# NEW COATING TECHNOLOGY AND PROCESSES

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## INTRODUCTION

Thermal spray coating on large components and composite substrates using recently developed thermoplastic and thermoset powder is available in today's market place. This small, but growing technology has been around since the 1980's but it is now gaining momentum. Improvements in equipment able to heat, melt, and discharge polymer powder materials, some with fillers such as fibers, powdered metal and ceramics, allow thermal spray operators to coat metal, wood, plastics, composites, glass and even paper with high performance coatings. Thermal spray coating can provide improved resistance to abrasion, corrosion, thermal and weathering in a variety of high technology applications from aircraft engines to steel structure maintenance.

For years, powder coatings could only be applied successfully in a shop environment. Even then, large components which did not fit into a cure oven could not be processed. The recent emergence of new process equipment and powder coating materials has changed this line of thinking.

During the past ten years major advances in thermal spray equipment, designs and systems have advanced to the point that the metallizing is now a one billion dollar global industry. The spraying of metallic and ceramic powders for commercial application in corrosion control and machinery restoration is a major part of routine maintenance in the U.S. military, aerospace and aeronautical industries.

Within the past few years, thermal spray equipment designed for the metallizing industry has been modified to spray polymers. The small but growing industry had to overcome such problems such as excessive heat, small spray patterns and low feed rates to make this an economical process.

Several new pieces of equipment based on a variety of fuel gas (propane, argon, hydrogen) and air systems have become available with spray patterns of 4 to 8 inches and spray rates of as high as 300 square feet per hour.

## Equipment Advances

Equipment designs range from the simple to the complex, with varying degrees of process parameter control. Equipment specifically designed to spray polymer coatings are available from companies such as Applied Polymer Systems, Tampa, Florida; Metco, Westbury, New York' Plastic Flamecoat Systems, Houston, Texas; UTP Welding Technologies, Houston, Texas; Eutectic Corporation, Charlotte, North Carolina; Alamo Supply Company, Houston, Texas; and American Thermoplastics, Inc., Mesa, Arizona. One can see that this is a growing industry with seven companies involved in manufacturing and sale of these systems. For many of them the polymer of choice is thermoplastic.

As shown in Figure 1, the polymer powders are injected through a flame during application. The flame serves to heat and melt the polymer as well as to thermally increase the substrate surface, so that the coating can flow onto the surface previously prepared by standard anchor pattern preparations. As the powder particles impinge the substrate, they coalesce and flow into a homogeneous coating. The two leading heat gun designs are plasma and flame, both described herein.

## Flame Spray Systems

[1]The flame spray coating technique has been developed within the last twelve years for application of thermoplastic powder coatings. Polyethylene, copolymers of ethylene and vinyl acetate, nylon and polyester powder coatings have been successfully applied by flame spraying. This technique permits powder coatings to be applied to practically any substrate, since the coated article does not undergo extensive additional heating to ensure film formation. In this way, substrates such as metal, wood, rubber and masonry can be successfully coated with powders if the coating itself has a proper adhesion to the substrate. The technique itself is relatively simple:

a. Powder coating is fluidized by compressed air and fed into the flame gun.

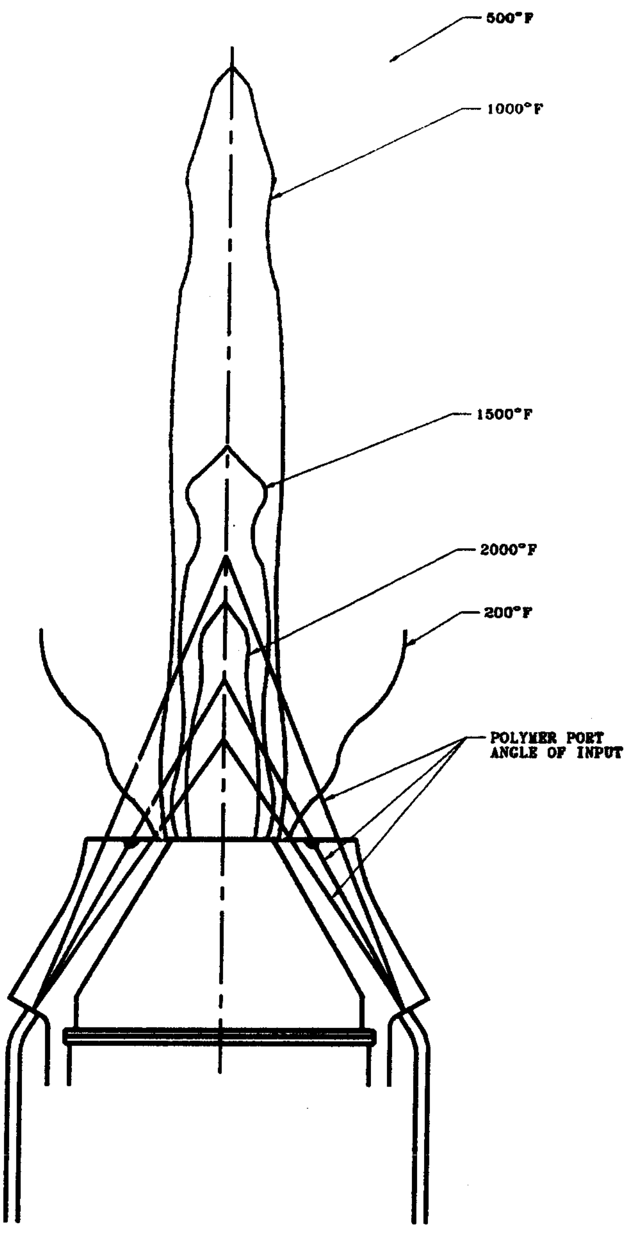


Figure 1. Polymer Plasma Flame Signature

b. The powder is then injected at high velocity through a flame of propane. The residence time of the powder in the flame and its vicinity is short, but just enough to allow complete melting of the powder particles.

c. The molten particles in the form of high viscosity droplets deposit on the substrate forming high-build film upon solidification.

An example of a flame spray gun disclosed in a patent of Oxacetylene Equip (U.S. Patent 1423176, 1985) is sketched in Figure 2 and 3. The gun has a body with air, combustion gas and powder material supply channels. The outlet of the powder channel is axially positioned at the gun mouthpiece with the channels for the combustion gas outlet situated at equal distances on the circumference concentric to the axial powder channel. The efficiency is increased by preventing the powder from burning in the flame since the concentric circumference diameter is 2.85-4.00 times the powder outlet channel diameter. The coating quality is increased when using liquified gas since the combustion gas outlet channel axis is at 6-9$^{0}$ to the powder channel axis, forming a converging flame. The amounts of air and combustion gas are regulated by control valves. The air passes through rough ejectors creating a refraction in the channel. The air and liquified gas mix in chambers forming a combustible mixture which flows to the mouthpiece nozzles. The powder particles entering the flame are heated and in a molten form are supplied onto the surface being coated. Refer to Figure 4.

Since the flame spray process does not involved oven heating, it is very suitable for field application on work pieces which are large or permanently fixed and thus not able to fit inside an oven. It has been reported that objects are such bridges, pipelines, storage tanks and rail cars are suitable surfaces to be coated with this technique. The nominal coating thicknesses reported are 3-5 mils and 6+ mils for most applications.

