A COMPARATIVE STUDY OF ARC WELDING AND RESISTANCE WELDING PROCESSES

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Abstract: This paper makes an in-depth comparative study of arc welding and resistance welding processes. The objective is to present the current challenges and future aspects of these welding processes and their usefulness as fabrication technology. The important considerations and application areas of both the techniques are discussed in this paper.

1INTRODUCTION

The *American Welding Society* (AWS) defines welding as "a materials joining process which produces coalescence of materials by heating them to suitable temperatures with or without the application of pressure or by the application of pressure alone and with or without the use of filler material" [1].

Mechanical parts are often highly complicated in design or large in size. Manufacturing a unit of such a part as a single entity is not always possible. However, it can be produced in the form of different components or structures and could be joined by several joining processes to get the complete unit or assembly. It is here that welding has been found the most useful fabrication technology in joining different components and synthesizing them into a whole system.

2ARC WELDING PROCESSES

One of the most popular and common types of welding in use today is arc welding. It uses an electric arc as the source of heat to melt and join metals. The arc is formed between the metal being worked on and an electrode connected to the arc welder. The electrode is manually or mechanically moved along the joint. The electrode is either a consumable wire or rod, or a nonconsumable carbon or tungsten rod which serves to carry the current and sustain the electric arc between its tip and the workpiece. When a nonconsumable electrode is used, a separate rod or wire can supply filler metal, if needed. The consumable electrode is specially prepared so that it not only conducts the current and sustains arc but also melts and supplies filler metal to the joint and may produce a slag covering as well.

The arc and the weld pool are protected from the ill effects of surrounding atmosphere by some type of an externally supplied inert or semi inert gas, known as a shielding gas, and/or coating electrode or using flux. These processes use either direct (DC) or alternating current (AC) for welding power supply to create and maintain an electric arc between an electrode and the base material to melt metals at the welding point.

The major arc welding processes are described below.

2.1Carbon Arc Welding (CAW)

It is the oldest known arc welding process in which fusion of metal is accomplished by the heat of an electric arc. The arc is established between a nonconsumable carbon (graphite) electrode and the workpiece (Fig.1). The weld can be made by the application of heat with or without the addition of filler material. When filler material is used it is normally of the same composition as the base metal and is added to the arc in the form of additional wire or rod. Though the carbon electrode (4-19 mm diameter and 300-450 mm length) is nonconsumable, but it infact disintegrates slowly and generates CO and CO_2 which replace the air around the arc and thus provide necessary protection. Normally DC power source of constant current type is used with straight polarity to keep the rate of disintegration low. The current carrying capacity of electrode depends upon its diameter and type.

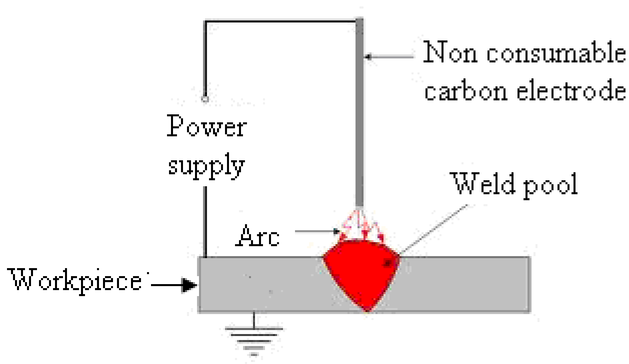


Figure 1: Carbon arc welding [2]

Although this process has been almost completely replaced by the newer processes used in the welding industry, it is still used in certain applications. The process produces adequate welds in thin sheet steel, but should be used with caution in any critical application because it provides only limited shielding from the atmosphere [3, 4].

A modification of carbon arc welding is **twin carbon electrode arc welding**. In this method, the arc is maintained between two carbon electrodes held in a special holder (Fig. 2). Current is switched on and by operating the mechanism of arc length adjustment the two electrodes are brought closer. They touch momentarily and separate, thus an arc is established. An AC supply is recommended for twin carbon arc welding. The electrodes employed are approximately of the same diameter as the workpiece thickness.

Twin carbon arc welding, though more complex than single carbon arc welding, possesses the advantage that the arc is independent of the job and can be moved anywhere without getting extinguished. Moreover, the workpiece is not a part of the electrical circuit.

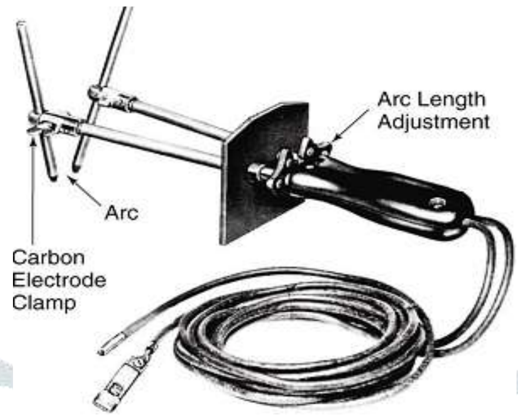


Figure 2: Twin carbon electrode setup

2.2Shielded Metal Arc Welding (SMAW)

This process is also known as **manual metal arc welding** (MMAW) or **stick welding** or **fusion welding**. It uses a consumable electrode of 2.5-6.3 mm diameter and 300-450 mm length, coated in flux to lay the weld. An AC or DC electric supply is used to form an electric arc between the electrode and the metals to be joined. Once the arc has been established, the molten metal from the tip of the electrode flows together with the molten metal from the edges of the base metal to form a sound joint. As the weld is laid, the flux coating of the electrode disintegrates, giving off vapors that serve as a shielding gas and providing a layer of slag, both of which protect the weld area from atmospheric contamination. Electrode coatings can consist of a number of different compounds, including rutile, calcium fluoride, cellulose, and iron powder.

Shielded metal arc welding equipment typically consists of a constant current welding power supply and an electrode, with an electrode holder, a ground clamp, and welding cables (leads) connecting the two (Fig. 3). The sizes and types of electrodes define the arc voltage requirements (within the overall range of 16-40 V) and the amperage requirements (within the overall range of 20-550 A).

The process is very versatile and simple. It is particularly dominant in the maintenance and repair industry, and is heavily used in the construction of steel structures and in industrial fabrication. SMAW is often used to weld carbon steel, low and high alloy steel, stainless steel, cast iron, and ductile iron. While less popular for nonferrous materials, it can be used on nickel and copper and their alloys and, in rare cases, on aluminium. As the process can be used in its manual mode only, it is slowly getting replaced by other processes for heavy applications.

