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RESISTANCE WELDING MANUAL

Revised Fourth Edition

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This Manual is intended to describe the basic fundamentals of Resistance Welding in its various applications with differing materials and equipment. It covers some safety considerations, but it is not a safety manual. It covers some materials standards, but, except where specifically identified (e.g., RWMA Electrode Material Standards), it does not set, describe or replace specific industrial or material standards or specifications. It describes the operations, but it is not an operating manual.

This Manual is not intended to replace rules, laws, regulations, standards, directions or specifications relating to safety, design, operations, materials or procedures. All relevant federal and state laws, regulations and standards and all privately created standards should be followed.

The Resistance Welder Manufacturers' Association, and those acting for it in preparation of this Manual, will not be responsible for any injury or person or property, or for compensatory, consequential or punitive damages or payments, resulting in whole or part from the use of this Manual.

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PREFACE

The Resistance Welder Manufacturers' Association (**RWMA**) takes extreme pride in presenting the Revised Fourth Edition of the *Resistance Welding Manual*. At its publishing, this work represents the latest and most complete compilation of basic information on resistance welding available anywhere. The text gathers together the most current data on resistance welding which includes: the different welding processes; types and weldability of various materials; and resistance welding equipment, such as welding machines, electrodes, jigs and fixtures, transformers, controls and power supplies. Also covered, are modern quality control (S.P.C.) and maintenance procedures.

This organization, representing North American builders of all types of resistance welding equipment, has a long tradition of providing practical information and assistance to those using and studying this vital welding process, and of developing standards to serve the entire resistance welding industry. The RWMA has grown in parallel with the industry it serves, reaching its greatest strength as resistance welding gains new recognition for speed and productivity in automotive, appliance, transport, aerospace, electronics and consumer goods manufacturing.

An organization such as the RWMA depends on countless hours of unpaid work by member and non-member representatives to bring a massive project like this reference work to fruition. For some individuals, publication of this book represents the finest possible testimony to their dedication.

The RWMA wishes to gratefully acknowledge the efforts of literally dozens of member delegates who gave unselfishly of their time working on this volume as part of the Association.

March, © 2003

RWMA, Philadelphia, PA

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The reference data provided in this revised edition is the product of an indeterminable amount of hours of charitable contribution by many professionals and organizations. Their work is deeply acknowledged by the RWMA Association; but more important, their contributions will serve to advance the comprehension of resistance welding throughout the welding industry. Additionally, state-of-the-art technology and practical resistance welding data will undoubtedly guide significant productivity achievements in the coming years. The entire Resistance Welding Industry will profit from their commitment to this manual.

The scope of coverage, both of resistance welding fundamentals and its advanced applications, will prove useful to engineers, managers and technicians who are endeavoring to increase their knowledge of resistance welding, upgrade product quality and maximize the use of their manufacturing resources. A comprehensive index has been provided which we hope will expedite quick access to information.Also included are illustrations, photographs, and tables to assist information gathering and troubleshooting.

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Fundamentals Of Resistance Welding

INTRODUCTION

Welding consists of the joining of two or more pieces of metal by the application of heat and sometimes of pressure.

Resistance welding embraces that branch of the welding art in which the welding heat in the parts to be welded is generated by the resistance offered by these parts to the passage of an electrical current. It differs from other forms of welding in that no extraneous materials, such as fluxes, filler rods, etc. are used; therefore, the metallography of the weld is not complicated by the addition of these materials. Resistance welding further differs from the fusion welding processes, by utilizing the application of mechanical force to forge the heated parts together. The effect of the force is to refine the grain structure, thus producing a weld with physical properties, in most cases, equal to the parent metal, and sometimes even superior.

Resistance welding machines and their operation often appear mysterious to the layman when he sees good welds being made quickly and easily. The same characteristics may lead the beginner to believe the process more simple, or more generally applicable, than is true. It is the aim of this introductory discussion to review the fundamentals of the process and to discuss some of the more basic details.

Welding is really a metallurgical process. Ordinary iron has been described as a suspension of ferrite crystals of variable compositions in a matrix of its own impurities. It is this matrix of impurities that increases the electrical resistance of all metals which is of real importance in electrical resistance welding.

RESISTANCE WELDING PROCESSES

Figure 1.1 illustrates, in graphic form, the resistance welding processes[1] and their relation to one another. It should be noted from this chart that the general subject of resistance welding may be broken into two general classifications according to the method of joining the parts. (The same classifications may also be applied to other welding processes).

1 See also the latest revision of *Standard Welding Terms and Definitions*, an American Welding Society (AWS) publication.

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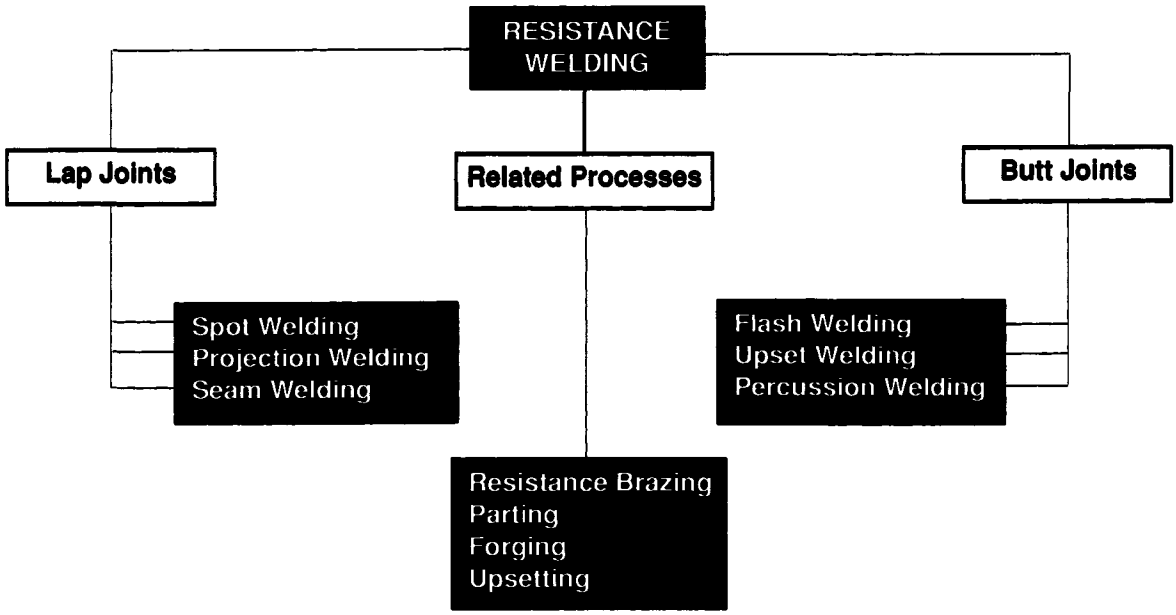


Fig. 1.1 - Resistance Welding Processes

Lap Joining. This is a method whereby the electrodes conduct the welding current and at the same time apply the welding force. This method includes not only any kind of lap joint but also any joint in sheets, plates, rods and bars in which the weld is not made end-to-end or edge-to-edge.

Spot Welding. Spot welding is the most widely used example of lap joining, and it is accomplished with shaped electrodes held essentially stationary while the weld is made.

Projection Welding. By forming projections in one or both of the workpieces, the current path is localized at the projections. This permits the use of flat electrodes, thus producing projection welds.

Pulsation Welding. Normally a spot or projection weld is made with a single application or impulse of current. If, however, the flow of current is interrupted and reapplied one or more times without release of electrode force, a pulsation weld results.

Seam Welding. Seam welding is quite similar to spot welding, but the electrodes revolve and are actually in motion while the weld is being made.

Roll Spot Welding. If interrupted current is used—regardless of whether the wheels rotate continuously or intermittently—and if the timing is such that the welds do not overlap, the resulting joint is called a roll spot weld.

Butt Joining. Butt joining is that method in which the weld takes place on the ends of bars or the edges of sheets or plates. The electrodes introduce current to the two members being welded, and may or may not be used to transmit the upset force. If they are used to transmit the upset force, it is accomplished through the gripping action of the electrodes or clamp jaws; otherwise, upset force is provided by means of auxiliary clamp members or backup members.

Flash Welding. If two rods or bars, for example, are clamped end-to-end, with the abutting ends making light contact with one another when current is applied, a flashing action develops. As this flashing proceeds, metal is burned away, requiring one piece to be moved toward the other to maintain the flashing action. As this takes place the ends of the two pieces attain welding temperature, at which time an upset force is applied, thereby completing the weld.

Upset Welding. If two rods or bars, for example, are clamped end-to-end in electrodes, held in contact with one another as welding current and force is applied, the resultant joint is an upset weld.

Percussion Welding. This is usually classed as a resistance welding process, although it technically is

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not, since no heat is generated by the resistance of the workpieces. Instead, the welding heat is generated by an arc developed with the two pieces becoming spark-gap electrodes. Actually, it is a process wherein coalescence is produced simultaneously over the entire area of abutting surfaces. The heat is obtained from an arc produced by a rapid discharge of stored electrical energy, with force percussively applied during or immediately following the electrical discharge.

Figure 1.2 illustrates the principal types of resistance welds; they are: spot welds, seam welds, projection welds, upset welds and flash welds.

RELATED PROCESSES

In addition to welding, related applications or processes, such as resistance brazing, parting, forging and upsetting are included in this general subject. This is because the heat required for these processes is also generated by the resistance of the parts to the passage of electrical current.

Resistance Brazing. Some metals, such as copper, silver, tungsten, molybdenum, etc., are difficult or impossible to resistance weld, but are very readily resistance brazed. In this case, the brazing methods used are similar to gas or furnace brazing, except that the parts are placed between suitable electrodes in a resistance welding machine and held under light contact force while current is applied. If the electrodes are tungsten, molybdenum or similar material, the brazing temperature is generated by the resistance of the workpieces. If the electrodes are carbon or graphite, they become white hot and essentially all the brazing is obtained by conduction from these electrodes. This type of brazing is frequently termed *incandescent brazing* and is usually used for brazing large sections, such as electrical conductors, bus bars, etc.

Resistance Parting. This is the reverse of upset welding—a bar or cable is placed in the welding electrodes, a current and a force is applied to separate the workpiece midway between the electrodes. As the metal gets hot, it stretches and finally parts. In the case of a solid bar, each piece will have a pointed end. With a cable there will be some tapering down where the individual strands fused together.

Electro-Forging and Upsetting. If a solid bar is clamped and current applied, as in an upset weld, that metal between the electrodes reaches a forging temperature and upsets or forges if a force is applied, similar to an upset weld.

FUNDAMENTALS OF THE RESISTANCE WELDING PROCESS

General Principles

Weld. By definition, a weld is a localized coalescence of metal heated to a suitable temperature. This definition is all-inclusive and takes no cognizance of the method by which the weld is made, nor of the quality of the weld. Fusion welds which are made without the application of force require liquefaction and resolidification of the molten metal to consummate the weld. The result is a cast structure.

A resistance weld, on the other hand, is made under localized force which is maintained until the weld zone solidifies. The resultant grain structure is, therefore, of a higher order than that of the cast structure encountered with fusion welds.

In order to better understand the nature of resistance welding and how it is accomplished, it is best to consider a simple spot weld. The basic principles apply to all other resistance welding and heating methods except flash and percussion welding.

Generation Of Heat. A spot weld is made by pressing two or more overlapping pieces of metal together while an electrical current is passed through a localized contact area to heat the metal forming the weld nugget to the welding temperature.

One of the principles of resistance welding is to generate the heat energy in the weld zone very rapidly so that the minimum amount of heat will be dissipated by conduction to the cooler adjacent material. This requires a high rate of heat generation and is accomplished by passing a large value of current through the

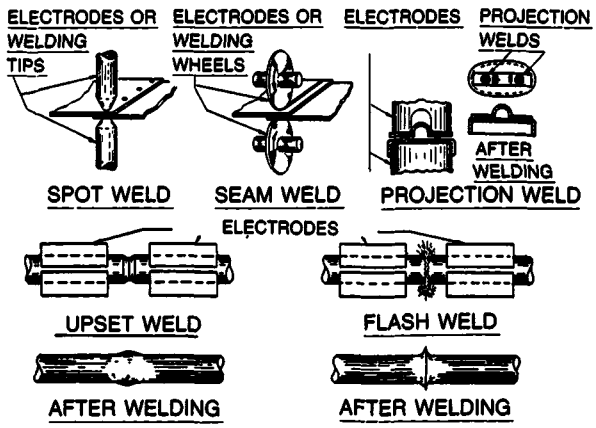


Fig. 1.2 - Principal Types Of Resistance Welds

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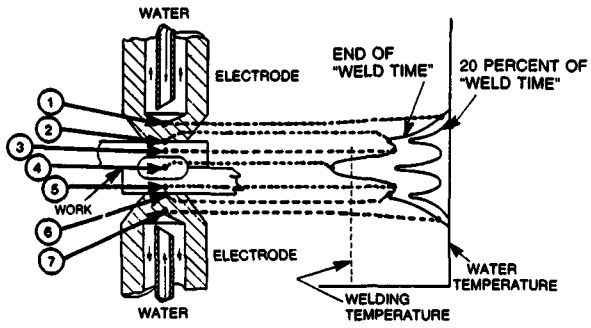


Fig. 1.3 - Temperature Gradient Of A Spot Weld

weld zone resistance for a short time interval. Another principle is to generate much more heat in the weld zone than in any other portion of the welding machine secondary circuit.

The theory and practice for achieving these two principles is stated as follows: heat energy is generated whenever an electrical current passes through an electrical resistance. The rate at which the heat is generated is given by:

$$W = I^2R \qquad (1)$$

where,

- **W** = Electrical power in watts.
- **I** = Current in amperes.
- **R** = Resistance in ohms.

If the power is applied over a time interval of **t** seconds, the heat energy developed in the resistance is:

$$Q = I^2Rt \qquad (2)$$

where,

- **Q** = Watt-seconds or joules.

It is evident from equation **(2)** that the magnitude of the heat energy generated can be varied by changing the value of any of the three factors of the equation. The **I** and **t** can be readily varied by adjustment of the welding control while **R**, the resistance of the workpieces being welded, is fixed for any one process. There are two types of electrical resistance present in the secondary circuit of a resistance welding machine; one is the volume resistance of the material in the circuit, including the workpieces, and the other is the interfacial resistance of contacting surfaces. Each of these is discussed below.

All metals have some degree of resistance to the passage of current. The resistance offered to direct current is known as resistivity and is the resistance of a standard volume measured at a known temperature. It is a function of the material composition, and it varies with temperature. The resistance is greater to the passage of alternating current (ac) due to the presence of eddy currents generated in the interior of the conductor. This is known as *skin effect* and increases with an increase in the frequency of the current and increase in the sectional area of the conductor. The actual resistance is termed effective resistance and is directly proportional to the conductor length and nearly inversely proportional to the sectional area, considering skin effect, if present.

Of the common metals, copper has the lowest resistivity and is used as a base for comparison with other metals. For comparison purposes, the reciprocal of resistivity is used. This is known as conductivity and copper has been assigned a value of 100 percent, with common steel, for example, at about 10 percent. Thus, a given current passing through equal volumes and sectional areas of copper and steel will result in the generation of heat energy approximately ten times greater in the steel than in the copper.

Interfacial resistance is the resistance to the passage of current across the contacting surfaces of two metals. The value varies with the metal composition, surface condition, contacting area and pressure. In general, this resistance follows the volume resistivity of the metals involved to some degree. For example, the same contact area at equal pressure of copper to copper surfaces usually has much less resistance than a steel to steel contacting surface, with a copper to steel surface somewhere between the two extremes. It is important to note that the interfacial resistance can vary greatly due to surface contamination and physical condition (i.e. parallelism, pits, etc.).

If good machine design and construction practice has been followed, and the proper welding electrodes are used, the interfacial resistance of the workpiece mating (faying) surfaces is usually greater than that of the effective volume resistance of any one section of the secondary circuit and greater than that of any other contacting surface.

All of the resistances involved in the machine secondary circuit are considered to be in series, and since the same current is passing through each one, the heat generated at any one location is proportional to the value of the resistance at that point.

Thus, the heat energy generated at the weld faying surface is greater than that at any other localized point

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in the secondary circuit and, during the first part of the "weld time" interval, is responsible for most of the heat input to the weld zone. As the "weld time" progresses, the effective volume resistance of the weld zone increases as the temperature rises and accounts for a greater portion of the heat generated.

The heat generated in the remainder of the secondary circuit is a loss and is dissipated by radiation, convection or conduction aided by water cooling. **Figure 1.3** shows a typical setup. There are seven resistances connected in series, as follows:

1. Upper electrode.
2. Contact between upper electrode and upper sheet.
3. Upper sheet.
4. Contact between upper and lower sheets (faying surfaces).
5. Lower sheet.
6. Contact between lower sheet and lower electrode.
7. Lower electrode.

From the preceding statements, heat will be generated in each of these sections in proportion to the resistance of each. However, welding heat is wanted only at point **4**, and efforts must be made to reduce the heat as much as possible at all other points. Referring to **Figure 1.3**, at the start of a weld the temperature at all parts is represented by the vertical line marked "water temperature". The point of greatest resistance is **4**; therefore, heat is rapidly developed there. Points of next greatest resistance are **2** and **6**, and the temperature rises rapidly at these points also, but not as fast as at point **4**. At the end of about one-fifth of the total time allowed for the weld, the heat gradient corresponds to the extreme right-hand scalloped curve.

It should be noted here that heat generated at **2** and **6** is rapidly dissipated into the contacting water-cooled electrodes **1** and **7**, whereas the heat at **4** is partially trapped and dissipation is much slower. Therefore, as the "weld time" progresses, the rate of rise for point **4** will be much more rapid than **2** or **6**. The welding temperature is indicated by the vertical dotted line. In a perfectly controlled weld, the welding temperature would just be reached by a minute area on the faying surfaces and grow into a nugget as the time progresses.

From the foregoing, the importance of timing is evident. The ideal situation is one in which the temperature rise in **zone 4** is maximum, and in all others a minimum. This leads to the following important considerations:

1. *Electrodes.* These should have high electrical conductivity to keep the internal heat generated to a minimum, and high thermal conductivity to dissipate the heat rapidly from **zones 2** and **6**. However, they must also have physical resistance to deformation caused by high electrode forces. This is particularly true at the contact surfaces where high temperatures and force concentration occur. Therefore, in the various alloys developed for electrodes, the best compromise has been adopted for each application.
2. *Contacting Surfaces.* These are **zone 2** and **6**. Here again, the electrical resistance must be kept at a minimum. This is done in two ways: *first*, by having smooth, clean work surfaces; *second*, by control of electrode force. Referring to the temperature gradient curve in **Figure 1.3**, if these surfaces are dirty, scaly or pitted, the temperature at these points will rise nearly as fast as at the faying surfaces, resulting in metal expulsion, electrode erosion, embedding, etc.

