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TECHNOLOGY HANDBOOK

Technology Utilization Division

WELDING FOR ELECTRONIC ASSEMBLIES

From George C. Marshall
Space Flight Center
Huntsville, Alabama

TIONAL AERONAUTICS AND SPACE ADMINISTRATION

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NOTICE

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FOREWORD

The Administrator of the National Aeronautics and Space Administration has established a Technology Utilization Program for "the rapid dissemination of information . . . on technological developments . . . which appear to be useful for general industrial application." From a variety of sources, such as NASA Research Centers and NASA contractors, space-related technology is screened, and that which has potential industrial use is made generally available. Thus American industry will receive information from the Nation's space program about developments in operating techniques, management systems, materials, processes, products, and analytical and design procedures. This publication is part of a series designed to provide this technical information.

This is the second in a series of volumes on Reliable Electrical Connections. This volume covers the theory requirements and fundamental techniques of interconnecting electronic components by resistance spot-welding. A thorough understanding of the theory of resistance spot-welding along with good workmanship and process control are the factors necessary to attain the required reliability.

THE DIRECTOR, *Technology Utilization Division*
National Aeronatics and Space Administration

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Chapter 1

INTRODUCTION

The trend toward package miniaturization has resulted in many new packaging concepts. One of the concepts presently in use is the welded package. The guidance systems of the Polaris, the test data system of the Dyna-Soar, portions of the Titan electronics, and portions of the Pershing Ground Support Equipment have used the welded package technique. The Saturn project has a number of welded packages either in use or in planning; for example, the guidance computer.

The welded package offers a greater reliability of operation than do other available packaging methods. Although welding is an old process, its use as an interconnection medium for electronic components is relatively new. Its first application to the electronic field was in the manufacture of vacuum tubes. In 1954, a research scientist at Hughes Aircraft Company proposed that the welded technique be adapted for the interconnection of electronic components. This technique has been developed to the point of application in the production of miniature electronic packages.

Welding is not a panacea for the interconnection problems and will never entirely replace soldering. Each method has its advantages and disadvantages; thus, careful consideration should be given to the method of interconnection to be used for any specific application.

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Chapter 2

FUNDAMENTALS

Welding is defined as the joining of two materials by the formation of a homogeneous alloy at the interface of the materials. Many welding processes are in use, as shown by figure 1. The process to be discussed here is the resistance spot-welding process. Other welding processes have been, or are now being, investigated as a means for interconnecting electronic components. Some of these processes are arc welding, ultrasonic welding, and percussion welding. However, these are still in the research and development stage.

Resistance spot-welding is a thermal process wherein the inherent resistance of the materials to the flow of electric current is employed to generate the required heat for welding. Basically, the materials to be welded are placed between two electrodes which exert pressure on the materials. A high intensity current is then passed through the electrodes and the materials to be welded for a precise length of time. The current flowing through the resistance of the materials generates heat which produces the weld.

JOINING MECHANISM

The joining mechanism of welding may be classified as being either a fusion or a forging action. The fundamental difference between the two mechanisms is the temperature at which the joining weld occurs. The heat generated is a function of the thermal and electrical characteristics of the materials to be welded. These characteristics govern which joining mechanism takes place. Figure 2 illustrates the two basic welds.

Fusion occurs when the temperature is great enough to cause melting of the weld materials at the point of interface. The molten materials are confined within the weld materials and, upon cooling, solidify to a cast structure, termed a "nugget," which binds the materials together. Lighter metals and materials such as iron, steel, and nickel exhibit this type of weld.

The forge weld is basically a solid state one. The temperature reached is not high enough to cause melting but high enough to cause the materials to reach a plastic state. The pressure exerted by the electrodes forces the materials into intimate contact, and the proximity of the atoms of the two materials at the interface causes a solid state bond. There is no evidence of a nugget in the forge process. Copper and other metals possessing low resistivity and high thermal conductivity are joined by this type of weld since it is difficult to localize the heat at the interface.