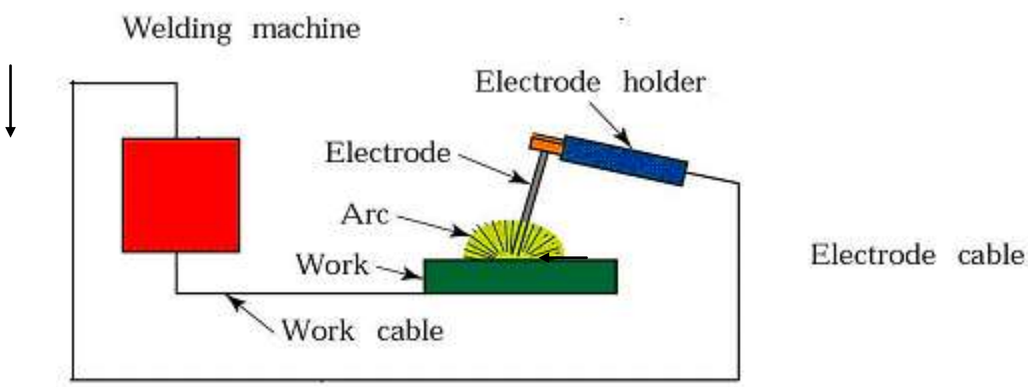


Figure 3: Shielded metal arc welding [5]

2.3Gas Tungsten Arc Welding (GTAW)

It is a welding process in which an arc is struck between a nonconsumable tungsten electrode (0.5-6.4 mmdiameter,75-610 mmlength) and the metal workpiece. The weld area is shielded by an inert gas to prevent contamination. Shielding gas is fed through the torch. Filler metal may or may not be added to the weld. When it is used, it is fed externally into the arc in the form of a rod or a wire.

The equipment required for the GTAW operation includes a welding torch utilizing a nonconsumable tungsten electrode, a constant current welding power supply, and a shielding gas source and other accessories such as water cooling system (Fig. 4).

Argon, helium, argon-helium, and argon-hydrogen mixtures are used for protection of the weld area. Because the process uses a tungsten electrode and inert gases, it is known in the shop as **TIG welding**. The correct name for the process, however, is gas tungsten arc welding.

GTAW uses either AC or DC supply with constant current power source, meaning that the current (and thus the heat) remains relatively constant, even if the arc distance and voltage change. This is important because majority of the applications of GTAW are manual or semiautomatic, requiring an operator to hold the torch. Maintaining a suitably steady arc distance is difficult if a constant voltage power source is used instead, since it can cause dramatic heat variations and make welding more difficult. The preferred polarity of the GTAW system depends largely on the type of metal being welded. It can be used in automatic welding of aluminium or magnesium when helium is used as a shielding gas and AC is preferred.

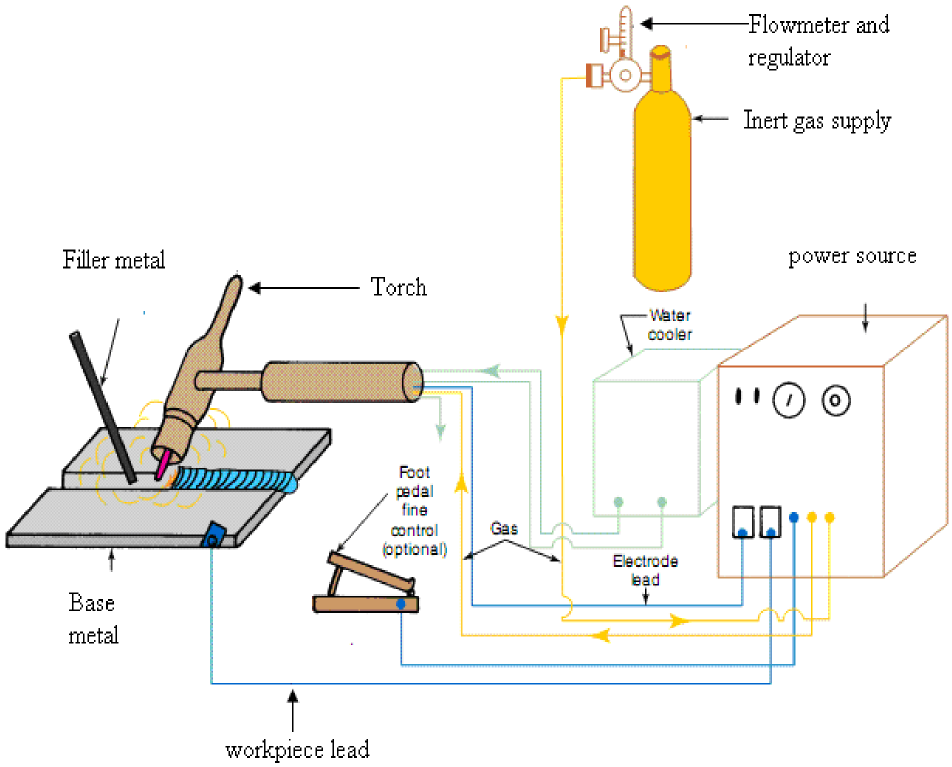


Figure 4: Gas tungsten arc welding station [6]

GTAW is most commonly used to weld stainless steel and nonferrous materials, such as aluminium and magnesium. It is applicable for metals that are hard to weld like titanium, monel, copper-nickel, and can also weld dissimilar metals to one another such as copper to brass and stainless steel to mild steel. It gives an extremely clean weld of high quality because no slag is produced, and is often used in areas where the quality demands are high like nuclear, chemistry, instrument industry, aircraft and food industries.
The main disadvantage of GTAW is the low filler metal deposition rate. Another disadvantage is that the hand-eye coordination necessary to accomplish the weld is difficult to learn, and requires a great deal of practice to become proficient [5, 6].

2.4Gas Metal Arc Welding (GMAW)

It is a welding process in which an arc is struck between a consumable metal electrode and the workpiece. The arc continuously melts the wire as it is fed to the weld puddle. Transfer of molten metal to weld pool takes place in different ways such as globular or spray type mode. The consumable electrode wire of 0.8-2.0 mm diameter is fed to the welding gun from a large spool that may hold several hundred feet of wire. The consumable electrode is the filler metal. The weld area is protected by an externally supplied shielding gas. It is capable of making excellent welds almost continuously. The welding skills required for this process are not as great as those required for some manual welding processes. In shop terms, this process is also known as metal inert gas or **MIG welding**.
Basic equipment for conventional GMAW consists of power source, electrode feed unit, welding torch and shielding gas regulator (Fig. 5). A constant voltage DC power source is most commonly used with GMAW, but constant current systems, as well as AC can be used. This process operates on “reverse” polarity. Currents of 50-600 amps are commonly used at voltages of 15-32 volts. The choice of a shielding gas depends on several factors, most importantly the type of material being welded and the process variation being used.

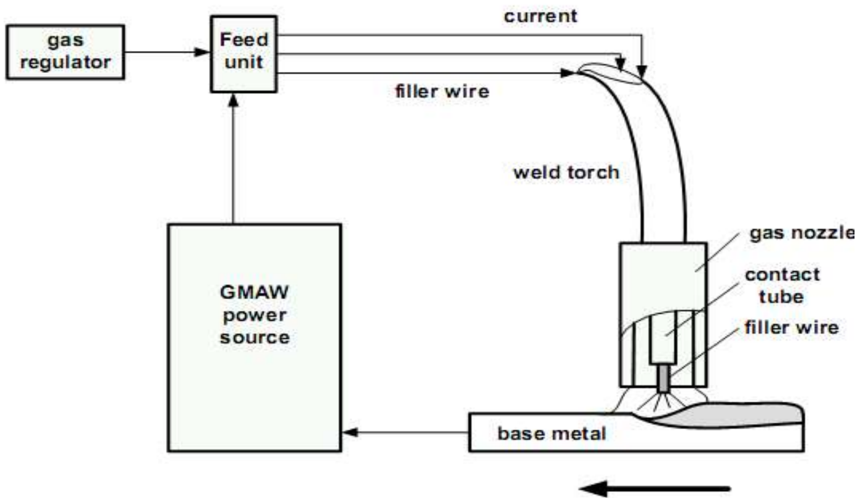


Figure 5: Gas metal arc welding [7]

Metals such as carbon steel, stainless steel, aluminium, and copper can be welded with this process in all positions by choosing the appropriate shielding gas, electrode, and welding conditions. It is a an automatic or semi automatic process, and finds extensive use in fabrication of structures, shipbuilding, domestic equipment and aircraft engine manufacturing industries [5, 6].

