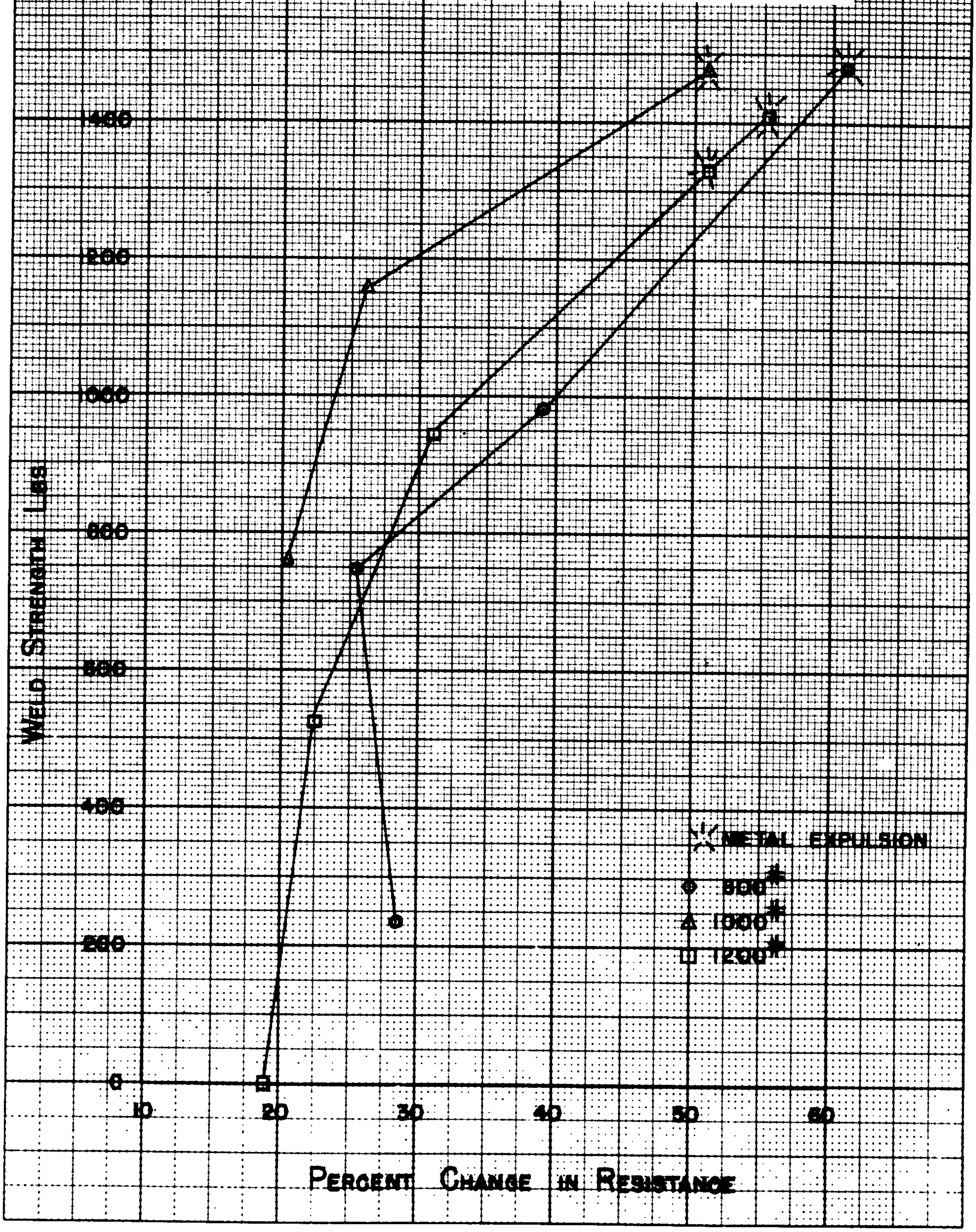


FIG.(57)

