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A Review on Advance Welding Processes

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Abstract:

This paper presents a review on advance welding process in practice. The objective is to present various aspects and relative merits of various welding processes in use in industries. The important considerations and application areas of these techniques are discussed in this paper.

1.Introduction

When compared with other joining methods, such as riveting and bolting, welded structures tend to be stronger, lighter weight and cheaper to produce. A large number of processes comprise the family of welding technologies, and include methods for welding metals, polymers, and ceramics, as well as emerging composite and engineering materials. These process variants of welding allow a great deal of flexibility in the design of components to be welded. They also encourage designing for optimal cost effectiveness in terms of productivity and product performance. Safety is also a major consideration when welding is adopted. This is because it uses electricity and flammable materials, and creates a lot of sparks in some instances.

Most of the welding processes could not get their due importance in the production scenario at the time of their developments, except for repair welding. However, at later stages all of them found their niches in manufacturing environment. Presently, welding is widely being used in fabrication of pressure vessels, bridges, building structures, air and space crafts, railway coaches, shipbuilding, automobiles, electrical, electronic and defense industries and general applications.

2.Solid State Welding Processes

Solid state welding processes produce coalescence by the application of pressure at welding temperature below the melting point of the base materials being joined, without the addition of a filler metal. Joining of two surfaces takes place by atomic bonding; process does not involve melting of the materials. As the surfaces are pressed together, atoms on the two surfaces attract each other to form bonds between the surfaces. The bonds thus formed are responsible for the joining process. Mechanical properties of the weld are similar to those of the parent metals. The process is commonly used for welding dissimilar materials, such as aluminium with steel in ship hulls or compound plates.

2.1.Forge Welding

Forge welding or smith welding is the oldest known welding process in which low carbon steel parts are heated to about 1,000 °C and then forged (hammered) together, either using a power hammer or manually, until they form a solid structure of metal. Besides being united by blows from a hammer, the workpieces may also be welded by being rolled, drawn or squeezed together. Flux is used to prevent the welding surfaces from oxidizing and producing a poor quality weld. Fluxes commonly used for low carbon steel are flour spar and borax.

One of the most famous applications of forge welding is in the production of pattern welded blades. An excellent living example of forge welded component of olden days is the *Iron Pillar* of Delhi.

Forge welding requires considerable skill on the part of the operator to achieve a good weld. It is restricted to wrought iron and mild steel. The process is of historic significance in the development of manufacturing technology; however, it is of minor commercial importance today.

2.2.Friction Welding

In friction welding, coalescence is achieved by frictional heat combined with pressure. The heat is generated by the friction between the two components surfaces, usually by rotation of one part relative to the other. Then the parts are driven toward each other with sufficient force to form a metallurgical bond. The sequence is portrayed in Fig. 1 for a typical application of this operation, welding of two cylindrical parts.

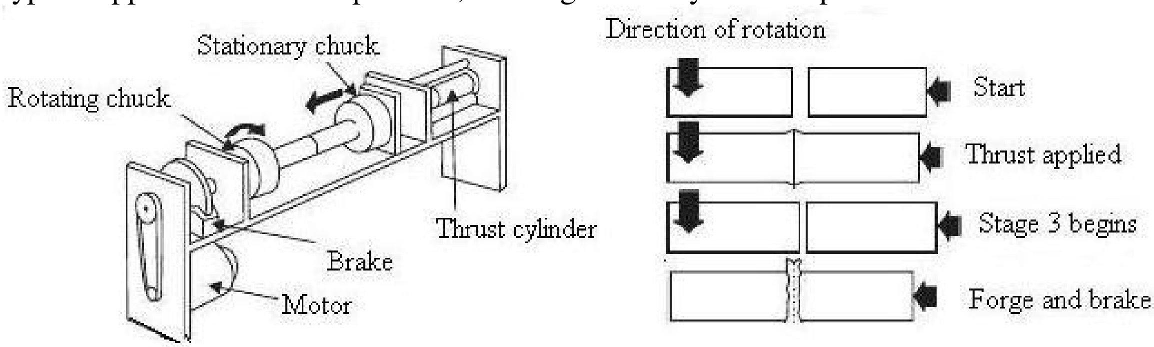


Figure 1: Friction welding [1]

The axial compression force upsets the parts, and the material displaced produces a flash. The flash must be subsequently trimmed to provide a smooth surface in the weld region. No filler metal, flux, or shielding gases are required.