2.5Plasma Arc Welding (PAW)

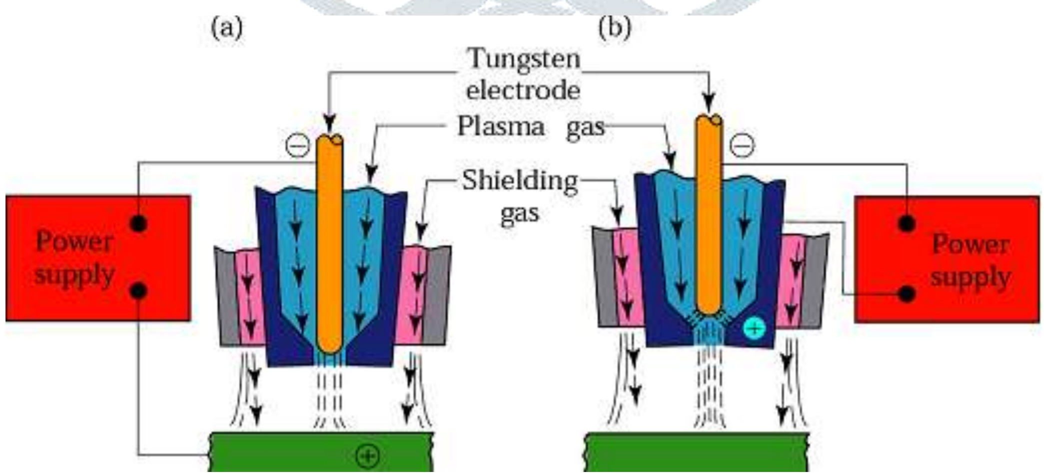
Plasma is defined as a flow of ionized gas. It is obtained by passing the gas through a high temperature arc which results in splitting the molecules of gas to atoms and then to ions and electrons. PAW uses this plasma to transfer an electric arc to a workpiece. The electric arc is formed between an electrode (which is usually but not always made of sintered tungsten) and the workpiece, as in GTAW. The arc in PAW is constricted by making it pass through a narrow passage in a water cooled copper nozzle tip which is itself surrounded by an outer nozzle through which the shielding gas flows.

The key difference from GTAW is that in PAW, by positioning the electrode within the body of the torch, the plasma arc can be separated from the shielding gas envelope. Copper nozzle which squeezes the arc, increases its pressure, temperature and heat intensely and thus improves arc stability, arc shape and heat transfer characteristics. The process employs two inert gases, one forms the arc plasma and the second shields the arc plasma. Filler metal may or may not be added. An argon-hydrogen mixture is generally used as the plasma and shielding gas. However, hydrogen cannot be used as a constituent when welding mild steel or reactive metals such as zirconium or titanium.

Equipment for PAW consists of a DC power supply of constant current, plasma console, water recirculation system, plasma welding torch and torch accessory kit (tips, collets, electrodes, and setup gages). The temperature of a constricted plasma arc may be of the order of 8,000-25,000 °C.

Plasma arc welding process can be divided into two basic types (Fig. 6):

1. **Non-transferred arc process**: The arc is formed between the electrode (–) and the water cooled constricting nozzle (+). Arc plasma comes out of the nozzle as a flame. The arc is independent of the workpiece.
2. **Transferred arc process**: The arc is formed between the electrode (–) and the workpiece (+). In other words, arc is transferred from the electrode to the workpiece.



Transferred Non-transferred

Figure 6: Plasma arc welding

Several basic PAW process variations are possible by varying the current, plasma gas flow rate, and orifice diameter. The variations include **micro-plasma** (<15 amps), **melt-in mode** (15-100 amps), **keyhole mode** (>100 amps).

The plasma process can gently yet consistently start an arc to the tip of wires or other small components and make repeatable welds with very short weld time periods. This is advantageous when welding components such as needles, wires, light bulb filaments, thermocouples, probes, and some surgical instruments. Typically the process is used for making piping and tubing made of steel and titanium.
Though the process has high potential for future use but it has certain drawbacks, e.g., the intense arc results in excessive ultraviolet and infrared radiations and high noise level which can be harmful for the health of operator [4].

2.6Submerged Arc Welding (SAW)

The *American Welding Society* defines submerged arc welding as "an arc welding process which produces coalescence of metals by heating them with an arc(s) between a bare electrode(s) and the workpiece. The arc and molten metal is shielded by a blanket of granular, fusible material on the work. Pressure is not used, and filler metal is obtained from the electrodes and sometimes from a supplemental source (welding rod, flux)."
This process is distinguished from other arc welding processes by the granular material, called flux, which covers the welding area. A thick layer of flux completely covers the molten metal thus preventing spatter and sparks as well as suppressing the intense ultraviolet radiation and fumes. It is responsible for high deposition rates and weld quality that characterize the SAW process in joining and surfacing applications.
Basically, in SAW, the end of a continuous bare wire electrode (1.6-6 mm diameter) is inserted into a mound of flux that covers the area or joint to be welded (Fig. 7). An arc is initiated, causing the base metal, electrode, and flux in the immediate vicinity to melt. The electrode is advanced in the direction of welding and mechanically fed into the arc, while flux is steadily added. The melted base metal and filler metal flow together to form a molten pool in the joint. A hopper and a feeding mechanism are used to provide a flow of flux over the joint being welded.

