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Modifications to ACM Classifier and Fine Powder Coating for Plastic Components

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Abstract

Fine powder coating can provide excellent surface appearance and low film thickness comparable to liquid coating. However, it's very difficult to produce fine powder products with narrow particle size distributions than coarse powder. Its electrostatic spraying method also requires the substrates to be conductive, which limits wider applications.

In this study, to ensure a narrow particle size distribution of fine powder products, nine kinds of modifications were conducted with the classifier of widely-used air classifying mill (ACM) by changing the air flow through it. For each kind of modification, the experiments were conducted under five operating conditions and were repeated for three times. According to the results of 150 samples, the particle sizes and particle size distributions of products were greatly affected by the classifier configuration. All nine kinds of modifications showed better performance than the original classifier in narrowing particle size distributions, without compromising any collection efficiency.

In addition, non-conductive plastics were employed as substrates in fine powder experiments, using two popular commercial coating powders. Results showed that lowering the particle sizes and narrowing particle size distributions of coating powders contributed to better surface finishes on the workpieces. Besides, due to the poor flowability of fine powder, different amounts of flow additives were used with fine coating powders, and the optimum amount of additives was selected considering the effects on both flowability and surface quality. Furthermore, utilizing high voltage was proven to be an effective method assisting pre-heating to increase transfer efficiency.

``Keywords

Classifier, particle size distribution, fine coating powder, plastic substrate, surface quality, flowability, transfer efficiency

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List of Abbreviations

ACM	Air Classifying Mill
VOC	Volatile Organic Compounds
PTRC	Particle Technology Research Center
AVA	Avalanche Angle
DOI	Distinctness of Image

Chapter 1 General Introduction

1.1 Powder Coating Technology

Powder is a dry, bulk solid composed of a large number of particles. Because of their larger specific area than same-weight bulk materials, powders are used in many fields, like catalysts, pharmaceuticals and coating. According to their average particle sizes, powders can be divided into coarse powders and fine powders, while coarse powders generally have better flowability than fine powders.

Powder coating technology was first developed in 1960's, which directly coat powder onto the substrate to form the coating film, assisted with a curing process [1]. Compared with conventional liquid coating, powder coating has the biggest advantage in zero use of any solvents, which eliminates the emission of volatile organic compounds (VOCs). Therefore, powder coating is an environmentally friendly coating technique. Besides, the recyclability of over-sprayed materials, good bonding ability and resistances to corrosion and scratch are also superior to conventional liquid coating. Powder coating has possessed a large share in the coating field yet.

A typical manufacturing process of powder coating materials includes extrusion, grinding, classification, and collection. Raw materials like resin, pigment, filler, curing agent, degassing agent and flow agent are firstly mixed and then fed into extruder to form uniform powder coating materials [2]. The products are then ground, classified and collected with desirable particle sizes and particle size distributions. Under the same particle size, the coating powders with narrower particle size distribution are more preferred. Compared with coarse powders, fine powders are more likely to have broader particle size distribution due to the longer grinding time.

1.2 Opportunities and Challenges of Powder Coating Technology

Thanks to its environmentally friendly coating process (no VOCs), recyclability of over-sprayed materials and good bonding ability, powder coatings have been applied in many fields, especially automobile industries, and the market is still growing. However, due to several disadvantages, powder coating technology cannot yet replace traditional liquid coating thoroughly.

One major reason is that for powder coating, larger film thickness is required than liquid coating to form smooth surfaces. Besides, the surface appearance is also inferior to liquid coating. In order to overcome these issues, Zhu and Zhang had come up with the fine powder coating technology in 2005 [3], where the average particle size of coating powders are reduced from 30~60 micron to 10~30 micron. Using fine powder coatings, much better surface appearance and lower film thickness, which are comparable to liquid coating, can be obtained. However, compared with coarse powders, fine powders produced by grinding machine are usually with broader particle size distribution, which have numerous over-ground small particles, resulting from longer grinding time. Another problem of fine powder is its poor flowability. Due to the increased inter-particle forces, fine powders are much more cohesive and difficult to handle than coarse powders [4], which make them hardly sprayable in applications. In order to improve its flowability, flow additives have to be added into fine powder for practical use.

Spraying method is another issue that restricts the wider applications of powder coating technology. Different from liquid coating, powder coating is achieved using electrostatic spraying method. In the conventional powder coating application processes, the powder particles are charged near the spray gun, and in this way can adhere to a grounded workpiece. Hence, it’s a basic requirement for the substrate to be conductive, which limits the powder coatings applications to be with metal components. Many researchers have been trying to find a way to apply powder coating with non-conductive or low-conductive materials, like plastic, wood, etc. Methods like substrate pretreatments and preheating have been explored by many researchers.