Machines used for friction welding have the appearance of an engine lathe. They require a high spindle speed (12,000 rpm) to turn one part at high speed and a means of applying an axial pressure (~ 50 kN/cm^2) between the rotating and the non-rotating parts. There are two types of friction welding variations, continuous drive friction welding and inertia welding.

Friction welding can produce high quality welds in a short cycle time, thus it is suitable for automatic mass production. The process is capable of welding carbon steels, alloy steels, stainless steels, aluminium alloys, copper alloys, nickel alloys. It can also be used to join many combinations of dissimilar metals. This is particularly useful in the aerospace field, where it is used to join light weight aluminium stock to high strength steels. It requires relatively expensive apparatus, similar to a machine tool. It is restricted to flat and angular butt welds, where one part is normal to the other part. One recent development of a special friction welding process, known as friction stir welding, has been used particularly on aluminium alloys.

2.3.Explosive Welding (EXW)

In explosive welding, also known as explosive bonding, parts to be welded are metallurgically bonded as a result of oblique impact pressure exerted on them by a controlled detonation of an explosive charge.

In this setup (Fig. 2), the two plates are in a parallel configuration, separated by a certain gap distance, with the explosive charge put above the upper plate, called the flyer plate. A buffer layer (rubber or plastic) is often used between the explosive and the flyer plate to protect its surface from the explosion effects. The lower plate, called the backer metal, rests on an anvil for support. When the explosive is detonated on the surface of the flyer plate, a high pressure pulse is generated, which propels the metal at a very high speed (2,400-3,600 m/s). If this piece of metal collides at an angle with another piece of metal, welding may occur. For welding to occur, a jetting action is required at the collision interface. This jet is the product of the surfaces of the two pieces of metals colliding. It cleans the metals and allows their surfaces to join under extremely high pressure. The metals do not commingle, they are atomically bonded. Due to this fact, any metal may be welded to any other metal.

The plate collision velocity is typically in the 250-500 m/s range and collision angle varies between 1-10 ^{o}. The pressure produced at the interface of the impacting plates by such a high velocity is the order of 70-700 kN/cm^2. The commonly used high explosive is ammonium nitrate. The standoff distance typically varies from 0.5 to 4 times the cladding sheet thickness. The process can weld a parent plate of thickness 0.025 mm-1 m (the maximum flyer plate thickness is one third that of the parent plate).

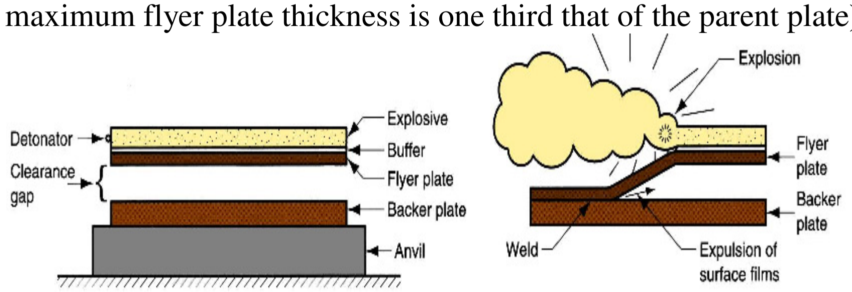


Figure 2: Explosive welding [2]

The advantage of explosive welding technique is high quality bonding, high strength, no distortions, no porosity, and no change of the metal microstructure. It is commonly used to bond two dissimilar metals, particularly in cladding of metals. Common applications are aluminium to steel or to titanium or to copper-nickel for shipboard construction and titanium to stainless steel for aerospace and aircraft application. More recently the process has been used to produce corrosion resistant pressure vessels, transition joints for shipbuilding, and heat exchangers for nuclear installations.Explosion welding is limited to the bonding of flat surfaces or coaxial cylindrical surfaces. Because of the unique safety and noise/vibration considerations, EXW is generally performed in relatively isolated facilities by companies specially engaged in explosives operations [3, 4].

2.4.Ultrasonic Welding

It produces coalescence through simultaneous application of localized high frequency vibratory energy and moderate clamping forces. Parts to be joined are held together under pressure and are then subjected to ultrasonic vibrations usually at a frequency of 20, 30 or 40 kHz.

