

Recommended Practices for Plasma Arc Cutting and Gouging



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Key Words—Plasma arc cutting, gouging,
constricted arc, ionizing gas, nozzle,
safety

AWS C5.2:2001
An American National Standard

Approved by
American National Standards Institute
May 4, 2001

Recommended Practices for Plasma Arc Cutting and Gouging

Supersedes AWS C5.2-83

Prepared by
AWS C5 Committee on Arc Welding and Cutting

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Abstract

This revised recommended practice provides information regarding current practices for plasma arc cutting and gouging. The document explains the basic principles of operation, methods of operation, system components and their installation, optimization of cut quality, and cost considerations. Safety aspects associated with the process are also discussed.



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International Standard Book Number: 0-87171-648-8

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Foreword

(This Foreword is not a part of [AWS C5.2:2001](#), *Recommended Practices for Plasma Arc Cutting and Gouging*, but is included for information purposes only.)

These recommended practices were first prepared by the AWS C5J Subcommittee on Plasma Arc Cutting of the AWS Committee on Arc Welding and Cutting in 1973. The document was revised and substantially expanded in 1983. This current revision provides additional updated information on the process principles, methods, equipment, and safety and health aspects.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS C5 Committee on Arc Welding and Cutting, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

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Recommended Practices for Plasma Arc Cutting and Gouging

1. General

1.1 Scope. This document describes the recommended practices of plasma arc cutting and gouging. It provides a brief history of its application process development and provides a general description of components used for the process, controls, power supplies, and process consumables. The types of cutting machines and the related control systems are described, along with associated pollution and hazard control methods. Methods of optimizing cut quality and economics associated with the process are discussed. Safety and health aspects associated with the plasma arc cutting and gouging process are discussed.

These recommended practices, prepared by the AWS C5J Subcommittee on Plasma Arc Cutting of the AWS Committee on Arc Welding and Cutting, are intended to guide plasma arc operators and supervisors in the use of plasma arc cutting and gouging equipment. These recommended practices are not intended to take the place of sound engineering principles and should be supplemented with the equipment manufacturers operation and safety instructions.

This standard makes use of the U.S. Customary Units. Approximate mathematical equivalents in the International System of Units (SI) are provided for comparison in parentheses () or in appropriate columns in tables and figures.

1.2 Introduction. A nontechnical description of plasma is “the fourth state of matter,” the three familiar states being solid, liquid, and gas. For a common substance such as water, these three states are ice, water, and steam. When energy in the form of heat is added to ice, the ice melts and forms water, as shown in Figure 1. When more energy is added, the water vaporizes into steam. By adding more energy to steam the water vapor will disassociate into hydrogen and oxygen. Additional energy will cause the hydrogen and oxygen to become ionized. These ionized gases are electronically conductive. The resulting high-temperature conductive gas is known as plasma.

1.3 General Process Description. Plasma arc cutting (PAC) is a process that severs metal by using the heat of a nozzle-constricted plasma arc to melt a localized area. The molten metal is removed by a high-velocity stream of high-temperature, ionized gas. Plasma arc gouging uses the same process to remove material from the surface of a plate without fully penetrating the workpiece. Welding research scientists discovered in the early 1950s that the characteristics of the open arc used in gas tungsten arc welding (GTAW) could be altered to perform cutting operations instead of welding. The arc was constricted by directing it through an orifice in a water-cooled copper nozzle located between the electrode and the workpiece, which greatly increased the arc’s power density. They discovered that constricting the arc into a well-focused column raised the arc’s voltage significantly, making it more concentrated than the open arc used for welding.

Figure 2 shows arcs operating at the same current. The plasma jet on the right is only moderately constricted by the nozzle, but it operates at about twice the voltage and it acts considerably hotter than the open arc (GTAW) on the left. Even higher energy intensity can be achieved by constricting the arc with a boundary layer of nonionized gas inside the nozzle bore. The effectiveness of this boundary layer can be increased by swirling the plasma gas and raising the flow rate, which forces the cool, non-ionized gas outward radially into a thicker boundary layer. This protects the nozzle orifice allowing it to operate at higher energy levels and prolonging its life.

The characteristics of the plasma jet vary according to the gas flow rate, nozzle orifice size and arc current, as well as the type of gas used (gases are discussed in 4.8). A low flow rate, for example, reduces the jet’s momentum and forms a highly concentrated heat source ideal for welding, but inadequate for cutting or gouging. Conversely, if the gas flow is increased sufficiently, the momentum of the plasma jet will be high enough to expel the metal melted by the heat of the plasma arc, resulting in gouging or cutting.