1.3 Research Objectives and Overviews

Corresponding to the limitations of powder coating, tremendous efforts have been made by the Particle Technology Research Center (PTRC) in recent years to narrow the particle size distributions of fine powder products and to find a practical method to apply powder coating with non-conductive/low-conductive substrates. The present study follows the whole process of powder coating application used in the industry and aims to attain the objectives as following:

- to modify the classifier of air classifying mill (ACM), which is a commonly used grinding machine in industries, and investigate its influences on products' particle sizes and particle size distributions;

- to apply powder coating on non-conductive plastic components using preheating method, which is different from conventional electrostatic spraying method; to investigate the influences of coating powders' particle sizes and particle size distributions;

- to apply flow additives with fine coating powders and evaluate the influences on flowabitliy and surface finish

1.4 Thesis structure

This thesis consists of five chapters and follows the "monograph" format as outlined in the Master's Programs of *General Thesis Regulations* by the School of Graduated and Postgraduate of Studies (SGPS) in the University of Western Ontario (UWO). The thesis structure is provided below.

Chapter 1 provides a general introduction to powder coating technology and its limitations. Research objectives, thesis structure and major contributions of this work are stated.

Chapter 2 presents the detailed background of powder flowability, fine powder coating technology, manufacturing process of coating powders and the powder coating applications with non-conductive substrates.

Chapter 3 evaluates the effects of nine different modifications on the classifier of air classifying mill (ACM). One hundred and fifty samples were produced using different modified classifiers along with the original classifier. The influences on particle sizes and particle size distributions were investigated.

Chapter 4 reports the experimental study with plastic components using two commercial coating powders. The influences of particle sizes and particle size distributions on surface finish were investigated. After that, different amounts of flow additives were added into fine powders to evaluate the influences on flowability and surface finishes. Voltages were applied in spray process as a complementary method assisting pre-heating method to increase the transfer efficiency, and the effects have also been evaluated.

Chapter 5 summarizes the general conclusions drawn from Chapter 3 and 4; the best modification on the classifier was chosen; as for the experiments with plastic components, influences of particle sizes, particle size distributions, the amount of additives and voltages were briefed.

Chapter 2 Literature Review

2.1 Powder

2.1.1 Powder Characterizations

Powders have been widely applied in pharmaceutical, petroleum refining, and powder coating area, etc. However, many problems like agglomeration, poor flowabitliy have limited the wider use of them. To solve these problems, the properties of powders have been investigated for decades and the flowability of powders, which is a measurement about how the powder will perform during handling processes, is one of the key parts.

In 1973, Geldart [5] proposed a powder classification system, which classified powders into four groups (A, B, C and D) according to their particle sizes and densities, and the flowability of each group has been elaborated. This classification of powder has been widely accepted and the chart is shown in Figure 2.1. According to the classification, Group A powders are the powder fall in 100~500μm, $\rho s < 1.4 g/cm^3$, and the Group B powders are between 40μm and 500μm, and $1.4 < \rho s < 5 g/cm^3$, these two groups of powders are easy to flow. Group C powders are mainly extremely fine and consequently the most cohesive particles, therefore it's very difficult to fluidize these powders. For the Group D powders, they are normally above 600μm and the fluidization requires very high energy.

In many applications, especially for powder coating applications, Group C powders are commonly used for its small particle sizes. In order to overcome its drawbacks in flowability, methods need to be applied, for example, the flow additives.

