A PLASMA SPRAY SYSTEM FOR DRY POWDER COATING MATERIAL

M. Stand
Sealectro Corporation, Mamaroneck, New York, U.S.A.

"Sealectrocote"(R) is a plasma system for spraying dry powder coating materials such as epoxy, polyurethane, nylon, etc. onto various substrates, e.g.: metallic, ceramic, wood, paper, etc. The equipment, a power supply, a plasma spray gun and a powder feeder are described briefly. A review of the structure and function of each component is given. The coating of three different products are discussed to illustrate the utility of the plasma system.

At Sealectro Corporation, New York, we have developed a plasma spray system for dry powder coating materials, of both the thermoset and the thermoplastic types. We call our system "Sealectrocote-II"(R). Of course, we can spray epoxies, polyester, polyurethane, nylon, vinyls, polyolefins, fluorocarbons, etc. Various substrates may be coated such as metallic, ceramic, wood, papers, and all sorts of others.

If that seems somewhat contradictory, all one has to recall is a general characteristic of an arc plasma, viz, there is a steep temperature gradient across the diameter of the plasma, i.e., from its center toward its periphery. The temperature also decreases, less rapidly in the direction of its flow. As long as its flow can be maintained laminar, the coating powders will ride on the surface, absorb sufficient heat to soften and melt the powder, so that when it impinges on the surface of the substrate it will fuse into a film. The arc plasma is a considerable source of heat. However, the thermal compatibility of the powder with respect to the substrate relates to the melting point of the powder and its heat of fusion rather than the temperature and heat content of the plasma. The characteristics of the coating, its performance in a given environment, adhesion, depend on the properties of the powder not on the plasma, although the plasma being an ionized medium, makes some significant contributions toward an improved quality of the coating. I shall discuss that in some detail somewhat later. One should remember the powder is the paint, the plasma is the brush.

- Figure 1 -

The general principles of plasma technology are fairly well known, therefore, there is no need to reiterate them here. A brief description of the Sealectrocote(R) plasma spray system would be in order. It is comprised of a power supply, a plasma spray gun and a powder feeder. I would like to review their structure and function briefly.

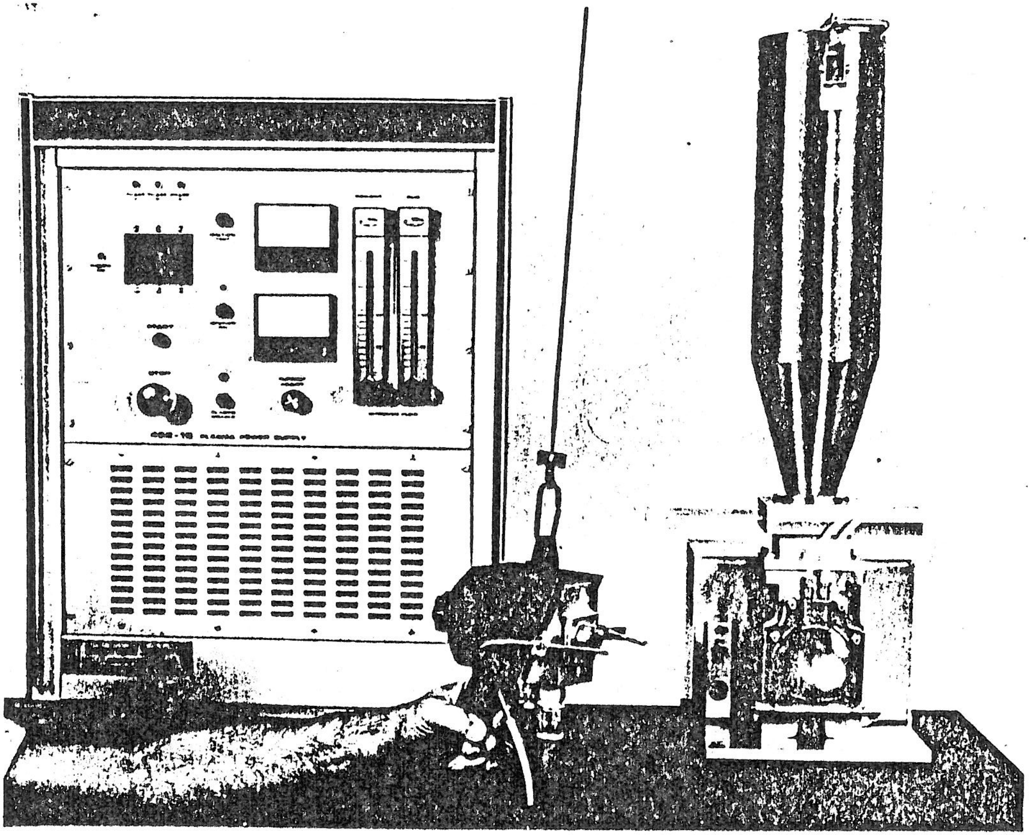

Figure I

The power supply is a pulse type, phase controlled, (3Ø, 60 amp each), AC to DC source having a highly regulated current output. This power supply performs three main functions:

* it provides an RF to energize the arc
** it boosts the voltage of the ionized gas to the glow level
*** it supplies a constant, well regulated current with a compliant voltage, sufficient to meet the requirements of the plasma.

