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Applications of Plasma in Material Processing

Chong Perk Lin
Faculty of Engineering and Technology, INTI International University, Malaysia

Federico A Roy Jr.
Faculty of Engineering and Technology, INTI International University, Malaysia

Saw Sor Heoh
Centre for Plasma Research, INTI International University, Malaysia

Lee Sing
Institute of Plasma Focus Studies, 32 Oakpark Drive, Chadstone, VIC 3148, Australia

Abstract

Plasma is essentially an ionized gas that has been heated to high temperature. Due to the increasing demand of micro-scale material processing, the use of plasma is common. This paper mainly focuses on material processing involving micro-scale specification, using plasma welding, plasma spraying and plasma cutting.

Introduction

Matter can be classified in terms of four states: solid, liquid, gas and plasma. The solid, liquid and gas can be distinguished by different strength level of the bond to hold their particles. The phase change from solid to liquid or from liquid to gas can be achieved by heating process, which takes place at constant temperature. Further heating the gas to certain level, the gas will become ionized gas that is known as plasma. There are a number of well-established ways of heating a gas to form plasma (Lucas, 1990), including compression, magnetic field, shock waves and direct heat exchanges.

Due to its high temperature, significant amount of heat energy can be stored in a plasma. This heat energy is particularly useful for material processing since this energy can be directed and manipulated in carefully controlled manner. The key advantage is that plasma allows micro-scale of material processing which ordinary material processing techniques cannot achieve. It is particularly worthwhile to explore the applications of plasma where micro-scale specification is crucial, in particular, plasma welding, plasma coating and plasma cutting. This paper looks at some of the details of plasma welding, plasma spraying, and plasma cutting.

Plasma ARC Welding

A typical welding process uses a non-consumable tungsten electrode to produce the weld. This is known as Tungsten Inert Gas (TIG) welding. A sheath of inert gas surrounds the electrode, the arc, and the area to be welded. This gas shielding process prevents oxidization of the weld and allows for the production of neat, clean welds. This welding process is used extensively in the manufacture of space vehicles, and is also frequently employed to weld

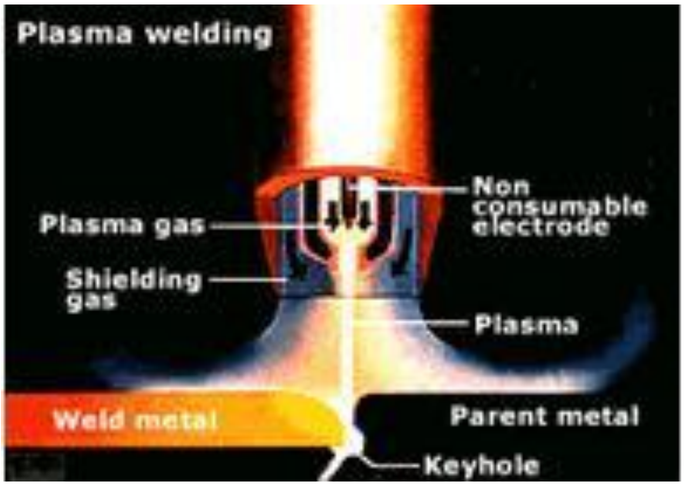

Figure 1. Plasma Welding (Courtesy of ESAB)

small-diameter, thin-wall tubing such as those used in the bicycle industry (Wikepedia, 2009).

However, TIG welding has a free-burning arc, which is unstable and tends to wander in the low current range. With increase in current, the arc-generated heat increases and the arc diameter also increases. This leads to a lack of concentrated heat in the work-piece, which results in a bigger seam and a larger heat-affected zone (Arcraft Plasma, 1992). For improving the quality of weld, the idea of using a constricted nozzle is introduced (Zhu *et al*, 2002).

Plasma arc welding (PAW) may be preferred, where constricting nozzle and two separate gas flows (plasma gas and shielding gas) are used, as shown in Figure 1. By forcing the plasma gas and arc through a constricted orifice, the torch delivers a high concentration of heat to a small area. With high performance welding equipment, the plasma process produces exceptionally high quality welds. In addition, the process is easy to operate because it is not sensitive to arc length variations and the needle- like arc formed can be aimed reliably and precisely. PAW is an advancement of TIG welding process. PAW can be used to join all metals that are weldable by TIG welding process (Wikipedia, 2009b). Particularly, PAW is used in micro-scale welding, where the thickness range from 0.05mm to 2mm (Burke, 1968), such as required for Pressure and Electrical Sensors, Seals, Cans, Enclosures, Microswitches, Valves, Electronic Components, and Miniature Tube to Fitting/Flange, Food and Dairy Equipment. (Profusion Technologies, 2003).

Plasma Spraying

Coatings can be used to solve material corrosion problems. Conventionally, liquid paint is used for coatings, but is particularly difficult to apply with a micro-scale material. In order to generate micro-scale coating, plasma spraying is necessary, where the coating thickness can be produced in the range of 40 – 50µm (B. Gudmundsson *et al*, 1980a). Due to the ability to spray to such fine tolerance, it is often possible to use components in the 'as sprayed' condition and so cut out machining operations.