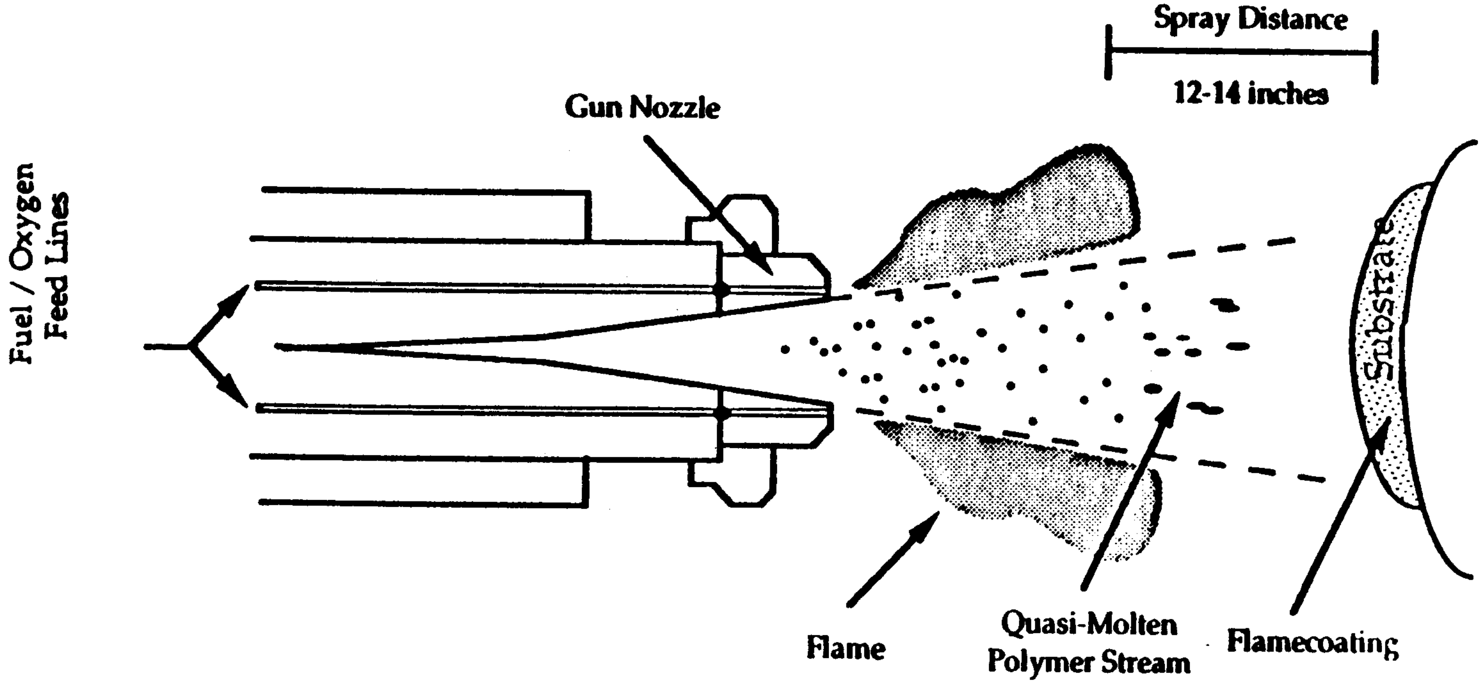


Figure 2. Flame Spray Gun

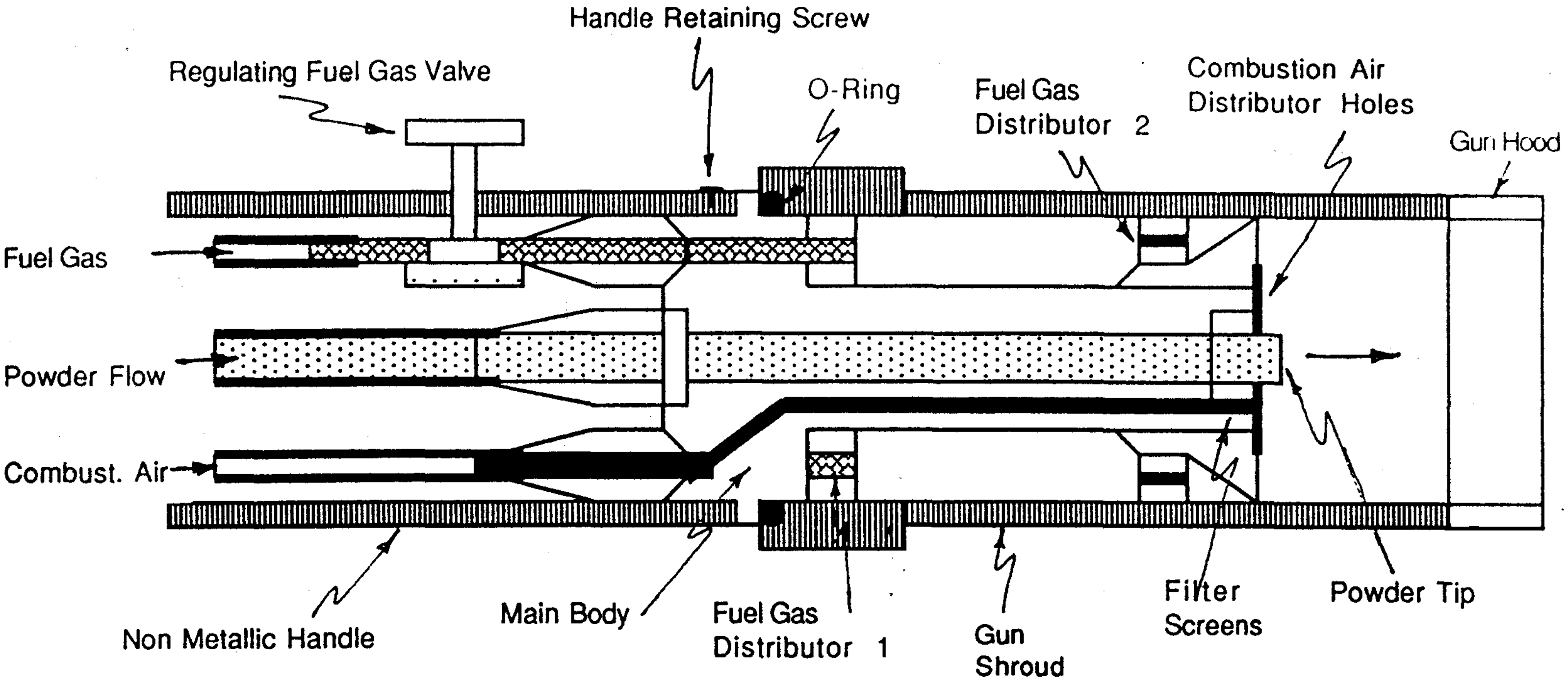


Figure 3. Schematic of Applicator Gun Assembly

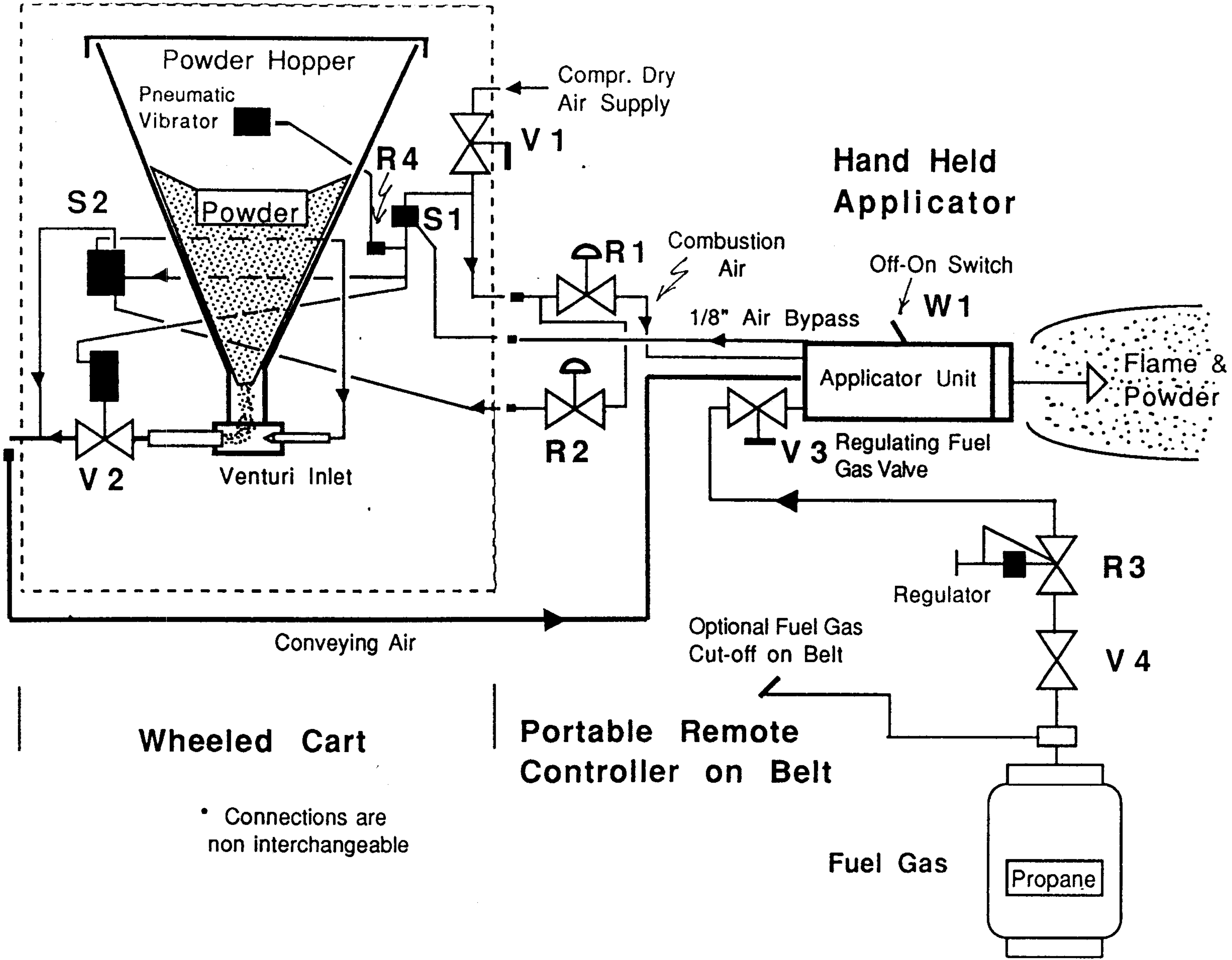


**Figure 4. Flame Spray Applicator System**

## Polymer Plasma Spray Application System

[2]In the scientific community, the term "plasma" is often considered the fourth state of matter after solid, liquid, and gas. This extremely hot substance consists of free electrons and positive ions. Although it conducts electricity, it is electrically neutral.

The polymer plasma system utilizes an inert gas passing through an electric arc between an anode and a cathode. The gas, typically argon, loses one of its electrons and becomes a highly energetic, extremely hot plasma. As the plasma leaves the internally water-cooled plasma generator in the gun, powdered thermoplastic or thermoset formulations and a carrier gas are introduced into the plasma stream in precisely controlled amounts. As the polymeric material is caught in the high velocity hot plasma stream, it absorbs the high heat, becomes molten, and is projected against the surface being coated at subsonic or, in some applications, supersonic speeds. When individual particles impact against the surface at high speeds (Refer to Figure 5), thermal and mechanical energies are transferred to the substrate, producing forces which favor high level bonding and excellent adhesion (Refer to Figures 6 and 7).

There are two factors which account for this enhanced adhesion. As the polymer particles are introduced into the plasma stream, the particles absorb the high plasma energy and melt. The molten particles then impact with the substrate at high velocity and fill the surface crevices to create excellent mechanical bonding. Secondly, on some substrates the plasma gas, which has a minor ultra-violet component, effects free radical production on the surface, which enhances the chemical bonding of the coating. A high density, thick coating of the properly selected polymer, which is well bonded to the surface, should provide the essential features of enhanced corrosion resistance.

There are several advantages to using a Polymer Plasma Spray Application System:

- No Pre-Heating
- No VOC's emitted
- Inert Atmosphere
- Minimal Surface Preparation
- Excellent Adhesion
- No Visible Discoloration
- No Detectable Pinholes
- Good Repairability
- No Blisters
- Good Flexibility
- High Deposition Rates
- Eliminates Curing Ovens
- Multi-Layered and Thick Coatings up to two inches
- Controlled Heating and Melting
- Good Surface Smoothness
- Sufficient, Uniform Thickness
- Single Monolithic Layer
- No Cracks or Crazes
- Good Surface Gloss
- Good Impact Strength