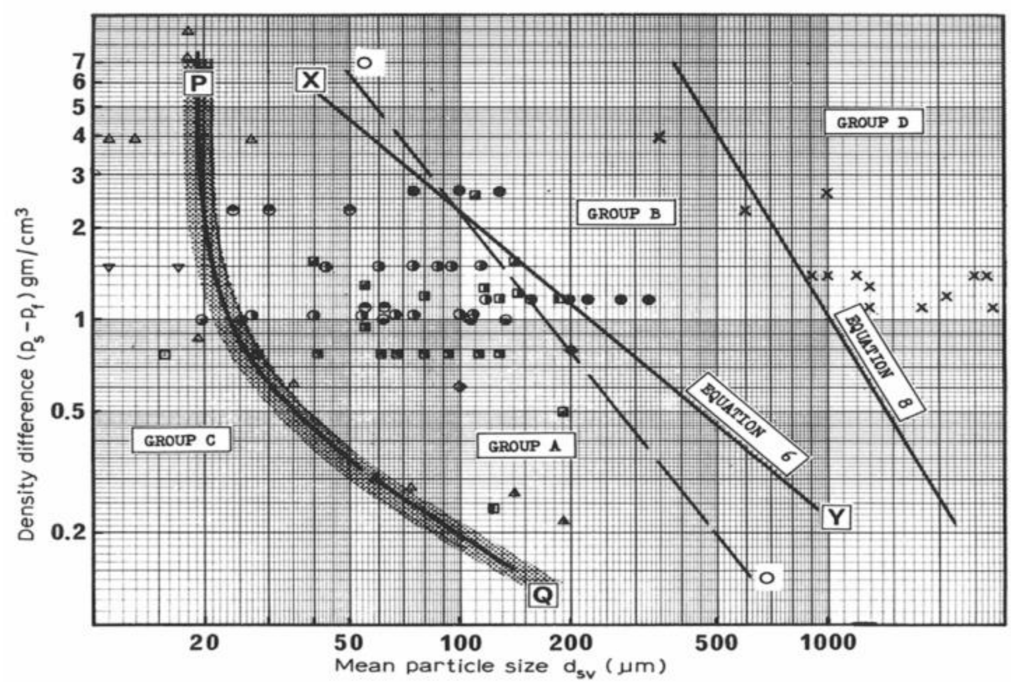


Figure 2.1: Geldart's chart for powder classifications [5]

Besides the Geldart's powder classification, many other classifications of powders have also been proposed by researchers, like the classification system came up by Jenike [6], which classified the powders into five groups according their flow function, from very free-flowing to very cohesive. Carr [7] rated powders' flowability by a score regarding to the results of angle of repose, and angle of fall, etc. as shown in Table 2.1. But still, identifying powder's flowability is very challenging due to the variations [8-9].

Table 2.1 Carr's flowability index [7]

Flow properties	Carr's flowability index
Very good	90-100
Fairy good	80-89
Good	70-79
Normal	60-69
Not good	40-59
Poor	20-39
Very poor	0-19

2.1.2 Flow Additive for Cohesive Powders

According to the previous works by other researchers, the fine powder's cohesion and poor flowability were due to the inter-particle forces. With the decrease of particle sizes, the particles become lighter, the gravity forces of particles have less effects on the particles, while relative magnitude of the inter-particle forces, especially Van der Waals force, increases and become dominant [10-18]. According to Visser J's work [14], the Van der Waals force F_v between two particles could be calculated by:

$$F_v = \frac{AR}{12H^2} \qquad \text{Eq. 2-1}$$

where A stands for the Hamaker coefficient; R presents the particle radius and H is the distance between two particles.

Many efforts have been made to solve the problems. One effort is to strictly control the particle size distributions, some limited success for coating powders with D_{50} around 22 to 25 microns has been reported [3], but the flowability and surface finish are still undesirable. Another effort is adding nano-size flow additives such as fumed silica to reduce the powder cohesion so that the flowability can be improved [19-22]. The nano-size additives could increase the distances among particles and according to Eq. 2-1, by increasing H the Van der Waals force F_v can be reduced. However, for coating powders, adding too much of additives would cause other problems like seeds and the loss of gloss on the coating surfaces.

2.2 Powder Coating Technology

Powder coating technology was first developed in early 1960's in North America. Different from conventional liquid coating, powder coating technology uses dry powder directly in coating process, without any solvent especially organic solvents. This is both economic and environmental friendly because it eliminates the VOCs (Volatile Organic Compounds). Furthermore, the over-sprayed materials can be recycled.

2.2.1 Powder Coating Materials

There are two main categories of powder coating materials: thermosets and thermoplastics. The thermosetting variety incorporates cross-linkers into the formulation and do not persist their original chemical compositions. Once the cross-linking reactions are completed, the materials would not be re-melted by the same heating process [23]

The thermoplastic powder coating materials do not undergo any additional actions in this process. Once the melting temperature is reached, it could melt into liquid and flows to form the surface, as the temperature cools down, they will return to solid state and form coatings.

In the powder coating market, most of the products are thermosetting coating powders because of the better bonding ability and mechanical properties compared with thermoplastic powder coating materials. Listed are several commonly used commercial thermosetting coating powders:

Epoxy coating powders

Epoxy coating powder system is a hard, impact resistant interior only formulation. For the most part, epoxy coatings are used as functional coatings for substrate protection where corrosion resistance, impact resistance, and good adhesion are essential. The primary limitation of epoxy-based coatings is poor weatherability and poor resistance to UV exposure. Typical applications include industrial equipment, automotive underbody components, metal furniture and appliances.

