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Investigation of the recyclability of powder coatings

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ABSTRACT

100% recyclability is one of the major advantages of powder coating. However, it can never be achieved in reality. Coating powders, especially finer powders with particle size below 30 μm, were found to have much worse flow performances after recycling from electrostatic spraying so as to decrease the recyclability. Therefore, this study was designed to investigate recycled coating powders to determine the underlying cause of decreased flow performance. The investigations were based upon three major factors that make the differences between original powder and its recycled powder: particle size, humidity exposure and flow additive concentration. By adjusting the three factors independently, the influences to powder flow properties were analyzed. Results showed that the decreased particle size of the recycled powder had the most significant effect on the flow properties. Additive concentration on the powder particles did not change with respect to the particle specific surface area after electrostatic spraying. Humidity had only a minor effect on the flow properties of powder coatings.

1. Introduction

Powder coating with no emission of volatile organic compounds (VOCs) is a clean process. It has received increasing attention as a result of stricter environmental regulations and its superior performance in many aspects when compared to liquid coatings [1,2]. One of the main advantages of the powder coating process is the potential to collect all over-sprayed material that did not adhere to the work piece and recycle it as reclaimed powder [3]. The amount of reclaimed powder produced in a powder coating operation depends upon many factors such as: the size and shape of the object, the powder coating material, the coating equipment, the equipment settings and application environments. It is not uncommon for more than 50% of the original powder to be recycled as reclaim. Although near 100% material utilization can be reached by reclaiming over-sprayed powders, the flow properties of the reclaimed powder always tend to deteriorate, which makes it more difficult to handle and apply the reclaimed powder [4,5].

The flow properties of a powder refer to the ability of free-flowing in normal handling processes. In order to improve the flow properties of reclaimed coating powders, they are often blended with virgin powder; however, this method is only effective if the reclaimed coating powders are blended at a low concentration. As a result, many powder coating applicators have an accumulation of reclaimed powder because its flow properties are too poor to apply alone and it cannot be blended at sufficient concentration to consume all of the reclaimed powder that is produced.

There are many causes that can lead to the decreased flow properties seen in reclaimed powders. In this work, three potential factors were investigated to determine their influence on the flow properties of reclaimed powders.

1. Reclaimed coating powders have a smaller particle size when compared to their virgin counterparts. This occurs because, during electrostatic spraying, the larger particles have a higher momentum than the smaller particles and are, therefore, less likely to be blown away from the work piece by the carrying gas or downward draft in the spray booth. The larger particles also hold a higher charge during electrostatic spraying, making them more likely to deposit on the work piece than smaller particles [6].
2. Reclaimed powders are exposed to moisture in the spray booth. This can affect the flow properties by introducing capillary interparticle forces and by changing the material properties of the coating through the absorption of water.
3. Nanoparticle additives, which are added to coating powders as flow aides, may change in concentration during the fluidization of the powder or during electrostatic spraying. A change in concentration of nanoparticle additives may explain the differences in flow properties between reclaimed and virgin powders.

The goal of this work was to individually investigate each of the aforementioned factors and determine which factor(s) have the most influence on the flow properties seen in reclaimed powders. By understanding the root causes of this flow property reduction issue,

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new technologies and handling procedures can be developed to improve the recycleability of reclaimed coating powders.

2. Materials and methods

Powder samples used for the investigation are polyurethane and polyester-epoxy fine powders with medium particle sizes of between 25 μm and 28 μm. The particle size is closely related to the flow properties of the powder. The small particle size of the fine powder can cause significant reduction in flow properties, because of the increased interparticle forces, primarily the van der Waals force [7]. To overcome this challenge, nano flow additives are introduced [8]. These additives are coated on the surfaces of the powder particles to increase the interparticle distances, so as to reduce the van der Waals force [9].

To address each of the possible factors leading to decreased flow properties in reclaimed powders, separate experiments were performed. The following techniques and equipment setups were used in this work:

2.1. Particle size distribution

The particle size distribution was obtained by laser diffraction measurement (Mastersizer 2000, Malvern Instruments, Worcestershire, UK) following standard test procedures. The results were reported by giving the values of D_{10}, D_{50}, D_{90}, and the specific surface area. D_{10}, D_{50}, and D_{90} stand for powder particle distribution. For example, D_{10} is defined as a diameter where 10 vol.% of the particles of the powder is less or is equal to the diameter. D_{10}, D_{90} are the popular parameters used to determine the amount of fine and coarse particles, and D_{50} represents the medium particle size of the powder samples. The specific surface area (SSA) is another output from the result defined as surface area per unit mass (m^2/kg). Powders collected from three different manufacturers were analyzed in this experiment.