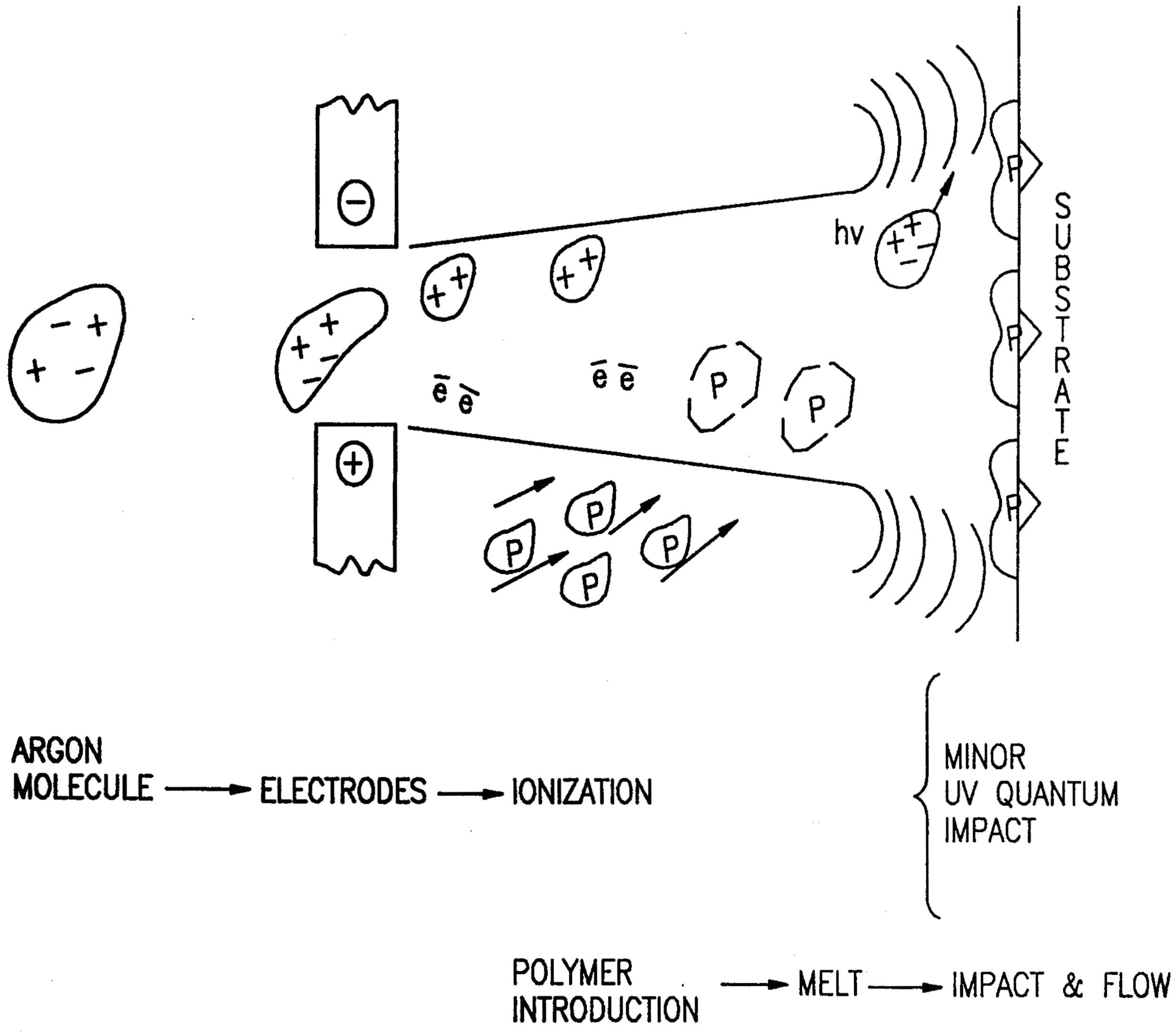


Figure 5. Polymer Plasma Spray Process

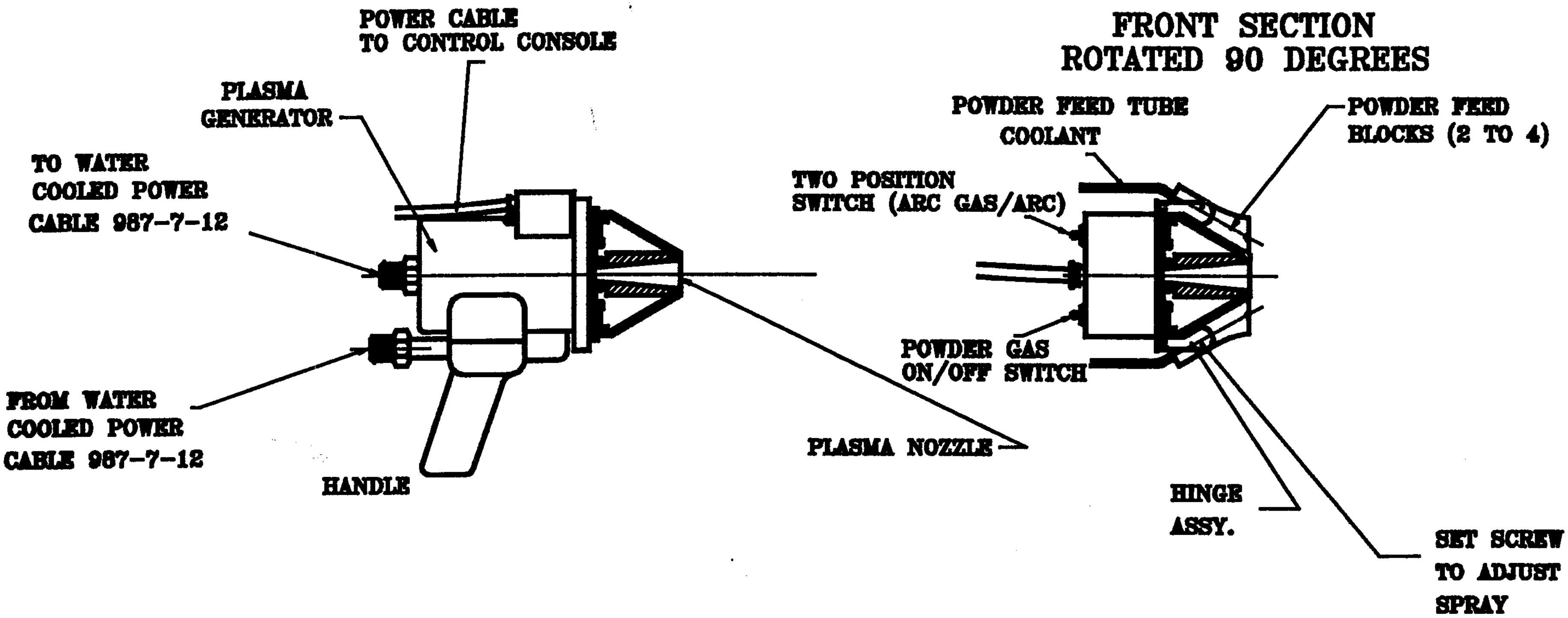


Figure 6. Polymer Plasma Spray Gun

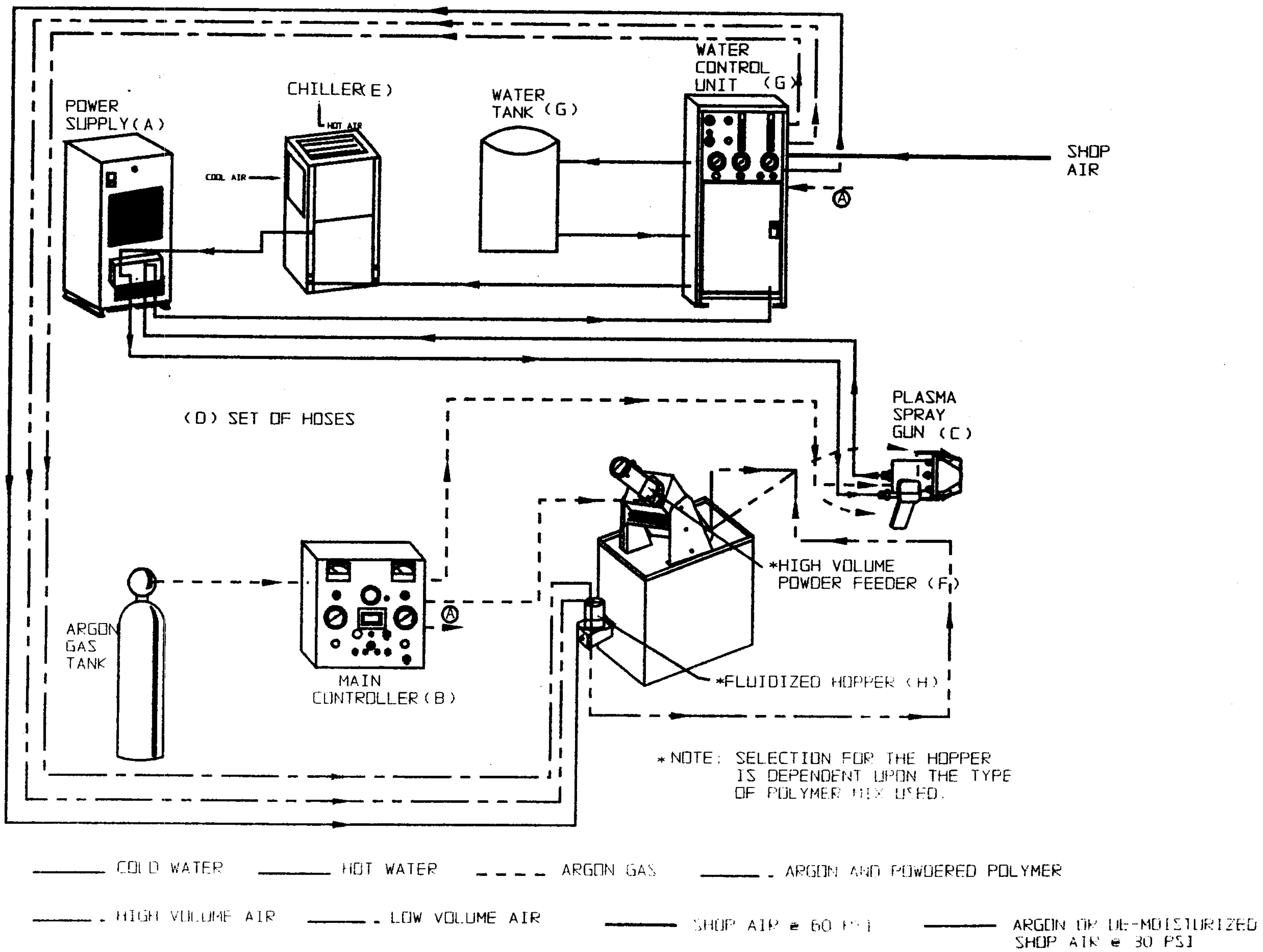


Figure 7. Polymer Plasma Spray System

## Thermoplastic Coatings

In conjunction with equipment development, polymer manufacturers have been synthesizing and formulating stabilized polymer systems to allow for the successful application of polymers via thermal spray processes. With the proper polymer system (pigments, stabilizers, flow modifiers, etc.) and equipment control, this technique has been used commercially to coat a wide variety of substrates including aluminum, carbon steel, stainless steel, concrete, asphalt, wood, plastics, fiberglass, and even paper. The advantages such coatings offer include 100% solids (no solvent) systems, unique chemical and abrasion resistance, and the ability to coat a substrate under almost any environmental condition.

While thermal spraying of plastics has existed for 20 years or more, successful applications have been limited due to poor equipment design (as stated earlier) and/or improper polymer application. Polymers used in many of these applications were chosen for specific properties or because of availability. While polymers like low density polyethylene, nylon, etc., have many desirable properties, they lack the most critical property for a viable coating -- adhesiveness!

Since electrostatic powder coating began in the 1960's, the powders used most predominately have been thermosetting types, such as epoxies and polyesters. However, history reveals that the very first powder coatings were fluidized bed applied thermoplastic powders, going back to the 1950's. The first electrostatically sprayed powders were thermoplastics as well. The compound word "thermoplastic" is derived from "thermo" (heat) and "plastic" (a large polymeric molecule built from repetitions of smaller chemical units). When heated these powders melt and flow. When cooled, the coating becomes solid again, but remains chemically unchanged. On the other hand, when heated, thermosetting powders undergo chemical changes and the molecules crosslink to create a different composition in the finished coating. Of the total powder coating market in North America, thermoplastic powders represent about 10%. Thermosetting powders command such a large market segment primarily because they more closely reproduced think-build, decorative paint finishes.

Thermoplastic powders have been associated with thicker-film-build functional coatings. Although they are still applied primarily by fluidized bed, thermoplastic powders can also be electrostatically sprayed. Fluidized bed applications include dishwasher racks, fencing, conduit and indoor/outdoor furniture. These coatings offer excellent weather, impact and chemical resistance with good durability in thicknesses ranging from eight to 40 mils. Because the coating remains chemically unchanged after melting and solidifying, second or third coats can be applied to gain additional protection or to correct coating defects, with each subsequent layer fusing into the previous one.

Electrostatically applied thermoplastics are found on refrigerator racks, prefabricated fence and other products such as light-gauge metals and wire cloth that cannot be fluidized bed coated. These coatings range in thickness from three to 15 mils and have the same basic properties as their thicker-film counterparts.