Polyester coating powders

Polyester coating powder are the most used of all coating powders in the U.S. market. Polyesters offer broad applications in many chemical fields. It has excellent weatherability and good transfer efficiency in coating process. And also, better film quality like high gloss and less yellowing can be provided [16].

Polyester-epoxy coating powders

Epoxy-polyester coating powders (hybrid coating powders), combine epoxy resin with polyester resin to form a powder with many of the same characteristics as the epoxies. Epoxy-polyester hybrid coatings are generally tough, flexible and have comparable prices to pure epoxy coatings. Hybrids provide some improvement in weatherability, but they will begin to chalk almost as fast as an epoxy coating. However, after initial chalking, the deterioration is slower. Some hybrids are less resistant to chemicals and solvents. Hybrids are likely to be used in many of the same applications as epoxies.

2.2.2 Powder Coating Process

For liquid coating, the coating ingredients are dissolved in the solvents which can be sprayed or brushed directly on the coating surface, after the evaporation of solvents, the coating film is formed.

Without the help of solvent, there are mainly two parts of the powder coating procedure, which are spraying and curing. In the first step, the powder would directly be sprayed onto the substrate. Many methods have been applied to transfer powders onto the substrate surface, including thermal spraying, fluidized bed coating and so on. However, nowadays the majority of powder coatings are achieved by electrostatic spraying, which could provide thinner films and better surface finishes. Electrostatic spraying was first used by the industry in 1963 [24]. In the spraying process, powders would first get charged and sprayed toward a grounded substrate. Due to the electrostatic forces, the powders adhere to the substrate (Figure 2.2). In the applications, corona charge spraying and tribo charge spraying are the two most commonly used spraying methods.

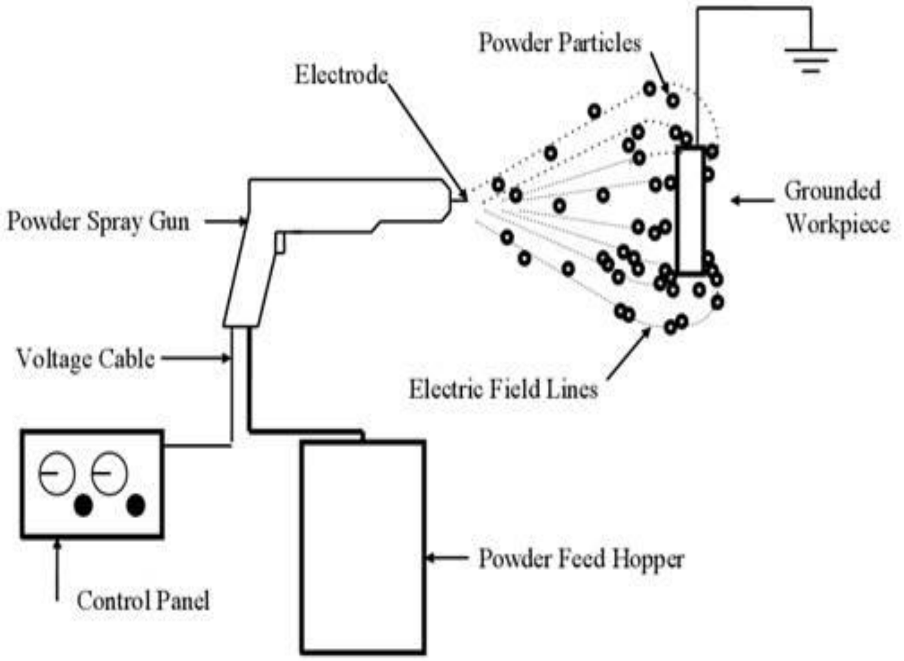


Figure 2.2 Electrostatic spraying process

After spraying, the coated workpiece would be heated up and the powders transferred to it would melt and form a coating film after curing.

2.3 Manufacturing Process for Powder Coating Materials

A typical procedure for producing powder coating materials includes: ***hot extrusion, grinding, classifying and collecting***. Each of the processes is reviewed in detail as follows.

Hot extrusion

Hot extrusion (or hot melt extrusion) is a mixing technique that has been developed by the industry for over 70 years [25]. The purpose of applying this process in powder coating industry is to mix additives and other ingredients into coating powders uniformly [26].