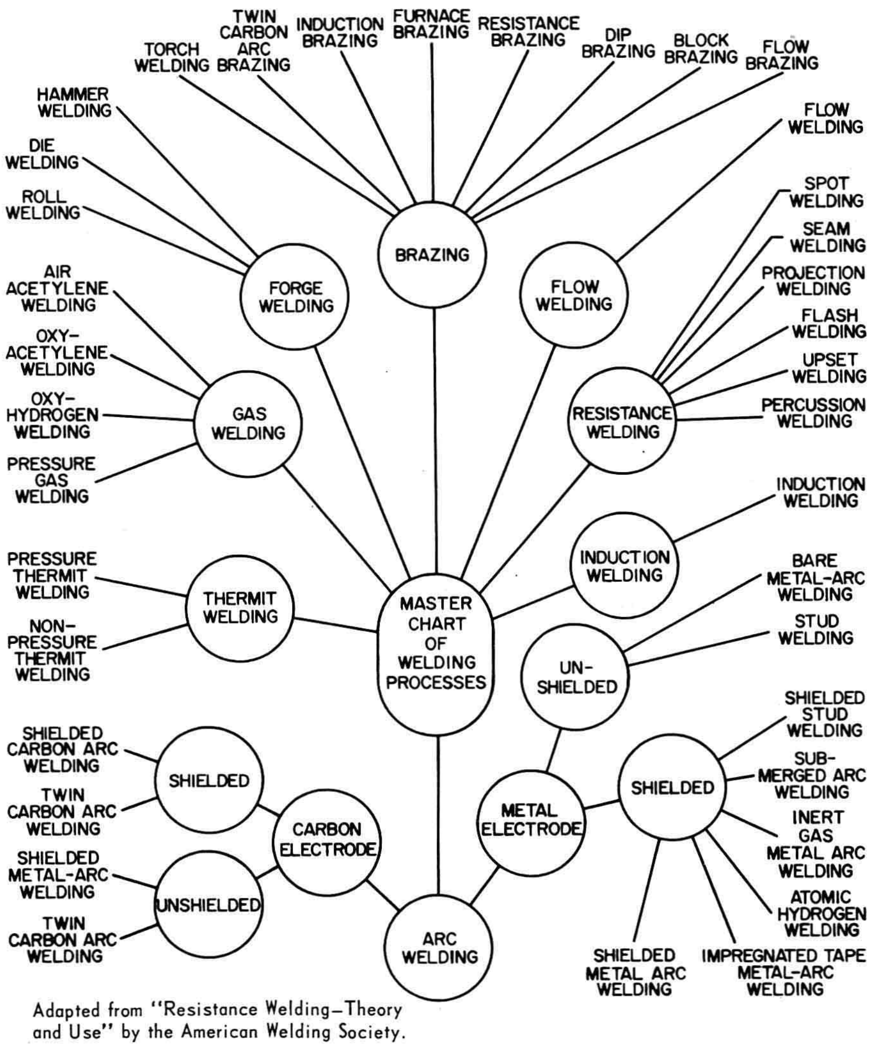
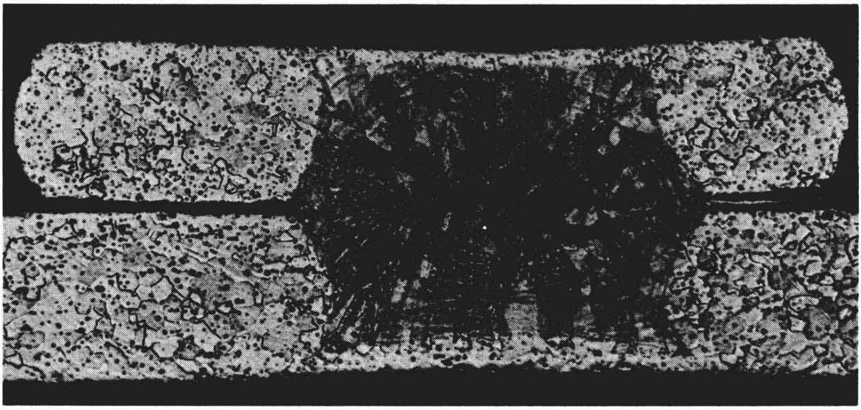
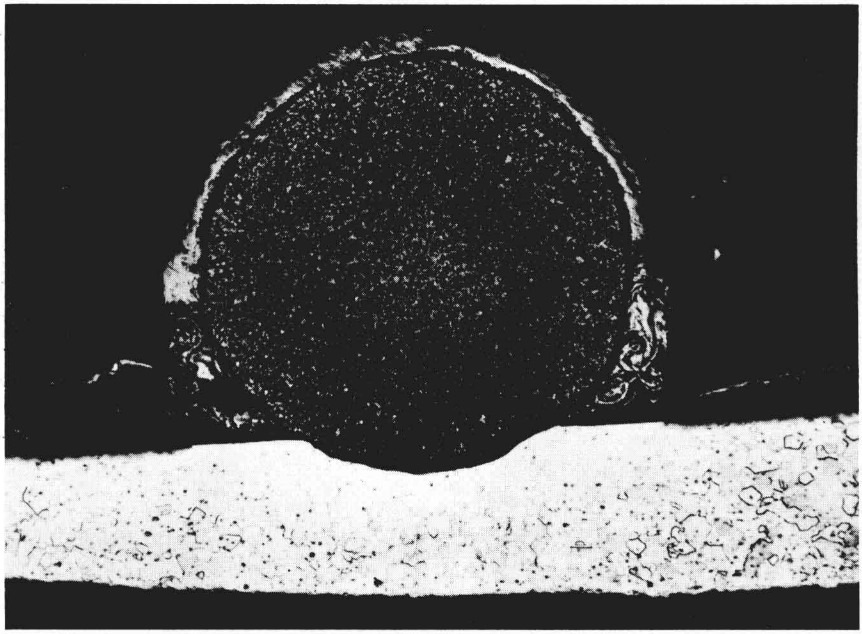


