Paper No. 679

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ABSTRACT

The present study is the result of an experimental investigation of the fluidized bed coating on mild steel specimens using Nylon-11and PVC powders. The effects of dipping time and preheat temperature on coating thickness were investigated. A preheat temperature of 265 ^{o}C to 270^{o}C for PVC and 350^{o}C to 360^{o}C for Nylon-11 is necessary to achieve an acceptable surface. The optimum thickness of 930 microns for nylon and 1407 microns for PVC was obtained on mild steel. To minimize errors in achieving the desired coating thickness, dipping time shorter than 5 sec is not recommended. Fluidized bed coating process does not require solvents and thus provides an environmentally friendly alternative to other techniques such as dipping, brushing, spraying etc. It also offers the advantage of efficient utilization of materials (nearly 100%), the ability to coat irregular shapes, high coating rates, simple and inexpensive equipment requirements, process automation, smooth and continuous coating applications. Graphs of coating thickness versus dipping time presented in this study enable the optimal choice of preheat temperature and dipping time to achieve the acceptable surface finish.

Keywords: *Coating, Fluidized bed Coating, Nylon and Poly vinyl chloride (PVC) coating on mild steel.*

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INTRODUCTION

Coatings are substances applied to the surface of a substrate to modify the functional properties of the substrate. Such surface modification dates from very early in the technical development of man. Coatings are used most frequently for protection of metal surface for corrosion protection, coating of wood to prevent decay and wrapping of food products with coated film to prevent spoilage [1].

Coating processes fall in the area of polymer fabrication technologies along with molding, extrusion, casting, forming and calendaring. In parts that must be constructed of metal for structural reasons, a plastic coating may be applied for decorative and /or functional purposes such as electrical insulation, corrosion protection and abrasion resistance.

Thin film powder coating, also referred to as a “dry painting” process, eliminates volatile organic compounds (VOCs), hazardous air pollutants, solvents and produces superior surface finish. There are four basic powder coating application processes, dip coating, electrostatic spraying, fluidized bed, and flame spray. For all application methods, surface preparation (i.e., cleaning and sometimes application of a conversion coating) is required to develop good coating adhesion to the work piece surface.

A Fluidized bed is an amazing thing to see. Plastic powder is fluidized by gently blowing air into the bottom of the tank and through a diffusion plate and finally, through the powder. Before the powder is fluidized, it’s about as penetrable as fine beach sand. Once the air goes on, the bed rises about 30%, and looks like its boiling at the surface. If hand is put into the bed, it goes in with no resistance at all, (and the bubbles tickle).

The part to be coated is preheated in an oven, and then dipped into the fluidized bed. As powder particles come in contact with the hot parts, they melt on creating the plastic coating. The plastic coating builds up quickly and uniformly. After the part is withdrawn, there may be enough heat left to completely fuse the coating and even melt the surface smooth. If there is enough residual heat, just cool, inspect and pack. Otherwise the part is returned to the oven for a very short time. The coating may be reheated to achieve a smoother finish. For a given object, the thickness of the coating is dependent on two process variables; preheat temperature of the object, and the amount of time for which it is immersed in the powder [2].

Fluidized bed plastic coatings usually are in the thickness range of 300-2000 microns. However, K.C Leong, G.Q.Lu, B.Rudolph [3] reported that coating thickness less than 400 micron is difficult to achieve with Nylon-11. K.C Leong and G.Q.Lu also reported increase in coating thickness with increase of preheat temperature and dip time [4]. Thicker coatings require using multiple dips or plastisol coating.

Fluidized bed coatings have the tremendous advantage of being remarkably uniform in thickness. These coatings eliminate the need for expensive and often toxic solvents, the control equipment, employee exposure, and the disposal requirements and liabilities associated with liquid coating (wet solvent) use. Because the powder is dry when fluidized, and overspray can be readily retrieved and recycled, regardless of the complexity of the system, resulting in shorter cleanup times. In all cases, the dry powder is separated from air stream by various vacuum and filtering methods and returned to a feed hopper for reuse. Powder efficiency (powder particles reaching the intended surface) approaches 100 percent. Other advantages over conventional spray painting include greater durability; improved corrosion resistance; electroplating; electrical insulation; ease of cleanliness; availability in any colour; and elimination of drips, runs and bubbles.