This coating thickness is essential for seal ring grooves of compressor, diesel engine piston ring, and turbine combustion chamber (TWI, 2008). Furthermore, the use of plasma

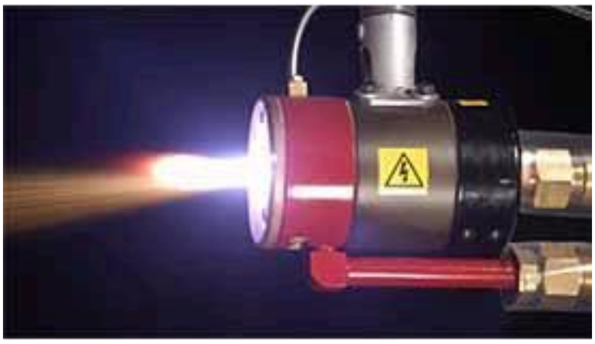

Figure 2. Plasma Spraying (Courtesy of TWI)

spray technique is extended to ceramic coating. For instance ceramic-coated piston is used for improving engine performance (Salman and Topal, 2008). Plasma coating produces smooth deposits of controlled thickness often resulting in reduced material and finishing cost. In addition, plasma coating can enhance the fatigue strength, the corrosion and wear resistance as well as load bearing capacity. (Hong Liang *et al*, 2004)

Plasma spraying is characterised by high temperatures (10,000K), high specific energy densities and high cooling rate (Ramazan, 2006). Plasma spraying processes uses a DC electric arc to generate a stream (see Figure 2), which involves injection of a metallic or ceramic powder into a high temperature plasma jet. During transportation through the plasma the powder melts and then solidifies on substrate impact to build up a plasma coating (B. Gudmundsson *et al*, 1980a). It is noted that melting behavior is an important factor that affects the coating quality (e.g adherence level, porosity level).

For a good melting behavior, the powder size range should be as tightly controlled as economically acceptable. In the case of vacuum plasma spraying a powder size range of 5-36µm is commonly used for deposition of metallic materials. (B. Gudmundsson *et al*, 1980b). A lower limit is necessary to avoid powder evaporation. A higher limit is necessary to allow all of the powder to be melted during transportation through the plasma.

Plasma Cutting

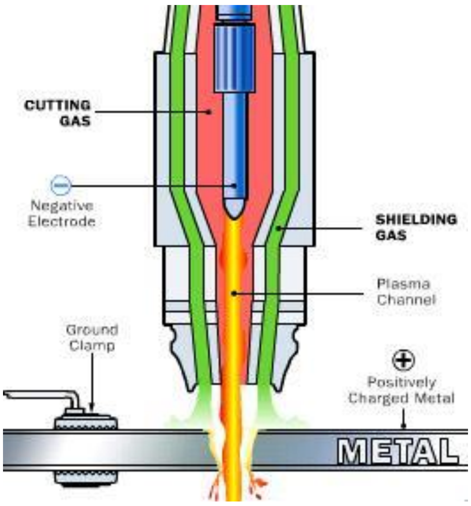

Figure 3. Plasma Cutting (Courtesy of Howstuffworks)

Cutting is a material remover process for manufacturing a free-form surface shape, which involves the use of cutting tool to 'cut off' metal pieces according to specified cutting path. Conventionally, cutting a high strength material not only leads to high level of tool wear but also shortens the tool life. Consequently, a high frequency in new tool replacement is unavoidable. In addition, conventional cutting method is not able to cope with micro-scale material. In order to avoid new tool replacement and to cope with micro-scale material, plasma cutting is preferred.

The underlying principle of plasma cutting is to deliver a high velocity jet of plasma to a metal work piece, the intense heat melts a thin area of metal and the high pressure gas blows the molten metal away leaving an edge, as shown in Figure 3. Initially, a pressurized gas, such as nitrogen, argon or oxygen is delivered through a small channel. Then, power is supplied to a negative electrode, which causes electric breakdown of the gas between the electrode and the metal. As the pressurized gas passes through the channel, the electric current heats up the pressurized gas creating a stream of plasma. This stream of plasma is at a temperature of 16000^{o}C, where the heat energy is sufficiently high to cut the metal piece. (Howstuffworks, 2008).

Plasma cutting tools can be either hand-held or mechanized. Hand-held installations use argon/hydrogen gas mixes and have a maximum cutting capacity of about 6.3cm thick stainless steel. Mechanized systems use argon/hydrogen, nitrogen, nitrogen/hydrogen or nitrogen/oxygen gas mixes and are capable of cutting up to 12.6cm thick stainless steel. The mechanized plasma cutting is able to cope with intricate shape, where micro-scale is involved. This cut produces high quality surface finish, which does not require further finishing process. (Burke, 1968)

Summary

The applications of plasma in material processing, including plasma welding, plasma spraying and plasma cutting have been discussed. The distinguishing feature of plasma material processing is the capability of handling micro-scale material. In addition, plasma material processing is more effective in coping with high strength material than the conventional methods. However, plasma material processing involves high temperature plasmas. The processes involved require a good understanding of plasma physics and plasma technology. Research in these relatively advanced areas of technology can be expected to produce further improvement to the processes and equipment needed for such applications.

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