   If the surfaces of metal sheets are highly magnified they will appear somewhat like a washboard or choppy body of water. When subjected to light force, the actual metal-to-metal contact may be only a small percentage of the entire area of contacting surface. As the force is increased these high spots are depressed, increasing the actual metal-to-metal contact, thus decreasing the resistance. This increased electrode force also decreases the resistance at the faying surfaces. The ideal solution would be to control the force exerted at the faying surfaces and the force exerted at the outside surfaces of the sheets separately, if it were possible. However, except for a few applications, the electrode material is softer than the workpieces; consequently, the application of a given force will result in better contact at the electrode contacting surfaces than at the faying surfaces.

   In some special applications, it is advantageous to increase the resistance of the interfaces by plating or by not disturbing the scale. This procedure has the great disadvantage of being very difficult to control. Furthermore, the plate or scale is absorbed in the weld nugget, and in most cases, it will have a weakening effect on the weld.

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3. *Work Materials.* In the foregoing, the two electrodes are assumed to be identical and the workpieces to be equal thicknesses of similar materials. If this relationship is changed, the heat gradient, **Figure 1.3**, will no longer be symmetrical. For example, if the upper sheet is stainless steel and the lower sheet of low carbon steel, the resistance and heat generation in **zone 2** will be increased, with the result that the nugget will be developed mostly in the upper sheet. The same thing will happen if the electrode contacting surfaces are of unequal area or if the electrodes have unequal conductivity, or if the workpiece thicknesses are unequal.

4. *Time.* Since heat energy is equal to the power multiplied by time **(t)** that it is applied, as shown by equation **(2)**, the time that the welding current exists becomes one of the factors controlling the total heat energy generated.

   In the heat gradient curve, **Figure 1.3**, time moves to the left from the starting point (solid vertical line). If the time is continued beyond that shown in the Figure, the temperature of zone 4 will pass the boiling point at minute areas of the workpiece material causing gas pockets. The result will be expulsion of metal particles, or a flash and sparks. If the contacting points, **2** and **6**, are scaly or pitted, the same thing may happen there. A continued application of current will cause the peaks to be less pronounced, the nugget will grow completely to the electrode faces and **zones 3** and **5** will become plastic, resulting in severe embedding of the electrodes. Furthermore, the heat-affected zone will pass far out into the sheets beyond the electrodes. In most cases, at some time during this interval, the radiation losses will equal the heat input, thus stopping further temperature rise.

   From the equations **(2)** and **(3)**, it is shown that the heat generated is proportional to the square of the current. Therefore, neglecting losses, doubling the current will quadruple the heat developed over any period of time. To a certain extent, time and current may be complementary; that is, a desired change of heat may be secured either by a change of current or by a change of time. However, it must be remembered that heat transfer is a question of time, and in the development of the proper nugget size, the time element cannot be shortened too much regardless of the increase in current. The first effects of insufficient timing are noticed when heat is generated too rapidly at the three contacting surfaces, resulting in pitting and surface flashing, especially at the electrode contacting surfaces.

   At the instant that the current is terminated, heat generation stops and the work starts to cool. Due to their thermal conductivity, water-cooled electrodes will rapidly return nearly to the cooling water temperature. The contacting surfaces **2** and **6** conduct heat into the electrodes, thus almost immediately leveling the peaks at these points, and the center gradually cools. The rate of cooling is determined by the same conditions which govern the amount of heat input. If, however, the electrodes are lifted immediately after the current stops, they will be unable to absorb heat from the weld, the peaks at the electrode surfaces will be increased, the valleys between peaks will disappear, and the cooling will be retarded. Also, since the pressure is removed while the weld is still plastic or molten, the weld may be of low quality. Since the rate of cooling of the weld has a metallurgical bearing on the properties of the weld nugget, it is sometimes necessary to control this cooling rate very accurately.

5. *Welding Force.* As shown in **Figure 22.2** of **Chapter 22**, for a given electrode geometry and work surface condition, the contact resistance is approximately inversely proportional to the electrode force. If the electrode face is in the form of a radius, greater force increases the effective contact area and reduces the current density. Thus, an increase in the electrode force reduces the heat generated.

6. *Shunting Effect.* In the previous discussion of the resistance components in the secondary circuit, they were considered as being in series. It remains to investigate the effect of parallel resistances. In the case of a single spot weld, a certain set of conditions were involved. If a second spot is made close to the first one, there will be a shunting effect, which is equivalent to two resistances in parallel. Current, according to Ohm's Law, will pass through the two paths in inverse proportion to their resistance. The action of the first weld has eliminated the interface resistance at that point, and since the electrode contacting surfaces are the same, the division of current will depend upon the ratio of the resistance of the second weld to the resistance of the current path through the first weld.

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Thus, in **Figure 1.4** the metal between the electrodes becomes a divided circuit; part of the current travels path **A** while the remainder travels the normal path **B**. If **A** is long, its resistance compared to **B** will be high, and the effect can be neglected. If **A** is short, an appreciable portion of the total current will be shunted. Another factor which must not be overlooked is that as path **B** rises in temperature, its resistance increases, adding to the shunting effect of path **A**. The materials being welded also have considerable bearing on the effect. Stainless steel, having high resistivity, is less influenced than common steel while aluminum is influenced more.

In seam welding, this shunting effect is very important because the spots are actually overlapping. The adverse effects are somewhat alleviated, however, because the temperature of the preceding spot in each case after the first is quite high; consequently, the resistance through that path is quite high.

Some controls are provided with a dual heat control, one for the first spot in a row of spot welds or a seam weld, then automatically shifting to a higher heat value to offset this shunting effect for the remaining welds.

7. *Multiple-Impulse Welding.* When welding heavy plates, multiple-impulse timing is frequently used. The principal advantage of this schedule is due to the fact that, during the "cool time" between impulses, the high thermal conductivity of the water-cooled electrodes dissipate more heat from the outer surfaces of the workpieces than is dissipated from the weld zone. This increases the temperature gradient between the weld zone and the outer workpiece surfaces allowing a greater heat input without unduly overheating the electrode to work contact areas when compared with making the same weld with a single impulse.

Projection Welding. So far only spot welding has been considered, but by an examination of the other processes, it becomes obvious that the fundamentals or principles involved are very much the same. In a projection weld the faying surface contact is controlled by the size and shape of the projection. The purpose of the projection is twofold: *first*, to create a better heat balance when unequal thicknesses of workpieces are welded; and *second*, to concentrate the weld into a smaller area on thick pieces. While this could be accomplished by using an electrode with a small face area, the results would not be the same. Severe marking, indentation and short electrode life would result. Projection welding also allows multiple welds to be made simultaneously in a confined area.

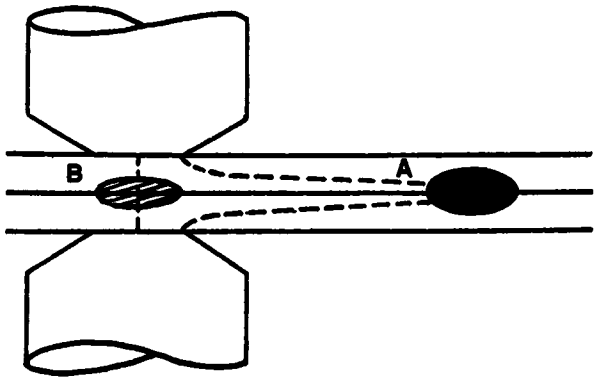


Fig. 1.4 - Shunting Effect Of Second And Subsequent Spot Welds

Upset Welding. The process of upset welding shows little variation from the preceding. In this case, though, the electrodes themselves exert less influence because the electrode contacting area is not limited. Therefore, electrode interface resistance in that area can be made negligible. However, with poor electrode fit or with scaly or rusty stock, a problem of overheating arises as in the case of spot welding. The abutting ends of the stock corresponds to the faying surfaces contact, and the stock projecting from the electrodes corresponds to **zones 3** and **5**, **Figure 1.3**.

The abutting ends must be well matched and must contact each other throughout the area.

The effect of shunting is not a factor in joining independent parts, but it is a major consideration if the part is a single piece such as a ring or a similar closed shape.

Flash Welding. Flash welding presents a somewhat different case, inasmuch as a considerable portion of the heat is generated by flashing action at the contacting ends. In all other forms of resistance welding, any foreign material on or in the interfaces, such as scale, dirt, etc., will be retained in the weld, and in most cases, it will weaken the weld. Flash welding eliminates this because all the material at the interfaces is burned away or forced out during the upset.

Due to the nature of the process, the abutting ends need not match up, in fact, for best results, they should not. Furthermore, there is no known limit to the section that can be flash welded. It is entirely a question of economics and available power.

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APPLICATIONS

Resistance welding is a far more flexible method of joining metals, and it is applicable to a greater range of sizes, shapes and materials than is generally appreciated. The flexibility feature may be examined from two viewpoints. For each of the principal resistance welding processes, machines are available ranging in size from small bench type welding machines to large installations in which the process is incorporated in an automated system with computer controls. Also, many of the standard types of welding machines can be used for several different types of welds by making comparatively simple changes in the electrodes and tooling. As for size limitations, there are found, at the lower end of the scale, such examples as the welding of tiny alloy tips to fountain pen points and joining wires of 0.001-in diameter and, in the upper ranges, welding sheets and plates having total thicknesses of one inch or more, flash welding solid rounds over 8-in diameter and flash welding plate edges in lengths up to 40 ft in the manufacture of pipe.

Several factors may determine whether a specific application requires the use of a standard or a special machine.

Due to the nature of resistance welding, it should be noted that the adaption of a standard machine to applications outside its range may necessitate modifications in either the electrical system or the mechanical system. The feature of flexibility, which has been mentioned above, has an important influence on the amount of work which a single machine can do. It is true that the process has made its most spectacular savings in mass production, but there are also countless short-run applications where the percentage savings are equally large. That is, for job shop operations it is not a question as to how many identical units are to be welded, but rather how many units involving the same range of thickness, diameter, etc., are to be welded. It is easily possible to keep a spot welding machine busy under conditions where individual production runs are completed in a few hours.

Resistance welding is used extensively in the manufacture of composite products. For instance, two steel castings may be flash welded together to form a part that cannot be molded into a single casting. Counterweights are flash welded to crank shafts because forged counterweights present an inferior grain flow structure. Dissimilar metals are resistance welded to provide, in a single piece, the best characteristics for differing purposes. High-speed cutting tools such as drills, reamers, etc., are flash welded to low carbon steel shanks, thus providing each end of the tool with the best metal for its particular use, and at the same time, economizing on the use of the more expensive high-speed steel.

Two or more pieces of steel (of like or unlike analysis) may be flash welded together to form a composite piece or forging, which, in addition to providing the best metal at the right place, permits considerable machining economies.

In the stamping industry there is a large number of production assemblies made up of two or more stampings. Costs can often be greatly reduced, and products improved, by building up with small components where the product part was formerly a forging or a casting of intricate design or one requiring a considerable amount of machining. This field of application is comparable to job shop production in that a few resistance welding machines are employed in the manufacture of a great many entirely unrelated products. Again, in a plant where electrical devices are manufactured, a press welding machine may be used for resistance brazing of many different kinds of nonferrous metal assemblies and for spot or projection welding of other parts. When production volume is high, however, a single machine will be kept busy on one type of operation. In any of these common situations, an analysis of the entire production cost often reveals that even greater savings can be effected than are indicated by comparing costs of resistance welding with other production methods, such as riveting, casting and forging.

Since all resistance welding processes are applicable to the production of sheet metal items, the first general division of application which suggests itself is containers. This may mean any type of tank, pail, receptacle, etc. and, depending upon the nature of the product, there are several processes from which to choose. Roll spot welding is satisfactory in some cases. For pressure tight seams, lap seam welding, mash seam welding, continuous seam welding or flash welding may be employed, according to the design, the requirements of the container and the availability of other fabrication machinery. Many sizes can be accommodated on one machine without major changes.

Another application of great importance in the manufacture of metal goods is the welding of small attachments, such as braces, brackets, pads, clips, etc., to formed sheet metal parts such as bases, covers, and

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trays. Examples of this are found in the manufacture of numerous automobile and aircraft parts, industrial equipment, office equipment, domestic goods such as furniture, heating appliances, cooking utensils and a great many miscellaneous hardware items.

The automobile industry has utilized resistance welding to the utmost for bodies, frames, housings, levers, braces, wheels, seats, and such smaller parts as spark plugs and electrical system components.

Its use in the aircraft industry was limited for a time because aircraft designers made maximum use of the lighter materials of high strength, in order to reduce the weight; also, many of these materials which have a high strength-weight ratio were difficult to weld. However, in recent years research has developed resistance welding methods which produce satisfactory results on these materials.

In the manufacture of railroad cars, the field of application for resistance welding is constantly increasing. Every improvement made in procedures and equipment broadens the application of the process.

Mention should be made of typical resistance welded products which have been in production for many years. The manufacture of resistance welded steel tubing, in sizes from 0.500-in to 5.00-in outside diameter, is an industry in itself. Several types of machines produce chain from rod by upset welding. Cross wire welding finds a huge volume of applications in the manufacture of wire fence, grilles, gratings, trays, baskets, guards, racks, reinforcements and shelves. Electrical appliances, such as refrigerators, washers, stoves, ovens, heaters, dishwashers, microwave ovens and irons, depend upon resistance welding for fast production. The same is true of office equipment and farming systems and equipment.

The list could be extended almost endlessly. Every metal product is a possible application. The range of applications in the immediate future is greater than ever before because recent refinements in equipment and improvements in procedures have paved the way for more efficient production and better quality of product.

ECONOMICS

The characteristic of resistance welding which has the greatest economic significance is the high speed of operation. Individual welds are normally made in fractions of a second, so that production rates are actually determined by the time required for feeding the work to the process and removing it after the weld is completed. In the case of most applications, no other process can accomplish a bond in so short a time.

Economies realized by resistance welding may also represent: savings in material, as compared to material that is lost, when forgings or castings are machined; savings due to the fact that extraneous metal is not added as in riveting, fusion welding, brazing and soldering; saving in machining operations and straightening operations after welding. Therefore, it is important when evaluating the possible economy in a new operation to investigate all such cost factors and to make final comparison on the basis of total production costs.

The greatly diversified nature of resistance welding and of the variables which affect its application, as regards both quality of product and economy of production, make it imperative to investigate several fundamental aspects in connection with any extensive project involving these processes. Although there are no hard or fast rules to govern the selection of process and equipment, the following general outline of economic factors will be helpful in many instances.

Labor Cost And Selection Of Equipment

Labor cost is often the determining factor in the selection of any welding operation. The cost of labor chargeable against any operation is divided into two elements:

1. Hourly rate of wages.
2. Production per hour.

From the combination of these two, the labor cost is determined.

In large plants, resistance welding machines are generally operated on the same basis as punch presses and production machine tools. The operator merely operates or feeds the machine, which requires nominal skill, and the setups are performed by skilled setup men.

The selection of resistance welding machine operators is not always as simple as may be inferred from the foregoing because the various forms of welding require varying degrees of skill or ability.

Spot Welding. The skill required of a spot weld operator depends both on the nature of the operation and the type of equipment used. Job shop and low volume operations usually call for foot or hand-operated equipment; consequently, satisfactory results depend, to a large measure, on the skill and experience of the

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operator. Also, the speed of operation, which contributes to the unit cost, is controlled to a large extent by dexterity on the operator's part.

High production jobs can best be performed on power-operated machines with all operating variables automatically controlled; in which case, the operator's duties consist only in correctly positioning the work and initiating the machine.

Projection Welding. Since this type of work almost invariably consists of joining two or more stampings, it is axiomatic that the operation be completely automatic. To accurately locate parts, projection welding machines are usually provided with locators, fixtures, etc.

Where several pieces are to be assembled together, the time required for loading the machine may justify the use of jigs, which may be externally loaded and unloaded by helpers. This is a problem, however, that must be determined for each individual case.

Dial or shuttle feed mechanisms can often be economically applied to press type spot or projection welding machines, greatly increasing their production. This is brought about by the fact that loading is accomplished during the welding operation and because ejection, or unloading can be, and is usually, automatic.

Multipoint Welding Machines. Medium and large size assemblies are often welded in large production machines in which the number and location of spots are beyond the range of the projection method. Here the labor element is very largely the determining factor in the selection of such a machine.

Portable Spot Welding Machines. As the mass of spot welded assemblies increases, the point is reached where it is more economical to move the welding machine to the work than to feed the work into a stationary machine. This is especially true where the work is of such a nature that one machine setup cannot be used for all welds. Another factor influencing the use of portable equipment is that it is often necessary to assemble the component parts in jigs; in which case, several operators may work on the same assembly simultaneously or one operator may use two or more guns—each gun designed for certain parts.

Seam Welding. Since seam welding, by its very nature, is a production operation, it must be classified as semi-automatic. Once the machine is set up, the operation consists merely of feeding work through the welding wheels. The setup itself, however, is similar to setups on other types of machines and requires skill and experience. The actual feeding or operation requires dexterity on the part of the operator, even more so than in the case of spot and projection welding. This required skill consists primarily in guiding the work to produce straight and uniform seams.

Some types of work, such as gasoline tanks and other containers, permit the use of iron-man work-support fixtures in which the work is automatically guided through the machine, thus reducing the operator's skill required. In many cases, the use of these fixtures permits one operator to operate two machines.

Flash Welding. Flash welding machines cover a greater variety of work than any other. They may be used for jobbing operations or for very high production, and the selection of the type of machine depends entirely on the overall range of work (i.e., sizes, etc.) required of the machine and the production expected.

For jobbing operations, even for a single weld, a flash weld can be economically used. For all low production operations, the simplest type should be used such as a hand clamp, hand-upset machine. This requires that the operator be an expert setup man as well as a skilled operator. Of all resistance welding operations, more skill is required for manual flash welding than any other.

For higher production runs, economy dictates the substitution of air or hydraulic clamps and an automatic upset mechanism. Automatic operation will not greatly increase the production, but does provide more uniform results, reduces the skill requirement and eliminates the fatigue factor, which usually enters into hand operation.

Flash welding machines can be furnished for general purpose work or may be special machines for some particular application. In many cases, special tooling may be required and could constitute half the cost of the machine. Since this tooling is only adaptable to one particular workpiece, rebuilding will be required to adapt it to some other job.

Many examples of tremendous savings accomplished by resistance welding have been given. What was thought to be a great saving several years ago is now being improved upon and greater savings made. Looking into the future, still greater savings may be visualized. In practically all of these cases, however, the cost reduction is primarily brought about through higher production requirements or a greater equipment and plant investment.

Electrical Operating Cost. Obviously, any production equipment which requires electrical power and

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energy for operation will contribute to the plant electrical utility billing. The electrical operating costs of resistance welding machines that require high power for a short time, followed by a much longer inactive interval, can be difficult to determine accurately. Spot and projection welding machines are typical examples.