There are several kinds of thermoplastic powder coatings, including: polyvinylchloride (PVC); polyamides (nylon 11 an 12); polyethylene (PE) in low-density (LDPE) and high-density (HDPE) versions; polypropylene (PP); ethylene vinyl acetate (EVA); and others included polymer alloys or combinations of materials. By bar the most widely used thermoplastic powder coatings are PVC and nylon.

Thermoplastic resins tend to be of high molecular weight and, therefore, require relatively high temperatures, (typically 300-350°F/149-212°C) to achieve melt and flow during application. In fluidized bed coating, both preheating and post-heating of the parts to be coated in generally practice to accurately control the heat history. Because of the high temperatures required during coating operation, polymer degradation may occur.

In general, thermoplastic powder coatings have excellent adhesion to most substrates. However, surface preparation comprising shot or sandblasting and/or priming is recommended. It is important to evaluate initial and long-term adhesion of the powder coating under consideration for a specific application, especially if long-term immersion or exposure to a liquid or vapor are specified.

Historically, many thermoplastic resins have been evaluated in powder coating processes, but few have the proper combination of physical properties, melt viscosity, thermal stability, and other necessary characteristics. What follows is a brief description of the most commonly used resins in thermoplastic powder coatings.

## Polyamides

Powder coatings based on nylon resins (polyamides) have been used since the development of the fluidized bed coating process and continue to be widely used today. Nylon-based coatings have many outstanding functional characteristics such as hardness, toughness, abrasion resistance, chemical and solvent resistance, as well as outstanding appearance characteristics. While there are some "self-priming" nylon powder coatings available, additional priming is recommended when performance requirements are more critical (i.e., coating of dishwater baskets, pipes, valves, and vessels for chemical service, and for coating medical instruments which are sterilized by autoclaving or chemical immersion). With the proper selection of components (raw materials), nylon powder coatings can be formulated to be FDA compliant for food contact applications. Nylon coatings can also be used in coating outdoor applications, such as lighting fixtures, poles, and seating.

### Polyolefins

Polyethylene and polypropylene resins also have a long history of use in powder coating. Polyethylene has excellent flow, and most coatings have a soft, waxy feel. Polypropylene grades, especially some copolymers, have greater elasticity than polyethylene and can approach plasticized PVC in softness. While chemical resistance is generally good, polyolefin-based coatings can deteriorate rapidly in contact with some solvents and detergents due to stress cracking. Polyolefin-based coatings must be properly stabilized for outdoor exposure or catastrophic failure will result, due to cracking and peeling. To combat poor adhesion, functionalized copolymers have been developed which significantly improve adhesion.

### Vinyls - Plasticized PVC

PVC-based powders possess a good balance of properties and a soft rubbery feel. With the proper primer, PVC coatings display good detergent and water resistance, and maintain adhesion after prolonged immersion at elevated temperatures necessary for applications such as coating dishwasher baskets. Properly formulated PVC coatings are acceptable for food contact applications and also possess good outdoor weathering characteristics.'