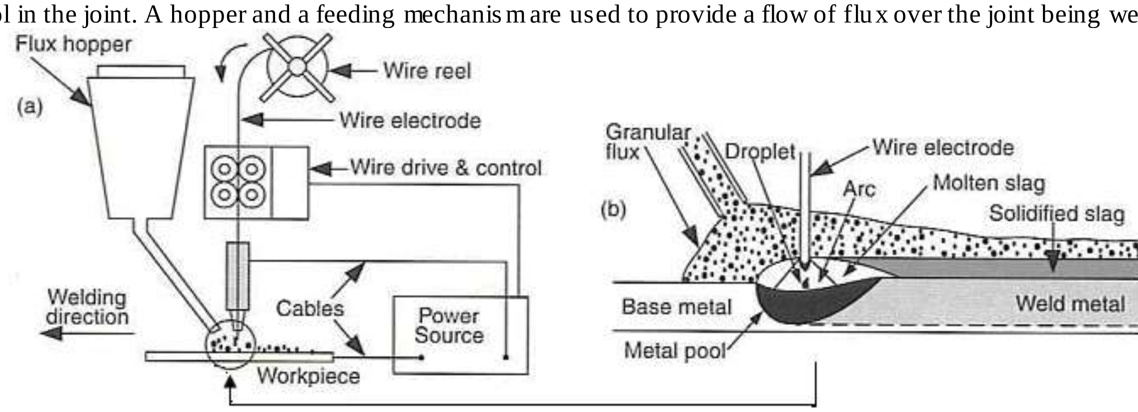


Figure 7: Submerged arc welding [8]

SAW is normally operated in the automatic or mechanized mode, however, semi automatic (hand-held) SAW guns with pressurized or gravity flux feed delivery are also available. Granular fusible flux consists of lime, silica, manganese oxide, calcium fluoride, and other compounds. AC or DC up to 2,000 amps on a single welding wire electrode has beenused and combinations of AC and DC are common on multiple electrode systems. Constant voltage (CV) welding power supplies are most commonly used. Equipment required for SAW includes power source, control unit, wire drive unit or head, flux storage, and nozzle (combines wire and flux in the joint).
This process can provide higher deposition rates and faster travel speeds, and the process is known to produce a very smooth bead with good penetration and excellent fusion. Multiple wires and heads are used for high deposition and large high travel speed joints. The process is widely used for fabrication of thick plates, pipes, pressure vessels, rail tanks, ships, heat exchangers etc. It has become a natural choice in fabrication industries because of its high reliability, smooth finish and high productivity.
This process is commercially suitable for welding of low carbon steel, high strength low alloy steel, nickel-base alloys and stainless steel. The process is normally limited to the flat or horizontal fillet welding positions, although horizontal groove position welds have been done with a special arrangement to support the flux [5].

2.7Arc Stud Welding (ASW)

Stud welding is a general term for joining a metal fastener (weld stud) or similar part to a workpiece. It is a unique process which combines arc and forge welding processes.In it, the base (end) of the stud is joined to the other flat workpiece by heating them with an arc drawn between the two. When the surface to be joined is properly heated, they are brought together under pressure. Stud welding guns are used to hold the studs and move them in proper sequence during welding. The power source and stud welding control system are set to control the amperage and the arc duration. The welding gun has a trigger activated circuit to initiate the weld and a lifting mechanism to draw the stud away from the base material and initiate the welding arc. The process is completed in a couple of seconds. The gun includes stud holding chuck, two legs, foot piece, and ferrule grip to hold ceramic ferrule. Welding sequence of control unit and process is broken down into four steps (Fig. 8).
There are two basic power supplies used to create the arc for welding studs. One type uses DC power sources similar to those used for SMAW. It is referred to as arc stud welding. The other type uses a capacitor storage bank to supply the arc power. It is known as **capacitor-discharge (CD) stud welding**. Stud welding uses a type of flux called a ferrule, a ceramic ring which concentrates the heat generated, prevents oxidation and retains the molten metal in the weld zone. The ferrule is broken off once the weld is completed. A ferrule is not used for CD stud welding and with some nonferrous metals.
The main equipment for stud welding consists of stud welding gun, time control unit, DC power source of 300-600 amps capacity, stud and ceramic ferrule.Welding grade studs are made of most commercially used metals and normally range in diameters from $^{1}/_{8}$-$1^{1}/_{4}$ " (3.2-31.8 mm) with lengths as required.

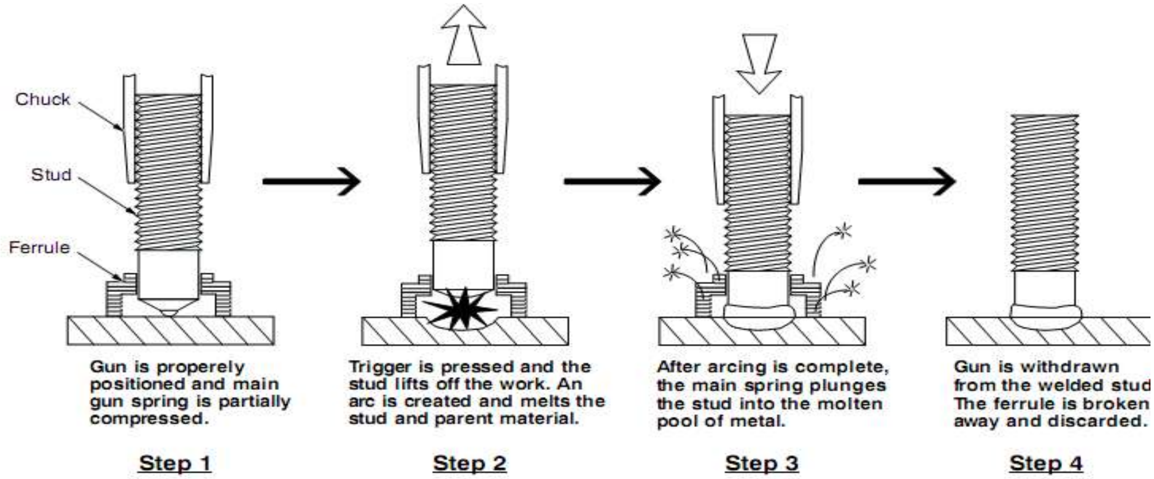


Figure 8: Arc stud welding

The process is used mainly for mild steel, low alloy steel, austenitic stainless steels. Other variants of the process can be utilized for welding lead-free brass, bronze, chrome-plated metals and aluminium. Typical applications include automobile bodies, electrical panels, shipbuilding, manufacturing and building construction industries [2, 4].

2.8Atomic Hydrogen Welding (AHW)

It is an arc welding process that uses an arc between two metal tungsten electrodes in a shielding atmosphere of hydrogen (Fig. 9). Filler metal may or may not be used. In this process, the arc is maintained entirely independent of the work or parts being welded. The work is a part of the electrical circuit only to the extent that a portion of the arc comes in contact with the work, at which time a voltage exists between the work and each electrode.

The welding heat is generated by passing a stream of hydrogen through an electric arc between two inclined electrodes. The high temperature of the arc dissociates molecules of the gas into atoms, a large quantity of heat being absorbed by the hydrogen during dissociation. When the atomic hydrogen strikes a relatively cold surface (weld zone), it recombines into its diatomic form and rapidly releases the stored heat. The flame at the point of reformation of molecular hydrogen has temperature ~4,000 °C, and can thus be used for welding. The process is, therefore, used when rapid welding is necessary, as for stainless steels and other special alloys. The hydrogen envelope prevents oxidation of both the metal and the tungsten electrodes, and it also reduces the risk of nitrogen pickup. The non-oxidizing characteristic is perhaps the most important in practice. The power source is a transformer that has an open circuit voltage of up to 300 volts to strike the arc, but welding current is low, with generally 10-20 amps being used.