Fluidized bed technique has been used to coat discrete objects and continuous webs such as wires, wire fencing and rolls of metal foil. Successful users now consider it as integrated finish system incorporated into production for the purpose of providing corrosion protection, abrasion resistance, electrical insulation and for decorative purposes. Typical applications include the coatings of rotors and stators in electric motors and generators; pipes, fittings and valves in fluid conveying systems, components of electrical appliances such as dishwashers, washing machines, refrigerators and for automotive components [3].

Parts can be coated with polyvinylchloride, nylon, polyethylene and epoxy. Fluidized bed plastic coatings are usually applied to metals, ceramics and glass.

In Fluidization, a gas or liquid is passed through a bed of solid particles, which is supported, on a perforated or porous plate. In the case of fluidized bed coating, air is passed through a bed of polymer particles. When the pressure drop of the flowing air through the bed equals or exceeds the weight of the bed, the powder particles become suspended and the bed exhibits liquid-like behavior. As shown in the figure 1, at gas flow rates less than the fluidization velocity, the bed is fixed bed and there is no movement of particles. At flow rates above minimum fluidization the bed expands and bubbles appear. The air velocity corresponding to a pressure drop that just equals the weight of the bed is referred to as the minimum fluidization velocity. At this flow rate all of the bed particles are completely suspended by the air stream. For a given system, minimum fluidization velocity can be determined from a pressure drop vs. air velocity diagram [4].

As airflow is increased above the minimum fluidization velocity, the bed may exhibit behaviors ranging from smooth fluidization to dilute fluidization in which powder can be transported by the air stream. Smooth fluidization is desirable for optimal performance in the powder coating process. The liquid-like nature of the fluidized powder bed allows a metal object to easily be dipped into it.

Polymer Powders

In present study two types of polymer powders Nylon-11 and polyvinyl chloride were used for coating mild steel. Nylon-11 has been used almost exclusively because it has low melt viscosities than Nylon-6,6. Nylon coating powders are available for electrostatic spray and fluidized-bed application. Nylon coatings are very tough, resistant to scratching and marring, have a pleasing appearance, and are suitable for food contact applications when properly formulated. These coatings are used for chair bases, hospital furniture, office equipment, knobs, handles, and other hardware.. Nylon coatings have good solvent and chemical resistance and are used for dishwasher baskets, food trays, hot water heaters, plating and chemical etching racks, and large diameter water pipes in power-generating stations.

Dishwasher baskets are coated with fluidized bed PVC powder. Other applications are washing machine retainer rings and various types of wire mesh and chain-link fencing. PVC coatings have a cost /performance balance that is difficult to match with any of the other thermoplastic materials. Properly formulated PVC powders have good outdoor weathering resistance and are used in many applications where good corrosion resistance is required. These coatings are also resistant to attack by most dilute chemicals except solvents. In addition PVC coatings achieve excellent edge coverage by fluidized bed coating technique, which cannot be achieved by other techniques.