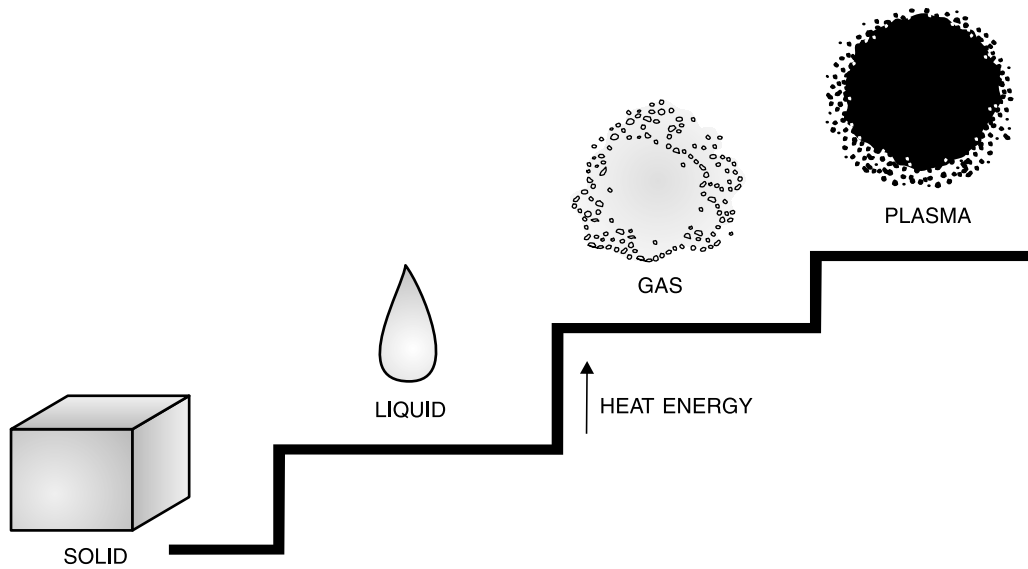


Figure 1—Plasma: The Fourth State of Matter

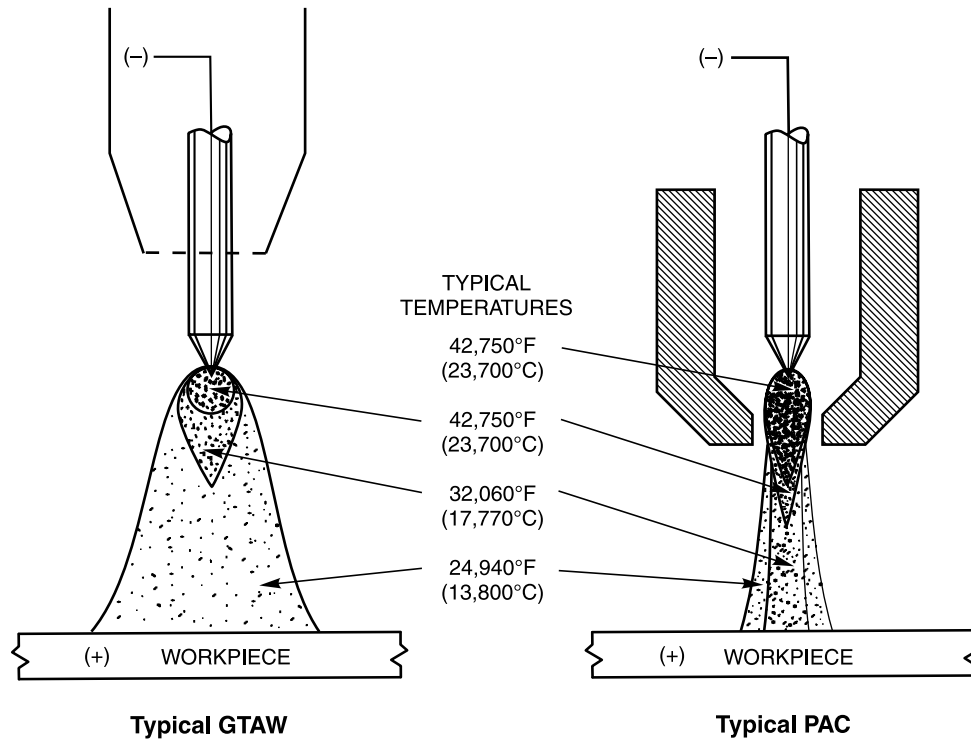


Figure 2—Temperature Differences Typical GTAW vs. Typical PAC

1.4 Principles of Operation. The circuitry of the basic plasma arc system is shown in Figure 3. The operating cycle begins by causing the plasma gas to flow around the electrode and out through the orifice in the nozzle. A DC open circuit potential of 250 V–400 V (negative polarity) is applied to the electrode, with the workpiece being at ground potential. After an ionized path is created between the electrode and the nozzle (see “Arc Initiation Methods” in 4.2), a main plasma arc (transferred arc) is then generated between the electrode and the workpiece. The cutting or gouging process can then proceed.

1.5 Individual Process Descriptions

1.5.1 Conventional Plasma Arc Cutting. The first plasma arc cutting process, developed during the 1950s, could cut any metal at relatively high cutting speeds. Disadvantages of early conventional plasma arc cuts included rough, angled cut surfaces and short electrode and nozzle life. Originally limited to mechanized cutting, conventional plasma arc cutting system designs have been significantly refined. Conventional plasma arc cutting systems are now available for both mechanized and hand-held cutting systems that employ single-gas, multiple-gas, and other process variations. There are now a number

of different types of plasma arc cutting systems. Descriptions of the different systems follow, listed in their order of chronological development.

1.5.2 Single-Gas Plasma Arc Cutting. A schematic of the basic single-gas torch is shown in Figure 4. After the plasma gas flows through the nozzle plenum which surrounds the electrode, and exits the nozzle’s orifice, the electrode receives a DC voltage. An ionized path is created between the electrode and the nozzle by a pilot arc or some other means. A main plasma arc is then generated between the electrode and the workpiece, after which the cutting or gouging process can proceed.

1.5.3 Dual-Flow (Shielded) Plasma Cutting. The dual-flow technique, developed in the early 1960s, added a second, outer nozzle (“shield cup”) to provide a passageway for a concentric flow of a shielding gas around the plasma gas. This is illustrated in Figure 5. Nitrogen, air, carbon dioxide, argon, oxygen and argon-hydrogen mixtures can be used as a shielding gas. The selection of the shielding medium is based on the type of metal to be cut or gouged, the metallurgical properties desired for the finished edge, and the physical properties of the edge, such as dross, squareness (bevel), smoothness, and flatness.