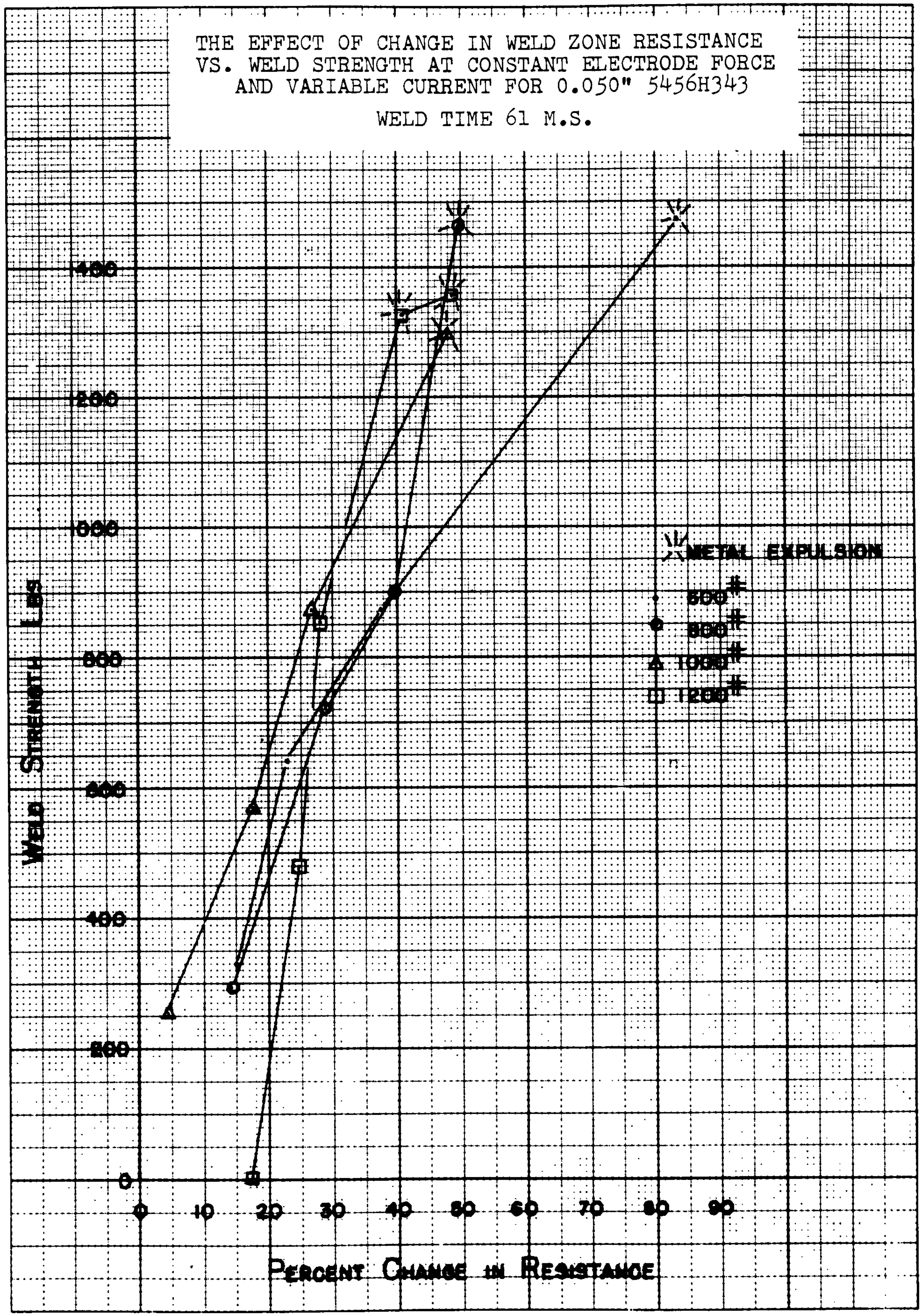

THE EFFECT OF CHANGE IN WELD ZONE RESISTANCE VS. WELD STRENGTH AT CONSTANT ELECTRODE FORCE AND VARIABLE CURRENT FOR 0.050" 5456H343
WELD TIME 61 M.S.
METAL EXPULSION
600#
800#
1000#
1200#
WELD STRENGTH LBS
1400
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
70
80
90
PERCENT CHANGE IN RESISTANCE

FIG. (58)