For this type of operation, two categories of billing can be involved. One is a demand charge which is usually based on the sum of the real power used plus the wattless power required because of the normally inherent low power factor of machines with secondary currents at the supply-line frequency. The billing demand is generally the average of all of the machine demands over a 15-min or 30-min time interval. Frequently, this cannot be accurately recorded by the utility metering; thus, the billing is based on a calculated or separately measured value. The other part of the billing is based on the energy used, expressed in kilowatthours (kWh). This is equal to the input power multiplied by time, in hours, that it is used. This can usually be metered and adds to the plant kWh billing.

Other machines, such as seam welding machines, which use power for longer time intervals, have a lower power to energy ratio, and most of the operating cost is due to the kWh use. Since electrical utility rate structures and billing practices vary, the utility involved should be consulted when calculating operating costs.

Material Savings

One of the advantages in favor of resistance welding over other forms of fabrication is the elimination of filler rods, fluxes, gas shielding, rivets and other added materials. In the case of lap seam joints, the amount of material required for the lap is usually less than that required for other joints, such as riveted or lock seam. Not only is the cost of the rivets eliminated, but also the cost of drilling or punching rivet holes. Other methods of welding require filler rod, gas shielding, fluxes, etc.; the cost of which has a definite bearing on the cost of the finished product.

The application of resistance welding has effected tremendous savings in the production of drills, taps, reamers and other perishable tools by welding high-speed tips to less expensive shanks. The same procedure is also carried out in the manufacture of axes, knives, shear blades and other similar tools.

Since flash welds can be stamped, drawn or rolled the same as the parent metal, savings can often be effected by flash welding stampings and shearing-scrap for fabrication onto other parts. In some cases, a small piece of steel (which may, in itself, be a piece of scrap) may be welded to a larger piece to produce an irregular stamping, thus reducing the amount of scrap from such a stamping.

Improvement In Product

The quality of resistance welding depends upon:

1. Quality of appearance.
2. Physical quality.

Spot Welds. Consumer demand for streamlined products extends to all industries with the result that pleasing appearance is one of the most important requisites of any product. Riveted joints are rapidly being discarded in favor of the smoother appearing spot, seam and flash welds. The latter presents no bumps for the accumulation of dirt, grease, etc. While it is not always possible to produce spot welds without marks, under certain conditions invisible spot welds can be made, and the finished product presents no trace of the weld. To accomplish this, however, it is usually necessary to do some buffing or polishing; although in most cases, polishing operations are required not only for the welds but also for the surfaces on which the welds are made.

While invisible welds can be made, control of welding variables must be closely maintained. This means stricter supervision, better machines, tooling and controls. It is not necessary to provide invisible welds except on highly finished parts. If spot welds are neatly and uniformly spaced, they are at least as good appearing as rivets and present no surface bumps.

Seam Welds. Seam welds can be made practically invisible, but the demand for this is infrequent, and the cost may be considerably greater. Since seam welds are usually located on flanges or in close proximity to folded edges, it is usually possible for the designer to locate seam welds so that invisibility is not essential. As in spot welds, a straight seam weld, while readily visible, need not detract from the appearance of any product.

Flash Welds. Flash welds, probably more than any other type of resistance weld, are easily rendered invisible. The burr or flash expelled by the welding operation is nearly always removed in two operations: trimming or scarfing and grinding or polishing. Trimming is accomplished by hand chipping or machine trimming. This operation leaves a very slight ridge at the weld which is completely removed by

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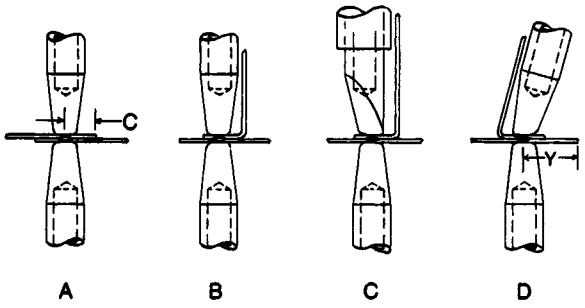


Fig. 1.5 - Some Typical Spot Welds

grinding and polishing. Highly finished products, such as automobile bodies, refrigerator cabinets and metal furniture have, for many years, been flash welded and all evidence of the weld completely obliterated.

Capital Investment

As with any industrial process, the final cost of any resistance welding operation depends considerably upon the cost and installation of equipment required. The cost of the equipment, in turn, depends to a large extent on production requirements.

General purpose machines, i.e., machines suitable for a general line of work, should be amortized over a period of five to fifteen years, depending upon the type and extent of usage. Machines which are designed for a specific operation may be so special as to be virtually useless for any other purpose. In this case, the machine cost must be written off during the life of the entire production process, often over a period of a few months. Many machines used in automotive production must be completely amortized in one year, or two at the most.

Resistance welding machine manufacturers have made substantial progress in the last few years toward standardization of types and sizes of standard machines which has held the cost of these machines to a minimum. A single special machine or fixture with special tooling, such as dies, locators, etc., must stand all engineering and development costs in addition to the manufacturing costs. Therefore, this special tooling should be carefully analyzed from an economical standpoint.

Installation costs depend upon size and location. The largest item of installation expense is usually electrical power feeders and associated protective equipment. Most machines require water service, and pneumatic machines require compressed air.

DESIGN PRINCIPLES

Proper design of component parts not only assures greater ease of making good welds, but also makes it possible to get maximum production speed and weld quality out of any resistance welding machine. Poor design, on the other hand, can easily defeat the purpose of resistance welding up to the point of making it impossible to obtain satisfactory welds. In many applications the differences between good and poor design practice are so small as to appear trivial, yet they are extremely important.

In general, the purpose of resistance welding is to obtain a high quality product with an economical means of manufacture. If the product cannot be manufactured at satisfactory cost with existing facilities, the earning power of additional equipment must be computed in relation to the expected demand for that product. The cost of operation needed to prepare parts for welding, such as blanking, forming, surface cleaning, may be more or less than for other joining methods. The type of finish may influence the selection of the process. The designer who is well informed on the fundamentals of the resistance welding processes and their scope of application can use this knowledge advantageously in finding the best answers to such questions.

Also, it is helpful to remember that there are often several resistance welding methods which may be used for a given assembly. The joining of parts may be done by spot welding, projection welding or resistance brazing. Seams may be made by roll spot welding, lap seam welding, mash seam welding or flash welding. Selection of the process can, therefore, be made only after consideration of all local conditions as well as the specific requirements of the product.

In addition to the selection of the process, other phases of design which can be determined only on the basis of conditions peculiar to the individual job are:

1. The process control specification.
2. Limits on permissible surface indentation, finished dimensions or tolerances, allowable deformation. etc.
3. Use of jigs and fixtures.
4. Welding sequence or operations sequence.
5. Suitability of the design for welding on available equipment (i.e., if stationary equipment, whether there is sufficient clearance for the work, if

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portable gun welding machines are used, whether weld locations are readily accessible).

Spot Welding

The following are some of the most important conditions and rules to observe in providing the proper design for spot welding.

Electrode Space. The very first consideration is the provision for sufficient electrode space. **Figure 1.5A** shows the ideal condition for a spot weld. At **Figure 1.5B** one of the sheets is turned up to form a flange joint. In this case, the width of the flange must be sufficient to provide electrode and electrode holder clearance. If the electrode or holder touches the turned up flange, there will be a partial shunting of current, weakening the weld and at the same time marking the sheet and electrode or holder. If the electrode clearance is limited, an offset electrode (as shown in **Figure 1.5C**) will help.

Sometimes it is necessary to fold the flange over to form an acute angle, as in **Figure 1.5D**. If this angle does not exceed 30° (from vertical), the best solution is to set the electrode holder in the horn at an angle. Thirty degrees is the standard and should not be exceeded; sometimes, however, an angle of 22.50° is used. If the angle exceeds 30°, an entirely special electrode setup should be used.

Edge Distance. The edge distance is the distance between the center of the electrode or weld to the edge of the sheet. This is dimension **C** in **Figure 1.5A**.

If the welds are made too close to the edge, there is insufficient body to support the weld nugget, resulting in cavities, metal expulsion and weak, defective welds.

Provision for Throat Depth. In **Figure 1.6, TD** represents the throat depth of the machine on which the workpieces are to be welded. Obviously dimension **Y**, in **Figure 1.5D**, must be less than the throat depth of the machine on which the weld is to be made. Due to the considerable losses incurred in deep throat machines, it is important to hold the required throat depth to a minimum. When this cannot be done or when it becomes impractical, indirect, series or push-pull welding should be considered.

Contacting Overlap. From the foregoing, it is evident that the minimum width of overlap of the two sheets is twice the minimum edge distance. This is true for both spot and seam welding. However, mash seam welds are made with a contacting overlap of about 1-½ times the stock thickness.[2]

Weld Strength. Standards for spot weld tensile-shear strength have been published for various materials. It is impossible to obtain a spot or seam welded joint with 100 percent strength. In the case of a seam weld, even under the best of conditions, there is a weld indentation which reduces the effective stock thickness at the edge of the seam. Additional paralleling seams cannot improve this condition. The maximum strength from any lap welded joint is about 90 percent of the strength of the parent metal.

Selection of Equipment. *Hand in hand with the* design of the product must be a good conception of the type of equipment on which the welds are to be made.

First, there is the choice between stationary or portable equipment. The principal determining factor is the bulk of the product. If it is bulky and heavy, it may be easier to bring the machine to the work rather than the work to a stationary machine; if the work is such that several parts should be located and assembled in a jig or fixture, then portable equipment should be considered for low volume production requirements. When the production will justify, special multiple electrode machines (designed specifically for the individual job) should be used.

Welding guns, whether used as a portable welding machine or in a multiple-electrode machine, are better adapted to special designs to permit reaching into difficult spot locations.

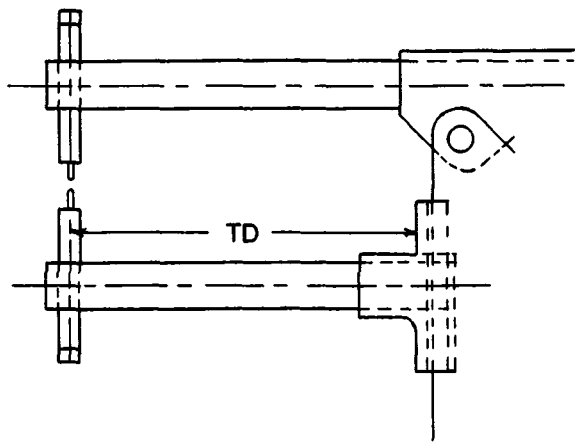


Fig. 1.6 - Throat Depth Of A Spot Welding Machine

2 For more details, refer to this subject in **Chapter 4**, "Seam Welding".

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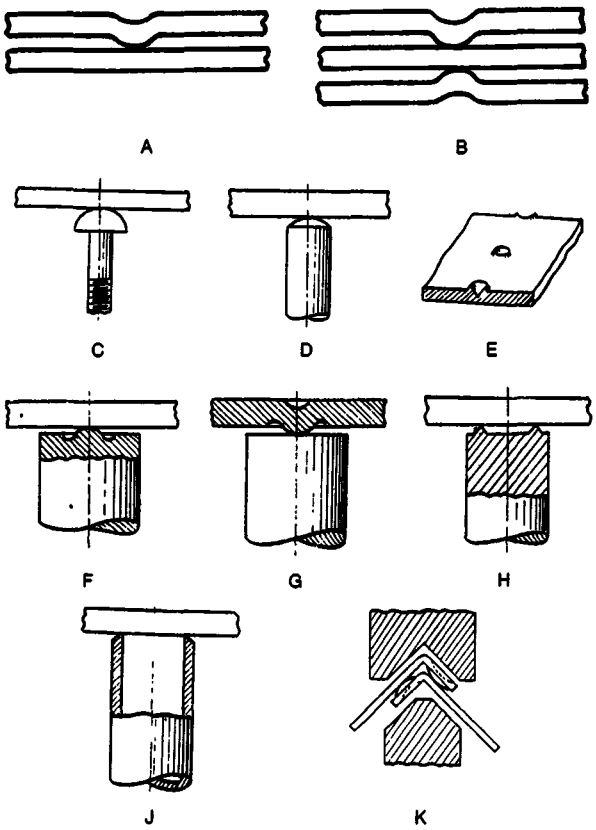


Fig. 1.7 - Types Of Projection Welds

- **A** — Shows the simplest type.
- **B** — Shows projection welding three thicknesses.
- **C** — Shows how a standard round head machine screw can be readily welded to a plate.
- **D** — A rounded bar or rod is welded to a plate.
- **E** — Shows projections made with a prick punch in a heavy sheet.
- **F** — Shows a preferred method of preparing the end of a bar or rod.
- **G** — The same projection may be placed in the plate as shown, and welded to a bar or another plate.
- **H** — An annular ring is machined into the bar.
- **J** — Shows a method of welding a tube to a plate.
- **K** — Projection welded corner joint with projections in each piece.

In referring to portable guns or machines, the degree of portability must not be over-estimated. Most portable guns are designed for maximum maneuverability. However, they must be connected to the transformer by electrical cables, plus air and water lines which tend to make them more or less clumsy or bulky. But, by proper counterbalancing, and design for minimum weight, they perform very satisfactorily. Of particular importance is the necessity for keeping the throat depth to a minimum.

Because of the necessity for the maneuverability of portable guns, they are almost invariably designed for a specific job. This results in an almost endless variety of special designs and electrode combinations.

Surface Conditions. The quality of the finished product will determine, to some extent, the type of material used. It should be clean, and free from mill scale, rust, dirt, grease, oil or paint.

Fitup of Parts. When stampings or forgings are welded, the component parts must fit properly before welding. Any pressure or force required to force the parts into the final fit will detract from the welding force, thus resulting in weakened, inferior or inconsistent welds. For this reason, it is necessary to give special attention to manufacturing tolerances of the component parts.

Unfortunately, some designers think that the welding operation can correct the misfit of component parts. While this is true, to a certain extent, on flash welding operations, it is seldom true on spot or seam welding.

Projection Welding

In practice, projection welds may take several forms, which makes it difficult to make a simple explanation or definition of the process. **Figure 1.7** shows the most important applications. There are, however, many variations. Many types of bolts, nuts and screws with specially prepared projections are available.

The reasons for and advantages of projection welding are numerous, but the following are probably the most important.

1. A row or group of spots may be more readily made, especially in heavy materials.
2. Electrode maintenance is lower.
3. Since there is no mushrooming of the electrodes, current density remains unchanged regardless of electrode wear.
4. Spots may be more readily made on angled or curved surfaces. This is particularly true when

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two or more spots are made at an angle to one another, as in **Figure 1.7K**.

5. Projections may be spaced closer together than conventional spots.
6. In most cases of multiple spots, projection welding equipment and tooling is simpler and less expensive.
7. Less metal to heat in projection welds requires less current per weld.

Cross Wire Welding

Cross wire welding is an application similar to projection welding and quite extensively used. **Figure 1.8** shows a typical cross wire weld. These are usually made with one bar or heavy wire, welded to several cross wires.

Typical applications are in the manufacture of stove and refrigerator racks, trays, baskets, bird cages and any number of similar wire products. The method used most is to assemble the various wires into a plastic or wooden jig and weld all cross wires, or at least, a number of them at one stroke of a press. Special indexing arrangements may be provided for loading and welding successive wires. As production justifies, automatic feeds with hopper or magazine loading may be used.

Other methods of making cross wire welds are by the spot welding technique, making only one cross wire weld at a time, or if more than one weld is made at one time, by using a separate pair of electrodes for each cross-over. If the cross wires are small enough and sufficiently close together, a seam welding machine with a circular electrode may be used.

Since the welding is the most expensive single operation on these products, careful consideration should be given the design to secure the most economical results.

Seam Welding

Because a seam weld is basically a series of overlapping spot welds, there is great similarity in the principles of good design practice for both processes.

It must be evident, however, that due to the size and shape of the seam welding electrode, questions of electrode clearance must be considered.

Since most seam welding applications involve standard machines, it is necessary to understand the types of these machines. **Figure 1.9** shows the two basic

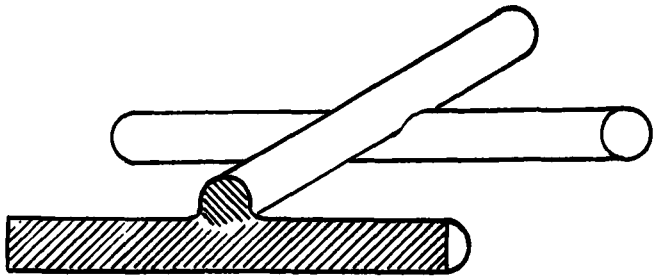


Fig. 1.8 - Section Of Typical Cross Wire Weld

types: **Figure 1.9A** is a *circular machine* in which the plane of rotation of the welding wheels is at a right angle to the throat (**TD**) of the machine; **Figure 1.9B** is a *longitudinal machine* in which the plane of rotation of the welding wheels is parallel to the throat of the machine.

Figure 1.10 shows a number of typical seam welding applications. The simplest of these is a plain lap weld, as shown at **Figure 1.10A**. This may be made on either type machine shown in **Figure 1.9**. If the length of the weld is long and the width short, it would be best to make it on a circular machine (**Figure 1.9A**). However, if the weld length is short and the width considerable in length, as in joining the ends of a circled band or shell, then the weld should be made on a longitudinal machine (**Figure 1.9B**). As in spot welding, it is desired to keep the throat depth of the machine to a minimum. **Figure 1.10B** shows a variation of condition from **1.10A**. Most joints of this nature must be made on circular machines. **Figure 1.10C** shows another variation, in which the flange is turned back at an angle. In this

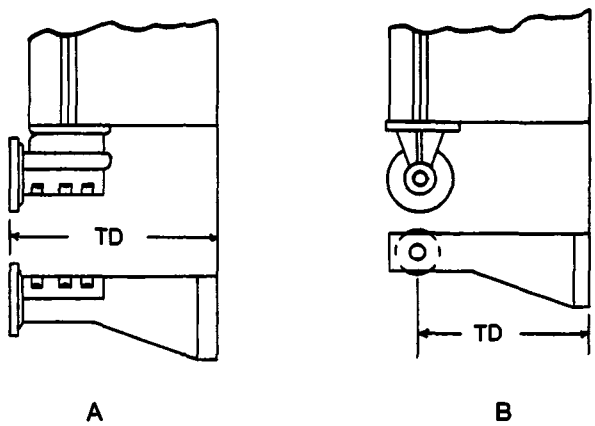


Fig. 1.9 - Types Of Seam Welding Setups

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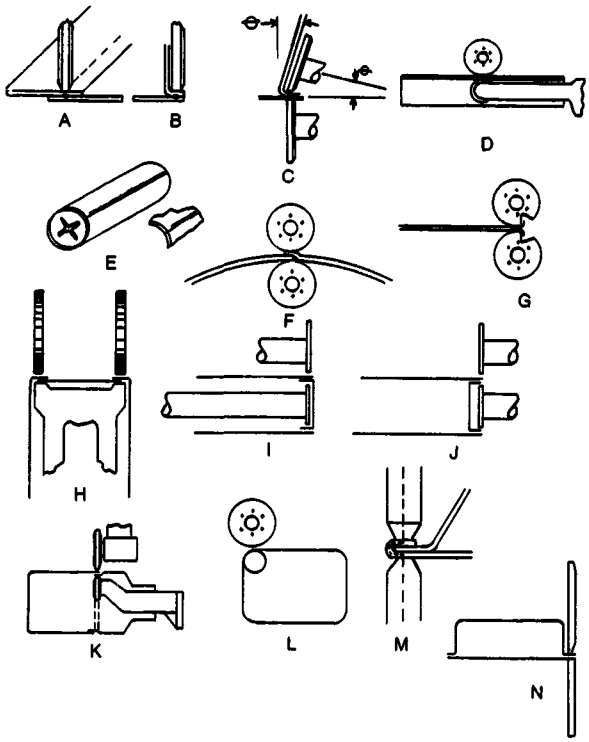


Fig. 1.10 - Seam Welding Applications

case, the upper shaft must be placed at the same angle as the work. This angle should not be greater than 6° for best results. Either upper, lower or both shafts may be set at an angle to suit the workpiece.