### Polyester

Polyester-based thermoplastic coatings have a look and feel similar to nylon coatings but they lack the solvent and abrasion resistance of nylon-based coatings. Polyester-based thermoplastic powders have good adhesion to most substrates and can be used without a primer. Most polyester powders also have good exterior durability and are used to coat items such as outdoor furniture, etc.

### Poly(Vinylidene Fluoride) - PVDF

Coatings based on PVDF are noted for their outstanding exterior durability. They possess better long-term weathering characteristics than any other powder coating material. PVDF coatings have a long history of performance in architectural applications applied by dispersion (conventional liquid) coating techniques. Poly(vinylidene fluoride)-based powder coatings also have exceptional electrical insulating properties and chemical resistance with the exception of hydrocarbon solvents. PVDF coatings are used to coat pumps, valves, piping, and other equipment used in the chemical process industries.

### Fluoropolymer - ECTFE

The coating, HALAR® ECTFE, is based on a 1:1 alternating copolymer of ethylene and chlorotrifluoroethylene, a chemical structure credited with giving the coating a unique combination of properties.

ECTFE resists corrosive chemicals and organic solvents, such as strong mineral and oxidizing acids, alkalies, metal etchants, and liquid oxygen. It also exhibits low permeability, an important characteristic for chemical environments.

"Of the fluoropolymer resins available, HALAR ECTFE is the least permeable to gases and liquids," says Raghu Rao, technical service engineer at Ausimont. "Thus, corrosive chemical substances cannot easily seep through the coating and attach the steel underneath."

For example, the medical industry is using ECTFE as a film for encapsulating pacemaker batteries. And some dental tool manufacturers are coating filling mixing spatulas with the copolymer because of its abrasion resistance.

ECTFE has continuous thermal rating of 300°F. While most fluoropolymers degrade when exposed to radiation, HALAR maintains useful properties in exposures to 200 megarads.

The resin is weldable, and impact resistance, add Rao. And, it outperforms PTFE and PFA in exposure to carbon dioxide, chlorine gas, and hydrochloric acid.

## Ethylene Acrylic Acid copolymers

Ethylene Acrylic Acid copolymers (referred to as EAA copolymers) bring a unique set of performance properties to the arena of thermally applied powder coatings. The acrylic acid functional moiety serves to promote adhesion to many substrates via hydrogen and ionomeric bonding. It is this inherent adhesiveness for which the food and packaging industry uses EAA copolymers, particularly for heat seal layers in structures where aluminum foil is the barrier.

### Application via Thermal Spray

The performance of thermal sprayed coatings is dependent on 1) the thermal history applied to the polymer and 2) the polymer's inherent properties. It is therefore critical to understand the "thermal" characteristics of various thermal spray equipment. Consideration must be given as to the type of fuels used (i.e., propane/air, acetylene/air, or propane/oxygen), powder feed systems, and flame controls. The heat output of the system is perhaps the single most important equipment factor in applying a viable coating.

What is frequently not understood in the application of thermoplastic powders via thermal spray equipment is the concept that the polymer may degraded during application long before any obvious changes in the coating can be seen. Such practices as baking the coating into the metal (flame polishing may detract from many of the desirable properties that can be obtained with thermoplastic coatings, particularly adhesiveness. Overheating the polymer can quickly lead to thermal degradation and subsequent reduction in performance of the coating. This can occur with no visual indication of degradation until the polymer begins to pyrolize or scorch. Consequently, a plastic thermal coating that looks acceptable may perform poorly in a given application. In the case of some thermoplastics, excessive thermal input may progressively crosslink the polymer to the point where complete delamination from the metal substrate can occur. In other polymer systems, chain scission is the primary mode of decomposition during application. Thus, it is critical to understand the limits of thermal input that a given coating can tolerate before significant crosslinking occurs.

What does this mean to the applicator and what procedures should be followed in correctly applying polymer powders via thermal spray equipment? The applicator must understand that there is a thermal window in which the polymer must be applied. If the powder is sprayed onto a cold substrate, the particles will solidify before they fully coalesce and the coating may have pinholes. Excessive heating can also cause pinholes as polymer decomposition generates off-gases which escape through the polymer coating. In either case, less than optimum coating performance may occur if these temperature limits are exceeded for extended periods of time (minutes). Figure 3 demonstrates this concept of the thermal window that exists with polymer coatings.

The optimum thermal window is polymer specific where each polymer chemistry has its own upper and lower temperature limits. The upper temperature limit is controlled by thermal degradation sensitivity and the lower temperature limit is controlled by the polymer melting point characteristics.

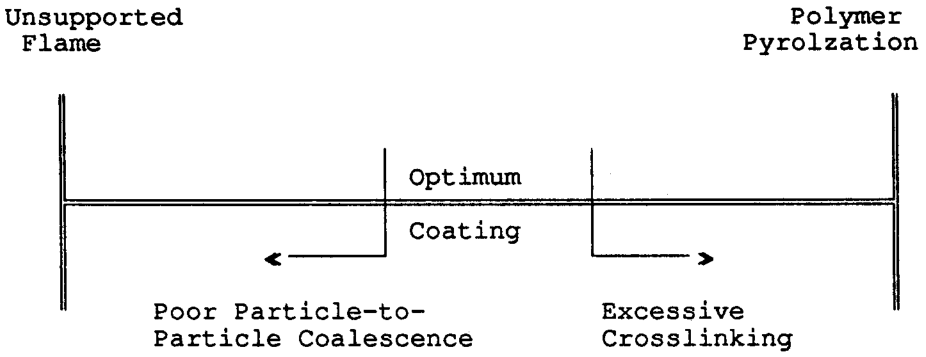


Figure 8. Gas Control Settings / Flame Temp

The objective in equipment design is to provide versatility in BTU input to meet the thermal application window of various polymers. Table 1 defines the upper and lower temperature limits of this window for thermoplastic polymers.

Table 1. Thermal Spray Parameters

| SUBSTRATE TEMPERATURE | CARBON STEEL |
|---|---|
| - pre-heat | 175 - 200°F |
| - wet-out | 300°F |
| - excessive crosslinking | ≥ 450°F |
| - scorching | ≥ 475°F |
| Coating Temperature | 320 - 425°F |
| Application Rate | 50-200 Ft.$^2$/hr. |
| Coverage Rate | 8 - 10 ft. $^2$/lb. |

The understanding of these temperature limits is critical to success. During application the upper temperature limits may be exceeded for brief periods (a few seconds) with minimal effects. Problems with coating performance begin to occur when thee limits are exceeded for several minutes as can occur when the substrate is overheated. Hand held optical pyrometers, which almost instantaneously measure the coating temperature via infrared sensors is an excellent tool for monitoring coating temperature and assuring that the substrate stays within the temperature limits.

It is important to understand the temperature constraints for ANY POLYMER SYSTEM used in thermal spray applications.

Table 2 presents a list of important physical properties for leading thermoplastic polymer coating systems.

## Surface Preparation

As with other coating systems, surface preparation is critical for optimum coating adhesion/performance. A white metal blast with 1.5-2.0 mil profile is recommended but excellent adhesion can be obtained with near white and commercial blast surfaces as well. The more free metal exposed, the more ionomeric bonding and thus adhesion the coating will have to the substrate.