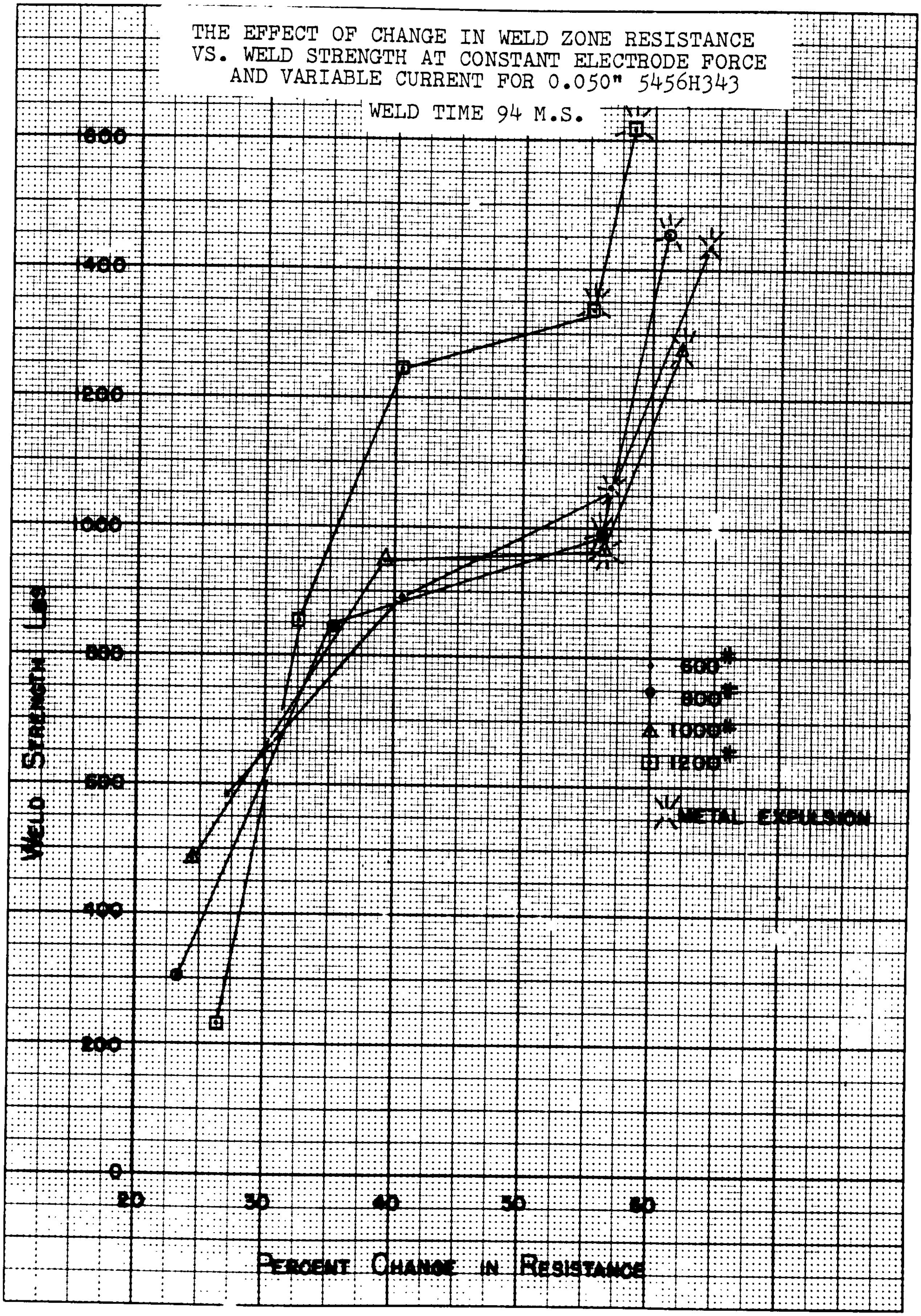
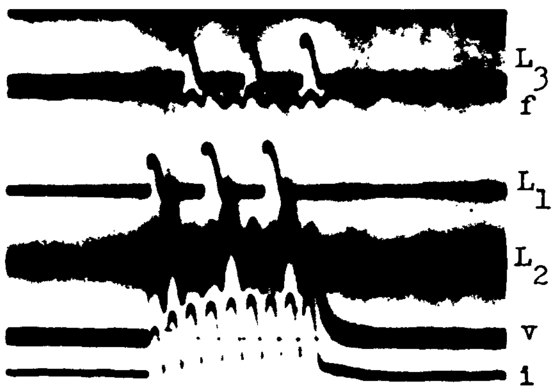

THE EFFECT OF CHANGE IN WELD ZONE RESISTANCE
VS. WELD STRENGTH AT CONSTANT ELECTRODE FORCE
AND VARIABLE CURRENT FOR 0.050" 5456H343
WELD TIME 94 M.S.
1600
1400
1200
1000
800
600
400
200
0
20
30
40
50
60
WELD STRENGTH LBS
PERCENT CHANGE IN RESISTANCE
600#
800#
1000#
1200#
METAL EXPULSION

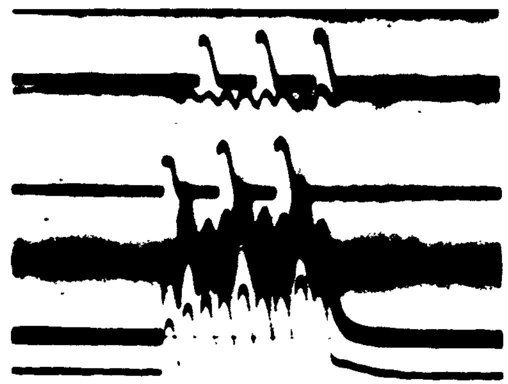
FIG.(59)

OSCILLOGRAPHIC TRACES OF SPOT WELDS
IN 0.050" 5456H343



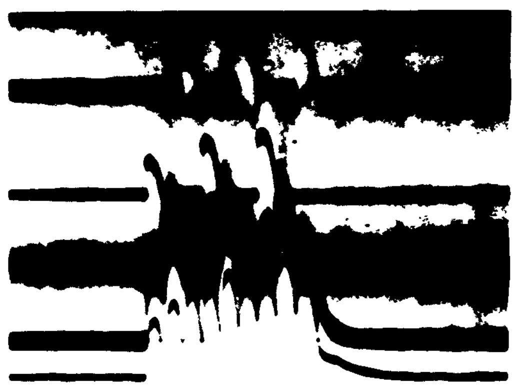
24600A 600 lbs. 61 M.S.
W.S. 285 lbs. %R 13.5 Pct.

a



29800A 600 lbs. 61 M.S.
W.S. 645 lbs. %R 23.5 Pct.