Figure 2.3 illustrates a typical hot extrusion process for powder coating materials. Raw materials such as resin, curing agent, pigment, degassing agent flow agent etc. are fed into the feeder and become melted due to the high temperature (90-100°C). The melted materials would be pushed to the mixing zone by screw. In this zone, the softened materials are subjected to high shear mixing during the inter-meshing motion of the screws.

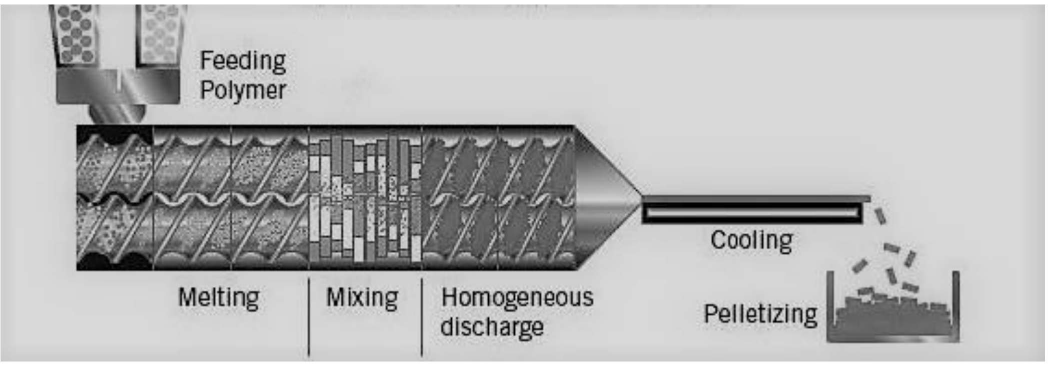


Figure 2.3: A typical hot extrusion process

The mixed materials would then come out of extruder, get cooled and rolled into sheet by two cooling drums. Finally, the sheet would be pelletized into chips.

Grinding

In order to turn the powder coating chips, which were produced by extruder, into sprayable powders, the grinding process must be applied. Using high speed rotor, the grinder could pulverize powder coating chips into micron-scale powders. Shown in Figure 2.4 is a typical rotor set-up. The chips are fed into the grinding chamber, while the rotor is running at high speed over 15000rpm. Due to the impacts, shears and rubbings between the rotating pins and the standing grooves, the chips will be finally broken into coating powders.

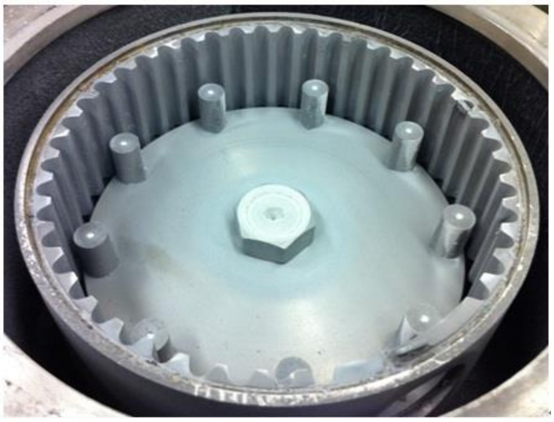


Figure 2.4 A grinding mill for powder coating

Classifying

Air classifiers could make sure the powder products have well-defined particle size distributions. The primarily ground powders are divided into coarse powder and fine powder by classifier. Many types of air classifiers are described in the literature [27-46]. They could be divided by the aerodynamic cycles or the method of powder feed.

Normally the classifiers can be categorized into gravitational classifier, cascade classifier, fluidized bed classifier, inertial air classifier, centrifugal air classifiers, rotor classifier and circulating air classifier [47]. For the air classifiers, the classification is mostly accomplished by the centrifugal force F_c and drag force F_d (Figure 2.5). However, due to the complex air flow, it is very difficult to reach ideal classification, the powders with undesirable particle sizes might pass through the classifier and get into products, which would cause a broad particle size distribution.