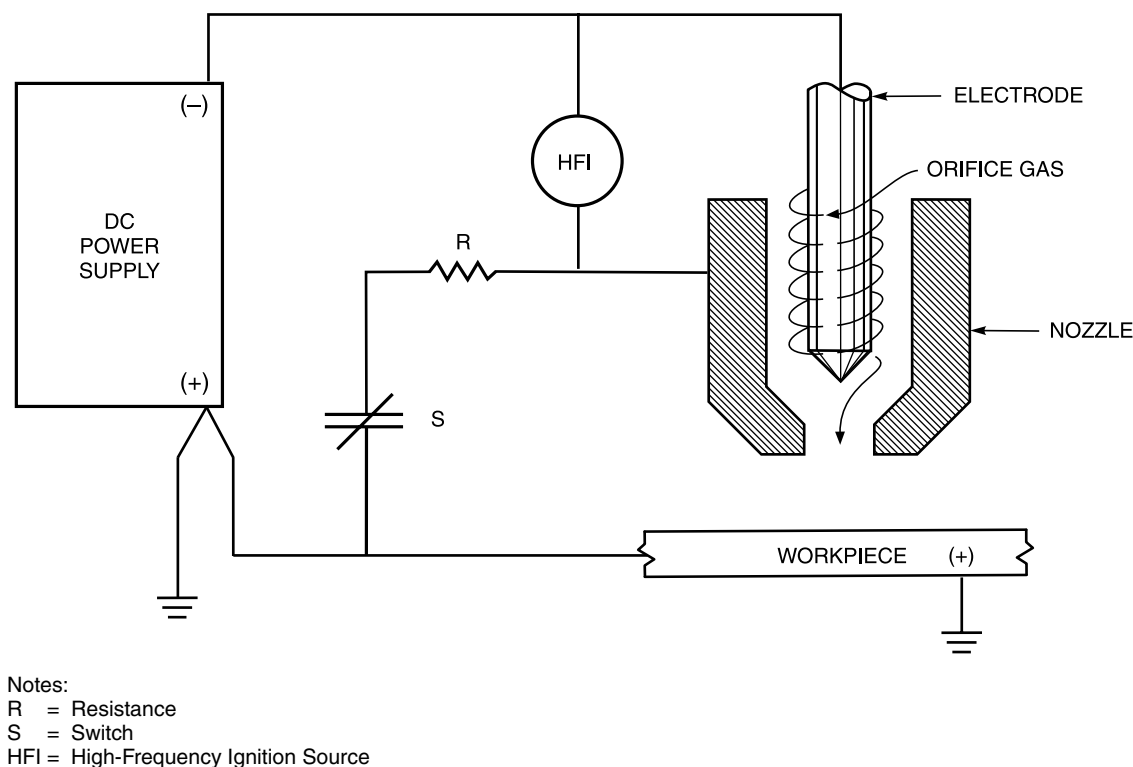


Figure 3—Plasma Arc Torch Circuitry

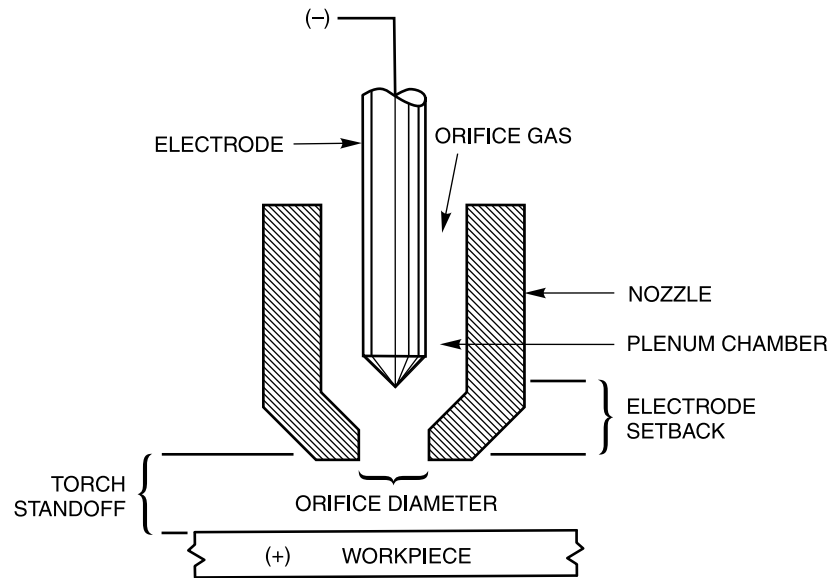


Figure 4—Single-Gas Plasma Arc Cutting

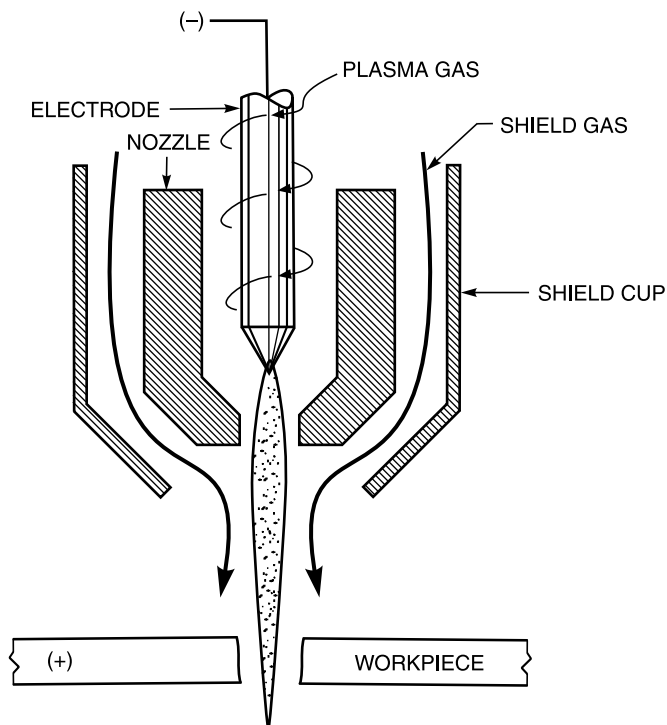


Figure 5—Dual-Flow Plasma Arc Cutting

The main advantages were reduced double-arcing, improved consumables life, faster cutting speeds on mild steel and improved cut surfaces by countering different metals' chemical reactive tendencies by a variety of gases available for shielding. Cut quality was not significantly improved, however, and cutting speeds on stainless steel and aluminum were essentially the same as that achieved by conventional, single-gas plasma arc cutting. Modern dual-flow systems are available for either mechanized or manual cutting.