FIGURE 1.—Master chart of welding processes.



a. Fusion-type weld exhibiting nugget (nickel to nickel, 0.010 in. x 0.047 in. ribbon).



b. Forge-type weld (0.010 in. x 0.047 in. nickel to 0.025 in diameter dumet).

FIGURE 2.—Basic types of welds.

Of the two basic welds, the fusion weld exhibits greater strength and is more desirable. However, the nature of the materials encountered in welding electronic components is such that most welds have been of the forge type.

HEAT GENERATION

From the previous paragraphs, it is obvious that heat must be generated to produce a weld. The heat is produced by a high intensity current flowing through the resistance of the materials to be welded.

Current flowing in a resistive circuit generates heat which may be expressed by equation (1).

Equation (1) $P=I^2R$

P = Power (watts)
I = Current (amps)
R = Resistance (ohms)

This equation gives an instantaneous value and does not take into consideration the element of time. Taking time into consideration, the equation becomes:

Equation (2) $W=0.24I^2RT$

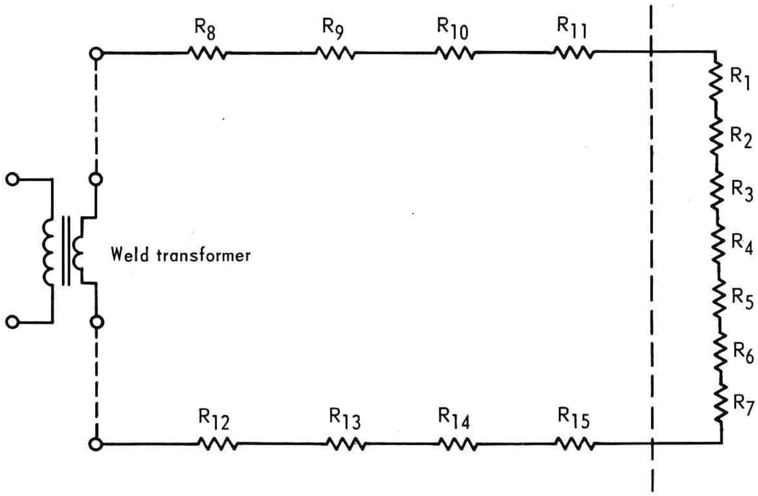
W = Energy (calories)
I = Current (amps)
R = Resistance (ohms)
T = Time (seconds)
0.24 = Conversion Factor