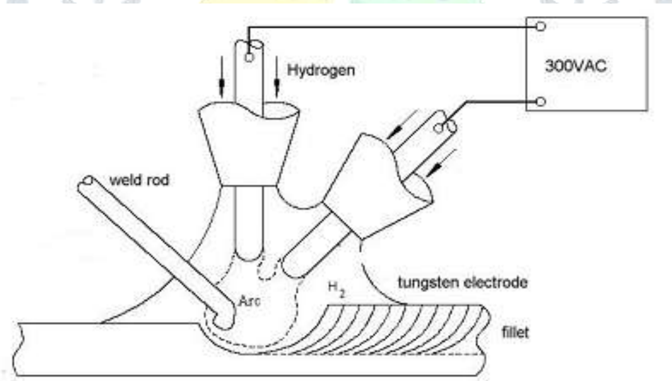


Figure 9: Atomic hydrogen welding

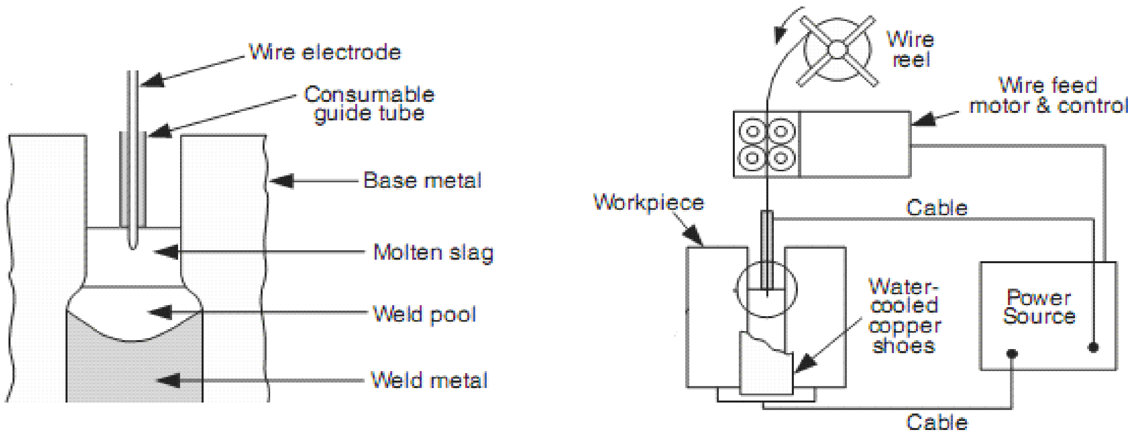
This process is being replaced by SMAW, mainly because of the availability of inexpensive inert gases. Although the process has limited industrial use today, atomic hydrogen welding is used to weld hard-to-weld metals, such as chrome, nickel, molybdenum, steels, inconel, monel, and stainless steel. Its main application is tool and die repair welding and for the manufacture of steel alloy chain [8].

2.9Electro Slag Welding (ESW)

This is a highly productive, single pass welding process for thick materials in a vertical or close to vertical position. As distinct from other fusion welding methods, it depends on the heat generated by the passage of an electric current from the welding rod to the workpiece through the molten pool of a high resistance conductive flux, or slag, hence the name electro slag welding.

The earlier discussed submerged arc welding (SAW) has proved less efficient on thicknesses over 50-60 mm. This is because of the difficulty andimpossibility of making well shaped welds with strong arcs in the down hand position in a single pass.Electroslag welding is a big step forward, and very efficient in these circumstances.

In the process, parts to be joined are positioned and a guide tube is positioned between the parts. Copper cooling shoes or dams are clamped to the sides, bottom and top of the joint and contain the molten slag and metal during the weld (Fig. 10). After the components are assembled, power is applied and the electrode wire is fed downward into the cavity formed by the edges of plate pieces being welded and two dams through the guide tube. A layer of flux is placed at the bottom of the trough. An electric arc is initially struck by this wire for a brief moment to heat the flux and convert it into slag. The molten slag extinguishes the arc, but the current continues to pass through it between the electrode and the work. The electrical resistance offered by molten slag to the electric current provides the heat necessary to melt the wire, the guide tube and the edges of the two components to be joined and to keep the process going. The internal temperature of bath is approximately 1,990 ^{o}C. Since the slag is less dense than liquid steel, it floats to the top and protects the metal from exposure to air. With continuing addition of weld wire, the molten steel fills the gap, solidifies and fuses the two components.



(a) Welding area enlarged. (b) Overall process

Figure 10: Electro slag welding

The electrode could be solid or flux cored, fed at a rate of 20-150 mm/s. One electrode is commonly used to make welds on materials with a thickness of 25-75 mm (1-3"), and thicker pieces generally require more electrodes. Fluxes for the process are usually combinations of oxides of silicon, calcium, magnesium and aluminium with some calcium fluoride always present. Both AC and DC power sources are used with rating of 1,000 amps at an open circuit voltage of 55 volts and a duty cycle of 100 %.

The process is employed essentially for welding low carbon steels. With appropriate precautions, it could also be applied to structural steels capable of higher mechanical properties. Plates and other heavy sections up to 450 mm are commonly welded by this process, e.g., building bridges, shipbuilding, vessels and containers, rails and other industrial applications.Disadvantages are comparatively high heat input levels, vertical-up position only, and the need to access the joint with a guide tube.

Recently, new modifications of the process have been developed, called **narrow gap improved electro slag welding** (NGI-ESW) that demonstrates that higher weld properties can be achieved and guaranteed [2, 5].

2.10Electro Gas Welding (EGW)

It is a development over ESWand resembles it in terms of its design and use. A major difference between the two is that the arc in EGW is not extinguished; instead it remains struck throughout the welding process. Instead of slag, the electrode is melted by an arc which burns in a shielding gas, in the same way as in MIG/MAG welding.

EGW is a continuous vertical position arc welding process in which an arc is struck between a consumable electrode and the workpiece (Fig. 11). The molten metal solidifies from the bottom up, joining the parts being welded together. The weld area is protected from atmospheric contamination by a separate shielding gas, or by the gas produced by the disintegration of a flux cored electrode wire. In general, the workpiece must be at least 10 mm thick; while the maximum thickness for one electrode is approximately20 mm. Additional electrodes make it possible to weld thicker workpieces.The shielding gas used for steel is CO_2 or Ar-CO_2 mixture.EGW uses a constant voltage DC welding power supply, and the electrode has positive polarity. The welding current can be 100-800 amps, while the voltage 30-50 volts. A wire feeder is used to supply the electrode.

EGW can be applied to low and medium carbonsteels, low alloy high strength steels, and stainless steels.Typical applications of EGW represent a whole collection of different manufactured structures, including storage tanks,nuclear components, ship subassemblies, bridges, oil drilling platforms, power generating equipment, and others where the advantages of the process determine its economy [86].