Figure 1.10D shows a typical longitudinal joint such as used in containers of all types. If production is high, the throat depth of the machine should slightly exceed the length of the seam. If the seam length exceeds 30-in, it is generally advisable to weld halfway in, turn the work around, and finish the weld from the other end.

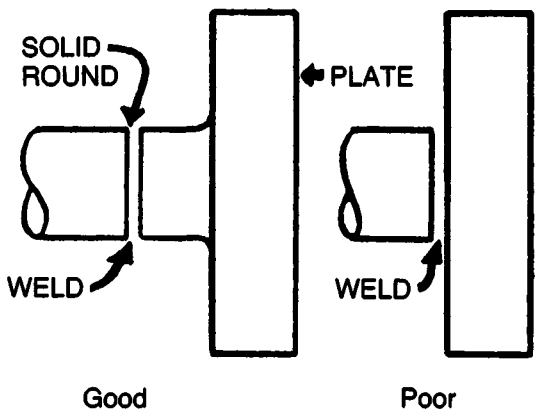


Fig. 1.11 - Correct And Incorrect Methods Of Flash Welding Bars To Plates Or Larger Bars

Many products that have a longitudinal weld have a circular weld also, such as welding in one or both heads. This operation is shown at **Figure 1.10E**. The longitudinal weld will leave a step or hump, as shown at **Figure 1.10F**, and equals the thickness of the stock. When the circular seam is made, there will be a slight gap at this point. Furthermore, unless both wheels are power driven, they may skid and may not be able to ride over this hump.

There are two ways of overcoming this. The best is to coin this double thickness down to a single thickness over the area where the circular weld crosses it. Another method is to notch out the overlap before making the longitudinal weld. This is shown at **Figure 1.10E**. However, this is often not satisfactory, difficult to control and almost invariably results in a certain percentage of leakers.

Where it is necessary to seam weld close to a turned up flange or side at a right angle to the weld, a pie or segment type wheel, as shown at **Figure 1.10G**, must be used. Obviously the height of the side or flange cannot exceed the possible depth of segment in the wheel. **Figure 1.10H** shows a special fixture that could be used for welding the bottom to a box. The sides are placed over the fixture, then the two welding wheels weld the two seams, simultaneously, in series. **Note** that the welding wheels contact the side flanges, forcing all the welding current through the welds. If the bottom piece was placed on top so as to contact the weld wheels, part of the current would pass through the bottom, bypassing the weld.

Figure 1.10I shows welding an in-turned bottom or end into a cylindrical container. Note that the lower arm must reach completely through the cylinder. This is basically a poor design for two reasons. *First*, it increases the cost of the machine and requires a higher kilovoltampere demand. *Second*, most containers are small in diameter, posing a problem in providing a sufficiently rigid and strong lower arm.

Figure 1.10K shows a case where a circular weld must be made in a necked-in container. A typical example is welding the breast to the body of a milk can.

Another problem is posed in **Figure 1.10L**. Here, it is required to weld the flanged bottom to a rectangular container. It is obvious that the corners must be rounded, and the minimum radius of these corners is about 2-in.

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Figure 1.10M shows a very poor and almost impossible seam welding application such as welding in the bottom of an oil can. It will be seen that the shunting effect is of major importance causing the major portion of the current to pass through the folded portion of the bottom, leaving the joints without sufficient current to make a satisfactory weld.

A much better design is shown at **Figure 1.10N**. Here the parts being welded are held in a rotating fixture, welding the assembly in one revolution. If production warrants it, the assembly could be placed in a different type of fixture with two welding wheels on top, making one-half revolution to complete the weld. A typical application is welding base plates to high explosive shells.

Upset Welding And Flash Welding

To a certain extent upset welding resembles projection welding. In **Figure 1.7D**, a rounded bar or rod is welded to a plate. However, if two rods are rounded, they may also be successfully upset welded, and it may not be necessary to specially prepare the ends in this manner. Wires and small rods are upset welded in this manner with no special preparation whatsoever. Chain links, wire racks and other wire products are also welded in this same manner.

In flash welding, the metal extruded at the upset, known as *flash,* sometimes poses a problem when it cannot be readily removed. In such cases an upset weld may be the answer. One of the common applications is the end-to-end welding of pipe or tubing. It is necessary to bevel the edges of one or preferably both abutting ends. Depending on quality and production requirements, the operation may be hand controlled in a relatively simple machine, in which case the actual weld will require several seconds, or with high capacity equipment and precision controls, highest quality welds may be made in a fraction of one second. In this case, virtually no flash is present either inside or outside of the pipe.

A flash weld is one of the types of metal joints that can be made to equal or exceed the strength of the parent metal. For this reason, and also because no end preparation is necessary, it is generally advisable to consider a flash weld wherever an upset weld is called for.

Important general principles of design for flash welding are:

1. Abutting sections should be identical in size and shape or nearly so.

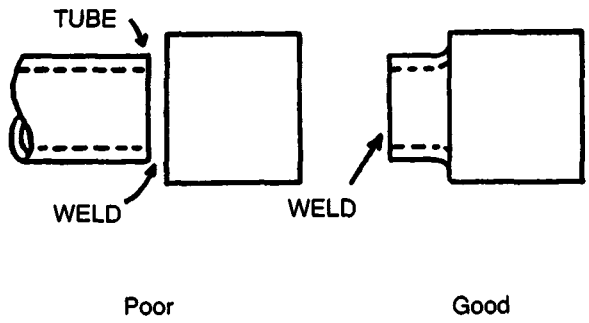


Fig. 1.12 - Correct And Incorrect Methods Of Flash Welding Tubes To Bars

2. The designer should work closely with the production department to be sure that allowance for upset is consistent with welding technique and will produce good welds.
3. While clean and tightly fitting surfaces are recommended in upset welding, this is not necessary for flash upset welding operations.
4. In all resistance upset and flash welding operations, it is desirable to specify clean, smooth and uniform surfaces for electrode contact in order to avoid electrode burns on the stock and to get maximum electrode life.
5. Allowance should be made for possible modification of properties due to metallurgical changes. The weld zone in flash welded air-hardenable steel parts is hard and of low ductility unless subsequent heat treatment is used. Also, strength properties in the parent metal, due to cold working, will generally be lowered by welding.
6. Part design should be such that the force exerted by the welding machine and the resisting forces of the workpieces are parallel.

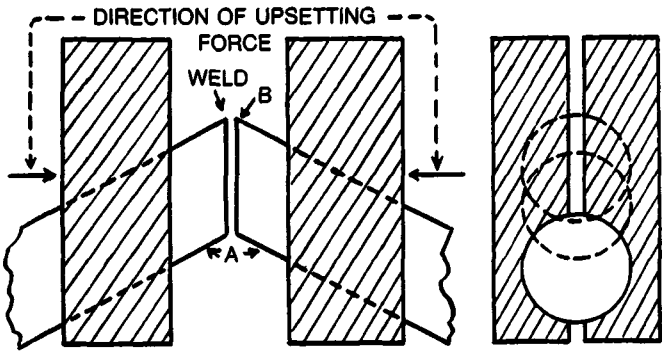


Fig. 1.13 - Bevel Or Miter Welds

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7. The shape of sections to be welded should permit holding them in alignment during the application of pressure, and sufficient amount of surface must be provided for clamping die contact.
8. Provision should be made, wherever possible, to back up the workpieces and thus absorb the upset reaction in these backups, rather than having to apply adequate clamping pressure to hold the work in the clamps by friction.

Figure 1.11 illustrated the correct and incorrect way to flash weld a bar to a flat plate, forging or other heavy section. The two pieces should be prepared to fulfill the requirements of condition **1** in the above. Also, if a tube is to be welded to a solid rod or forging of the same or different outside diameter, the solid member should be prepared as illustrated in **Figure 1.12**.

Figure 1.13 illustrates the conditions for making a bevel or miter joint. The most common application of this is miter welds in window sash and metal frames of all kinds. The more acute the angle **A**, the more difficulty is experienced in making a weld.

MATERIALS

It is not possible to state with finality what materials may or may not be satisfactorily resistance welded by one or more of the several processes. The principal reason is that there is no accepted definition or understanding of what constitutes a satisfactory weld. A weld that may be satisfactory for one application may not be for another.

Most of the common metals may be readily spot welded. Principal exceptions are silver, copper, lead and zinc. Even these may be welded under certain conditions. For example, the main difficulty with copper and silver is that due to their high electrical and thermal conductivity, the material readily welds to the electrodes themselves. If electrode material such as tungsten or molybdenum is used, the resistance of the joint between the electrode and work is greater than between the two pieces being welded. The result is often such severe surface marking and indentation as to render the finished work unacceptable.

The various types of steel possess the unique quality of a wide plastic range. That is, the temperature range from the point at which it starts to soften to the point at which it becomes liquid. This entire range runs approximately 1000° F, over which a considerable portion of the weld may be consummated.

By comparison, the plastic range for the aluminum alloys is only 50° F to 100° F. This is the principal reason for the necessity of precision controls for aluminum and various other metals with a narrow plastic range.

Other metals, such as tin and lead fall into this category. In the case of aluminum and magnesium, a tremendous amount of research has been done to bring spot welding of these alloys up to their present standards of perfection. There is very little application for spot or other types of resistance welding on lead, zinc or tin; consequently, limited processes have been developed.

Usually, those metals that cannot be satisfactorily spot welded may be either soft soldered or brazed.

LIMITATIONS

In considering advantages of various resistance welding processes, we must not overlook some of the limitations.

Job welding, or making one weld to a setup is practical with the proper kind of spot welding machine. Such equipment is commonly and advantageously used in sheet metal shops for making boxes, cabinets, machine guards, signs, etc. Portable welding machines, gun welding machines and fixtures are essentially production machines and justify their expense only when a sufficient number of assemblies are to be made.

The same is true with projection welds. It takes a certain outlay or investment to produce the first assembly, after which others are made very inexpensively.

Of all resistance welding processes, flash welding is the most readily adaptable to job shop work. Large forge shops use it extensively to produce a single weld of a kind, the same as would be done by arc welding in any shop. However, if extensive tooling or special fixtures are required, then the minimum production requirements must be taken into consideration.

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Spot Welding

INTRODUCTION

The principal use of resistance spot welding is to join overlapping sheets of metal when the joint does not have to be gas-tight or liquid-tight. Fabrication by this process is economical and fast since separate fasteners are not required. Although commercial production of assemblies is generally limited to sheet thicknesses of up to about 0.125-in, plates up to 0.250-in or more can be joined. Spot welding is used for the fabrication of many sheet metal products such as appliances, automotive bodies, enclosures and furniture. The process can be readily automated and a variety of resistance welding machines are available from a number of sources. Most metals can be resistance welded if the required equipment is used and suitable welding schedules are followed.

FUNDAMENTALS OF THE PROCESS

General Principles

A resistance spot weld is made by passing current, for a timed interval, through the workpieces from electrodes which apply the welding force. The current is continued until fusion takes place at the faying surfaces of the workpieces. The electrode force is applied before, during and after the current time interval.[1]

Figure 2.1 is a simplified drawing of the minimum equipment required. Either or both of the electrode holders are attached to a force system that is capable of moving the holders toward and away from the work and producing the required welding force. A control device is also necessary to energize the transformer for a timed interval during the application of the welding force and to program the electrode holder motion. If the motion and force is by manual means, current timing only is required. More involved systems are used when the assembly has complex geometry, requires multiple welds, automatic indexing or metallurgy needing more than one force or current level or application.

Figure 2.2 shows the typical temperature distribution existing at the end of "weld time", and **Figure 2.3** depicts the relationship of the electrode force and welding current versus time for a basic spot weld.

1 Refer to **Section 2, Chapters 7 thru 15.**

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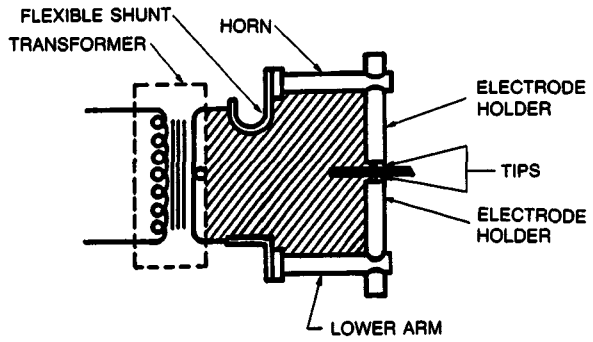


Fig. 2.1 - Typical Spot Welding Secondary Circuit

The thickness and analysis of the workpieces do not have to be the same, and stack-ups of more than two pieces can be joined.

The parts must overlap and the overlap must not be less than twice the distance between the work edge and the weld location that is required in order to prevent expulsion and distortion. The edge distance necessary is a function of the workpiece thickness and composition.

For single welds made in sequence a minimum weld spacing is required so as to limit the current shunted through previously made welds to acceptable values. This distance is also a function of the work thickness and composition.

The faying surfaces at the weld location should be flat and parallel. Lighter gauges need not be in intimate contact before the electrode force is applied provided that the force required to bring them into contact does not reduce the welding force to less than that necessary and that the work is not deformed.

When welding materials of different analysis and/or thickness, it is sometimes difficult to obtain the optimum penetration and diameter of the fusion zone in each workpiece. This effect is known as improper heat balance and can be improved by using electrodes which differ from each other in either metallurgical characteristics, size or face contour.

Data from production processes and laboratory work has resulted in the compilation of suggested welding schedules which can be used as a guide for the selection of equipment and the development of welding schedules for a number of materials in various thicknesses.[2]

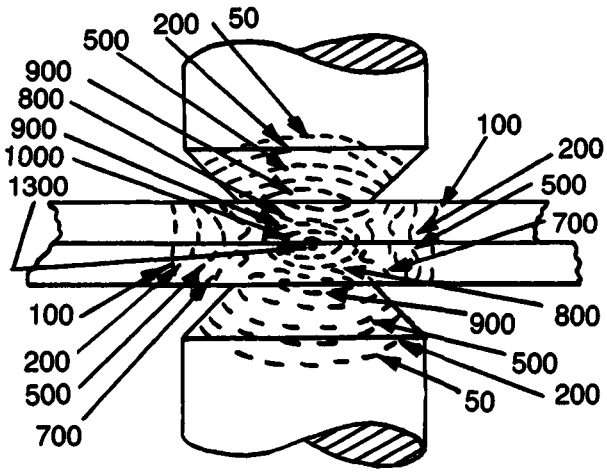


Fig. 2.2 - Estimated Instantaneous Spot Welding Temperatures In Degrees Celsius At The Instant Of Completion Of Welds

TYPES OF WELDS

There are *four general categories* of resistance spot welds for which standard definitions have been written, and a number of variations of each.[3] These are: direct, parallel, series and indirect. The differences are mainly due to the current path through the weldment and the arrangement and shape of the electrodes. Each of the four types are discussed below.

Although the descriptions and illustrations of the various spot welding processes are generally given with the work surface in a horizontal plane, in actual practice the work can be in any plane if the axis of the

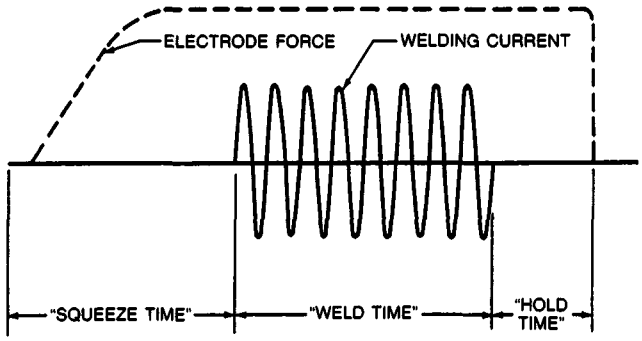


Fig. 2.3 - Single-Impulse Resistance Spot Welding Schedule

2 Refer to **Section 2.**
3 Refer to ANSI/AWS A3.0-89, *Standard Welding Terms and Definitions.*

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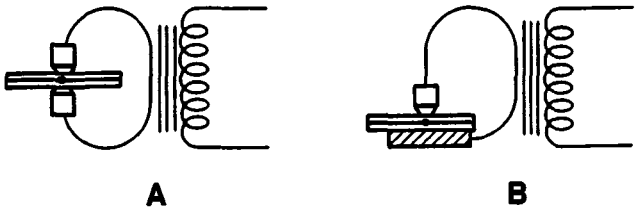


Fig. 2.4 - Direct Welding

tip face and the direction of the welding force are both normal to the work surface.

Direct Welds

In a direct weld the current path is directly through the work between opposed electrodes. **Figures 2.4A** and **2.4B** show two types of direct welds. **Figure 2.4A** is a basic spot weld and is the easiest to produce since the electrodes can be of optimum diameter and face contour. Most welding schedules are based on this type of weld.

If the correct welding schedule and upper electrode contour is used, the lower electrode (usually fixed) can be a block of electrically conducting material. The surface contacting the work may be flat, or with a radius, such as a cylinder. An electrode with a flat surface is shown in **Figure 2.4B**.

Because of the difference in the geometry of the work-contacting areas of the electrode and the mandrel, the heat balance is not as good as it is for **Figure 2.4A**, if the workpieces are identical. If they are not, this method can be used to reduce the heat input in the material contacting the mandrel. This arrangement may also be required because of the shape of the assembly or for reduced surface marking.

Parallel Welds

In this variation, two or more direct welds, usually closely spaced, are made simultaneously with the welding current for all welds supplied by one transformer. This requires that all of the elements that are involved in the spot welding process be nearly equal for each weld. Of these, the welding current is the most difficult to equalize. A method for approaching this is discussed later.