An ultrasonic welding machine consists of four main components – power supply, converter, amplitude modifying device commonly called a booster and acoustic tool known as horn or sonotrode (Fig. 3). The power supply changes electricity from the mains frequency of 50-60 Hz to a high frequency of 20, 30 or 40 kHz. This electrical energy is supplied to the converter. Within the converter, discs of piezoelectric material are sandwiched between two metal sections. The converter changes the electrical energy into mechanical vibratory energy at ultrasonic frequencies. The vibratory energy is then transmitted through the booster, which increases the amplitude of the sound waves. The sound waves are then transmitted to the horn. The horn is an acoustic tool that transfers the vibratory energy directly to the parts being assembled, and it also applies a welding pressure. The vibrations are transmitted through the workpiece to the joint area. Here the vibratory energy is converted to heat through friction. The heat softens or melts the material, and joins the parts together.

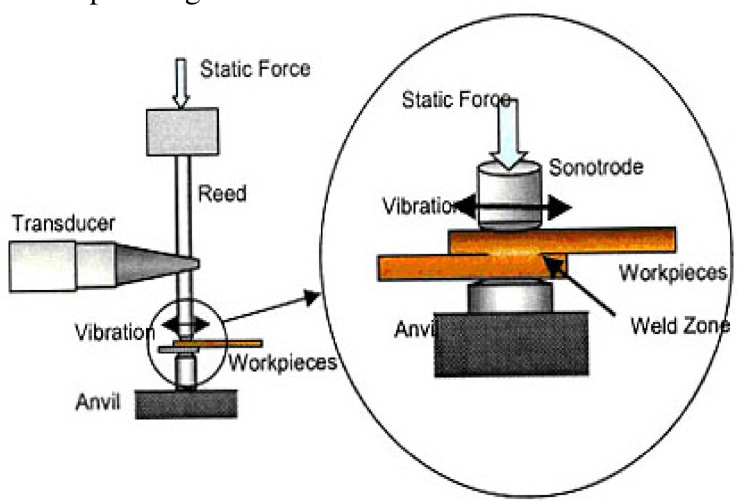


Figure 3: Ultrasonic welding

The process is fast, economical, easily automated, and well suited for mass production. It is commonly used for joining thermoplastic parts and dissimilar materials like aluminium to steel or to tungsten, and nickel to brass. The applications of ultrasonic welding are extensive and are found in many industries including electrical and computer, automotive and aerospace, medical, and packaging. These include liquid bearing vessels, switches, fuel filters, microcircuit connections, hospital gowns, sterile garments, masks, toys, sealing containers, tubes and packaging of dangerous materials such as explosives and other reactive chemicals.

The main limitation of the process is that the maximum component length that can be welded by a single horn is approximately 250 mm [5].

2.5.Cold Pressure Welding

In this process, pressure is used to produce a weld at room temperature with substantial deformation of the weld. Unlike in the fusion welding processes, no liquid or molten phase is present in the joint. Welding is accomplished by using high pressures on clean interfacing materials. The principle involves pressing the parts together with such force that plastic deformation causes any residual oxide layers to be pressed out and a metallic bond to be made (Fig. 4). The pressure may be applied manually or with power driven sources. Because of the plastic deformation involved, it is necessary that at least one (but preferably both) of the mating parts be ductile. In order to produce satisfactory metallurgical bond in cold welding, it is essential to remove the contamination layers between the surfaces of two metals to be joined. These layers are composed of oxides, grease, humidity and dust particles.

If the pressure is applied by means of rolls to cause deformation at the faying surfaces then this process is termed as **roll welding**.

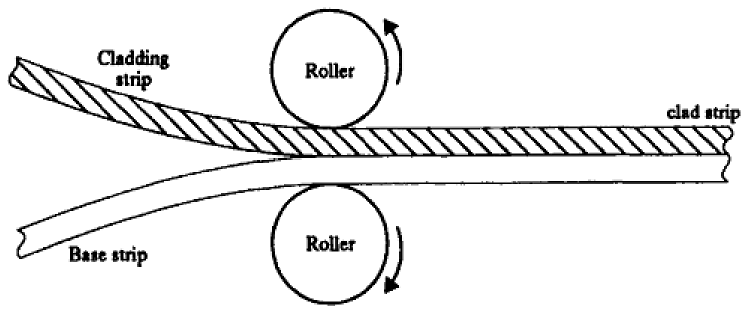


Figure 4: Cold pressure welding [6]

The method is often used for electrical connections, as well as to weld dissimilar metals such as aluminium to stainless steel. An example is the connection terminal of copper which can be cold pressure welded to aluminium conductors. Applications of cold welding include cladding stainless steel to mild steel for corrosion resistance, joining of wire, sealing of heat sensitive containers such as those containing explosives and detonators and producing sandwich strips for coins. Butt joints are primarily used for joining wires and rods of 0.5-12 mm diameters. Where the application demands joining of lapped sheets to themselves or bars, a series of small welds can be used [7].