The current must be maintained rather constant for the rapidly streaming gas, the flow rate of which may be varied while passing through the plasma gun.

The power supply was designed and constructed to be portable. Its dimensions are (91x53x64) cm, and it weighs about 182 kg. It may be placed on a Jeep or a small truck with its own energy source, or it may be plugged into an available electrical power outlet. Controls for the power level, for the gas flow rate for both plasma gun and powder feeder, are on the power supply. Wired into the power supply are safety switches which, in case of power surges, a drop in gas pressure, or a drop in cooling water flow, will shut down the plasma spray system.

The plasma gun is essentially a set of electrodes, a tungsten cathode and copper anode, encased in some brass blocks which act as heat sinks. Water cools the whole system, quite efficiently. After eight hours running time at maximum power level, the temperature of the water rises only about 2-3^{o}C.

The structure of the gun is such that when inserting the cathode it is automatically centered with respect to the anode. A gas distribution ring assures a uniform supply, a cone of gas, entering the arc gap. The arc gap may be varied. Using nitrogen, it may be increased to 1'38 mm and still maintain a stable arc.

When struck a circular arc forms, which within a second is transformed into a plasma streaming out of the anode. The elliptic surface inside the anode collimates the gas stream and thereby contributes to a more stable laminar flow. Varying the arc gap varies the power level, which can be brought back to a previous level by varying the gas flow rate. The maximum power which can be drawn from the supply is 15 KW. For most spray applications a range of 6.5-7.5 KWH is quite sufficient.

Nitrogen is used to generate the plasma. A number of reasons contributed to its choice. It is quite inert. At the operating level of ionization the amount of UV radiation is less than 0.1%. This is important, because of the ill effects of UV on personal health, and most plastics are equally sensitive, tending to depolymerize. Nitrogen radiates fairly strongly in the infrared at that level, contributing to a more efficient heat transfer. Last, but not least, nitrogen is fairly inexpensive, being a by-product in the liquification of oxygen.

The powder feeder, also, is simple and versatile. A feed screw in the main chamber transports the powder into the fluidizing chamber where the nitrogen piks up the powder transporting it to the plasma gun.

A variable speed motor attached to the feeder allows for metering precise quantities into the fluidizing chamber. In this manner powder of less than one g/min to several kg/hr may be transported to the gun, in a smooth nonpulsating flow. The hopper on the top of the feeder has a capacity of only 12 lbs. It is better to feed from a larger reservoir to the hopper than directly to the feeder. It will prevent the powder from being compacted.

The plasma spray system, Sealectrocote(R), has been designed to spray "dry powder coating materials". These materials are mainly synthetic resins, modified with all sorts of additives plus pigments to achieve a desired coating. These resins, both thermoset and thermoplastic types may be sprayed. Each has its own set of problems, with thermosets, like epoxies or polyesters, generally it relates to cure; with thermoplastics it relates to adhesion. However, it is possible to spray almost all plastics onto almost any substrate.

The following three examples will illustrate the versatility of the plasma spray method and system.

The prothesis in hip joint replacement surgery is made of a Cr-Co-Mo alloy. The prothesis is cemented inside the tibia with polymethyl methacrylate (PMMA). The acrylate is an excellent adhesive, however, the bond attained under the circumstances is not always at its optimum. The problem is that after some time, as a result of non-uniform loading, excess stresses, an essentially hostile environment, the probability increases that the bond may weaken and fail. A loose prothesis is a very painful affair. The first surgery is very traumatic, the second is even more so.

An analysis of what constitutes an optimum bond at the PMMA metal interface indicates that favorable, easily reproducible conditions could be obtained if the substrate surface were treated appropriately. Based on wettability studies and contact angle measurements, it was found that interfacial energies could be related to polar interactions consisting only of acid-base reactions. The oxides, on the surface of the alloy, Cr-Co-Mo, appear to be p-type oxides and act as electron acceptors. PMMA is a basic polymer and is strongly absorbed on the acidic surfaces. By correlating surface acidity and basicity with appropriate properties and measurements, bond strength and the conditions for optimum bond strength may be defined. The conditions are more easily reproduced at a production facility than in a surgical operating room.