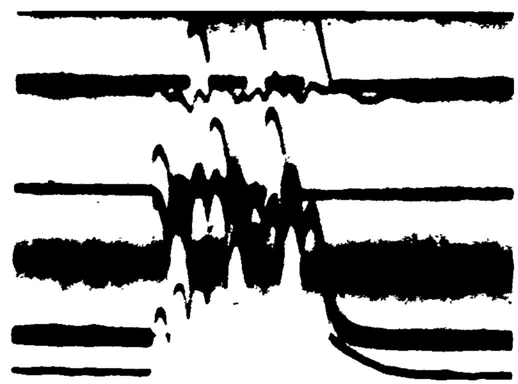
b



36900A 600 lbs. 61 M.S.
W.S. 915 lbs. %R 40.5 Pct.

c

TIME ⟶



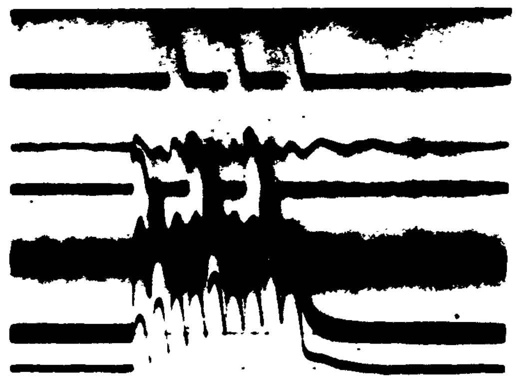
51800 600 lbs. 61 M.S.
W.S. 1520 lbs. %R 83.5 Pct.

d

FIGURE 60

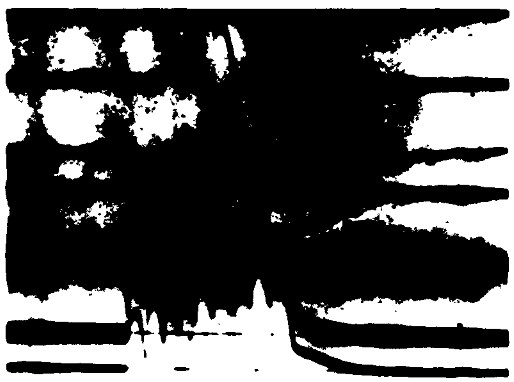
OSCILLOGRAPHIC TRACES OF SPOT WELDS
IN 0.050" 5456H343

26800A 800 lbs. 61 M.S.
W.S. 260 lbs. %R 21 Pct.



32800A 800 lbs. 61 M.S.
W.S. 710 lbs. %R 30.0 Pct.