2.6.Diffusion Welding

It produces coalescence of the faying surfaces by the application of pressure and elevated temperatures. The principal mechanism is inter-diffusion of atoms across the interface. The two materials are pressed together at an elevated temperature usually between 50-70 % of the absolute melting point of the parent material, for a time ranging from a few minutes to a few hours. The surfaces to be joined must be clean, flat and accurately machined. The pressure is used to relieve the voids that may occur due to different surface topographies. Diffusion bonding of most metals is conducted in vacuum or in an inert atmosphere (dry nitrogen, argon or helium) in order to reduce detrimental oxidation of the faying surfaces. Heating is usually accomplished in an induction furnace.

Diffusion welding is normally used on sheet metal structures. The process is used to join both similar and dissimilar metals, and in the latter case a filler layer of a different metal is often sandwiched between the two base metals to promote diffusion, e.g. joining of titanium alloy with stainless steel can be achieved by having interlayer made of Ni/Cu/V combination. Thus, the joint will have stainless steel/Ni/Cu/V/Ti-Al-4V interface. Typical materials that are welded include steel to tungsten, stainless steel to titanium, gold to copper alloys, copper to titanium, etc.

Diffusion welding is used in aerospace, electronics, nuclear applications, manufacturing composite materials. Al/Zr joints are used in nuclear fuel element constructions. The process is used in aerospace industry for fabricating complex shaped components of titanium from simple structure shapes [7].

2.7.Hot Pressure Welding

It produces coalescence of materials with heat and the application of pressure sufficient to produce macro deformation of the base metal. Fusion of materials takes place at the point of contact of the parts to be welded, by the application of heat and pressure that leads to deformation. The deformation of the surface results in cracking of the surface oxide film and increasing the area of clean metal. The process is generally accomplished in closed chambers where vacuum or a shielding medium may be used. There is one variation of hot pressure welding, hot isostatic pressure welding, which involves applying pressure with the help of a hot inert gas in a pressure vessel.

The most important parameter of the process is the pressure sequence cycle, possibly being developed by trial and error. Pressure in the range of 40-70 MPa must be available. The materials commonly joined by hot pressure welding are carbon, low alloy steels, and certain nonferrous metals. It is used primarily in the production of weldments for the aerospace industry and welding of railroad sections and steel reinforcing bars [7].

3.Radiant Energy Welding Processes

In radiant energy method, a stream of electrons or a beam of electromagnetic radiations is used to provide heat at the point of welding. Unlike the arc or gas welding processes, this process can be carried out in vacuum or at low pressure and hence the welds of highest quality can be produced.

3.1 Electron Beam Welding (EBW)

Electron beam welding is a fusion welding process in which coalescence is produced by the heat obtained from the concentrated beam composed of high velocity electrons. The electrons strike the workpiece, their kinetic energy changes to thermal energy, thereby vaporizing, melting and fusing the workpiece metal. Welding is often done in a vacuum environment to prevent dispersion of the electron beam.

In the equipment for this process, electrons are emitted by a cathode, accelerated by a ring shaped anode, focused by means of an electromagnetic coil, and finally they impinge on the workpiece (Fig. 5). The cathode of the electron beam gun is a negatively charged filament. The work handling system maneuvers the job under the beam in a desired manner to complete the weld. The beam currents and the accelerating voltages employed for typical EBW vary over the ranges of 50-1,000 mA and 30-175 kV, respectively. The beam power is an indicator of its ability to do work, and determines the power density (generally 100-10,000 kW/in^2).

Depending upon the degree of vacuum used, the three commercial versions of the EBW process are: hard vacuum, soft vacuum and non-vacuum. With a very high power density in EBW, full-penetration keyholing is possible even in thick workpieces. Joints that require multiple pass arc welding can be welded in a single pass at a high welding speed. Consequently, the total heat input per unit length of the weld is much lower than that in arc welding, resulting in a very narrow heat affected zone and little distortion. The major advantage of the process is its tremendous penetration.