Parallel welding has *two advantages* when compared with making the same welds in sequence. One advantage is that multiple welds can be made in the same time interval that is required for one weld; the other advantage is that the shunting current through adjacent welds is less thus usually allowing the minimum weld spacing to be reduced.

As mentioned above, the welding currents for each weld must be nearly equal. If two or more circuits are fed from a common transformer secondary winding, the current in each circuit will not be equal unless the impedances of each circuit are identical, and this becomes increasingly difficult to do as the number of circuits increases. Much better balance can be achieved by using a transformer with multiple secondary windings with each winding feeding one circuit. Such an arrangement is shown in **Figure 2.5**.

Series Welds

Figures 2.6A and **2.6B** show two variations of series welding. The secondary circuit is connected to two contoured electrodes which contact the workpiece from the same side and a current conducting backup mandrel is used. **Note** that a weld is made by each electrode.

Figure 2.6A shows a basic series welding circuit. There are three parallel current paths between the electrodes. The *first* is through the upper workpiece and contributes very little to the generation of heat at the faying surfaces. It does, however, generate heat in the material at the contacting surfaces of the electrodes and results in greater indentation and marking than would be present if the same weld were made by the direct welding process. This is a shunting current and it will become greater as the electrode spacing is decreased and/or the thickness of the upper workpiece is increased. Thus, this effect limits the minimum electrode spacing and the thickness of the material contacting the electrode. Conversely, this current will decrease slightly as the resistance of the mandrel is decreased.

The *second* path is through the lower material and the *third* is through the backup mandrel. Increasing the sectional area or conductivity of the mandrel will increase the current in this path and tends to improve

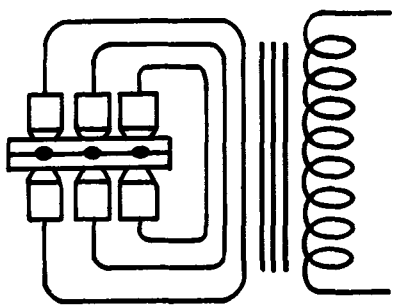


Fig. 2.5 - Parallel Welding

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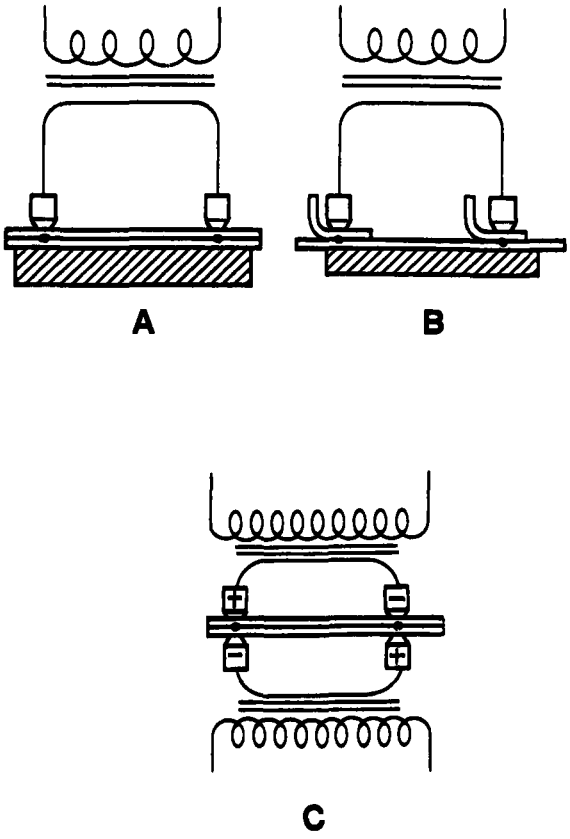


Fig. 2.6 - Series Welding

the welding results. Both of these currents pass through the faying surfaces and generate the heat required for the weld.

Figure 2.6B shows a series weld in which the upper workpiece is not continuous between the electrodes thus eliminating the shunting current. The welding conditions for this arrangement are similar to those for an indirect weld which is discussed later in this Chapter.

The principal advantages of the series welding circuits discussed above are the ability to make welds with the electrodes and secondary circuit on only one side of the weldment and the absence of objectional marking on the opposite surface. However, when compared to direct welding, the electrode marking is more severe and the heat balance is not as good due to the flat surface of the mandrel.

Figure 2.6C illustrates another variation of series welding known as push-pull welding. Here the electrodes are connected to separate secondary circuits on each side of the weldment with the polarities arranged as shown. Although shunting current is still present,

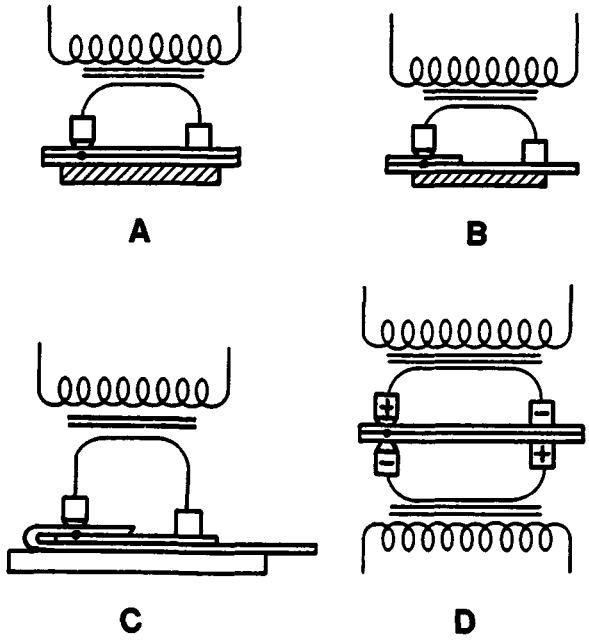


Fig. 2.7 - Indirect Welding

and now in both workpieces, the voltage between opposing electrodes increases the ratio of welding current to shunting current when compared with the circuit shown in **Figure 2.6A**. **Note** that this arrangement requires electrode access to both sides of the weldment, and that there will be electrode marking on both sides of the workpiece.

Indirect Welds

Figures 2.7A through **2.7D** show a number of indirect welding arrangements. **Figure 2.7A** is identical to the circuit of **Figure 2.6A** for series welding except that only one of the electrodes is contoured. Thus, only one weld is made rather than two as is done in the series circuit. This indirect version can be used when the underside of the weldment is not accessible for an electrode and the connection of the other secondary terminal; electrode marking is not permissible on this side and only when one weld is required. The same constraints given for series welding also apply to this circuit.

Figure 2.7C shows the welding of a clinch flange. In this the mandrel can be nonconducting and will almost entirely eliminate marking on the show side of the weldment.

Figure 2.7D is an indirect push-pull arrangement. This is the same as **Figure 2.6C** except that only one set

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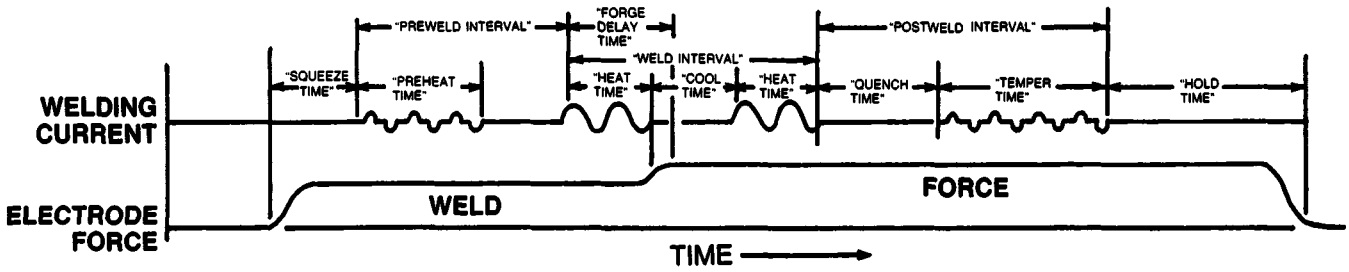


Fig. 2.8 - Complex Weld Cycle

of opposing electrodes is contoured thereby making only one weld.

ELECTRODES

In order to achieve the best results in any spot welding operation, it is necessary to use the proper electrodes for the application. Selection of the alloy is important since this can help modify the heat balance or reduce the tip wear. The tip face diameter and contour must also be considered since these factors control the welding pressure and current density which must be within an acceptable range for satisfactory results. Incorrect tip face geometry will also result in increased surface marking.

Although there are many alloys, types, sizes and shapes of electrodes commercially available, there are six standard nose configurations and, of these, there are three that are most frequently used for spot welding. These are: flat, radiused and domed. Most of the welding schedules are based on one of these three shapes. Other sizes and shapes are often required to conform to the contour of the weldment or to suit other conditions. Each of the electrodes are manufactured using a number of different alloys to provide the best combination of electrical and mechanical properties for a particular welding operation.[4]

MATERIALS

From the standpoint of resistance spot welding, metals that are suitable for welding can be grouped into two broad categories: ferrous and nonferrous. Ferrous metals can be further classified as being nonhardenable or hardenable by temperature change.

Ferrous

Ferrous metals, such as low carbon steel, that do not have their physical properties unduly changed by the rapid decrease in temperature that normally occurs at the end of "weld time", require only simple equipment providing one level of welding force and current. Other metals, such as high carbon and some alloy steels, may need equipment providing multiple force and current functions as illustrated in **Figure 2.8**.[2]

Nonferrous

Nonferrous metals are usually more difficult to weld. This is due primarily to their narrow plastic range, low bulk resistance and greater thermal conductivity. "Weld time" is generally less and the welding current higher than for the same thickness of ferrous material. This results in a more rapid expansion and contraction of the material between the electrodes thus requiring good dynamic welding force capability of the welding machine. In many cases a postweld interval with a dual force system is desirable. Upslope and downslope control of the welding current, as shown by **Figure 2.9**, decreases the rate of expansion and shrinkage and usually improves the welding results.

Dissimilar Materials

Dissimilar materials are somewhat difficult to weld because of their different thermal and electrical properties, melting temperatures, plastic ranges and the alloys formed in the weld nugget. Modification of the welding schedule and the use of an electrode with a smaller face area and lower electrical and thermal conductivity contacting the material of greater conductivity will tend to improve the heat balance. It is advisable to make test welds to determine the weld quality obtainable for any proposed project.

Thickness

For any one weldment the thickness of the workpieces dictates the magnitude of the welding current,

4 Refer to **Chapter 18**, "Electrodes".

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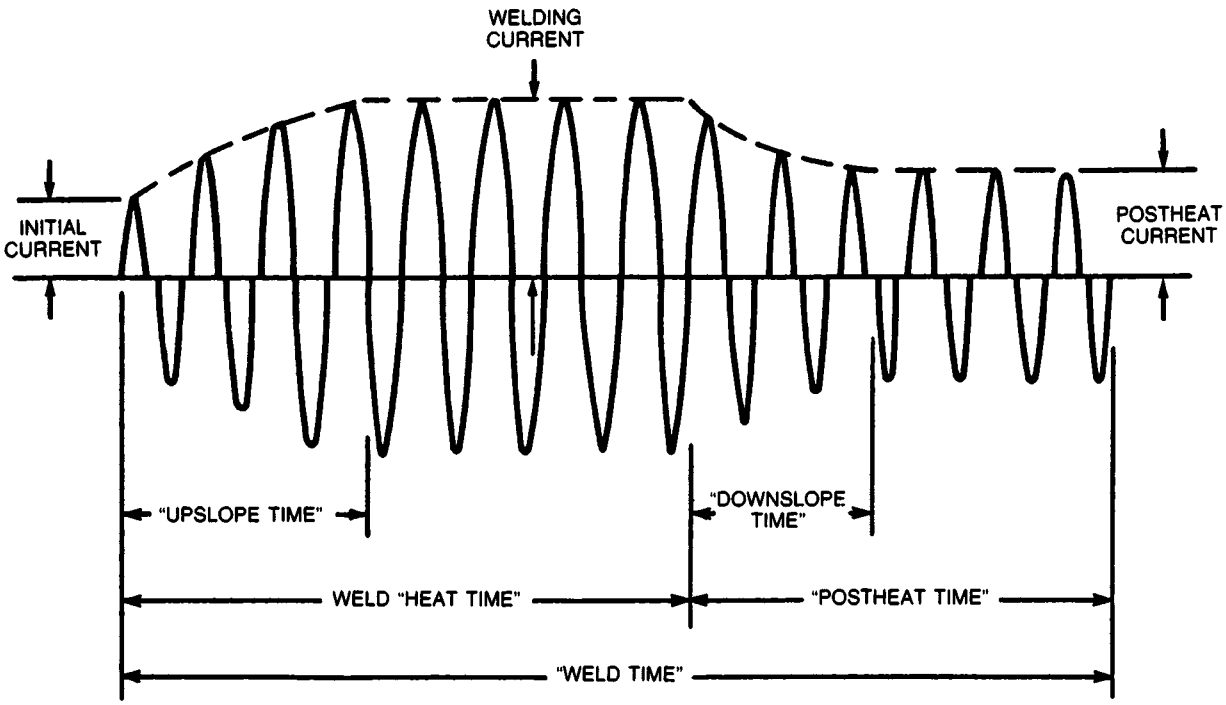


Fig. 2.9 - Welding Current With Upslope & Downslope Features

force, electrode geometry and the welding schedule required.

Suggested welding schedules are included in **Section 2** for many commonly welded materials in thicknesses from 0.005-in to 0.500-in. Although there are some data for thicknesses less and greater than this, it is generally advisable to evaluate test welds for thicknesses outside of this range.

For most materials dissimilar thicknesses can be joined if the ratio does not exceed 4 to 1. Heat balance can become a problem since the greater bulk resistance of the thicker piece produces more heat than that of the thinner piece. This can be partially corrected by the use of an electrode of larger surface area and/or higher thermal and electrical conductivity contacting the heavier material.

Some weldments may require joining layers of equal or dissimilar thicknesses. For equal thicknesses of three or four layers of the same material, general welding practice can be used with somewhat more welding current. Little data are available for more than four layers.

If all thicknesses are not equal, it is difficult to achieve the correct heat balance to give equal fusion at each faying surface. The selection of the electrode diameter, contour and alloy is usually determined by the thickness of the outer pieces.[5]

Surface Condition

Ideally, the workpiece surface should be free of any substances that will degrade the welding operation. These can range from applied material such as paint or oil, to oxidation products in the form of thin films to heavy scale.

Except in the case of stainless steel, light oil is usually not objectionable unless embedded with dirt.

Since most surface contaminants have high electrical resistance, excessive heat is generated at the area of electrode contact and at the faying surface. This results in partial welding of the tip surface to the material, producing short tip life and degraded surface appearance. At the faying surface, metal expulsion may occur and slag inclusions or voids are frequently found in the fusion zone.

The conditions described above are usually not consistent over all of the work surface and will produce variations in the welding results.

When required, the material should be cleaned by suitable chemical or mechanical means.

5 Refer to **Chapter 7, Table 7.5.**

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WELD QUALITY

The quality of a resistance spot weld is usually judged by the degree to which all of the factors that enter into the formation of the weld meet specified criteria. The *principal factors* are: diameter, symmetry and penetration of the fusion zone, internal discontinuities, metallurgy and hardness of the weld nugget, sheet separation, surface indentation and marking. Some of these determine the weld strength while the others involve appearance.

Since the weld quality required depends on the application, material and, in some instances, compliance with user specifications, the relative importance of the factors will vary. As an example, for most commercial applications using low carbon steel, strength, surface appearance and sheet separation are probably the most important.

Strength

The strength required for a spot weld is usually specified in pounds per weld and is the result of the combined effects of a number of factors such as fusion zone diameter and penetration, hardness, metallurgy, internal discontinuities and external defects.

Weld strength is measured by a number of standardized tests which subject the weld to different types of loading. Some of these are: tension-shear, tension, torsion, impact and fatigue.

The tension-shear test loads the weld by subjecting the two pieces of the joint to separating forces which are opposing and act parallel to the sheet surfaces. Since most spot welded joints are designed to be loaded in the same manner, the tension-shear test is a logical method for evaluating spot weld strength when the joint is loaded in this way. Welding schedules usually include the tensile-shear strength to be expected for the material and thickness involved. Within practical limits, the weld strength increases as the nugget diameter becomes greater.

Although it has some effect on the tensile-shear strength, the hardness of the fusion zone becomes more of a factor contributing to weld failure when the weld is subjected to impact forces or vibration. For this situation excessive hardness may result in failure due to cracking or fatigue. This condition may be present if the proper welding schedule with a postweld interval is not used with steels which are time-temperature sensitive.

Radiographs taken normal to the workpiece surface and visual hardness surveys of the etched surface of a section of the fusion zone are used to determine weld diameter, penetration, voids, cracks, hardness and metallurgical characteristics. Any or all of these tests are used to assess weld quality for various weldments.[6]

Commercial welds can often be evaluated in the production area by visual inspection and a peel test.

Surface Appearance

It is often desirable to produce welded assemblies with little or no surface marking. This is difficult to do, especially on the surface contacted by a contoured electrode. Ideally, the weld surface should be smooth and round and free of deep electrode indentation, cracks and burns, or fusion marks.

The most noticeable marking is due to electrode indentation and occurs when the compressive strength of the material contacted by the electrode decreases as fusion takes place and allows the electrode face to move below the workpiece surface. This indentation can become severe when an electrode with a small face area is used with excessively high current density or pressure. In addition to detracting from the appearance, excessive indentation can lower the weld strength.

Asymmetrical indentation, which usually produces a semicircular ridge at the periphery of the weld location, is caused either by the electrode moving laterally with respect to the surface, or by an electrode with a symmetrical face contour approaching the work surface at an angle. **Note** that the electrode axis does not have to be normal to the work surface if the tip face is contoured so as to accept this position.

A flat surface is used when minimum surface marking is the most important of the factors affecting weld quality. However, this can result in a shallow depression caused by the expansion and contraction of the fusion zone. This can be kept to a minimum by using a welding current and "weld time" at values no greater than that required to produce a weld with the required strength.

Pits, cracks, and incipient surface fusion are particularly objectionable since, in addition to degrading the surface appearance, they may give the impression that the weld is defective. While this is occasionally true, these defects are more often caused by poor electrode

6 Refer to **Chapter 24**, "Quality Control".

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maintenance, surface contamination or a welding schedule resulting in excessive heat generation or insufficient welding force.

Although normally not considered as objectionable surface marking, a color change may be present at the weld location due to the weld heat. This can be very evident with some materials such as stainless and bright-plated steel and usually cannot be eliminated.

Sheet Separation

Some degree of separation between the faying surfaces of the sheets is always present. This separation is due to the expansion and contraction of the fusion zone as well as the lever action of the electrode force acting against the relatively soft material at the weld with the fulcrum of the lever being the harder material outside of the weld zone. The greater electrode force required for heavier stock usually increases the separation.