Surface contamination is certainly a concern, particularly in regard to trace salts and chemicals. Any oil or chemical contamination can cause pinholes in the coating during application by either degassing from the heated surface after the coating is applied or causing the coating to lose adhesion to the contaminated surface and allowing the molten coatings to separate.

Table 2. Thermoplastic Resins and Associated Material Property Data

| PROPERTY | ASTM Method | Polyurethane Thermoplastic Elastomer | | FEP | PFA | Polyimide (NEW TPI) | Polyamide-imide(s) [Torlon] | Aromatic polyester poly-P-oxybenzoyl |
|---|---|---|---|---|---|---|---|---|
| | | High Hardness Polyester | High Hardness Polyether | | | | | |
| Transition Temperature (°F) | | | | | | | | |
| Tm | | | | 554 | 575 | 730 | | 1100 |
| Tg | | -50 | -50 | | | 480 | 527 | |
| Extrusion Processing Temperature (°F) | | 370-410 | 380-440 | 600 | – | 735-790 | – | N/A |
| Mold (linear) shrinkage (in/in) | D955 | 0.005-0.015 | 0.008-0.012 | 0.01 | – | 0.8 | – | – |
| Tensile strength at break (psi) | D638 | 4,000-11,000 | 6,000-7,240 | 3,500 | 3,600 | 13,400 | 27,000 | 5,500 |
| Elongation at break (%) | D638,D1708 | 110-550 | 340-425 | 325 | 300 | 90 | 2-15 | |
| Elongation at Yield (%) | | >50 | >50 | ≤2* | ≤2* | – | ≤2-6 | – |
| Max. Continuous use temp (°F) | | -50 to 212 | -50 to 180 | 392 | 500 | 550 | 428 | – |
| Relative Hardness | | | | | | | | |
| Rockwell | D785 | | | | | M95-M105 | E86 | |
| Shore | D2240 | D46-78 | D55-75 | D55 | D60 | | | D50 |
| Coefficient of linear expansion ($10^{-5}$/°F) | D696 | – | – | 8-12 | 14-21 | 9.9 | 2 | 67 |
| Specific gravity | D792 | 1.15 - 1.28 | 1.14 - 1.21 | 2.15 | 2.15 | 1.33 | 1.41 | 1.44 |
| Water absorption (%) (24 hr, 1/8 in thick specimen) | D570 | 0.3 | – | <.01 | <.03 | 0.1 | 0.3 | – |
| Suppliers | | Goodrich, Mobay, Ohio Rubber, Upjohn | | DuPont | DuPont | Mitsui | Amoco | Sohio |
| <u>Solvent Resistance</u> | | | | | | | | |
| Water | | Good | Good-Excellent | Excellent | Excellent | Good-Excellent | Good-Excellent | Excellent |
| Aliphatic Hydrocarbons | | Excellent | Excellent | Excellent | Excellent | Excellent | Excellent | Excellent |
| Aromatic Hydrocarbons | | Fair-Good | Fair-Good | Excellent | Excellent | Excellent | Excellent | Excellent |
| Halogenated Hydrocarbons | | Poor-Fair | Fair-Good | Excellent | Excellent | Excellent | Excellent | Excellent |

*Creeps and undergoes cold flow below yield point.

Table 2. Thermoplastic Resins and Associated Material Property Data (continued)

| PROPERTY | Polyether-etherketone [PEEK] | Copolyether-Ester TPE | Polyether/Amide Block Copolymer TPE | Nylon 11 | PPS | ABS | Polyetherimide (Ultem) |
|---|---|---|---|---|---|---|---|
| Transition Temperature (°F) | | | | | | | |
| Tm | 650 | 424 | 375 | 365-394 | 536 | | |
| Tg | 289 | | | | 266 | 180 | 419 |
| Extrusion Processing Temperature (°F) | – | 460-500 | 340-460 | 390-475 | 600 | 435 | -- |
| Mold (linear) shrinkage (in/in) | 1.1 | 0.003-0.014 | – | 0.012 | 0.005 | 0.005 | 0.007 |
| Tensile strength at break (psi) | 14,500 | 2,000-6,400 | 2,000-7,000 | 8,000 | 23,000 | 5,000 | 15,200 |
| Elongation at break (%) | 50 | 250-600 | 350-680 | 300 | 2-10 | 10-100 | 60 |
| Elongation at Yield (%) | 5 | >50 | >50 | 20 | 2 | 5 | 7 |
| Max. Continuous use temp (°F) | 480 | 300 | 300 | -- | 428 | 150 | 338 |
| Relative Hardness | | | | | | | |
| Rockwell | R126 | | | R108 | R93-123 | R93-111 | M114 |
| Shore | | D40-72 | A75-D36 | | | | |
| Coefficient of linear expansion ($10^{-5}$/°F) | 2.6-6 | 5-10 | 12 | 6 | 10 | 4-5.3 | 3 |
| Specific gravity | 1.4 | 1.15 - 1.25 | 1.02 | 1.04 | 1.4 | 1.05 | 1.27 |
| Water absorption (%) (24 hr, 1/8 in thick specimen) | 0.5 | 0.18-0.72 | 1.0 - 1.3 | .03 | 0.1 | -- | 0.25 |
| Suppliers | ICI | DuPont,Celanese | Atochem,Huls | Atochem | General Electric | DuPont | General Electric |
| Solvent Resistance | | | | | | | |
| Water | Excellent | Excellent | Excellent | Good | Excellent | Good-Excellent | Excellent |
| Aliphatic Hydrocarbons | Good-Excellent | Good-Excellent | Good | Good | Excellent | Poor | Good |
| Aromatic Hydrocarbons | Good-Excellent | Excellent | Good | Good | Excellent | Poor | Poor |
| Halogenated Hydrocarbons | Good-Excellent | Poor-Fair | Good | Poor-Fair | Excellent | Poor | Poor |

## Successful Application

Recently the U.S. Army Missile Command worked with APS to develop a thermally sprayed polymeric coating that could be used as external protection layers on graphite-epoxy composite rocket motor cases. Based on future programs, several missile systems offer considerable potential for composite application. A Dept of Defense requirement for "insensitive ammunitions" (missiles made with materials that dampen ordnance explosion under fire conditions) could add to the operational requirements for composites. Polymer matrices tend to break down in a fuel -fire environment before a missiles propellant ignites, thereby creating a sparkler effect instead of a skyrocket. See Photograph 1.