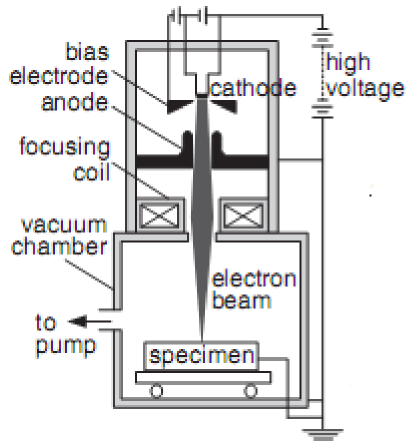


Figure 5: Electron beam welding [8]

Welding can be done over a wide range of thicknesses (0.1-100 mm) and dissimilar metals can be easily welded due to precise heat control. EBW may be used for joining metals that can hardly be welded by other welding methods: refractory metals (tungsten, molybdenum, niobium) and chemically active metals (titanium, zirconium, beryllium). The process is used mainly for fabricating structures that have stringent quality, strength, and joint reliability requirements. Typical applications of EBW include fabrication of large casing structures and fuel tanks for ballistic, naval and cruise missiles, welding of gears and fabrication of fuel rods and other components of the nuclear power reactors. EBW is cost effective for many mass production applications, such as welding of pistons that have an oil cooling cavity.

A disadvantage of this process is its high capital cost to operate [7, 9].

3.2.Laser Beam Welding (LBW)

LBW and EBW processes are quite similar, differing most notably in their source of power. LBW employs a highly focused laser beam, while EBW is done in vacuum and uses an electron beam. Both have a very high energy density (~1 MW/cm^2), making deep weld penetration possible and minimizing the size of the weld area. Both processes are extremely fast, and are easily automated, making them highly productive.

In LBW heat is generated by a focused laser beam impinging on the joint (Fig. 6). A laser consists of a high power coherent monochromatic light beam which can be focused to a small spot, producing a very high energy density. Laser is the acronym for light amplification by stimulated emission of radiation. The laser beam can be focused and directed by optical means to achieve high power. The focus point is arranged to fall on or slightly below the surface of the workpiece. The material immediately melts, with some even being vaporized. The process does not require a vacuum chamber. The shielding gas for protecting the molten metal can be directed sideways to blow and deflect the plasma away from the beam path. Helium is often preferred to argon as the shielding gas for high power LBW because of greater penetration depth.

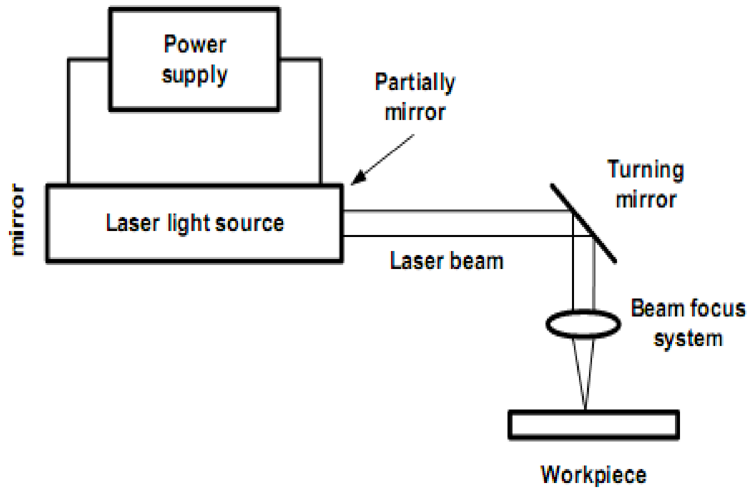


Figure 6: Laser beam welding

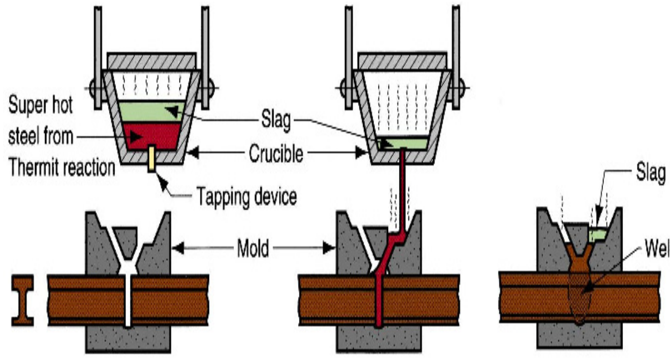
The most common types of welding lasers are the CO_2 laser and the Nd:YAG laser, with the latter tending to be used for thinner materials and the former for thicker ones. A continuous or pulsed laser beam may be used depending upon the application. Milliseconds long pulses are used to weld thin materials such as razor blades, while continuous laser systems are employed for deep welds.