2.2. Flow properties

Flow properties were evaluated using a combination of powder characterization methods, such as: rotational bed expansion ratio (RBER), angle of repose (AOR), and avalanche angle (AVA) [10–12].

The fluidized bed expansion ratio was measured using a rotating drum (Revolution Powder Analyzer, Mercury Scientific Inc., Sandy Hook, CT, USA). In this test, 120 mL of powder (tapped volume) is placed into a transparent drum (diameter of 10.9 cm, length of 3.5 cm) and the drum is rotated at increasing speeds. As the drum rotates faster, more air becomes entrained into the powder and volume of the powder increases. To gauge how well a powder fluidizes, the volumetric expansion ratio (current powder volume divided by the initial powder volume) was measured via a video camera and computer software. The maximum rotating speed of the drum for the measurement was set at 70 rpm, because the powder could start to rotate with the drum at a higher speed due to the centrifugal force. A high rotating bed expansion ratio indicates that a powder is easily fluidized. A rotating fluidized bed was used in this work instead of a traditional fluidized bed because the rotating drum allowed the powder sample to be sealed, without the possibility for loss of powder and loss/gain of moisture during testing. The results are reported as RBER.

AOR for each powder was measured using a powder characteristic tester (PT-N Powder Characteristic Tester, Hosokawa Micron Powder Systems Co., Summit, NJ, USA). To measure the AOR, the powder sample was slowly dispensed onto a flat surface to form a pile. The AOR was then taken as the angle between the surface of the pile and the flat surface. Six AOR measurements were completed for each sample and the average is provided.

The AVA was measured using the same Revolution Powder Analyzer as used for RBER. This instrument works by placing a known amount of powder into a transparent drum and monitoring how the powder flows as the drum is rotated. The AVA was determined by rotating 120 mL of powder (tapped volume) at 0.6 rpm and measuring the maximum angle that the powder achieves before it avalanches (collapses) to the bottom of the drum. This test was performed until 200 avalanches occur and the average was calculated.

Among these three powder characterization methods, the RBER is a representation of the dynamic powder flow property, and the other two methods are the representations of more static powder flow properties. The dynamic flow property indicates how well the powder flow during fluidization or pneumatic transportation. On the other hand, the more static flow property indicates how easy the powder gets agglomerated. Overall, a larger RBER value, a smaller AOR value and a smaller AVA value imply better flow properties of a powder.

2.3. Moisture exposure

Moisture absorption is one difference in between virgin powders and reclaimed powders. It is generally believed that low humidity is required to maintain the flow properties of coating powders and enormous effort is given to keeping virgin powders dry. On coating powder production and application lines, care is taken to store virgin powders in sealed packages and in a well air-conditioned environment. When used, virgin powders are fluidized and pneumatically transported using air with a dew point below −100 °F (Lis, 2008). However, when virgin powders are applied in the spray booth, they are exposed to an environment with a relative humidity typically between 50 and 70%. This level of humidity is maintained during electrostatic spraying to help encourage charge relaxation and prevent back ionization, but it is uncertain how such exposure to moisture affects the flow properties of reclaimed powder. Throughout the spraying process, the reclaimed powder is periodically removed from the spray booth and stored in an air conditioned room until it is used.

To investigate the effects of moisture exposure, coating powders were exposed to a humidified environment for duration up to 580 h. Over 500 g powder sample was placed in a beaker (diameter of 12.5 cm, depth of 18.3 cm) and placed in a sealed barrel (diameter of 28.5 cm, depth of 43.8 cm), which contained about 1.5 L of water. The measured relative humidity inside the barrel was 99%. Since the powders were exposed to moisture while in a settled state (not fluidized), no material loss would occur during the process. Moisture absorption was measured by weight gain and the flow properties were evaluated by RBER, AOR and AVA.

2.4. Additive concentration

The concentration of the nanometer sized additive was determined using *ASTM D5630-06 Standard Test Method for Ash Content in Plastics* [13] as a guideline. Under this test method, powder coating samples were heated at 550 °C in a ceramic crucible to remove all combustible material from the powder coating, leaving behind an ash of non-combustible material (including the nanometer sized flow additives). For this test work, an acrylic clear coat powder (DuPont Performance Coatings: Acrylpulverklarlack) was used because it does not contain inorganic fillers or pigments that would also remain in ash. By using acrylic clear coat powders, the non-combustible component of the powder is predominantly the additive, and any changes in ash weight can be directly correlated to additive concentration in the powder sample. These acrylic powders were ground using an air classifying mill (ACM) and loaded with 0.8 wt.% nano additives.

During electrostatic spraying, three types of powders collected for additive concentration analysis were denoted: virgin, transferred and reclaimed powders. The virgin powder was the powder prior to the spraying; the transferred powder was the powder attached to the