Equation (2) computes the amount of energy generated by a given quantity of current flowing through any specified value of resistance for a precise length of time.

RESISTANCE OF THE WELD CIRCUIT

The resistance of the weld circuit appears as shown in figure 3. The current will be the same at any given point in a series circuit, and the heat generated at this point will be directly proportional to the resistance at this point. Heat generated anywhere but at the place of the weld is wasted energy. Therefore, all resistances of the weld circuit, other than at the point of the weld, should be minimized. Of the resistances shown in figure 3, all but seven can be eliminated in the analysis of the weld circuit.

A number of factors will influence the resistance of the contact areas. The resistance of zones 2, 4, and 6 varies with electrode pressure, cleanliness, resistivity, geometry of the electrodes, and the materials.



R_1 and R_7 - resistance of electrode
R_2 and R_6 - contact resistance between electrode and work material
R_3 and R_5 - resistance of work materials
R_4 - contact resistance at interface of work materials
R_8 and R_{12} - contact resistance between cables and power supply
R_9 and R_{13} - resistance of cables
R_{10} and R_{14} - contact resistance between cables and weld head
R_{11} and R_{15} - contact resistance between electrode clamp and electrode

NOTES

1. Resistances R_8 through R_{15} are equipment design factors. In a well-designed machine, these resistances will be minimized.
2. Resistances R_1 through R_7 will depend on the electrode and work materials. These resistances affect the heat generation at the weld point.

FIGURE 3.—**Resistances of the weld circuit.**

TIME

The equation for heat generation shows that the heat produced is proportional to the time duration of current flow. Thus, time duration must be precisely controlled to produce consistent welds. In the case of stored energy equipment, this time is fixed and may be considered a constant. The pulse width of most stored energy machines is in the range of 1 to 3 milliseconds, although equipment is available with longer pulse durations.

CURRENT

The current flowing in the weld circuit plays the largest role in the generation of heat, since the heat produced is proportional to the square of the current. However, the amount of current flowing in the weld circuit is a functional result of the weld circuit resistance and applied voltage.

HEAT BALANCE

When the maximum amount of heat is produced at the interface of the two materials to be welded, namely zone 4 in figure 4, the fusion zones in the pieces of material to be joined undergo approximately the same degree of heating. This is the desired condition and is termed heat balance.

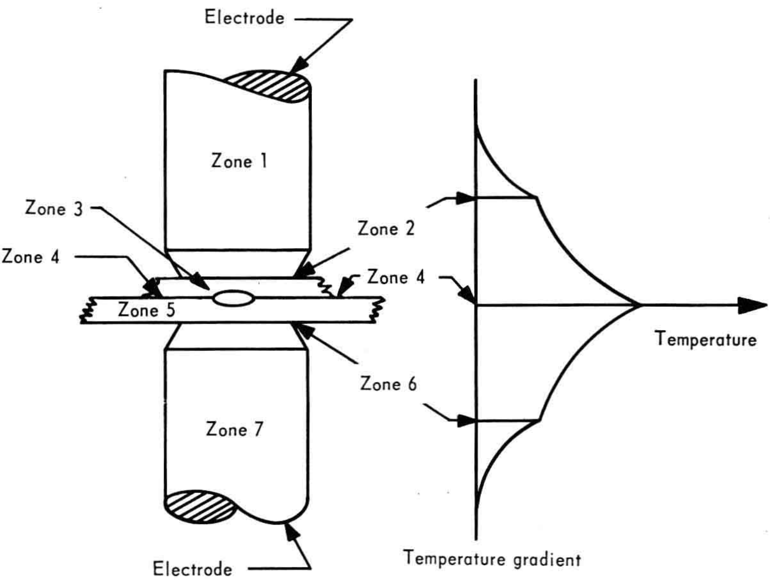


FIGURE 4.—Resistance zones and temperature gradients of resistance spot-welding.