EXPERIMENTAL

Equipment Design

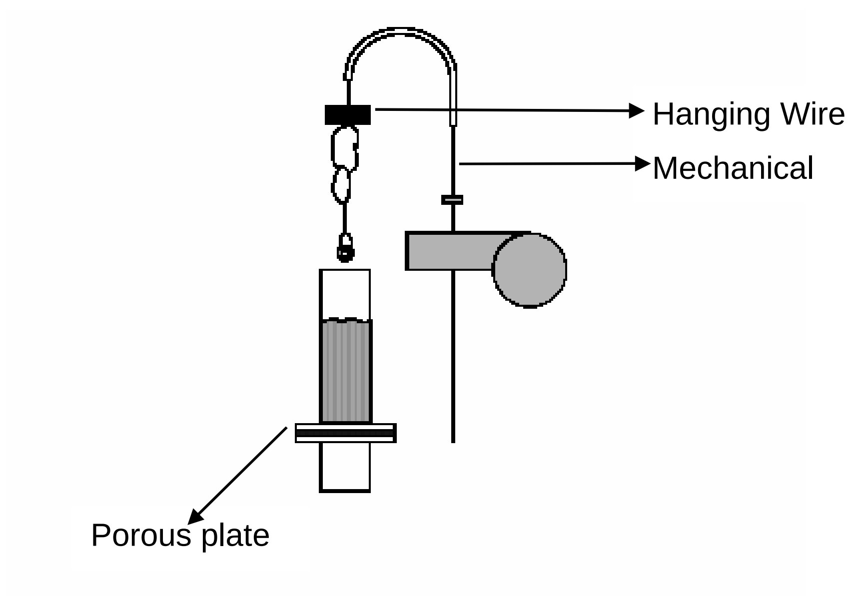

Figure. 1: Setup for Fluidized bed coating.

The fluidized bed was fabricated from clear Plastic (acrylic) tube with a diameter of 3.3” and a height of 60”. A distribution chamber is attached at the lower end of the tube to produce uniform fluidization throughout the bed. Dry air enters the bed through the distribution chamber through a regulating valve. The distributor plate is a polyethylene porous sheet manufactured specifically for heat-treating fluidized beds. The drop mechanism for the metal samples was fabricated by bending stainless steel tubing into a U-shape and running a thin metal cable through the center of the tube. An attachment device was placed at one end to hook a wire loop to it and the other end had an adjustable stop. Figure-1 illustrates the complete set up of apparatus.

Specimens

Mild steel specimens were cut from a sheet having dimensions 2.5” x 1.5” x 0.25”. A small hole having diameter of 0.15” was grooved in the samples at the centre of the top for hanging the samples with metallic wire in the fluidized bed.

Surface Preparation of Specimens

Surface of specimens were prepared to remove any grease, dirt and oxide. This was done by first of all dipping the specimens in alkaline cleaning solution having a composition 5%Na_2CO_3, 5%$NaHCO_3$, 2%Trisodium Phosphate, 0.5% Fatty Acid Ester to remove any organic soils present on the surface followed by rinsing in water. Then the specimens were pickled in 5%H_2SO_4 followed by neutralization and rinsing to remove any oxide present on the surface. Pickled specimens were then immersed in iron phosphate solution to achieve phosphate coating over the surface. This surface preparation technique will serve to achieve better adhesion and uniformity in the coating with superior corrosion protection.

Sieve Analysis of the Powders

The powders were sieved using standard sieves (Tyler, USA). The mean particle size of Nylon-11and PVC calculated from the sieved mass fractions was 106 micron and 63 micron respectively.

Procedure for the Coating

Powders were dried prior to coating in the oven at temperature of 105 ^{o}C to drive off any moisture present. The powder was placed in the fluidized bed and the air was blown from the bottom at high pressure to mix the powder thoroughly for a few minutes. Then the airflow rate was adjusted to achieve a fluidization condition in the bed. Coating experiments were performed at a fluidization velocity of 0.02 m/s as shown in figure. 2, which is higher than the minimum fluidization velocity as it is obvious from graph figure. 3 for achieving boiling liquid like situation in the fluidized bed powder to enable the metal specimens easily dipped in the fluidized bed.

Specimens were preheated at various temperatures and were immersed in the fluidized bed for different time intervals. Then the specimens were withdrawn from the bed and allowed to cool in air followed by water quenching. This would ensure excellent surface finish of the coating with minimum defects. Both nylon-11 and PVC coating were applied at different preheated temperatures and time.

Coated specimens were cut transverse to their cross-section and coating thickness was measured by using ocular micrometer.