The laser beam has been used to weld carbon steels, high strength low alloy steels, aluminium, stainless steel and titanium. The process can weld most diverse combination of metals used in micro electronics such as gold and silicon, germanium and gold, copper and aluminium. LBW is being used for an extensive variety of applications in the automotive, semiconductor, and electronic industries. More recently, it has been used in such diverse fields as medical instruments manufacturing where heart pace makers and dental instruments are laser welded, and nuclear and naval equipment where containers and sheet metal are also laser welded. Material thickness up to 10 mm has been successfully welded by this process.

Like EBW, the equipment cost is very high, and precise joint setup and alignment are required. Developments in this area include **laser hybrid welding**, which uses principles from both LBW and arc welding for even better weld properties [1, 7, 8].

4.Thermit Welding

Thermit welding is an exothermic welding process in which workpieces are joined by heat obtained from chemical reaction of a thermit mixture consisting of iron oxide and aluminium powder. Commonly 5 parts of iron oxide red powder (rust) and 3 parts of aluminium powder by weight is ignited at high temperatures, resulting in molten iron and slag (Al_2O_3) releasing enormous amount of heat (Fig. 7). The molten iron is the actual welding material; aluminium oxide is much less dense than liquid iron and floats to the top allowing liquid iron to fill the mould surrounding the part to be welded. The mould and slag is removed after the solidification of metal is complete, to give the necessary shape to the weld.



Thermit ignited metal flows into mold   crucible tapped, superheated   metal solidifies to produce weld joint

Figure 7: Thermit welding [2]

Thermit welding has been used for many special applications such as welding stern frames for *Liberty* ships of World War II era. This process is extensively used for joining rails at site, reinforcing bars, large thick I beams and for joining of copper aluminium conductors for electronic industry.

The process consumes more time and is best suited for remote locations where sophisticated welding equipments and power supply cannot be arranged [4, 7].

5.Gas Welding Processes

Gas welding is one of the oldest methods of welding; however, its use today is a lot less common. Nevertheless, it is a versatile method because it can weld most of the commonly employed engineering materials and their alloys.

Oxyfuel gas welding is a general term used to describe any welding process that uses a fuel gas combined with oxygen to produce a flame. The flame is the source of the heat that is used to melt the metals at the joint. The commonly used gases are acetylene, hydrogen and natural gas. There are three major processes in this group: oxyhydrogen, oxyacetylene and pressure gas welding. Oxyhydrogen welding uses hydrogen as fuel gas; however, it is not very popular.

5.1.Oxyacetylene Welding (OAW)

It is the most commonly used gas welding process because of its high flame temperature, which is produced by the combustion mixture of acetylene with oxygen directed by a torch. The intense heat of the flame (3,482 ^{o}C) melts the surface of the base metal to form a molten pool. Filler metal is added to fill gaps or grooves. As the flame moves along the joint, the melted base metal and filler metal solidify to produce the weld.

Equipment for OAW essentially consists of gas bottles, pressure regulators, gas hoses, flashback arresters and welding torches (Fig. 8). The main advantage of the process is that the equipment is simple, portable, and inexpensive. Therefore, it is convenient for maintenance and repair applications. Metal thicknesses up to about 6 mm can be welded. Applications for gas welding include welding of pipes and tubes.

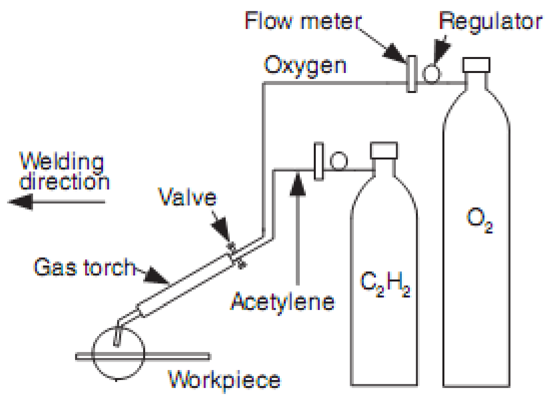


Figure 8: Oxyacetylene welding [8]