The objective, which was accomplished by plasma spray, was to place a thin coating of partially polymerized PMMA onto an especially prepared surface of the (Cr-Co-Mo) alloy prothesis. This

PMMA film is to adhere to that surface with maximum strength, and subsequently serve as a base for adhesion to the PMMA grout with which the prothesis is cemented into the tibia.

The prothesis rides in the acetibular cup which is cemented into the hip. The acetibular cup is made of Ultra High Molecular Weight Polyethylene (UHMWPE); the cement is also PMMA. The same fundamental aspects of adhesion and bond strength which apply at a plastic/metal interface are equally valid for a plastic/plastic interface. However, different parameters require greater emphasis and that must be reflected in the substrate surface preparation.

When joining two thermoplastic polymers, the one having the higher surface tension (surface free energy) is defined as the substrate, the other as the adhesive. If the surface tension of the liquid (molten) polymer is greater than that of the substrate, it won't wet its surface, thereby severely impeding adhesion. This is precisely the condition with obtains at the PMMA/UHMWPE interface. There are a number of methods available to increase wettability and thereby bondability of a plastic substrate surface. Electric corona or activated gas plasma treatment is very effective toward that end. For PE's, in particular, nitrogen or oxygen plasmas have pronounced effects. Either of those two ionized gases will combine with hydrogen on the polymer surface providing for active bonding sites, as well as enter the surface to establish more bonding sites.

In practice, the UHMWPE acetibular cup is subjected first to a brief plasma exposure. Then using the same gun a thin coating of PMMA is applied to the surface which subsequently is cemented to the hip with PMMA grout.

Another example is gas and oil transmission pipe. These pipes range in diameter from about 2 inch to 40 inch (5-102cm); recently some 60 inch (152cm) diameter pipe has come into use. Although there are some differences in design and materials specifications, generally they are made of steel with a projected service life of about 20 years. Corrosion protection is most important. It must meet a wide range of environmental conditions, with additional variables of whether the pipe is above ground, buried or submerged in water, on or off shore.

Experience and much research has taught that epoxy coatings are most suitable to provide corrosion protection within such a range of conditions. Specifications call for a coating thickness of 14-15 mil (0.36-0.38mm). There are some exceptions where a lesser thickness will suffice.

Currently, the majority of pipe is electro-statically coated. Subsequently, by means of an eddy current device, the coating is tested for "holidays", a form of micro porosity or a skin bridging a porosity beneath. The eddy current device will cause an arc to burn through such a "holiday" to the pipe. "Holidays" are a serious problem of electrostatically produced coatings.

Increasing coating thickness does not solve the problem. Plasma sprayed coatings do not produce "holidays" to such an extent, even at thicknesses as low as 6 mil (0.15mm). The amount of "holidays" does not increase after impact tests up to 200 lbs. (90.7mg) in plasma sprayed coatings, whereas severe cracks occur in electro-statically produced coatings. An effort is underway to modify and improve some epoxy powders to make them more suitable for plasma coating.

During the course of the pipe coating project, the plasma spray system was operated at -50°F. (-45.6°C.) and 50 mile-an-hour (80.5 kw/hr) gales. The plasma system performed quite well and some spoiled coating sections were covered. It did touch-up and repair, although the high winds interfered with the powder stream. There were problems, but not fundamental ones. They developed because some of the design and the material of construction had not been considered for an arctic environment.

The versatility of the plasma spray method is illustrated by another application. The fuel tanks of commercial aircraft, or "fuel cells" as they are called, have various shapes and configurations to fit the wings and other spaces in the aircraft to make most efficient use of available space for carrying adequate amounts of fuel. The structure of such "fuel cells" is of no consequence within the context of this paper, except that they are made of a polyurethane coated nylon fabric. The method of manufacturing these "fuel cells" is a complex tedious procedure. Among the many steps is the coating of the nylon fabric. This is done by applying a two-component, liquid polyurethane mix, which subsequently takes 24 hours to cure.

Polyurethane powder can be sprayed directly onto the nylon fabric by means of the plasma gun to produce an appropriate, cured coating. It elimates not only the two-component liquid material, which has a limited pot life, but also many other steps in the manufacturing procedure. There are some problems, of course. Adhesion is one; wetting and penetration of the fabric by the molten polyurethane is another. Some progress has been made by special surface treatment of the fabric, such as acetylation. Additionally, there is a differential in the coeficient of expansion of polyurethane and nylon, resulting in a wrinkling of the fabric. These and some other problems are in the process of being resolved.