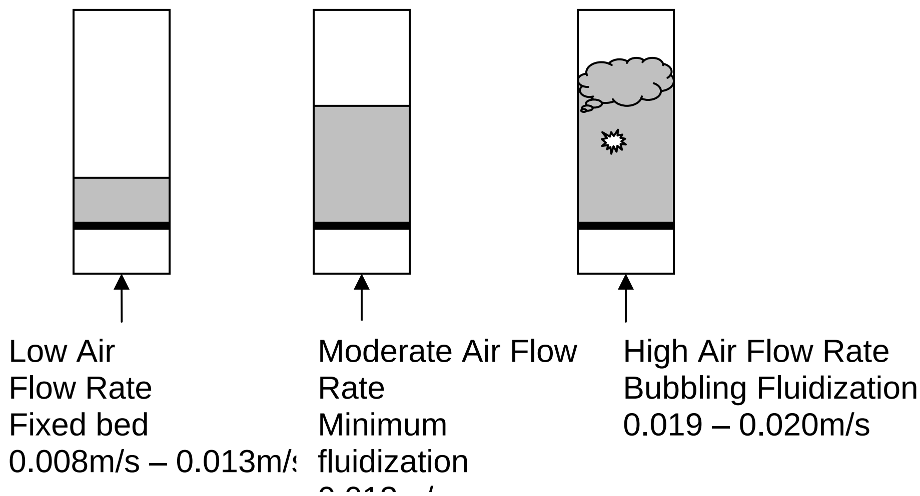

Figure. 2: Fluidization Regimes.

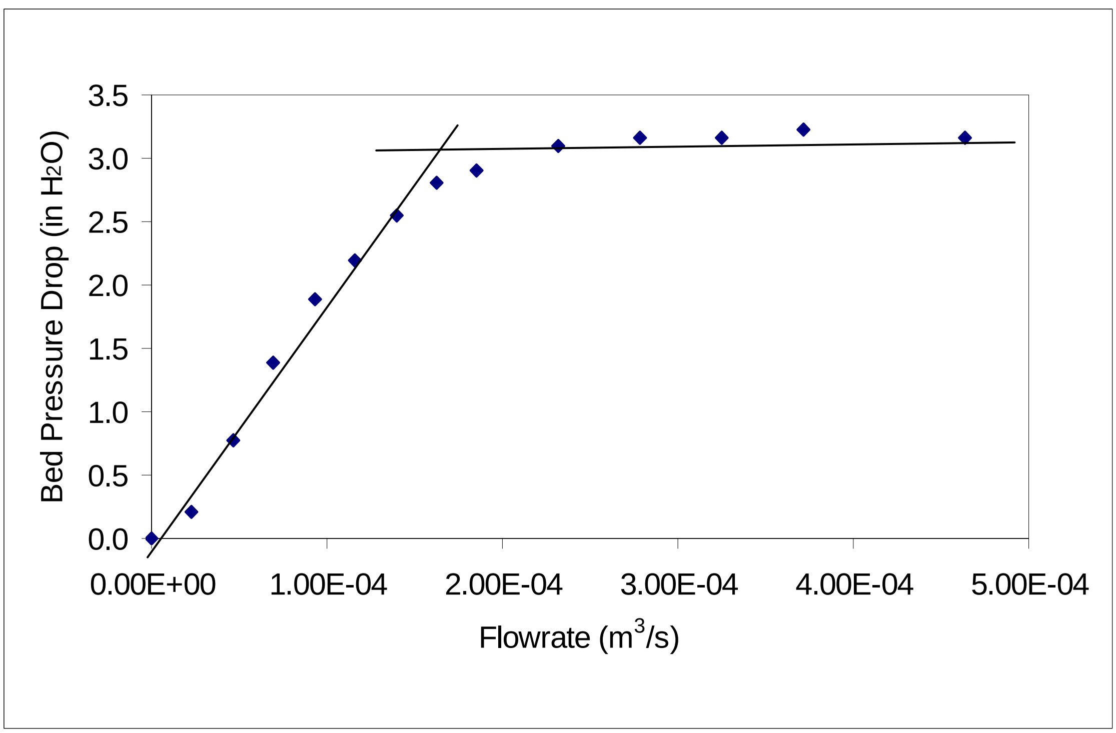

Figure 3: Determination of Minimum Fluidization.