TIME ⟶

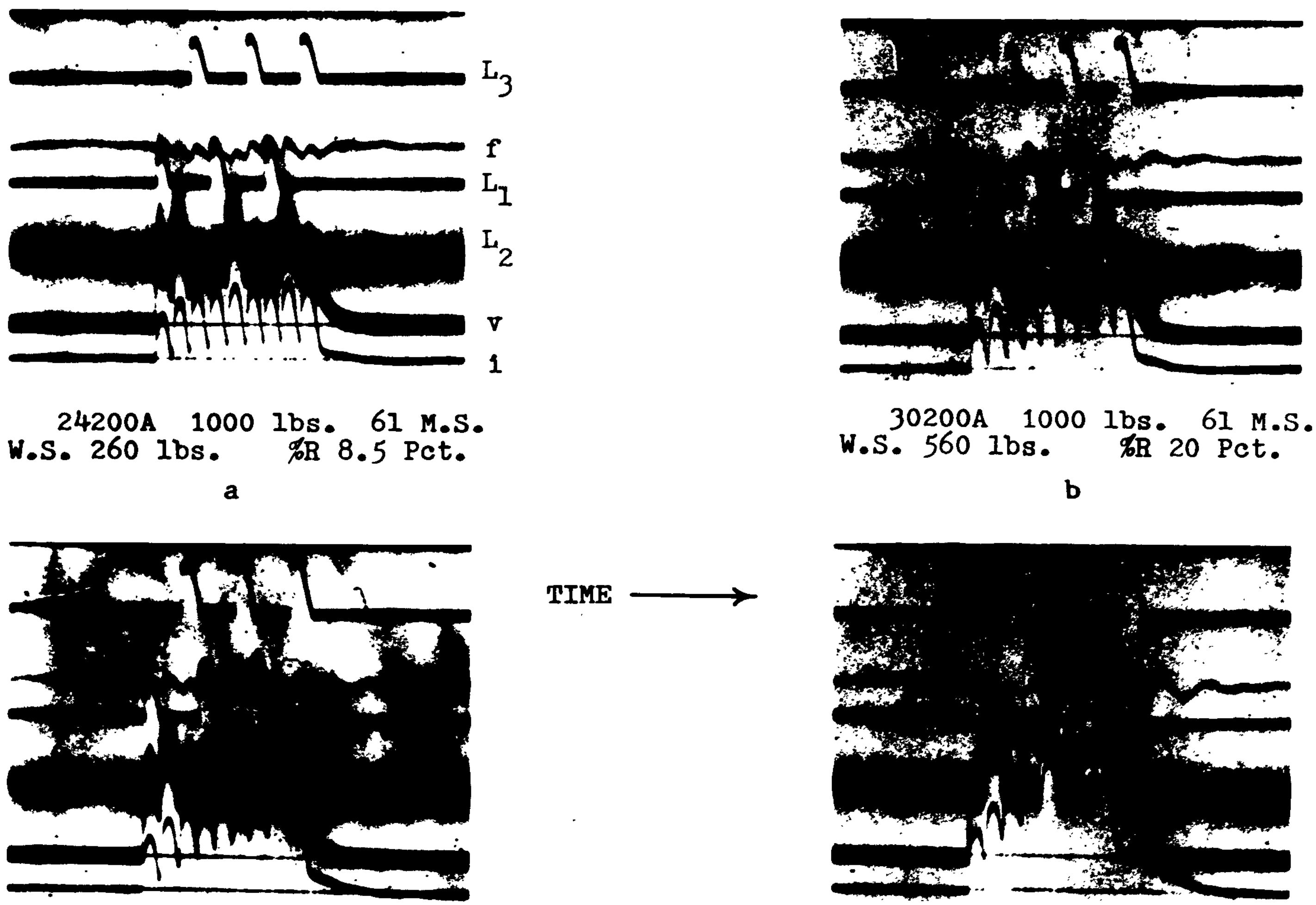


39500A 800 lbs. 61 M.S.
W.S. 860 lbs. %R 44.5 Pct.

57000A 800 lbs. 61 M.S.
W.S. 1415 lbs. %R 56 Pct.

FIGURE 61

OSCILLOGRAPHIC TRACES OF SPOT WELDS
IN 0.050" 5456H343



24200A 1000 lbs. 61 M.S.
W.S. 260 lbs. %R 8.5 Pct.

a

30200A 1000 lbs. 61 M.S.
W.S. 560 lbs. %R 20 Pct.

b

TIME →

36900A 1000 lbs. 61 M.S.
W.S. 870 lbs. %R 26.5 Pct.

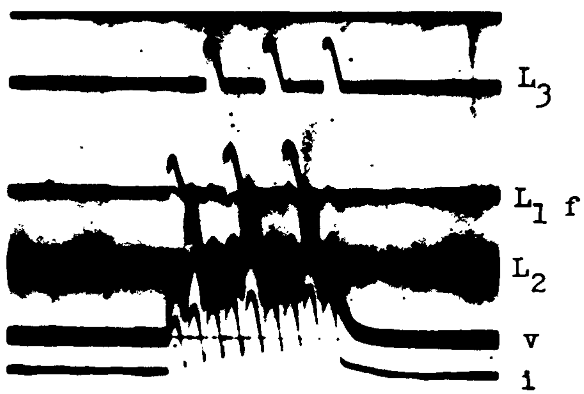
c

49000A 1000 lbs. 61 M.S.
W.S. 1290 lbs. %R 47 Pct.

d

FIGURE 62

OSCILLOGRAPHIC TRACES OF SPOT WELDS
IN 0.050" 5456H343



26800A 1200 lbs. 61 M.S.
W.S. No Weld %R 17 Pct.

34000A 1200 lbs. 61 M.S.
W.S. 460 lbs. %R 24 Pct.