Combustion of acetylene proceeds in two stages:

1. Inner core of the flame: $C_2H_2 + O_2 = 2CO + H_2$ + heat
2. Outer envelope of the flame: $2CO + H_2 + 1.5O_2 = 2CO_2 + H_2O$ + heat

Depending on the proportion of the fuel gas and oxygen in the combustion mixture, the three types of welding flames can be obtained: neutral (equal levels of oxygen and acetylene), oxidizing (excess of oxygen), and carburizing (excess of acetylene gas) (Fig. 9). The basic requirement for a good weld is that the size and type of the flame should be suited to the type of work. Neutral flame has the widest application such as welding of low carbon steel, cast steel, cast iron etc. Oxidizing flame is preferred for steel, brass and bronze, whereas carburizing or reducing flame is used for welding of aluminum and nickel. The OAW is not recommended for welding reactive metals such as titanium and zirconium because of its limited protection power and low welding speed [1, 4, 8].

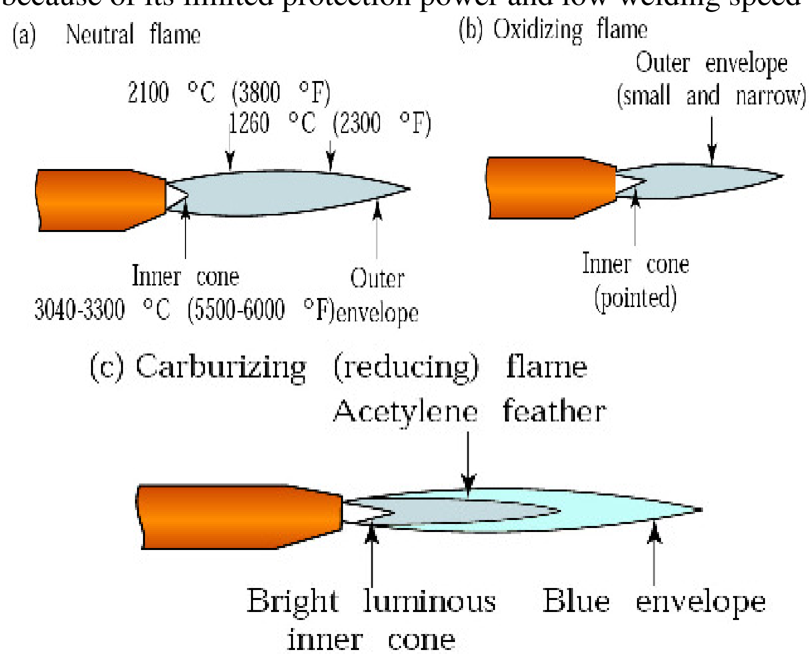


Figure 9: Types of oxyacetylene flames [9]

5.2.Pressure Gas Welding

Pressure gas welding is a slight variant of the oxyfuel gas welding process, the parts to be joined are heated by oxyacetylene flame and then axial pressure of 3-7 N/mm^2 is applied (Fig. 10). The joint is normally of an upset weld type and the process does not require filler material. Most commonly, the process is used for joining of reinforcing steel bars [4].

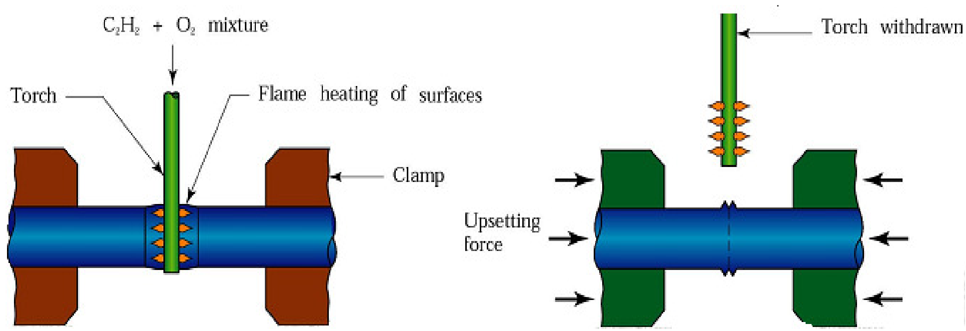


Figure 10: Pressure gas welding [9]

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