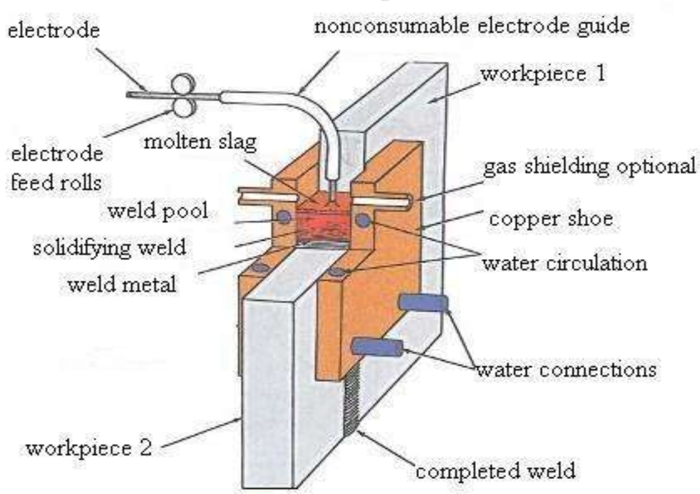


Figure 11: Electro gas welding

3RESISTANCE WELDING PROCESSES

Resistance welding is a group of welding processes in which coalescence is produced by the heat obtained from resistance of the work to electric current in a circuit of which the work is a part and by the application of pressure.

Resistance welding processes differ from all other processes, since filler metal is rarely used and fluxes are not employed. The force applied before, during, and after the current flow forces the heated parts together so that coalescence occurs. Pressure is required throughout the entire welding cycle to assure a continuous electrical circuit through the work.

To create heat, copper electrodes pass an electric current through the workpieces. The heat generated depends on the electrical resistance and thermal conductivity of the metal, and the time during which the current is applied. The heat generated is expressed by the equation $\boldsymbol{E = I^2 \cdot R \cdot t}$, where E is the heat energy, I is the current, R is the electrical resistance and t is the time during which the current is applied.

The resistance is a function of the resistivity and surface condition of the parent material, the size, shape and material of the electrodes and the pressure applied by the electrodes. This type of welding is particularly well suited to all forms of automatic operations. Depending on the shape of the workpieces and the form of the electrodes, resistance welding processes can be classified into several variants as described below [1].

3.1Resistance SpotWelding (RSW)

Overlapping sheets of metal are joined in this process by applying electric current and pressure with copper electrodes in the zone to weld (Fig. 12). Copper is used for electrodes because it has low electrical resistance and high thermal conductivity. Spot welding operation is composed of three steps – squeezing, welding and holding. Squeezing consists of applying the weld force to the workpieces in order to obtain the appropriate amount of pressure, prior to welding. During welding, the electric current passes through the workpieces, while the welding force is maintained, generating heat. In the course of the holding stage current is switched off and weld force maintained, allowing the weld to forge and cool under pressure.

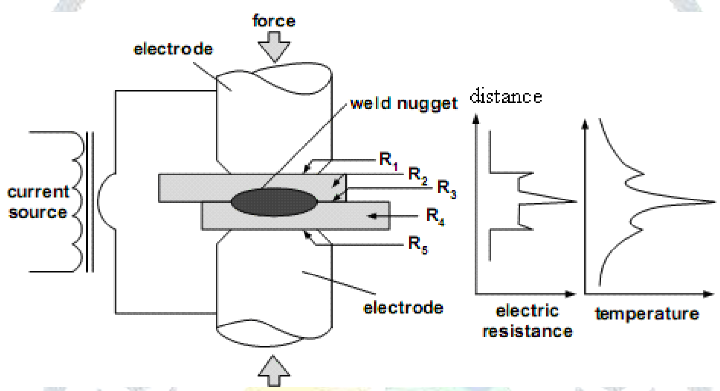


Figure 12: Resistance spot welding

The heat generated depends basically on the electrical current, time for which it is used and on the electrical resistance of materials between electrodes. This inter-electrode resistance is composed of five separate resistances, as indicated in the figure. Resistances R_1 and R_5 are undesirable because they produce heating and consequently degradation of the electrodes. Resistances R_2 and R_4 are the resistances of the workpieces and they assume particular importance in the final period of the weld. Low resistive materials are difficult to weld because of reduced heat generated in the pieces. Resistance R_3 is the most important because it determines nugget formation, assuring the establishment of the weld. The nugget is a volume of melted material that forms in the interface of workpieces with a diameter similar to that of the electrodes.

Spot welding machines are composed of an electrical circuit, which provides welding current, control circuit that regulates welding current and welding time, and mechanical system used to apply welding force.

The process has extensive application in welding of carbon steels because they have higher electrical resistivity and lower thermal conductivity than the electrodes made of copper. Aluminium alloys have an electrical resistivity and thermal conductivity that are closer to those of the copper, making difficult the welding operation of these materials, requiring higher levels of current, which can damage the electrode tips. Other materials such as galvanized steels, heat resisting alloys and reactive metals are also welded by this process. Since the process is very competitive, it is widely used in automotive, aerospace and industrial and domestic equipment manufacturing industries.

The major advantages of this process are the high welding speed and low thermal distortion, respectively faster and lower than in conventional arc welding processes, suitability for automation, the need of low skilled operators and the absence of joint preparation or filler metal. Some limitations of this process are the need for lap joints in thin materials, usually up to a thickness of 4 mm, the joints are not tight and the initial equipment costs are higher than those of conventional arc welding equipment [7].

3.2Resistance Seam Welding(RSEW)

It is similar to RSW. It uses a wheel shaped copper alloy electrode to make either a series of overlapping spot welds to form a continuously welded and leak tight seam, or a number of spot welds spaced apart – **roll-spot welding** (Fig. 13). The electrodes are not opened between spots. The electrode wheels apply a constant force to the workpieces and rotate at a controlled speed. The welding current is normally pulsed to give a series of discrete spots, but may be continuous for certain high speed applications where gaps could otherwise occur between individual spots. The amount of overlap between spots is 25-50 %. The heat generated during welding is high and the rollers must be cooled by using water cooling arrangements, so that distortion of rollers can be avoided.

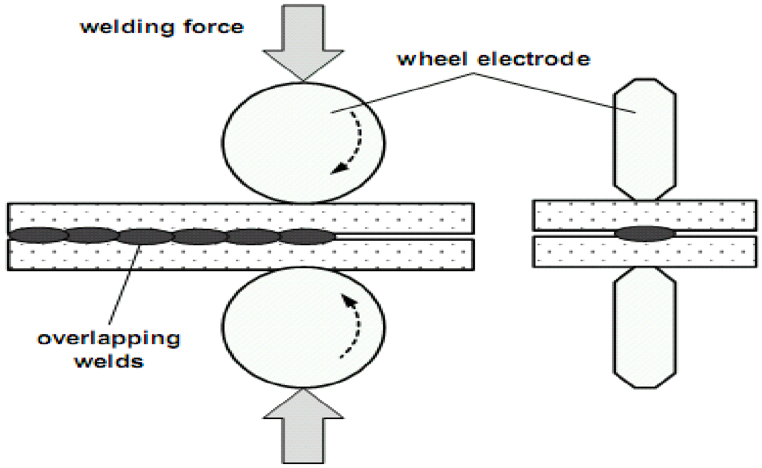


Figure 13: Resistance seam welding

Electrode wheels of 50-610 mm diameters are made of the same materials as those of RSW electrodes and can have internal or external cooling. Current in conventional RSEW machines ranges from 20 to 30 kA; though maximum current up to 100 kA may be applied in welding of light alloys. Clamping forces between 2 to 16 kN and welding speeds ranging from 1 to 12 m/min are used for steels, though lower values are applied for aluminium alloys.