Separation can also be aggravated by the expulsion of molten metal from the periphery of the fusion zone due to surface contamination, poor fitup or the use of an incorrect welding schedule. In addition to contributing to separation, expulsion can also result in voids in the weld nugget. Expulsion is generally audible.

Internal Discontinuities

Internal discontinuities include cracks, porosity or cavities, and foreign metallic inclusions. Cracks and porosity or cavities are generally present to some degree in commercial production welds. They usually have little effect on the weld strength if located near the center of the nugget. Detection normally requires visual observation of an etched section of the weld nugget. Cracks are probably the least acceptable although large cavities caused by expulsion are generally considered as defects.

In general, numerous or large discontinuities are not desirable and are usually caused by the use of an incorrect welding schedule resulting in excessive weld current and/or "weld time", low force or short "hold time".

IMPLEMENTATION

The items discussed below are those that usually enter into the selection of the spot welding process and the type of equipment required for weldments that are generally produced in production quantities and which can be fabricated using accepted production welding processes.

The material analysis and thickness should be considered first since these will determine the machine electrical and mechanical capabilities, and the basic control functions required.

Movement of the work in and out of the welding station can be done either manually or automatically. The size, shape, weight, number of welds involved and the production requirements will influence the method used.

Single point machines that make one weld for each machine cycle are usually considered when the work can be moved manually. The **RWMA** has written standards for this type of equipment that stipulates the welding current and force, and the transformer thermal rating for each size. The current, force and transformer rating are coordinated so as to be compatible with the range of welding schedules normally used with each size.

When the work size, shape or complexity requires automatic handling, special equipment (with one or more welding stations) and transfer or shuttle feeding mechanisms can be used. This type of equipment is also considered when the number of welds required for each assembly is relatively large and/or the production quantity is high.

The handling of small weldments in quantity is frequently automated by feeding the parts from hoppers to stations on intermittently rotating tables which are mounted on single point machines. One or more machines can be used and the welds are made during the dwell periods of the table rotation. Automatic ejection is also used.

In some cases, when the weldment is difficult to transport by any practical means, manually portable welding guns are sometimes used. When justified by production and economics, robot systems are an alternative. These assure good repetitive positioning accuracy and are not subject to fatigue.[7]

The type of weld employed is determined largely by the equipment involved, surface appearance and weld quality required, and experience.

7 Refer to **Chapter 16,** "Machines", **Chapter 17,** "Jigs, Fixtures and Tooling" and **Chapter 20,** "Welding Controls".

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3

Projection Welding

INTRODUCTION

In the preceding Chapter we saw how size and shape of the welding electrodes was of great importance in determining the size, strength and quality of the weld. It was also noted that all of the welding current is concentrated in the electrode tip. This current is in the order of thousands of amperes per square inch. Therefore, electrode strength or hardness is sometimes sacrificed in order to obtain maximum electrical conductivity. This results in more rapid electrode wear and/or mushrooming.

Projection welding is a resistance process by which the current and heating during welding are localized at a predetermined point by the design of the parts being welded. This is usually accomplished by a projection, or embossment, on one or both of the workpieces.

It can readily be seen that the size of the electrode tip has no bearing in projection welding and that the current density may be considerably reduced, permitting the use of harder and tougher electrode materials.

A projection may be embossed in a sheet of metal, it may be produced on a solid piece of metal by machining, or produced on the edge in a punch press in any of several ways. The height may be anywhere from a few thousandths of an inch to 0.125-in or more depending on the thickness of the material to be welded. The purpose of projections is to concentrate the current and force at predetermined points. In this modification of the spot welding process the concentration of the welding current is determined by the preparation of the workpieces rather than by the size or shape of the electrodes.

There are several advantages to be gained by the use of projections, namely:

1. Ease of obtaining satisfactory heat balance for welding difficult combinations.
2. More uniform results in many applications.
3. Increased output per machine because of making several welds simultaneously.
4. Longer electrode life.
5. Welds may be placed more closely together.
6. Parts are more easily welded in an assembly fixture.
7. Finish, or surface appearance, is often improved.
8. Parts may be projection welded that could not be otherwise resistance welded.

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The advantages will be discussed as numbered:

1. The major portions of the heat tends to develop in the part bearing the projections during the welding operation. Weldments composed of thickness ratios of 4 (or more) to 1 are sometimes difficult to spot weld. The flexibility of selecting the projection size and its location allow ratios of 6 (or more) to 1 to be readily projection welded. For this reason the projections should be produced on the heavier of the two pieces of the same metal or, if possible, on the piece of higher conductivity if dissimilar metals are being joined. The reverse can, however, be used under some conditions.
2. Uniform projections may be readily obtained on a punch press. The effect of variables such as contact area between the parts and electrode mushrooming are reduced. The surface condition of the parts has less effect than in spot welding. If a part requires several welds, they can be made simultaneously, thus avoiding difficulties due to shunt currents. Both the location and strength of the resulting welds are more reliable.
3. The only limits to the number of welds that can be simultaneously made seems to be the ability to control force and current so that they are equally divided between the welds, and the capacity of the equipment. It is much easier to achieve the proper division of force and current with projections than with flat surfaces. When several welds, approximately six or eight are needed, they are usually made simultaneously.
4. In many cases, the areas to be joined are flat except for the projections. In such cases the electrodes are flat and large enough to contact a large area. In other cases, when the surface to be contacted is irregular in shape, the electrode is fitted to the surface so that a high force may be applied without distorting the part. A large current may be introduced without damaging the surface. Electrodes with large contact surfaces show little wear and consequently require less attention or maintenance.
5. If two spot welds are located too closely together, current from the second weld is shunted through the preceding weld. Since projection welds are made simultaneously, there is less trouble due to shunting. However, if they are placed too closely together irregularities in forming the projections may lead to poor distribution of the current. The only *limitations* on the arrangement or spacing of projections are the ease of equalizing the distribution of force and current and the size of the machine. If, however, more than three projections are welded simultaneously, the height of the projections must be uniform within close limits, to avoid having some of the projections fused before others have made contact. Multiple-impulse welding or the use of upslope may be helpful in this case.
6. In a conventional spot welding machine parts may be located by an assembly fixture and moved to make a second or third spot weld. When using projections, the fixture may be mounted solidly on the machine. The parts are simply placed in a nest and with one operation of the machine all the welds are made at once. One part may be located in relation to the other by punching holes in one and matching them with semi-punchings from the other.
7. When small parts, such as brackets or handles, are to be welded to large pieces, they are difficult to locate in a spot welding machine, resulting in misplaced spots or extruded metal. In these cases, neat embossing would be less unsightly and a fitted electrode would not mark the exposed surface. Projection welding results in better control of the finished appearance.
8. Thoughtful design with ingenious preparation of metal parts can make practical the use of resistance welding with its great savings in quantity production of parts for which it was previously considered unsuitable. For instance, in handling heavy steel stampings or forgings, when spot welding is out of the question, the welding force and current can be localized by projections, either swaged, forged or coined.[1]

Scaly, dirty or painted surfaces can be projection welded. The concentration of the welding force on the tip of the projection may be sufficient to break through the paint or scale surface and get the weld started, after which, the heat from this start may melt and vaporize the surrounding surfaces contaminates, permitting the weld to be completed. This, however, is a poor and unreliable substitute for clean stock.

1 Refer to the AWS *Welding Handbook*, note, there are some limitations in comparison to spot and seam welding.

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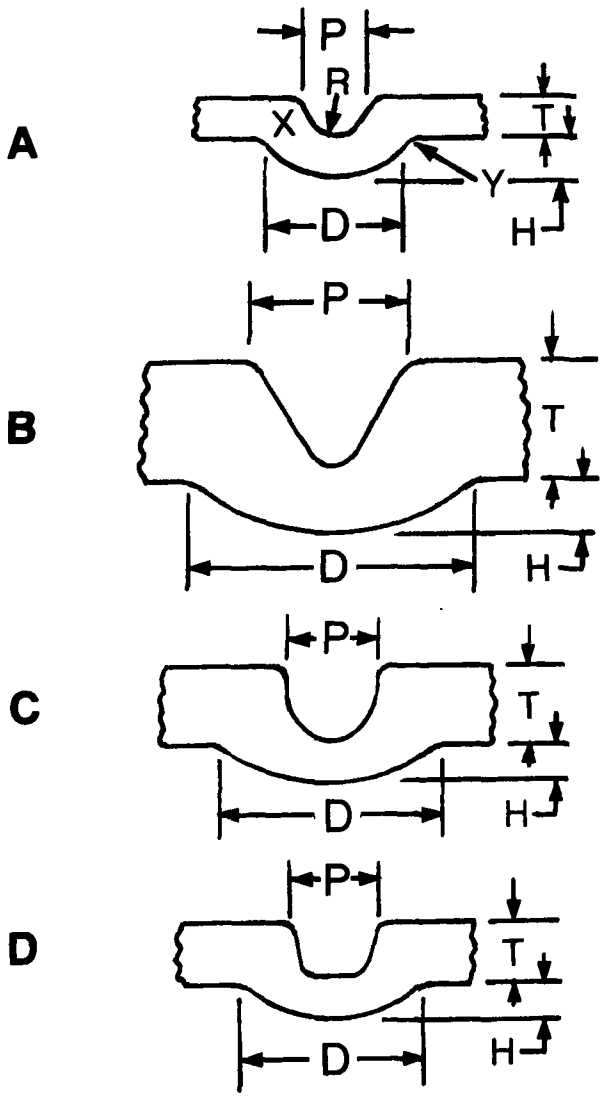


Fig. 3.1 - Four Variations Of Simple Bubble Type Projection

Applications For Projection Welding

The application for projection welding is only limited by the ingenuity of the designer. The principal uses of projection welding are those in which punched, stamped, or formed parts are assembled with the embossments being formed during the stamping operation. The projection is usually circular in shape, but may be of almost any regular design. The circular shape has advantages, both in welding, as well as in the simplicity of punch and die design.

Projection welding is also applicable to parts made on a screw machine. The projection is turned on the screw machine part by using a form tool. This part may be used in connection with a stamping, a flat, or a formed sheet, in order to produce the assembled piece.

There are also specialized applications of projection welding bolts and nuts. These applications have increased in recent years in the automotive and heavy appliance industries. There are numerous applications where these parts are hopper or magazine fed into either the upper or lower electrode. Therefore, it is only necessary for the operator to position the part to which the nut or screw is welded and manually cycle the machine to make the weld.

Not all materials can be projection welded. There is little application for any material except steel. Several attempts have been made to projection weld aluminum, but experience shows that the initial welding force usually crushes the projection before the application of current. However, forged or coined solid projections will not be crushed under this force and have proved successful in some applications. The same condition exists for other nonferrous metals.

TYPES OF PROJECTIONS

Bubble—Button Type Projections

The simplest and most commonly used projection is the *bubble* or *button* type, of which there are four variations illustrated in **Figure 3.1**. In all four illustrations, 'P' is the punch diameter; 'D' is the die diameter, which is also the projection diameter; 'H' is the projection height; and 'T' the stock thickness.

Figure 3.1A shows a spherical radius on the punch. It should be noted in all cases that the metal extruded by the punch is essentially equal to the metal extruded into the die. The radius of the punch has the same center as the radius of the extruded projection, and in a balanced projection, there is no change in stock thickness.

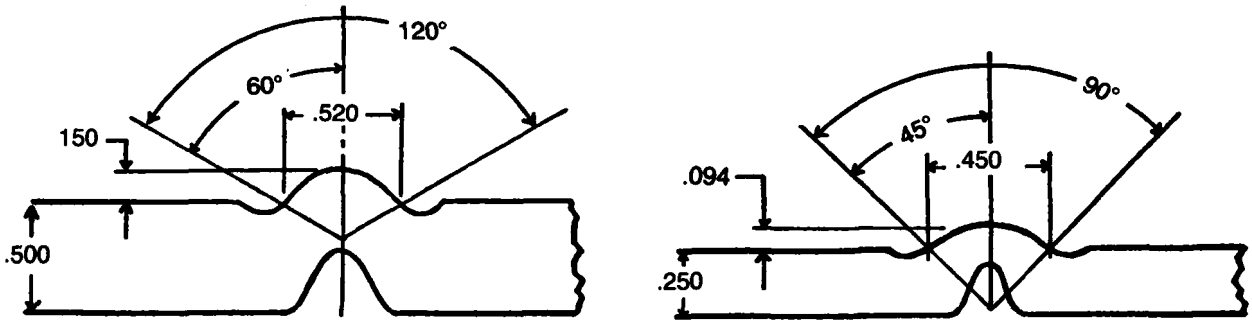
Figure 3.1B shows a conical punch and larger projection diameter. In this and the succeeding types, the stock is thinned out at the center of the projection.

Figure 3.1C shows a spherical punch with large projection diameter.

Figure 3.1D shows a truncated punch with large projection diameter.

In all cases, there should be no sharp edges in the die, at 'Y' in **Figure 3.1A**, as this introduces a notch effect which reduces the shear strength. There should be no thinning of stock thickness in area 'X' in **Figure 3.1A**, as this will reduce both the shear and tensile strength.

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NOTE:
- DIMENSIONS SHOWN ARE IN INCHES.

Fig. 3.2 - Details Of Projections Recommended For 0.500-In And 0.250-In Stock

Design Of Projections

In projection welding parts of unequal thicknesses, the projections are usually placed in the thicker piece. Projection dimensions should be proportioned to the thinner piece. If the thicker piece is not over 1.500 to 2 times greater than the thinner piece the projections should be in the thinner piece. Projection welds of the type shown in **Figure 3.1** are satisfactory for stock thicknesses up to about 0.125-in. Above this, the projection will not be completely forged back, resulting in a ridge around the projection area 'Y' in **Figure 3.1A** which, in turn, produces an undesirable sheet separation.

To overcome this, projections in stock over about 0.250-in thick are made with an annular cavity, as shown in **Figure 3.2**. This cavity acts as a reservoir for excess metal squeezed out from the projection and allows the two pieces to be set down tightly. **Figure 3.2** shows details of this type of projection recommended for 0.250-in and 0.500-in stock. The volume of the cavity below the stock surface should be about 70 percent of the stock projecting above the stock surface. **Figures 3.3** and **3.4** show a representative production assembly of heavy stampings assembled with this type of projection. The four stampings forming the complete assembly range from 0.250-in to 0.500-in thick.

So far, we have considered only projections in two flat sheets or plates, with the application of welding force normal to the surface of the stock. There are many applications where the welding force is at an angle other than 90° from the stock. Generally speaking, projection welds may be made down to an angle of about 45°. In this case, elongated projections should be used. The *minor diameter* should be the same as that required for 90° welds, and the *major diameter* should

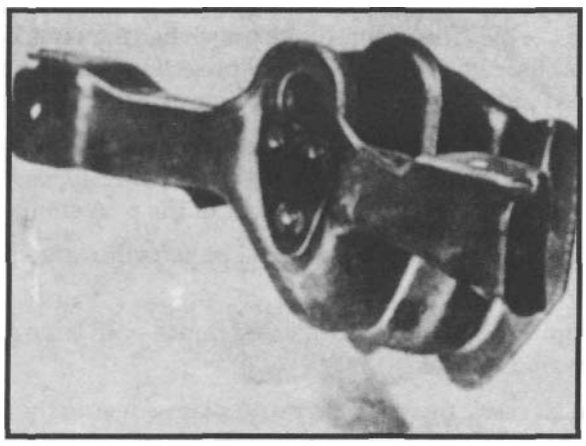


Fig. 3.3 - Projection Welded Front Axle And Radiator Support For Tractors

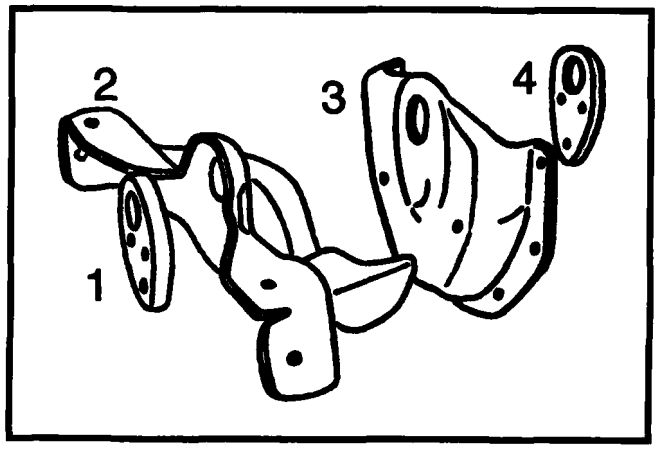


Fig. 3.4 - General Outlines Of The Stampings Used In Figure 3.3

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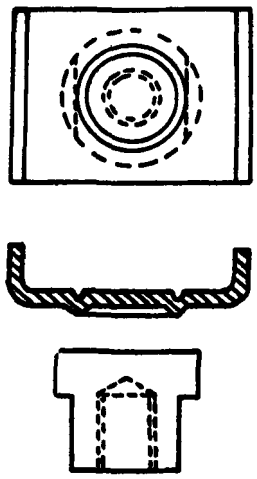


Fig. 3.5 - Embossed Annular Projection

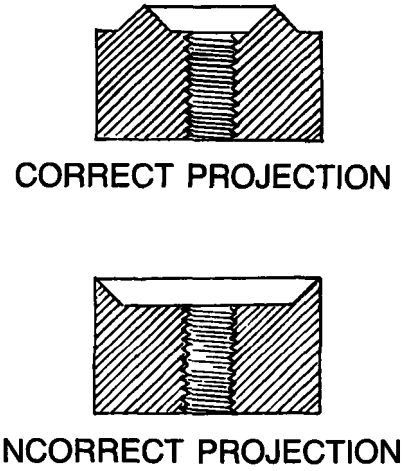


Fig. 3.6 - Correct And Incorrect Location Of Annular Projection

be equal to the minor diameter times one plus the tangent of the angle at which the stock is inclined from the horizontal plane.