1.5.4 Air Plasma Arc Cutting. Researchers in the early 1960s discovered that the oxygen content of air could increase mild steel cutting speeds by 25%, which would reduce operating costs. But there were disadvantages with oxidizing plasma gases: electrode life was very short, and oxidized cut surfaces were a disadvantage in some cases. Air plasma arc cutting systems did not gain wide use until the 1980s, when electrode improvements and cutting at lower currents helped overcome these problems.

1.5.5 Water Shield Plasma Arc Cutting (Mechanized only). This mid-1960s variation on dual-flow mechanized plasma arc cutting substituted water for the

shield gas. The cooling effect of the water improved nozzle life and the appearance of the cut surfaces (mainly on stainless steels), but squareness, speed and the tendency to form dross along the kerf were not measurably improved.

1.5.6 Water Injection Plasma Arc Cutting (Mechanized only). In the late 1960s, a process was developed that used water to constrict the arc as well as to shield it. The water strikes the arc as a high-velocity spray, either radially or in a tangential (swirling) manner, as illustrated in Figure 6. Greater arc constriction can be achieved through water injection than by the nozzle alone. This advance increased cut speeds and squareness, and eliminated dross on mild steel.

Nitrogen became the preferred gas for water-injection plasma arc cutting of all metals, offering good parts life, eliminating double-arcing, and improving squareness and cutting performance. Air or oxygen may also be used as the plasma gas. The cooling provided by the injection water permits the use of a ceramic material in the lower portion of the nozzle. This feature extends nozzle life, improves piercing capability of the torch, and acts as a barrier against double-arcing between the nozzle and the workpiece.

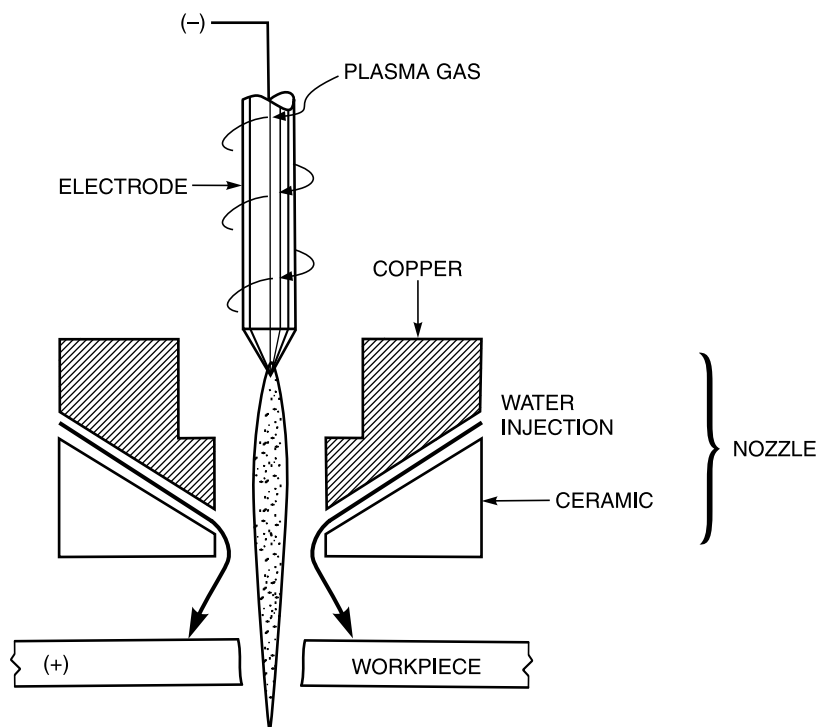


Figure 6—Water Injection Plasma Arc Cutting

1.5.7 Low-Current Air Plasma Arc Cutting. The main disadvantage of short consumable parts life for air plasma arc cutting was overcome in the early 1980s with the introduction of lower current air plasma systems. These plasma systems were typically 100 amps or less and gas cooled. Many companies introduced smaller, easier-to-operate, less expensive systems—including hand-held cutting systems—and helped plasma arc cutting become the process of choice for the first time in many industries.