RSEW is largely used in the automotive industry as well as in manufacturing of heat exchangers, non pressurized tanks and several types of cans. Main advantages of this process when compared with RSW are the capacity to produce gas tight and liquid tight welds as well as the possibility of reduction of the overlap width of the sheets. However, the weld must progress in a straight line or in a uniformly curved line of large radius and thermal distortion can be higher than in RSW [5, 7].

3.3Projection Welding (PW)

Projection welding is a modification of spot welding in which a number of spot welds are made at one time. To achieve this, small projections are made on one part by embossing (sheet metal parts) or machining (solid metal parts) usually on thicker or higher electrical conductivity part of the joint. These act to localize the heat of the welding circuit, because when placed together, the parts or sheets touch only at the points of projections. Projection collapses due to heat and pressure and a fused nugget is formed at the interface.

The equipment used in PW process is similar to that used for spot welding except that the rod electrodes are replaced by the flat copper platens or dies (Fig. 14).

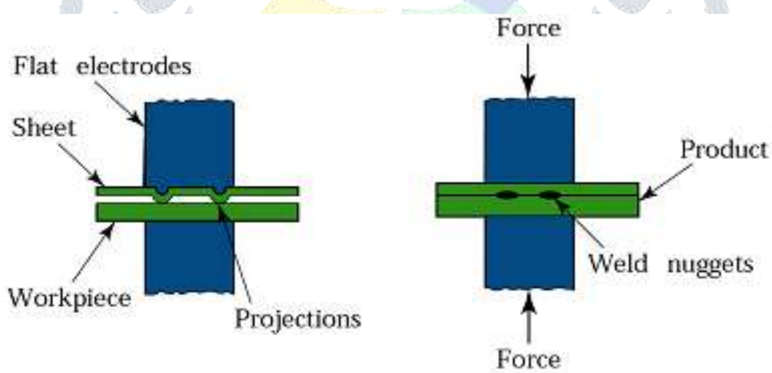


Figure 14: Projection welding

Projection welding finds wide use in joining small attachments to sheet structure, weld studs, nuts, and other screw machine parts to metal plate and particularly applicable to mass production work. Reinforcement rings are often projection welded around holes in sheet metal tanks. It is not used for seams longer than 250 mm. Cross wire welding is another important application of this process. Cross wire products include such items as racks, grills, wire baskets, concrete reinforcing mesh.

Low carbon steels, high carbon and low alloy steels, stainless and high alloy steel, nickel base alloys, copper and its alloys are materials suitable for projection welding. The major advantage of this process is that electrode life is increased because larger contact surfaces are used [4].

3.4Flash Welding (FW)

This process produces a weld at the faying surfaces of a butt joint by a flashing action and by the application of pressure after heating is substantially completed. The flashing action is caused by very high current densities at small contact points between the workpieces. It forcibly expels the material from the joint as the workpieces are slowly moved together. The weld is completed by a rapid upsetting of the workpieces. The flashing and upsetting are accompanied by expulsion of metal from the joint (Fig. 15).

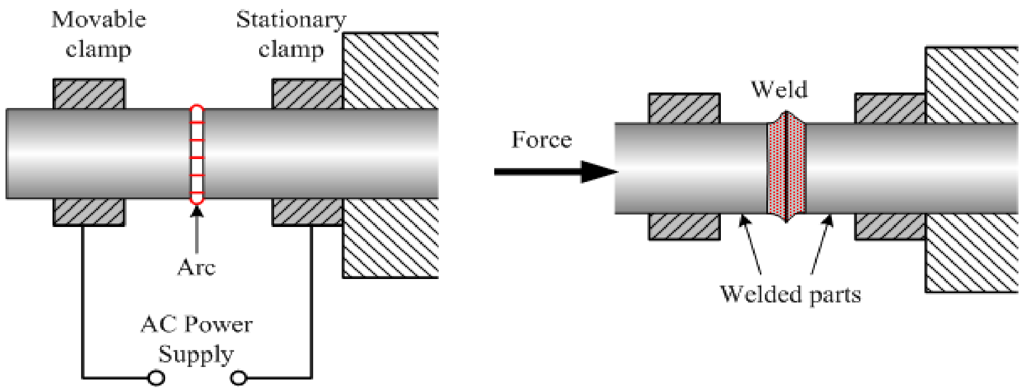


Figure 15: Flash welding

The components to be joined are clamped in jaws of flash welding machine, one piece is held firmly by a clamping device attached to a stationary platen, while the other piece is clamped to a movable platen. During the welding operation, there is an intense flashing arc and heating of the metal on the surfaces abutting each other. After a predetermined time, the two pieces are forced together and joining occurs at the interface. Current flow is possible because of the light contact between the two parts being flash welded. Heat is generated by the flashing and is localized in the area between the two parts. The surfaces are brought to the melting point and expelled through the abutting area. As soon as this material is flashed away, another small arc is formed which continues until the entire abutting surfaces are at the melting temperature. Pressure is then applied. The arcs are extinguished and upsetting occurs.
The upset force is around 7 kN/cm^2 for mild steel and nearly four times that for high strength materials. For tubing or hollow members, the pressures are reduced. Clamps must provide suitable electrical contacts for heavy currents and usually have wear resistance copper alloy inserts in water cooled blocks. The distance between the jaws after welding compared to the distance before welding is known as the burn-off. It can be from $^1/_8$" (3.2 mm) for thin material up to several inches for heavy material.
Welding currents are high and are related to the following: 50 kVA/in^{2}of cross section for 8 seconds. It is desirable to use the lowest flashing voltage at a desired flashing speed. The lowest voltage is normally 2-5 volts/in^2 of cross section of the weld.
Flash Welding can be used for joining many ferrous and nonferrous alloys and combinations of dissimilar metals. Flash butt welding is widely employed in the wheel rims for automobiles, long welded rails, aircraft, window frames etc. In the case of mooring chain manufacturing, it is often the best and sometimes the only possible method. Flash butt welding is considered superior to upset butt welding [1, 4].

3.5Upset Welding (UW)

In upset welding or **resistance butt welding**, coalescence is produced simultaneously over the entire area of abutting surfaces or progressively along a joint, by the heat obtained from resistance to electric current through the area where those surfaces are in contact. Pressure is applied before heating is started and is maintained throughout the heating period.
The parts are clamped in the welding machine and force is applied bringing them tightly together (Fig. 16). High amperage current is then passed through the joint, which heats the abutting surfaces. When they have been heated to a suitable forging temperature, an upsetting force is applied and the current is stopped. The high temperature of the work at the abutting surfaces plus the high pressure causes coalescence to take place. After cooling, the force is released and the weld is completed.