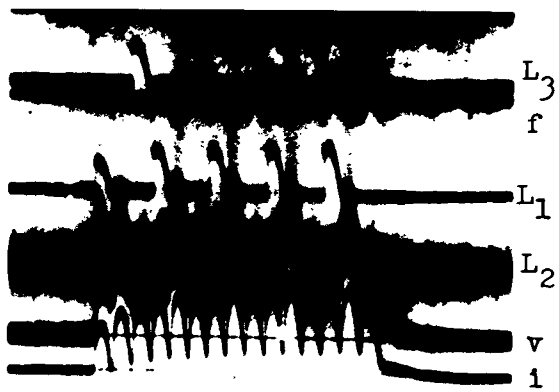
TIME →

39000A 1200 lbs. 61 M.S.
W.S. 845 lbs. %R 27.8 Pct

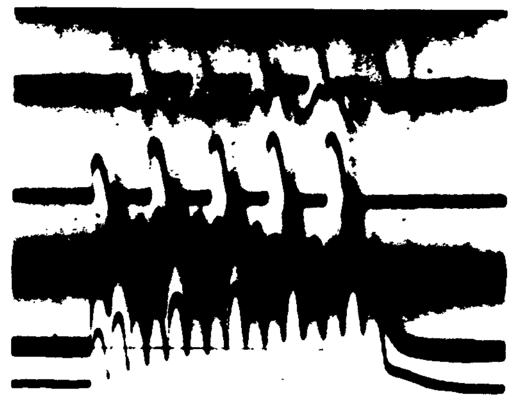
55300A 1200 lbs. 61 M.S.
W.S. 1330 lbs. %R 40.2 Pct.

FIGURE 63

OSCILLOGRAPHIC TRACES OF SPOT WELDS
IN 0.050" 5456H343

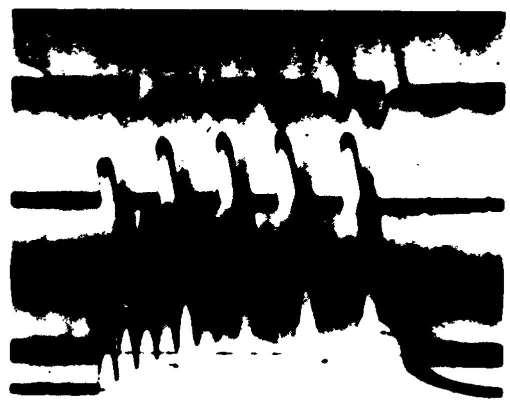


25500A 600 lbs. 94 M.S.
W.S. 580 lbs. %R 27 Pct.

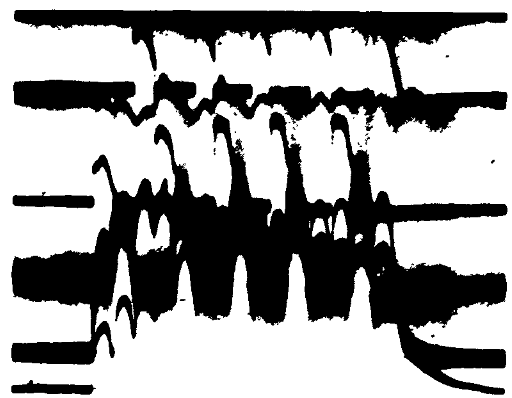


34400A 600 lbs. 94 M.S.
W.S. 890 lbs. %R 40.4 Pct.

TIME →



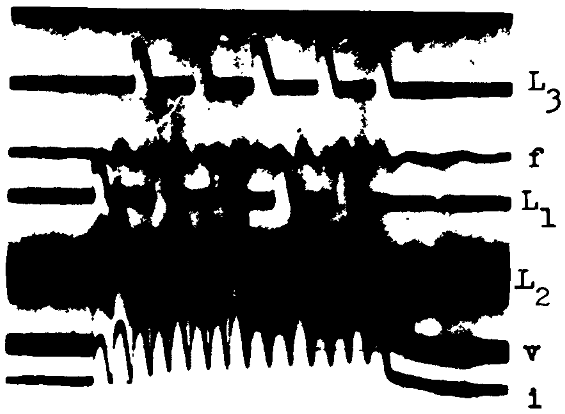
41200A 600 lbs. 94 M.S.
W.S. 1055 lbs. %R 51 Pct.



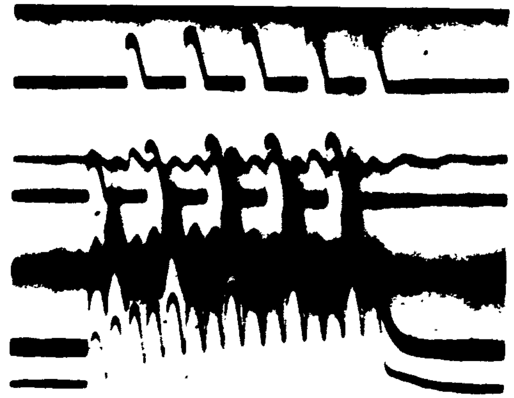
57800A 600 lbs. 94 M.S.
W.S. 1425 lbs. %R 64 Pct.

FIGURE 64

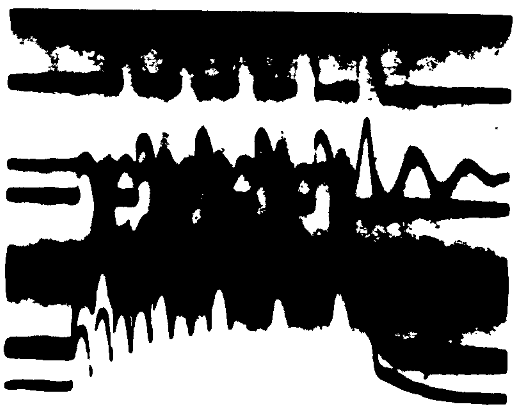
OSCILLOGRAPHIC TRACES OF SPOT WELDS
IN 0.050" 5456H343



25900A 800 lbs. 94 M.S.
W.S. 295 lbs. %R 23.5 Pct.