RESULTS AND DISCUSSION

Preheating temperature about 100°C above the fusion point of powders, which is 360°C for Nylon-11 and 270°C for PVC were selected, at this temperature powder particles fuse together to form a continuous film. In all cases it is observed that coating is formed at the rapid rate when the specimen is dipped in the fluidized bed. Generally graph shows that coating thickness increases with time.

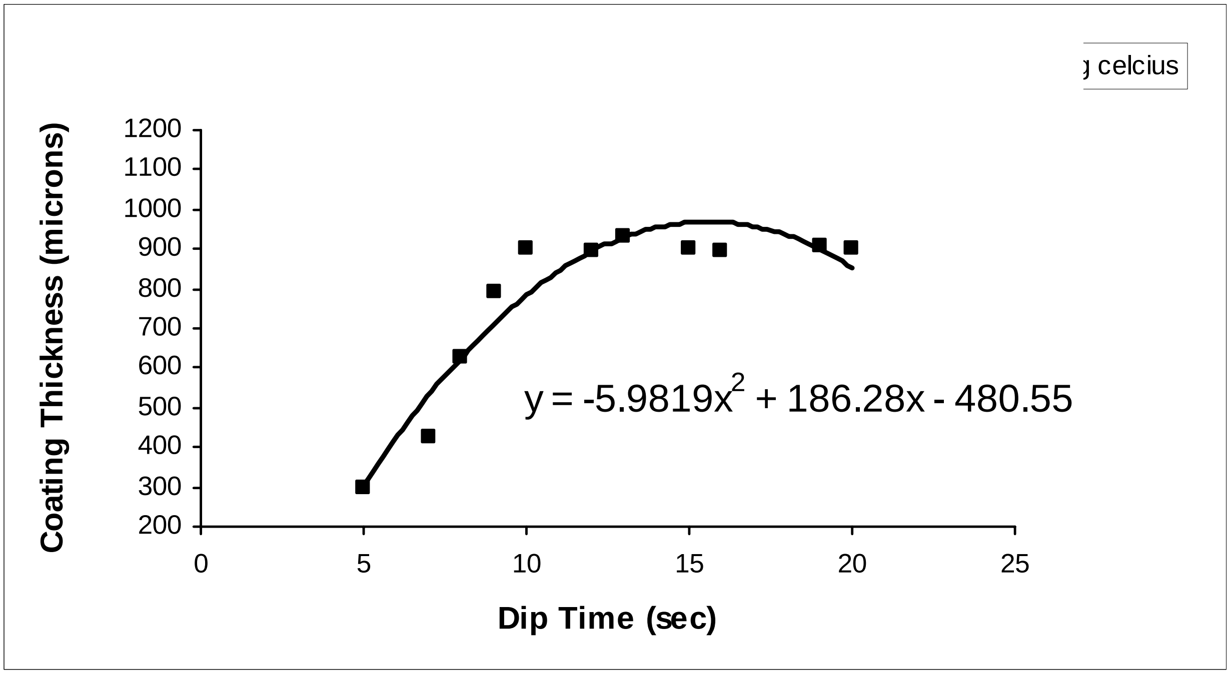

Figure. 4: Coating thickness in microns Vs Dip time (sec) for Nylon coating at 300°C.

It can be seen from figure. 4 that thickness of Nylon-11 coating on mild steel increases linearly with dipping time, reaching to maximum thickness of 930 microns at 360°C in 13 seconds, however there is no any significant increase in the coating thickness with increase of dipping time as shown in Table 1. However an acceptable coating of minimum thickness of 300 microns for Nylon-11 is achieved in a dip time of 5 sec. It was also observed that some particles of powder get adhere to the surface without fusing because there is no enough heat available for melting due to insulation caused by Nylon-11 coating.

Table 1: Effect of dipping time on coating thickness at 360°C for Nylon coating.