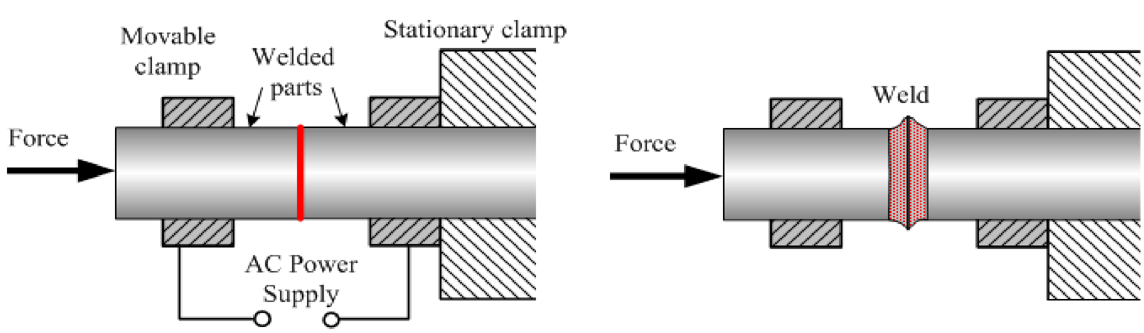


Figure 16: Upset welding

The equipment used for upset welding is very similar to that used for FW. It can be used only if the parts to be welded are equal in cross sectional area. The difference from FW is that in UW no arcing (and hence flashing) takes place between the surfaces being joined. Heat application in FW precedes the pressure whereas in butt welding constant pressure is applied during the heating process which eliminates flashing.
UW has the advantage of creating no flash spatter and a smooth and symmetrical upset. It is used principally on nonferrous materials for welding bars, rods, wire, tubing, large sized rings and cylinders etc. The important application of this process is the large scale production of tubes and pipes at high rate of production [4].

3.6Percussion Welding (PEW)

It produces coalescence of the abutting members using heat from an arc produced by a rapid discharge of electrical energy. Pressure is applied progressively during or immediately following the electrical discharge. The process is quite similar to FW and UW, but is limited to parts of the same geometry and cross section. It is more complex than the other two processes in that heat is obtained from an arc produced at the abutting surfaces by the very rapid discharge of stored electrical energy across a rapidly decreasing air gap. This is immediately followed by application of pressure to provide an impact bringing the two parts together in a progressive percussive manner (Fig. 1.17).

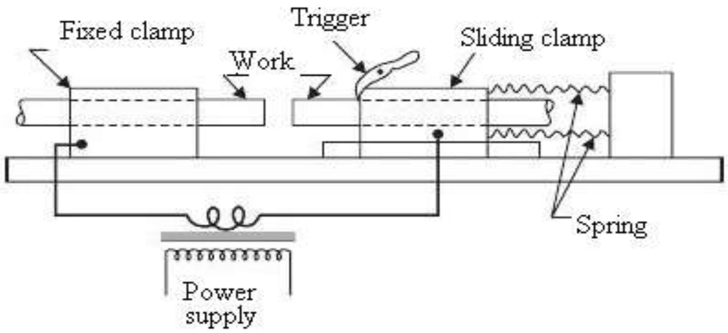


Figure 17: Percussion welding

The advantage of the process is that there is an extremely shallow depth of heating and time cycle is very short(0.001-0.1 sec). Percussion welding is used to join dissimilar metals together, e.g. stellite tips to tool shanks, copper to aluminium or stainless steel, silvercontact tips to copper, copper to nichrome, zinc to steel. This is widely used in electronic industry and is a good method for joining small diameter wires (0.05-0.4 mm). These welds are produced without flash or upset at the joint. This type of welding is limited to the materials having the same cross sectional areas (up to 650 mm^2) and geometries [4].

3.7High Frequency Resistance Welding (HFRW)

In HFRW, a high frequencycurrent (300~1,000 kHz) isapplied to the welding area, and a squeezeforce is applied to the workpiece heatedfrom the heat resistance. Acontactor is applied to the workpiece to directly provide the current (Fig. 18).

The resistance heat is concentrated on the welding surface due to the skin effect wherein the current is concentrated on the conductor surface on account of the high frequency, and the proximity effect wherein the current is concentrated on the surface of two conductors as they approach each other. The resistance heat generated by the current causes partial melting, and the melting surface is compressed by the squeeze roller, excreting oxided material from the melting surface to generate a weld.

The process is ideally suited for making pipes, tubing, structural shapes and other manufactured items made from continuous strips of material. Materials that can be successfully welded into tubes and pipes include carbon steels, stainless steels, aluminium, copper, brass, and titanium. The major advantage of HFRW is the relatively high welding speeds, sometimes greater than 100 m/min, which can be obtained [8, 9].

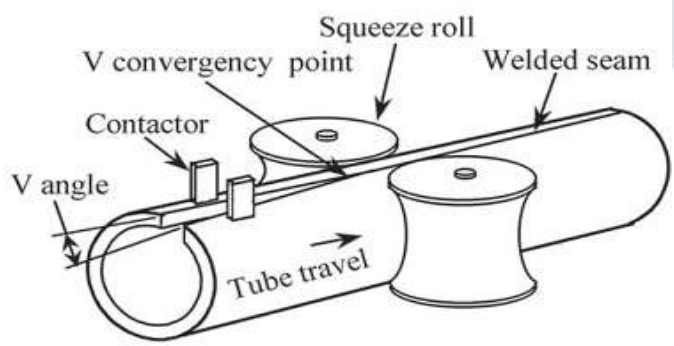


Figure 18: High frequency resistance welding

3.8High Frequency Induction Welding (HFIW)

This process differs from HFRW in that the current is induced in the surfacelayer by a coil wound around the workpiece. This causes surface layer to be heated. Weld is formed by a forging action ofthe joint.

An induction coil is used in inducing high frequency current to generate heat. The weld current is transmitted to the material through the coil in front of the weld point (Fig. 19). The coil does not contact the tube or work. The electrical current is induced into the material through magnetic fields that surround the tube. Closure of the tube isaccomplished by a set of pinch rolls at a “vee” location of the configuration. Currentflow in the tube occurs around the body of the tube, along the edges of the vee, and finally acrossthe apex of the vee itself. The vee effectively acts as a current concentrator; localizing the heat. HFIW eliminates contact marks and reduces the setup required when changing tube size. The process typically uses current frequency of 100~450 kHz.

HFIW is primarilyused in joining small diameter steel pipes,while HFRW is used for largediameters.

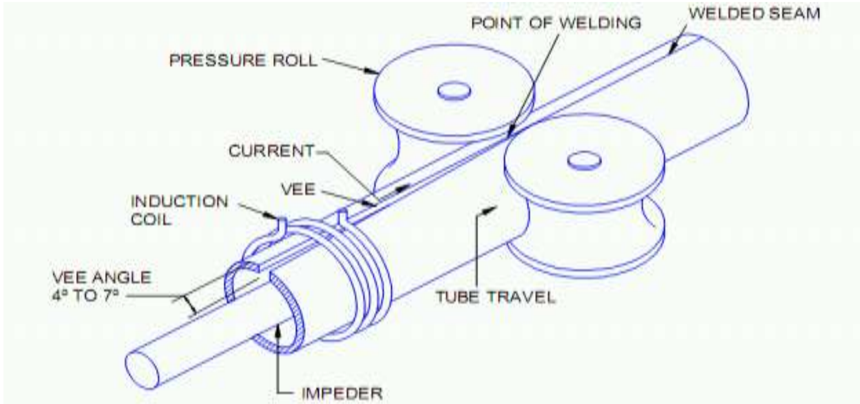


Figure 19: High frequency induction welding

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