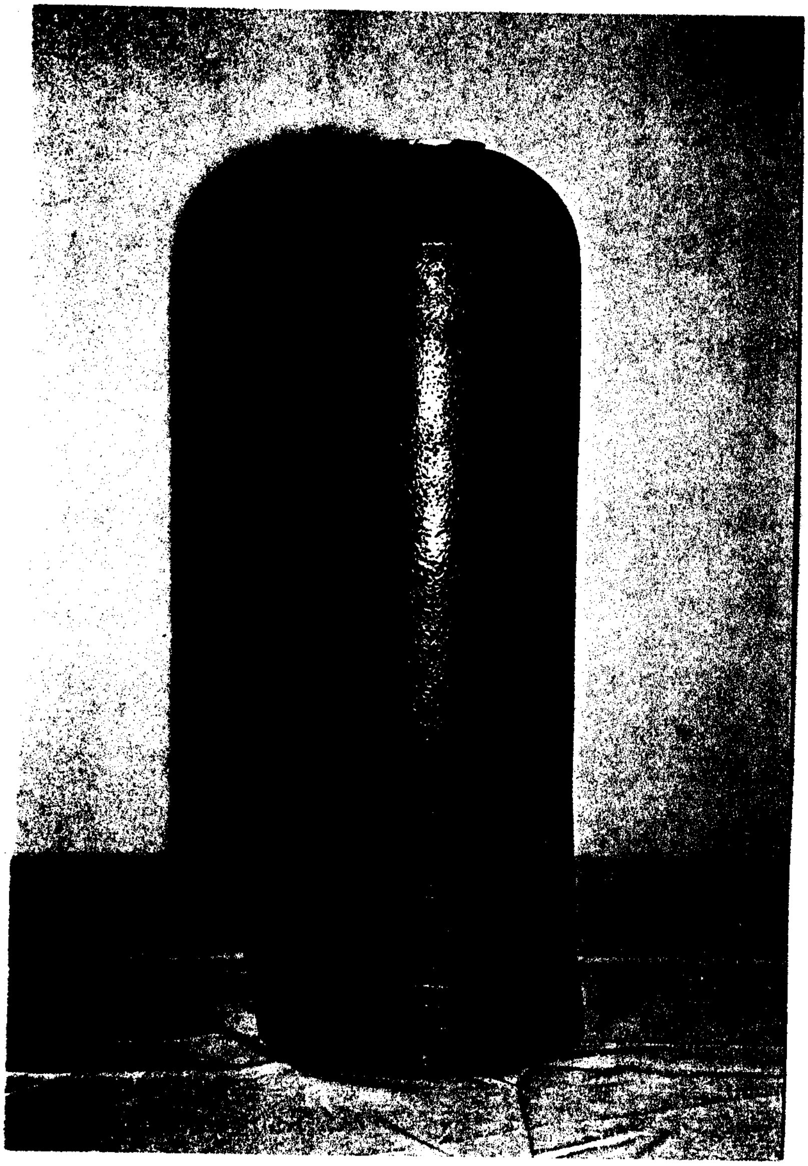
Special plasma applied coatings protect the case from aerodynamic heating, moisture absorption and electrostatic discharge. A two layered coating was developed, the first layer, inner is electrically conductive and highly resistant to moisture absorption and transmission. The coating has 3% elongation capability without microcracking and will withstand an operating temperature range of -65°F to 300°F. The metallic filler chosen was 99% pure copper powder, of a mean particle size 50 micron. This was blended with a thermoplastic polymer - Ultra high Molecular Weight Polyethylene (UHMWPE). The copper powder was blended with the polymer at a 80% by weight ratio.

The result was a 20 mil coating applied directly to the graphite epoxy composite motor case surface. Than an external insulation layer coating was required. The UHMWPE polymer was chosen for several reasons. Coefficient of expansion, resistance to moisture, maximum ablative characteristics, good thermal conductivity and diffusitivity.

This polymer was then blended with a 30% by weight silica ceramic fiber material for an 80 mil coating thickness. The result was a multilayered coating which met the customer requirements. In all tests, the advantage of using this method were that both of the coatings were applied without subjecting the composite rocket motor case to high heat loads in a curing oven. Coating thickness and polymer vs filler loading blends were controlled better than conventional industry methods. All of which allows this method to be 23% more cost effective.

## Truck Bed/Flame Coating Demonstration (30 July, 1992)

[3]The U.S. Air Force prepared a 6' carbon steel personnel stand used in the paint stripping hanger and a 10 ton dump truck bed for flame coating at Robins AFB. Both units were given an aggressive white metal sandblast (SP-5, estimated minimum 2 mil anchor pattern) prior to coating. The AT flame spray system was used for both coating operations. All coating was performed outdoors under high temperature and humidity conditions (90°F, 75% RH).



Photograph 1.

U.S. Army Composite Rock Motor Case with Multilayered Protective Coating

[3]About 1 hour was required to coat the personnel stand with black, UV stabilized Dow 3 MI Envelon. A 10-15 mil coating was deposited on the entire stand. The 1-1/2" square tubular structural frame was coated quickly and effectively. Difficulty was experienced, however, in flame coating the thin (approximately 1/6" thick) formed sheet metal tread support runners. The small mass of these elements resulted in rapid temperature buildup during the coating process. The problem was overcome by coating the runners with several rapid passes and allowing the metal/coating to cool between passes. Using this technique, the powder can be applied somewhat "dry" (partially melted) and flame brushed (flame only) on subsequent passes. The tread gratings and tread/runner connection detail provided an excellent challenge to the maneuverability and capability of the flame spray gun. The operator was able to successfully coat and encapsulate these features by approached the work piece from various directions as is commonly done with conventional paint spray guns.

The 10 ton truck bed measured 14' X 6'8" X 3' deep (4' high tailgate). The bed was fabricated from angle-reinforced carbon steel sheet metal (approximately 1/8" thick). A base coat of black, UV stabilized 3 MI Dow Envelon was applied with the AT system. The low melt index material was selected for toughness. The 15 foot long hose bundle length allowed the application to stand inside the truck bed with the propane bottle and powder hopper console located on the ground adjacent to the vehicle. A 5-7 mil base coat was applied in approximately 6 hours of coating activity. No significant problems were encountered either with the coating or with the equipment during this operation. Robins AFB environmental personnel monitored application emissions exposure during most of the coating process.

A topcoat of 30 MI, UV stabilized PF-111 black DuPont Nucrel was applied to the truck bed on the following day with the AT system. The topcoat was applied to build total thickness to 15 mils (nominal) and to improve the release characteristics of the coating. As indicated previously, the 30 MI polymer flows more readily, is easier to apply and produces a smoother finish (less "orange peel") than the 3 MI formulations. The topcoat was applied to the entire truck bed in approximately four hours.

No equipment or coating problems were encountered during the topcoat application. It was noted, however, that coating outdoors is difficult with these application systems when winds are blowing. Even a gentle (5-10 mph) breeze can cause flame/powder deflection or flame blow-back which can be uncomfortable for the operator and which significantly slows the application process. Flame coating in wind protected areas is recommended.

## CONCLUSIONS

Powder coatings based on thermoplastic polymers are appropriate for specific applications in which the unique coating properties are an advantage. Thermal spray processes can successfully apply coatings as long as the application parameters are understood and followed. As newly developed melt compounded powders and technologically designed equipment are developed together with a better understanding of process dynamics, applications should continue to grow successfully.

Perhaps the single greatest advantage these copolymers may have over other thermoplastic powder coatings is their inherent adhesiveness to metal substrates such as aluminum, carbon steel and other polar substrates. When properly applied, thermoplastic powder coatings can offer the following advantages over conventional field-applied coatings:

100% solid materials

Excellent abrasion resistance

Excellent specific chemical resistance

Easy repairability

Excellent salt fog resistance

Excellent adhesion

May be applied in all weather conditions

A "non-stick" surface

No cure times

Excellent low temperature performance

Although use of these materials is currently specialized, as field experience is gained and awareness increases, the range of applications for site-applied powder coatings will inevitably grow.

# REFERENCES

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[3] "Environmentally Compliant Thermoplastic Powder Coatings". U.S. Air Force Laboratory and Field Test, Contract No. F09603-90-D-2215, December 18, 1993.