1.5.8 Oxygen Plasma Arc Cutting (Mechanized only). Oxygen plasma arc cutting's major disadvantage—unacceptably short parts life—was overcome in the early 1980s, with the introduction of the water-injected oxygen plasma arc cutting process for cutting mild steel. Cutting speeds were significantly increased and lower cutting current levels produced smooth, square cuts that could be easily welded without rework. The use of hafnium and zirconium electrodes allowed the use of oxygen for cutting mild steel. The virtual elimination of dross, high-cut speeds, and cut surface quality outweighed the shorter than desired consumable parts life.

1.5.8.1 Extending Consumables Life for Oxygen Plasma Arc Cutting Techniques. Plasma arc cutting systems manufacturers' R&D efforts concentrated on making longer-lasting consumable parts for air and oxygen plasma arc cutting during the late 1980s. Because mild steel cutting dominates the industry, and oxygen-based plasma arc cutting provides the fastest method for cutting mild steel, interest in air and oxygen plasma arc cutting has always been high. Plasma system manufacturers achieved extended electrode and nozzle life with techniques that control the cutting current and gases far more precisely than previous processes. Plasma arc cutting operators using systems that incorporate these new techniques can greatly increase their productivity and reduce the cost of cutting; they use fewer parts and reduce downtime by changing parts less frequently.

1.5.9 High-Current-Density Plasma Arc Cutting (Mechanized only). The plasma arc cutting industry's response to laser cutting came in the early 1990s with the introduction of a new generation of dual-flow plasma arc cutting that offered cleaner, squarer, more precise cutting than conventional, shielded, or injected plasma arc cutting processes. These precision systems have some capabilities and characteristics in common. Each involves "super-constriction" to increase the arc's current density and reduce the kerf width, as well as precise control by the system over the gas flow and current to extend consumable parts life.

These dual-gas systems can cut all metals well, using oxygen, air or nitrogen as the plasma gas, and oxygen, air, nitrogen, methane, propane, carbon dioxide and com-

binations as shield gases. Key characteristics of torch assemblies, particularly alignment of the consumable parts, are designed with tighter tolerances than other types of plasma systems. The advantages of high-current-density plasma arc cutting include narrow kerfs, square, dross-free cuts, long consumable parts life and a choice of shield gases to produce uncontaminated cuts.

While not comparable to all laser cutting, high-current-density plasma arc cutting fills an important middle ground between plasma arc and laser cutting. In metals up to 1/2 in. (13 mm) thick, high-density plasma arc cutting significantly outperforms conventional plasma arc cutting in terms of cut edge quality. The cut edge quality is comparable to that of laser cutting. High-current density plasma arc cutting systems represent lower purchase and maintenance costs than laser cutting systems, and require less operator training than laser cutting systems.

1.6 Commonly Processed Base Metals. Although most conductive metals can be cut, mild steel, stainless steel, and aluminum alloys represent the majority of materials processed in the worldwide welding and cutting industries. The rapid increase in plasma arc cutting that started in the 1980s has been due to its ability to cut most mild steel—the single dominant metal—faster and more economically than oxyfuel gas cutting, and its ability to cut stainless steel or aluminum alloys, which oxyfuel gas cutting cannot cut.

1.6.1 Mild Steel. Prior to the 1980s, most mild steel plate was cut using oxyfuel processes, for two main reasons: the first was that, even though conventional plasma arc cutting offered higher cutting speeds, it also required a sacrifice in cut quality. The second reason—perhaps more significant—was that many of the shape tracing machines could not operate reliably at the higher speeds at which the plasma arc cutting process was capable of cutting.

Since then, the quality of plasma arc cuts has been greatly improved, and the introduction of numerically controlled shape cutting machines has made high-speed plasma arc cutting routine.

As a result, the most rapid plasma arc cutting growth has been in mechanized cutting of steel using air or oxygen as the plasma gas. The high-cutting speeds and cut quality achievable with air and oxygen plasma arc cutting, plus the capabilities of computer numeric control (CNC) cutting machines, contribute to increased productivity at high quality levels.

The cost of cutting with plasma, oxyfuel, and laser systems is discussed in Section 7, Economics.

1.6.2 Stainless Steel, Nickel and Cobalt Base and Aluminum Alloys. Another reason for the rapid growth of plasma arc cutting is the increased use of stainless steel, nickel and cobalt base and aluminum alloys in