32800A 800 lbs. 94 M.S.
W.S. 850 lbs. %R 35.1 Pct.



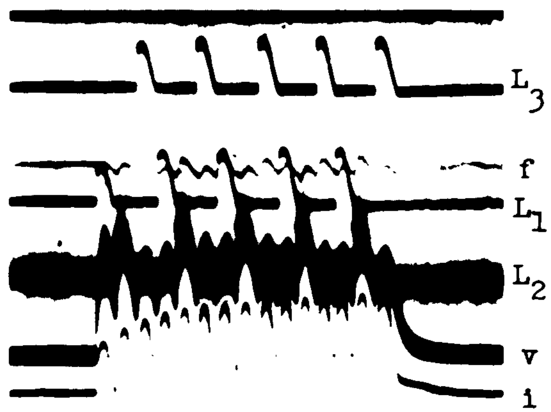
40300A 800 lbs. 94 M.S.
W.S. 987 lbs. %R 56.2 Pct.

TIME ⟶

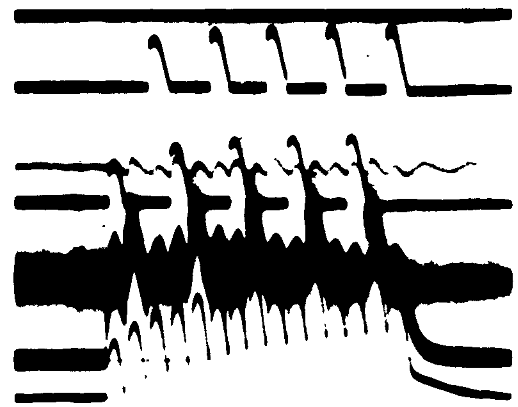
60400A 800 lbs. 94 M.S.
W.S. 1455 lbs. %R 61.2 Pct.

FIGURE 65

OSCILLOGRAPHIC TRACES OF SPOT WELDS
IN 0.050" 5456H343



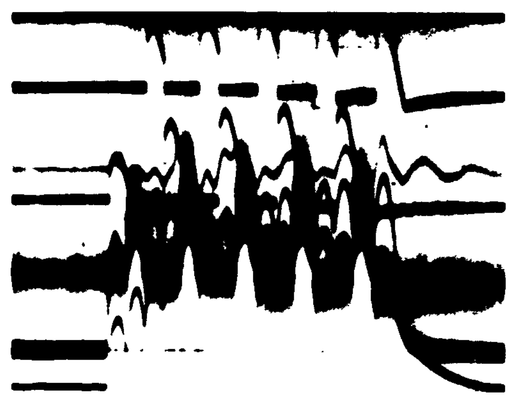
28500A 1000 lbs. 94 M.S.
W.S. 480 lbs. %R 24.7 Pct.



36500A 1000 lbs. 94 M.S.
W.S. 947 lbs. %R 39.1 Pct.

TIME ⟶

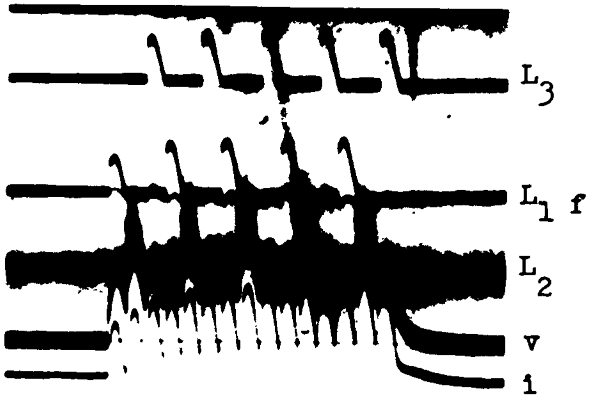
45500A 1000 lbs. 94 M.S.
W.S. 962 lbs. %R 56.1 Pct.



62900A 1000 lbs. 94 M.S.
W.S. 1277 lbs. %R 62.7 Pct.