A projection in sheet material should meet the following requirements:

1. It must be rigid enough to support the initial weld force before the current is applied.
2. It must have sufficient mass to raise a spot or weld nugget in the plane surface to welding temperature. If it is too small it will collapse before the other surface is heated.
3. It should collapse without extruding between the parts.
4. The part surfaces should be in intimate contact after welding.
5. It should not be partially sheared. Such projections are weak, tear out easily and are of low shear strength.
6. It should be easy to form, so that the punch and die require little maintenance.
7. It should cause minimal distortion of the part during forming.[2]

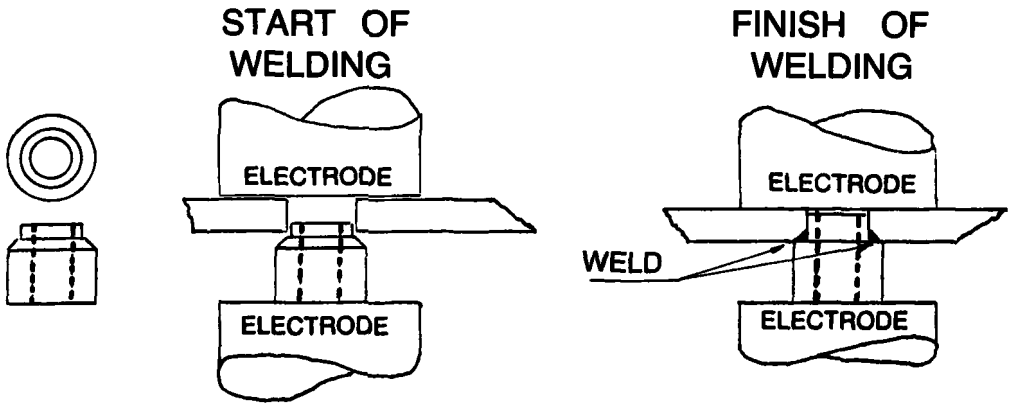


Fig. 3.7 - Preparation Of Parts For Projection Welding Nut Or Bushing To Sheet

2 Refer to **Table 3.4** and **3.5**, "Punch and Die Dimensions".

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Fig. 3.8 - Application Of Elongated Projections On Flat Sheet For Corner Welds

Annular And Other Special Types

The methods of preparation which make projection welding possible are frequently specialized to suit particular conditions, so that only general directions can be indicated. Annular or ring projections are frequently used on screw machine parts and for applications which require a pressure-tight joint around a hole between two parts. Such preparation also gives high strength when a large stud or boss is to be applied to thin sheet material. In some applications it is preferable to form a ring type projection in the sheet, as shown in **Figure 3.5**.

Figure 3.6 illustrates a screw machine product. The ring, if located on the very edge will squeeze out, leaving a poor weld. Annular projections may have either rounded tops or sharp 90° edges (45 ° each way). The latter is frequently used on screw machine parts which are applied to sheet stock. The rounded top gives a better heat balance when applied to heavier parts. The annular projection is used in sheet parts to be joined around a hole.

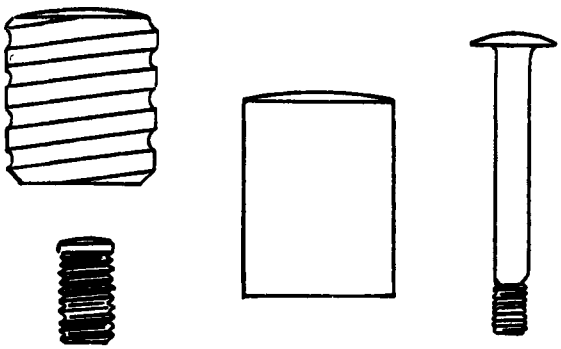


Fig. 3.9 - Typical Screw And Stud Parts Suitable For Projection Welding

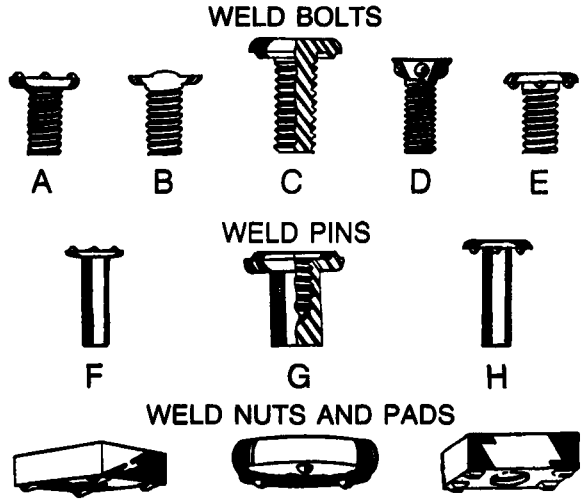


Fig. 3.10 - Standard Nuts, Bolts And Pins Provided With Forged Or Coined Projections For Welding

The annular projections in screw machine parts or forgings where the stock thickness is sufficient to warrant it, should have annular cavities on either side of the projection. This is particularly desirable in applications similar to that shown in **Figure 3.6**, as it will prevent flash from fouling the threads.

Figure 3.7 shows a special application for welding studs, bushings, etc., into metal openings. The sheet metal stock must have a minimum thickness of 0.125-in for this type of weld to be practical. The hole in the sheet must be punched cleanly and the pilot of the stud should be just a few thousandths (0.005-in-.010-in) smaller than the hole. The shoulder angle is approximately 45°. As the weld is made, the edge of the sheet fuses into the angular shoulder, thus making a strong air and water-tight joint. Such welds are frequently made in hot water tanks and similar applications.

Another type of projection that is frequently used is shown in **Figure 3.8**.This consists of an elongated projection running completely off the edge of the sheet. The edge of another sheet is welded to it. An example application is the welding of bottoms into round or rectangular containers without flanges. They cannot be made air or water-tight.

Weld Nuts, Bolts And Screws

The simplest application of screws and bolts suitable for welding is shown in **Figure 3.9**. This merely consists of any rod, stud or screw with a radiused head

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Fig. 3.11 - Illustrating Use Of Insulated Locating Pin For Welding Nut

which constitutes the projection. A round or oval head screw without the slot constitutes an ideal application. In this case, it is not necessary to clamp the screw, but merely to provide a socket in the lower electrode. Electrical contact is made on the under side of the head.

If the screw or rod has no head, it is necessary to clamp it in a hand toggle or air operated fixture which also contains the lower electrode. If the threads are sharp, as in the lower left **Figure 3.9**, the clamp fixture should be provided with a backup to take the thrust of the welding force, otherwise the clamp pressure required to hold the part against slipping may not only damage the threads, but also cause rapid electrode wear and misalignment of parts.

Many types of studs and nuts are commercially available on the market prepared ready for projection welding. Examples are shown in **Figure 3.10**.

To weld a countersunk screw head into sheet material, four flutes or bosses are formed on the contacting surface of the head as shown in the top row of **Figure 3.10**, the sheet being punched to form a countersunk contacting surface.

The preferred application for all weld nuts and bolts is that the design be such that the welds are in compression rather than tension. In **Figure 3.10**, *top row*, the two screws **A** and **B** do not meet this requirement, while the other three **C**, **D** and **E** do. In the *center row*, **F** does not, **H** does, and the center **G** may or may not, depending on which side the screw is on.

All of these parts can readily be hopper fed.

Location of the parts on the sheet can be accomplished by means of a pilot pin, in cases where a hole is used, or by stops and locators, where there is no hole.

Figure 3.11 shows an insulated pilot in the lower electrode, over which the sheet and weld nut are located. If the nut is hopper fed, it is more practical to be loaded into the upper electrode.

Figure 3.12 shows an application where the weld nut has its own pilot over which the sheet is located. If this

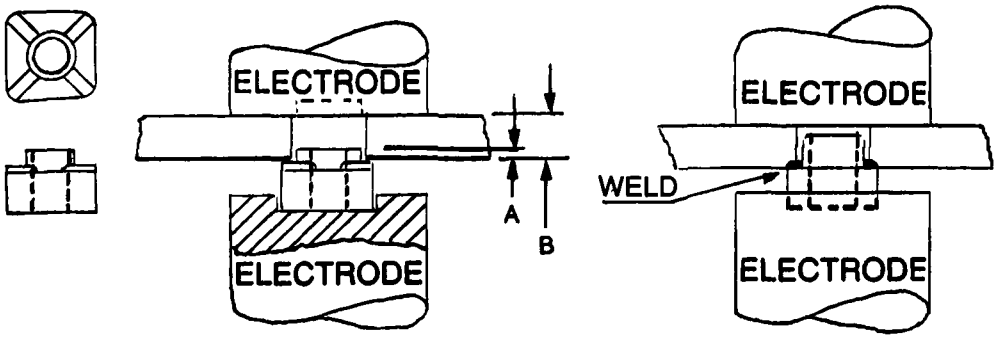


Fig. 3.12 - Recessed Electrode For Locating Nut For Welding

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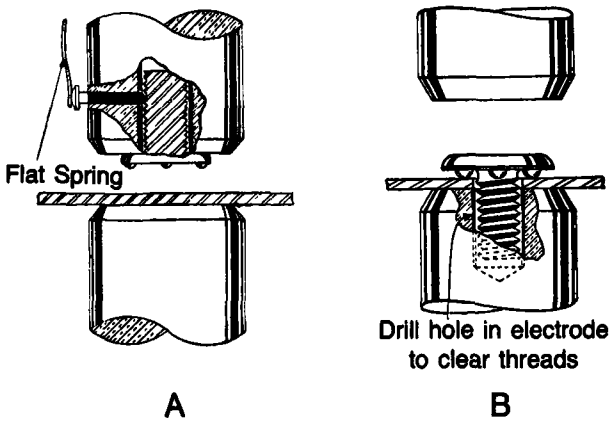


Fig. 3.13 - Two Methods Of Providing Accurate Location For Projection Welding Bolts To Sheet

nut is hopper fed, it should be loaded into the lower electrode.

Figure 3.13A shows a weld bolt loaded into the upper electrode and held in place by a spring detent. The sheet, having no hole, must be positioned by outside stops or gages. In **Figure 3.13B**, the bolt is first inserted in the hole in the sheet. The bolt shank is then inserted in the recess in the lower electrode.

GENERAL PRINCIPLES

Projection Weld Formation

A study of the formation of a projection weld illustrates the need for proper projection formation and adequate resistance welding equipment. The projection collapse during welding is almost complete at 20 percent of the "weld time". The welding tooling must follow this movement to apply the proper electrode force to avoid loss of projection by excessive metal expulsion. *Eight stages* may be said to be encountered in projection weld formation. These are illustrated by a series of macrophotos in **Figure 3.14**.

Referring to **Figure 3.14**, *Stages 2 through 4*, the projection is collapsing and bonding is taking place as is evident by the increase in strength. At *Stage 6*, the interface has disappeared and slight nugget formation has appeared. Many projection welds end at this stage and possess consistent shear strength. As the current continues, the nugget formation becomes more evident in *Stage 7*. Further "weld time" will substantially increase the nugget diameter and penetration which is evident in *Stage 8*.

Projection weld formation depends in part on current magnitude. Unless the magnitude is sufficient for definite nugget formation, the weld appearance will be typified by *Stage 6*, regardless of the "weld time". If four projection welds are made simultaneously using a common electrode to furnish the current and force, it will be difficult to form nuggets of equal size. The difficulty increases with the number of projections. Special tooling to aid equal distribution of force and current, examples of which are shown in **Figure 3.15** and **3.16**, will improve the equality of nugget diameters.

Welding Current

The welding current must be of sufficient magnitude to cause fusion before projection collapse. The rigidity of the projection against collapse is a function of metal thickness becoming greater as the thickness increases. With greater rigidity more flexibility prevails for adjusting the current magnitude and its pattern. In thin materials (0.020-in and less) the range of weld current and "weld time" is narrow. Recommended values are listed in **Tables 3.1, 3.2** and **3.3** as a function of the metal thickness. **Table 3.4** can be used with **Table 3.2** and **Table 3.5** with **Table 3.3**.

Nugget formation, beyond *Stage 6* in **Figure 3.14**, is seldom necessary in projection welding. Welding schedules listed for one projection will produce well defined nuggets. The nugget formation approaches *Stage 6* as schedules for three or more projections are used.

The tendency for metal expulsion for a given projection size increases as the current magnitude increases since the welding current must pass through a small area.[3] The use of multiple-impulse welding or upslope control, which gradually increases the current magnitude with time, minimizes this problem.

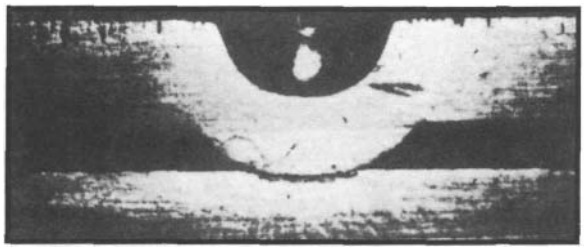
Electrode Force

The electrode force has four principal functions:

1. It must hold the projection firmly against the mating part during the initial period of "weld time" where the current density is high and the collapse rate is rapid. A force loss and metal expulsion will result if the welding electrode cannot follow the projection collapse.

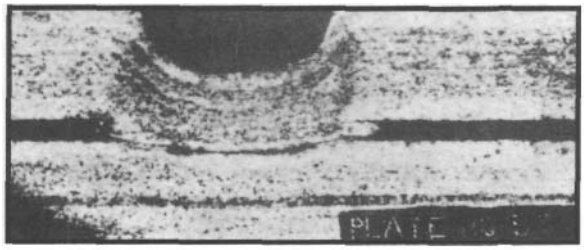
3 See *Stage I* in **Figure 3.14**.

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Stage 1

- Cold setdown and no current. Original projection height of 0.050-in decreases 0.010-in caused by 0.008-in indentation and 0.002-in projection collapse. Sheet separation is 0.040-in.



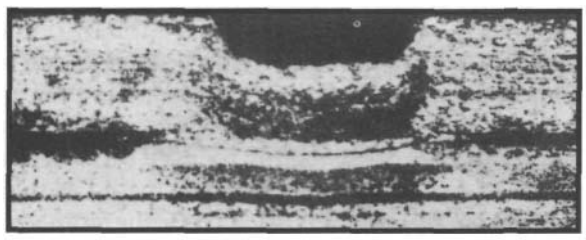
Stage 2

- One cycle "weld time". Pressure weld forms with tensile-shear strength of 1050 lb. Sheet separation is 0.010-in. *(With two cycle "weld time", tensile-shear strength of 1750 lb is obtained, with sheet separation of 0.007-in).*



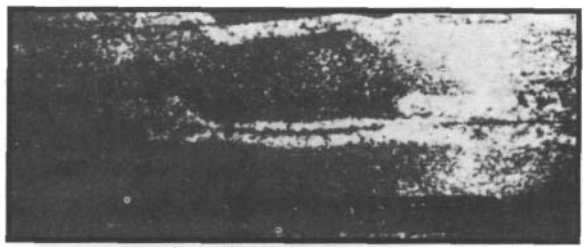
Stage 3

- Four cycle "weld time"—tensile-shear strength of 2300 lb and sheet separation of 0.005-in.



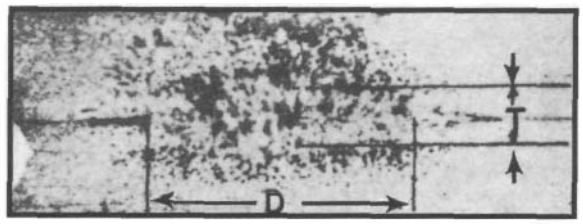
Stage 4

- Six cycle "weld time" resulting in tensile-shear strength of 2600 lb wherein sheet separation is 0.005-in. *(Eight cycle "weld time" gives strength of 3000 lb, with sheet separation equal to 0.002-in).*



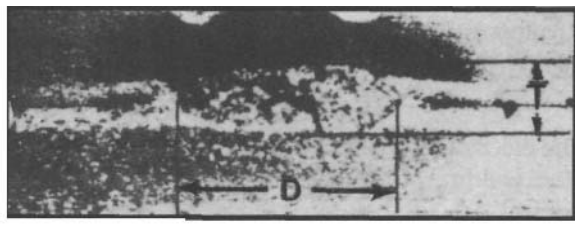
Stage 5

- Ten cycle "weld time" and tensile-shear strength of 2500 lb with sheet separation of 0.002-in—this is the last stage of welding without nugget formation.



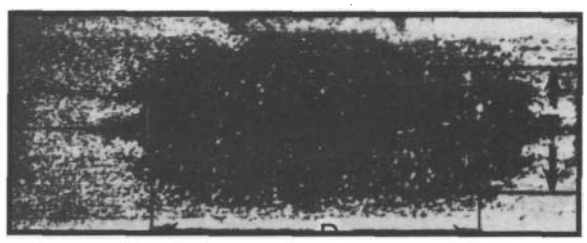
Stage 6

- Twelve cycle "weld time" with strength of 3100 lb, with sheet separation of 0.001-in. **Note** that nugget formation has started and that the nugget diameter is 0.150-in. *(With fourteen cycle "weld time", the strength is 3200 lb, with no sheet separation. The nugget diameter is 0.160-in).*



Stage 7

- Using a recommended sixteen cycle "weld time", tensile-shear strength reaches 3700 lb, with no sheet separation. The nugget diameter is 0.160-in.



Stage 8

- At twenty cycle "weld time", the tensile-shear strength reaches 4000 lb, and the nugget diameter is 0.300-in. *(Stage 8 indicates an increase in nugget size with increased "weld time").*

Fig. 3.14 • Projection Weld Formation In Double Thickness Of 0.092-in Thick Low Carbon Steel—**Schedule A Of Table 3.3.**

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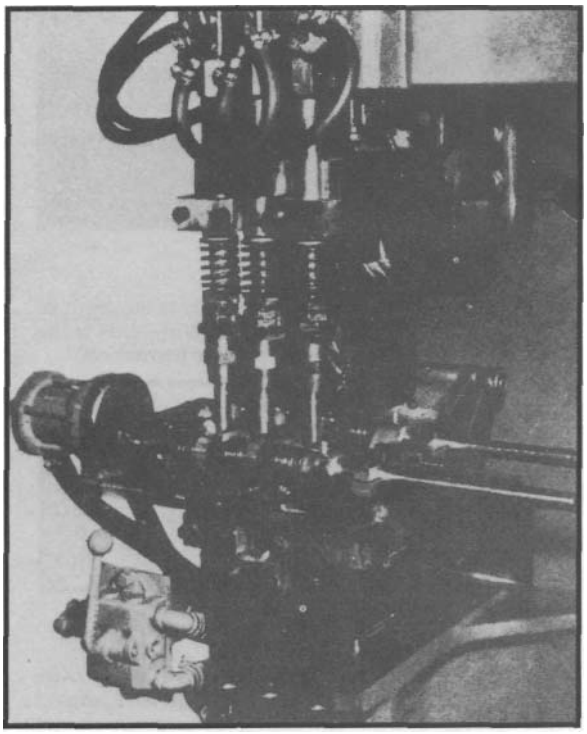


Fig. 3.15 -
• Spring-loaded low inertia electrode holders provide an economical means of obtaining a uniform force pattern and aid in equal current division.