When different types of materials, or materials of different thicknesses, are to be joined, zones 3 and 5 present different values of resistance to the weld current and therefore shift the temperature gradient curve so that heat balance no longer occurs. The resistance of the materials to be welded is the biggest factor in heat balance, although the resistance of the electrodes must also be considered.

Heat balance is affected by all of the following:

a. Relative thermal and electrical conductivities of materials to be joined.
b. Relative geometry of parts at joint.
c. Thermal and electrical conductivities of the electrodes.

d. Geometry of electrodes.

By judicious choice of electrode material and proper electrode geometric design, the problem of improper heat balance can be solved. The methods employed to create proper heat balance are discussed in the section dealing with electrodes.

The seven zones of weld circuit resistance and their related heat gradients are shown in figure 4. Zones 1 and 7 represent the resistance of the electrode materials. The temperature at these zones is fairly low because of the relatively low resistance and large radiative surface of the electrode. The areas labeled 2 and 6 represent the contact resistance between the electrodes and the weld materials. The temperature at these points is fairly high and approximates fusion temperature. However, because of the conductivity of the electrodes, part of the heat is conducted away from these zones, and fusion temperatures are not reached. Zones 3 and 5 are resistance zones due to the internal resistances of the weld materials. The temperature gradient is increasing here and is close to the fusion temperature. The zone labeled 4 presents the largest resistance and, consequently, reaches the highest temperature. This zone is the contact resistance at the interface of the weld materials. The heat generated at this point is isolated from the electrodes by the hot spots of zones 2 and 6.

PRESSURE

Equation (2) takes into account the electrical variables of the weld circuit. However, it does not reflect the pressure requirement which is essential to provide forging. The pressure exerted by the electrodes on the work materials serves three main functions:

a. Contains the molten nugget during current flow when high internal pressures are built up as a result of the heat of welding.
b. Maintains intimate contact between the materials to be welded and also between the materials and electrodes.
c. Provides forging action during nugget solidification so that thermal shrinkage will not promote cracking or porosity.

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Chapter 3

DETERMINATION OF OPTIMUM PARAMETERS

Since pressure, time, and energy are the controllable variables for producing a weld, proper application of these variables is of paramount importance for producing the optimum weld.

The operator must prepare an iso-strength diagram to determine which parameter of each variable will result in the strongest, most *consistent* weld. The iso-strength diagram is a graphical representation expressing the strength of the weld as a function of energy and pressure. When the diagram is completed, it will show the operator which parameters are most suitable for producing optimum welds with specific materials.

On the iso-strength diagram, pressure is plotted on the ordinate end energy on the abscissa. At each set of coordinates within the plot, the strength of the weld produced at these coordinates is recorded. The plot may be completed by selecting increments of energy and pressure and then producing welds at each coordinate point. However, this is a lengthy procedure, and a statistical approach has been developed which produces the same results in a much shorter period.

The statistical approach involves selecting an arbitrary set of starting points. Several welds are made at this point and pull-tested. The average breaking strength of this group of welds is then recorded at the coordinate point on the iso-strength diagram. Four additional points are selected at definite increments of pressure and energy in such a manner that the four points fall around the initial point. A number of welds are made at each of these points, pull-tested, and the average break-strength recorded at the respective coordinate points. The point which displays the highest break-strength is the direction in which future tests proceed. Select another arbitrary point that is in the direction indicated by the preceding test. Use the aformentioned procedure to determine the direction in which to continue testing. This procedure continues until the point is reached where "spitting" occurs. The diagram is then analyzed and the region which exhibits