FIGURE 66

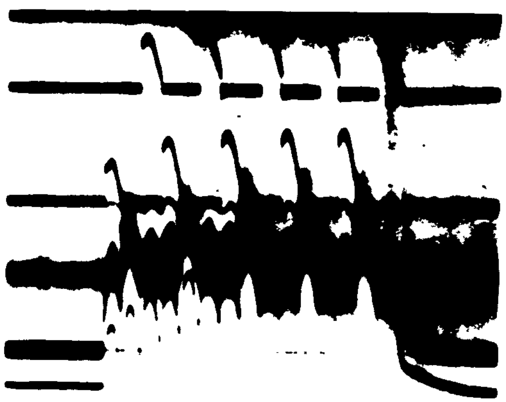
OSCILLOGRAPHIC TRACES OF SPOT WELDS
IN 0.050" 5456H343



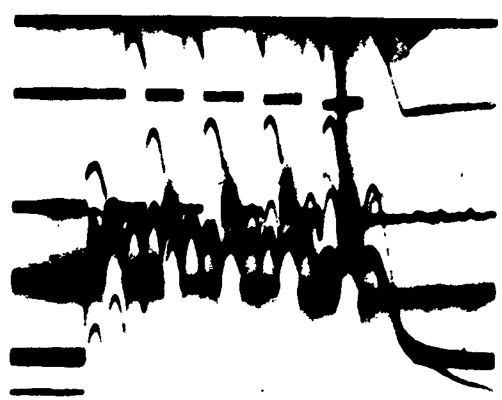
29800A 1200 lbs. 94 M.S.
W.S. 227 lbs. %R 26.6 Pct.

36100A 1200 lbs. 94 M.S.
W.S. 852 lbs. %R 29.4 Pct.

TIME ⟶



43400A 1200 lbs. 94 M.S.
W.S. 1243 lbs. %R 40.4 Pct.



62500A 1200 lbs. 94 M.S.
W.S. 1330 lbs. %R 55.4 Pct.

FIGURE 67

WELD CROSS SECTIONS FOR 2024T3 AND
7075T6 SPOT WELDS

0.050" 2024T3

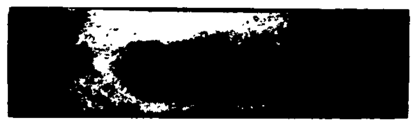
35000A 1000 lbs. 61 M.S.
W.D. No. Weld Pene. 0 Pct. %R 21 Pct.

38000A 1000 lbs. 61 M.S.
W.D. 0.190 in. Pene. 50 Pct. %R 27.5 Pct.

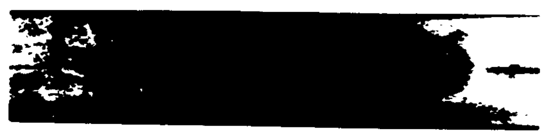
52000A 800 lbs. 61 M.S.
W.D. 0.259 in. Pene. 71/100 Pct %R 44 Pct.

0.050" 7075T6

26000A 1000 lbs. 61 M.S.
W.D. 0.070 in. Pene. 21 Pct. %R 18 Pct.



39000A 1000 lbs. 61 M.S.
W.D. 0.200 in. Pene. 65 Pct. %R 35 Pct.



43000A 1000 lbs. 94 M.S.
W.D. 0.256 in. Pene. 76 Pct. %R 42 Pct.

FIGURE 68

TYPICAL WELD STRUCTURES FOR SEVERAL WELD SCHEDULES IN 0.050" ALUMINUM ALLOYS

0.050" 5086H34

Weld Schedule

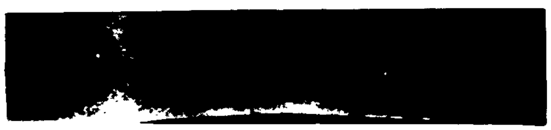
33000A 1200 lbs. 61 M.S.

Weld Properties	Weld Dia.	Pen.	Res. Drop
	0.110"	22 Pct.	11 Pct.

Weld Schedule

39000A 1000 lbs. 61 M.S.

Weld Properties	Weld Dia.	Pen.	Res. Drop
	0.183"	49 Pct.	26 Pct.



Weld Schedule

62000A 800 lbs. 61 M.S.

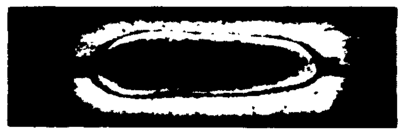
Weld Properties	Weld Dia.	Pen.	Res. Drop
	0.260"	82/100 Pct.	49 Pct.

0.050" 5456H343

Weld Schedule

26000A 800 lbs. 61 M.S.

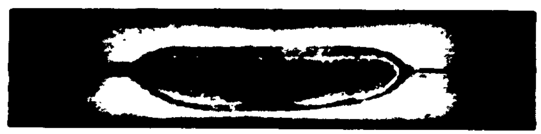
Weld Properties	Weld Dia.	Pen.	Res. Drop
	0.110"	31 Pct.	14 Pct.



Weld Schedule

37000A 1000 lbs. 61 M.S.

Weld Properties	Weld Dia.	Pen.	Res. Drop
	0.210"	60 Pct.	26 Pct.



Weld Schedule

44000A 1000 lbs. 94 M.S.

Weld Properties	Weld Dia.	Pen.	Res. Drop.
	0.240"	65 Pct.	56 Pct.

FIGURE 69