Dip time(s)	5	7	8	9	10	12	13	15	16	19	20
Coating thickness (micron)	300	425	625	790	900	895	930	900	895	905	900

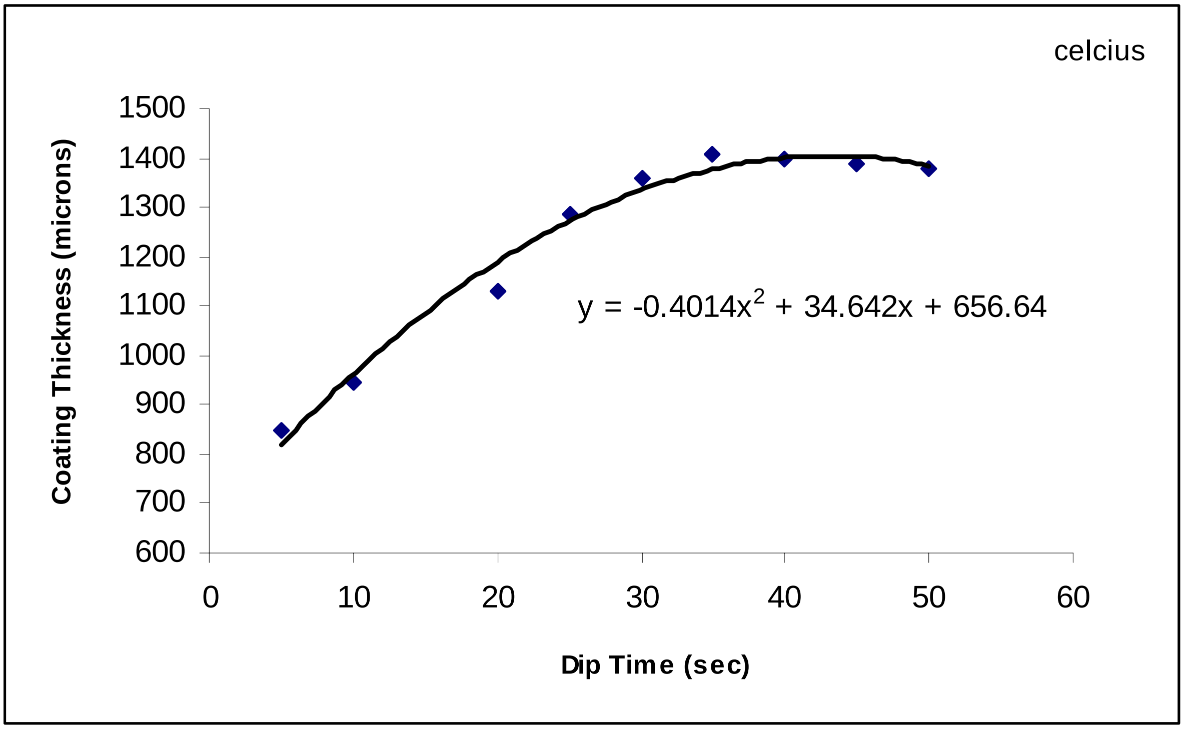

Figure 5: Coating thickness in microns Vs Dip time (sec) for PVC coating at 270°C.

It may be observed from fig-5 that coating thickness of PVC also increases with increase of dipping time, reaching to a maximum thickness of 1407 microns at 270°C in 35 sec, after that there is no any significant increase in coating thickness as also shown in Table 2. It was also observed that some of the powder remained attach over the previous coating layer can be fused by post coating treatment by placing the sample in the oven at a temperature of 270±10°C until uniform coating is achieved.

Table 2: Effect of dipping time on coating thickness at 270°C for PVC coating.

Dip time(s)	5	10	20	25	30	35	40	45	50
Coating thickness (micron)	848	945	1128	1288	1360	1407	1400	1388	1380

CONCLUSIONS

1. Maximum thickness i.e. 930 microns of Nylon-11 coating on mild steel was achieved at a preheat temperature of 360^{o}C with a dip time of 13 second.
2. The minimum coating thickness of 300 microns of Nylon-11 was obtained in 5-second dip time.
3. Uniform PVC coatings of thickness 1407 microns can be achieved at preheat temperature of mild steel 270^{o}C with dip time of 35 second. It was further monitored that with increase of dip time there was no any significant increase in coating thickness of PVC because of very less heat is available for melting the resin particles.
4. Mild steel was found a better material for fluidized bed coating process.

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