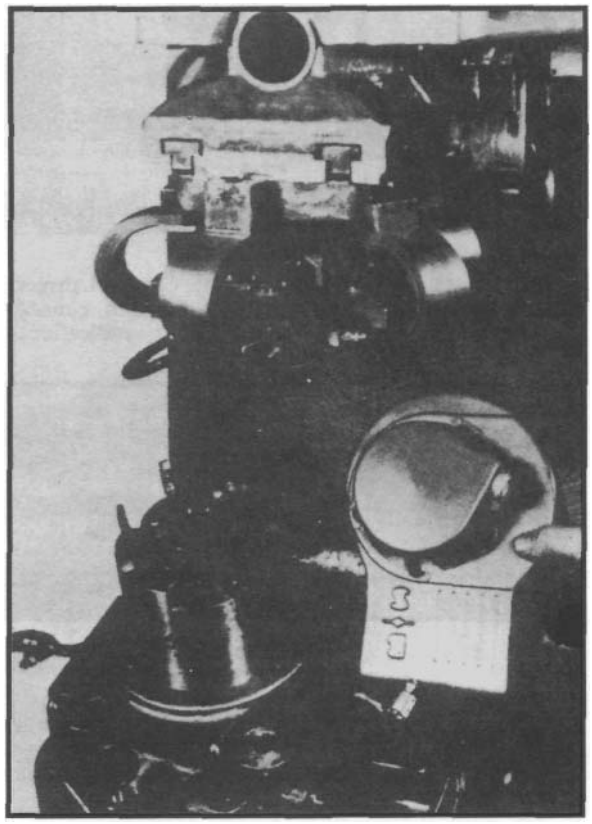


Fig. 3.16 -
• Hydraulic-equalized electrode holders equalize the force pattern and aid current distribution—may be used when the force magnitude exceeds the spring-loaded type in **Figure 3.15**. Ten projection welds are made simultaneously with this tooling.

2. The electrode force must cause complete collapse after welding, so the resulting sheet separation is minimized. The height of the projection is related to the magnitude of the electrode force, assuming the same projection base dimension. The higher the projection, the higher must be the electrode force to obtain complete collapse.
3. The electrode force has a major influence on the degree of porosity in the weld nugget. It must be low enough to give proper projection collapse without metal expulsion and yet high enough to produce comparatively sound welds. In some cases, especially in the thicker materials, these requirements are so divergent that a weld force is used to make the welds, followed by a forge force, applied after "weld time", to minimize porosity.[4]
4. The suitable dynamic force characteristic must prevail without producing excessive initial impact force. The impact force should be no greater than the welding force, otherwise the initial contact area will change, influencing the welding results.

Evidence of excessive impact force is the formation of ring welds, or fusion around the periphery of the projection leaving a partially welded center. If one projection is being welded, it must resist the total impact force. As the number of projections is increased, the impact force is consequently reduced on each one. The speed of a machine ram can be increased as the number of projections increase and the impact force absorbed by each projection will remain constant.

The electrode force has an influence on weld size. The size will increase within limits with decreasing electrode force if the welding current is held constant.

4 See **Figure 3.15** and **3.16**.

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"Weld Time"

The value of "weld time" will be dependent on the welding current and projection rigidity. As a working approximation, the relationship can be expressed as:

$$I^2t = I_1^2t_1$$

in which I is the current in amperes at time t in seconds. I_1 is the current in amperes at time t_1 in seconds.

A working range of adjustment is presented in **Table 3.2**. Projection welds made with the shortest times are not necessarily of the best quality. A short "weld time" requires a correspondingly high welding current. The high current must initially pass through a small contact area, raising the current density and increasing the tendency for expulsion.[5]

This problem is aggravated by the use of multiple projections as the height tolerance will vary the initial contact area per projection. Consequently, for welding multiple projections, it is suggested that longer "weld time" be used. Multiple-impulse welding or upslope control is recommended if available. Projection welding, unlike spot welding, requires considerable ram movement while the projection is collapsing. In a normal projection weld the collapse is essentially complete in the first 20 percent of the "weld time" period. Thus, as the overall "weld time" is shortened, the welding ram must follow up at an increasingly higher speed. This can be a severe requirement for a large press welding machine; an example is **Figure 3.17** with its inherent mass and inertia.

Electrodes Or Dies

Using electrodes of proper design and alloy is a major factor in making projection welds. There are two basic types of electrodes:

1. Large flat electrodes, often made from bar stock.
2. A series of local contact surfaces[6] made by relieving a bar between projections or by brazing inserts of hard copper alloy to the bar.

Flat electrodes are not recommended on weldments which are distorted from the projection forming operation. The distortion prevents the weld force and current from entering directly above the projections and results in unequal current and force division. Flat electrodes are advisable when welding a few projections in a localized area.

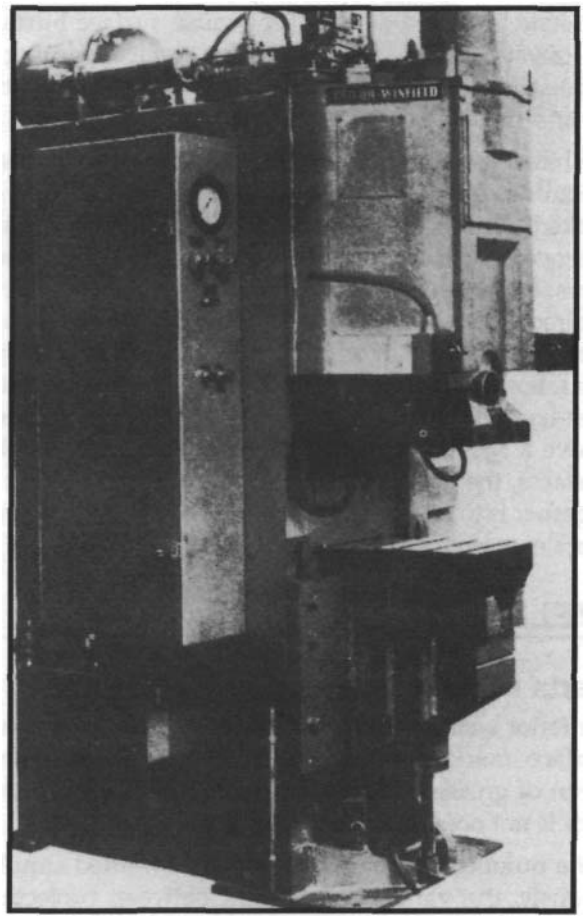


Fig. 3.17 -
• Hydraulically operated press welder with 18,000 lb force.

Flat electrodes or local contact surface electrodes can be made from **RWMA** Class 2, Class 3 or Class 4 alloys. Class 3 is recommended. The localized contact area type of electrode tends to equalize the total current and force in spite of distortion or tolerance of the weldment. This type of electrode is recommended as best for all projection welding, and especially in those applications involving four or more projections.

If a hard electrode material is required, an economical solution is to use a composite electrode of copper backing with the appropriate hard facing. The facing suggested here is a copper-tungsten material brazed to the copper under controlled conditions(**Figure 3.18C**).[7] The ideal electrode material is one which is as hard as

5 See **Table 3.1** and **Table 3.2**.
6 See **Figure 3.18** (**RWMA** Class 10, 11 or 12 is the recommended material for the insert).

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possible but does not crack or cause surface burning on the weldment. If cracking or surface burning is encountered, a softer material with higher conductivity and ductility is required.

While it is not the intent here to discuss the details of electrode design, two other factors must not be overlooked. These are the desirability of water cooling and the need for clean and firmly bolted contacting surfaces. Water cooling (either directly on the electrode or indirectly on the electrode holder) is desirable and may be required to avoid overheating and resulting oxidation. This is important in the case of precipitation-hardening type alloys which lose their hardness above a specific temperature.[7] As with all contacting surfaces, the reason for cleaning and firmly bolting all together is to reduce the contact resistances which generate excessive heating.

WELD QUALITY

Parts Preparation

Inferior welds with varying degrees of expulsion and surface marking will result if the weldment is not clean of grease, rust, scale or dirt. A slightly oily surface is not objectionable.

If a number of projections are to be welded simultaneously, the variation in height between projections should be confined to 3 percent of the height of the projection. Excessive variation in height will cause expulsion and will exaggerate the formation of unequal weld diameters.

In preparing the weldment, it is imperative that shearing burrs **(Figure 3.18A)** be eliminated. As the projection collapses, burrs form shunting paths for both current and force. Uncontrolled shunting makes it impossible to produce consistent welds.

In any welding operation, the less variation in part tolerance before welding, the more consistent the weldments will be. The welding equipment will not successfully finish-form the weldment **(Figure 3.18B)**. This mechanical operation has a tremendous effect on the equalization of the electrode force over each projection in a multiple projection weld. Without proper equalization, the weld quality will vary widely.

Projection Size And Shape

There are many opinions regarding the proper size and shape of embossed projections. A compromise is required between the best formation for welding and ease of mechanical forming. The majority of projections recommended in this Chapter are made with nonbottoming punches. This avoids tool breakage if material thickness varies slightly. In thin materials, the annular shape projection is suggested and it is not difficult to form. The simple, dimple type would not weld properly.

In heavy materials, a recessed type of projection is suggested to minimize sheet separation. It would be used if the simple type projection produced too much separation in a specific application.

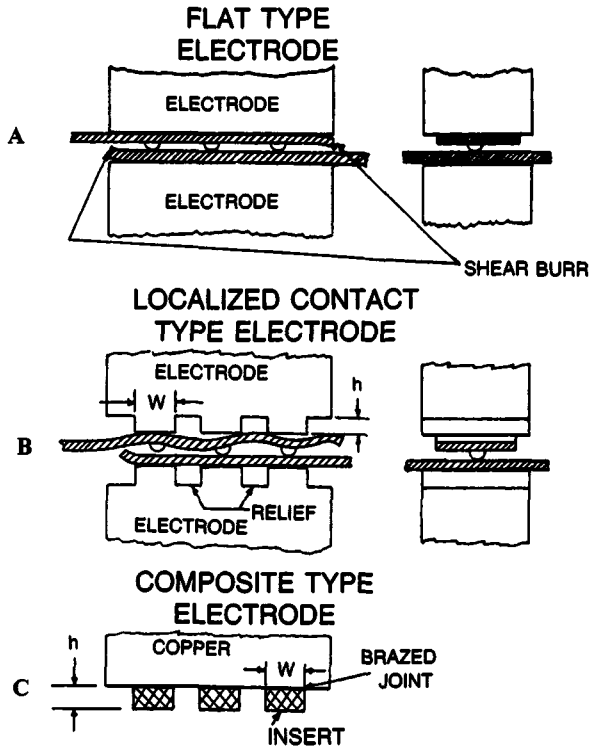


Fig. 3.18 -
• Projection welding electrodes (W is approximately 3 times the projection diameter but not less than 0.500-in; h ranges from 0.120-in to 0.250-in and the insert diameter equals W).

Materials

Not all metals can be welded by projection welding. The metal must be strong enough to support the pro-

7 Refer to **Chapter 18**, "Electrodes".

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TABLE 3.1 PROJECTION WELDING • Of Low Carbon[1] Steel[2] — **0.011-in to 0.019-in** Thickness *(Two Equal Thicknesses)*

t Inch	USS Gauge	Minimum Spacing ℄ To ℄ Inch	Minimum Contact Overlap Inch	"Weld[4] Time" Cycles	Electrode[3] Force lb	Welding* Current Amperes	Tensile-Shear Strength[5] Each Projection One lb	Tensile-Shear Strength[5] Each Projection Two or More lb
0.011	31	0.31	0.25	6	110	5200	190	145
0.019	26	0.31	0.25	6	225	5400	400	280

- **1.** Low carbon steel — **SAE 1010 — 42,000 – 55,000** psi ultimate.
- **2.** Surface of steel may be oiled lightly but free from grease, scale and dirt.
- **3.** Based on 60 Hz
- **4.** Electrode force contains no factor to further form poorly made parts.
- **5.** Approximate strength per projection — depends on joint design.
- * **Starting values** shown are based on experience of member companies.

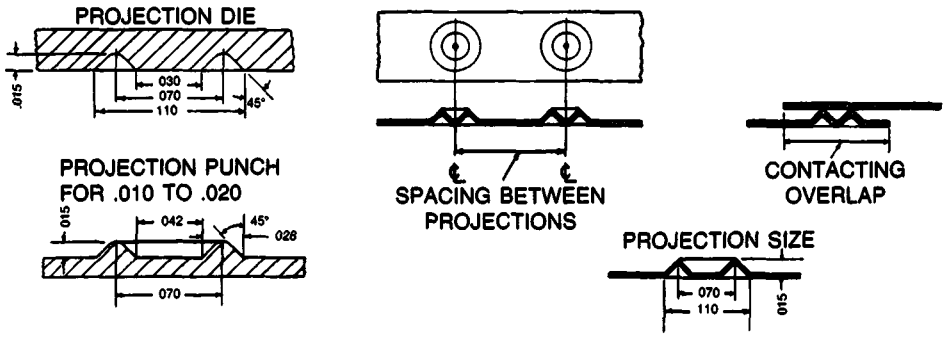


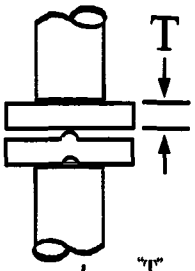
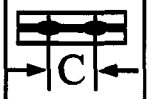
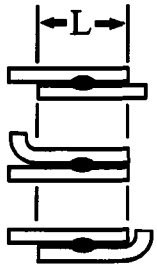
TABLE 3.2 PROJECTION WELDING • Of Low Carbon[1] Steel[2] — **0.153-in to 0.245-in** Thickness *(Two Equal Thicknesses)*

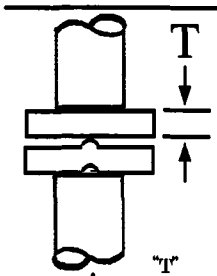
Thickness Inch	Thickness USS Gauge	Projection Size Diam Inch	Projection Size Height Inch	Minimum Spacing ℄ To ℄ Inch	Minimum Contact Overlap Inch	Electrode Force Weld lb	Electrode Force Forge lb	"Up-slope[4] Time" Cycles	"Weld[4] Time" Cycles	Welding* Current Amperes	Tensile-Shear[5] Strength lb
Schedule A — Welding Normal Size Welds											
0.153	9	0.330	0.062	1.75	0.9	2000	4000	15	60	15,400	7,500
0.164	8	0.350	0.068	1.80	0.95	2300	4600	15	70	16,100	8,100
0.179	7	0.390	0.080	1.90	1.0	2630	5260	20	82	17,400	9,500
0.195	6	0.410	0.084	2.00	1.05	2930	5860	20	98	18,800	11,300
0.210	5	0.440	0.092	2.10	1.15	3180	6360	25	112	20,200	12,500
0.225	4	0.470	0.100	1.30	1.20	3610	7220	25	126	21,500	15,000
0.245	3	0.530	0.112	2.50	1.30	3900	7800	30	145	23,300	17,300
Schedule B — Welding Small Size Welds											
0.153	9	0.270	0.058	1.60	0.75	1400	2800	15	60	11,100	5,100
0.164	8	0.290	0.062	1.65	0.80	1425	2850	15	70	11,800	5,500
0.179	7	0.310	0.067	1.70	0.85	1500	3000	20	82	12,800	6,500
0.195	6	0.330	0.072	1.75	0.90	1600	3200	20	98	13,900	7,700
0.210	5	0.350	0.077	1.80	0.95	1730	3460	25	112	14,900	8,500
0.225	4	0.370	0.082	1.90	1.00	1870	3740	25	126	16,000	10,400
0.245	3	0.390	0.088	2.10	1.10	2100	4200	30	145	17,300	12,000

- **1.** Low carbon steel — **SAE 1005-1010 — 42,000 – 55,000** psi ultimate.
- **2.** Surface of steel may be oiled lightly but free from grease, scale and dirt.
- **3.** On single force welds use only weld force as electrode force. Electrode force contains no factor to further form poorly made parts.
- **4.** Based on 60 Hz
- **5.** Tensile-shear strength per projection depends on the joint design.
- * **Starting values** shown are based on experience of member companies.

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TABLE 3.3
RECOMMENDED PRACTICES FOR PROJECTION WELDS IN LOW CARBON STEEL

DATA COMMON TO ALL CLASSES OF PROJECTION WELDS						WELDING SCHEDULE A FOR A SINGLE PROJECTION			
Thickness		Projection Size		Minimum Weld Spacing	Minimum Contacting Overlap	Weld Time	Net Electrode Force	Welding Current*	Minimum Tension-Shear Strength
									
MFG. GAUGE	"T" THICKNESS Inch (mm)	Diameter, Inch	Height, Inch	"C" INCH	"L" INCH	CYCLES (60 HZ)	POUNDS	AMPERES (approx.)	POUNDS
25	.021 (0.53)	.090	.025	0 38	0.25	3	150	4,400	370
23	.027 (0.69)	090	.025	0.38	0 25	3	195	5,500	500
21	.033 (0.84)	.110	.035	0 50	0.38	3	240	6,600	700
19	.042 (1.07)	110	.035	0.50	0 38	5	330	8,000	1,060
18	.048 (1 22)	140	038	0.75	0.50	8	400	8,800	1,300
16	.060 (1.52)	150	042	0.75	0.50	10	550	10,300	1,800
14	.075 (1.91)	.180	.048	0.88	0 50	14	800	1,800	2,425
13	.090 (2.29)	210	050	1.06	0.62	16	1,020	13,150	3,250
12	.105 (2.67)	240	.055	1.25	0 75	19	1,250	14,100	3,850
11	.120 (3.04)	270	.058	1.50	0 81	22	1,500	14,800	4,800
10	.135 (3.43)	300	.062	1.63	0.88	24	1,650	15,300	5,500

WELDING SCHEDULE B FOR 2 – 3 PROJECTIONS						WELDING SCHEDULE C FOR 4 OR MORE PROJECTIONS			
Thickness		Total Weld Time Do not mult. Per projection	Net Electrode Force per each projection	Welding Current* per each projection	Min. Tension-Shear per each projection	Total Weld Time Do not mult. Per projection	Net Electrode Force per each projection	Welding Current* per each projection	Min. Tension-Shear per each projection
									
MFG GAUGE	"T" THICKNESS Inch (mm)	CYCLES (60 HZ)	POUNDS	AMPERES (approx.)	POUNDS	CYCLES (60 HZ)	POUNDS	AMPERES (approx.)	POUNDS
25	.021 (0 53)	6	150	3,850	325	6	80	2,900	290
23	.027 (0 69)	6	150	4,450	425	8	100	3,300	340
21	.033 (0 84)	6	150	5,100	525	11	125	3,800	425
19	.042 (1 07)	10	210	6,000	875	15	160	4,300	720
18	.048 (1.22)	16	270	6,500	1,100	19	220	4,400	875
16	.060 (1.52)	20	365	7,650	1,575	25	330	5,400	1,225
14	.075 (1 91)	28	530	8,850	2,150	34	470	6,400	1,750
13	.090 (2.29)	32	680	9,750	2,800	42	610	7,200	2,325
12	.105 (2.67)	38	830	10,600	3,450	50	740	8,300	2,900
11	.120 (3.04)	45	1,000	11,300	4,200	60	900	9,200	3,600
10	.135 (3.43)	48	1,100	11,850	4,850	66	1,000	9,900	4,250

* **Starting values** shown are based on experience of member companies
- Material should be free from scale oxides, paint, grease and heavy oil
- Electrode Material: **RWMA CLASS 3 or 11**

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