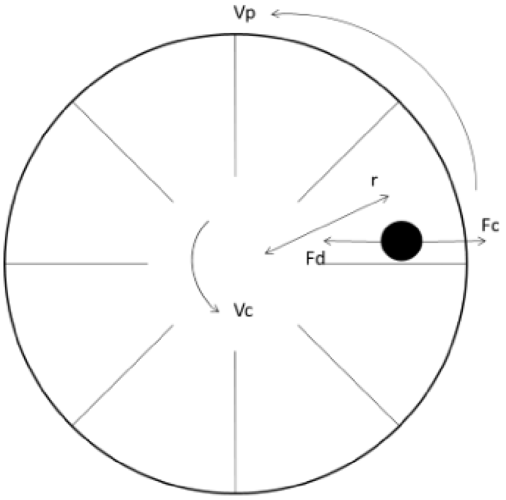


Figure 2.5 Forces acting on particle within a rotating classifier (Top view)

Collecting

Collecting is a necessary process to separate coating powders from air. The commonly used collecting equipment is cyclone, which is a classic separator invented in 1800's [48]. Rotational effects and gravity are used to separate solid from air. A typical cyclone set-up is shown Figure 2.6.

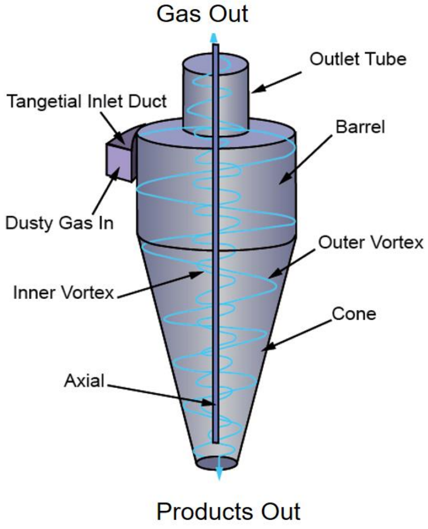


Figure 2.6. A typical cyclone for collecting coating powders

The air classifying mill

Air classifying mill (ACM) is a continuous-operating machine which combines grinding, classifying and collecting process into one stage operation. The schematic of ACM is shown in Figure 2.7. By changing the feeder speed, air speed, rotor speed and classifier speed, the particle sizes and particle size distributions of products can be adjusted.

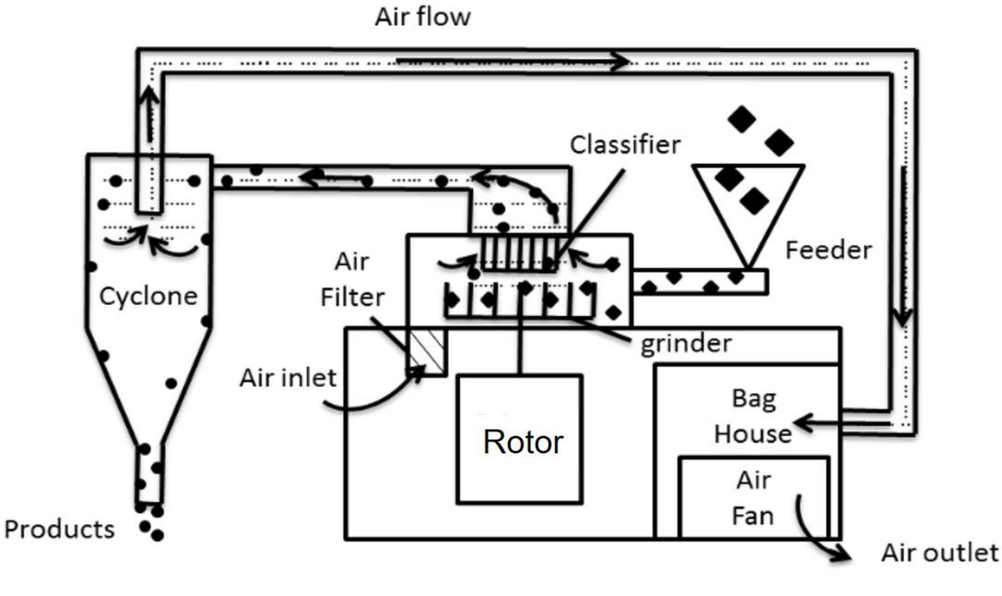


Figure 2.7 The sketch of ACM operation

2.4 Fine Powder Coating

Although powder coating technology has so many advantages, it hasn't been widely used to substitute liquid coating. One of the major reasons is its mediocre surface finishes regarding the film thickness, gloss, distinctness of image and aesthetic appearance. These drawbacks are inherent from its large particle sizes (D_{50}>30μm). By applying fine powder coating in applications, these problems could be greatly relieved. If fine coating powders (10μm <D_{50} <25μm) is applied, the surface quality is comparable with that of liquid coating, which means the use of fine powder coating would significantly benefit the coatings industry (Figure 2.9) [49].

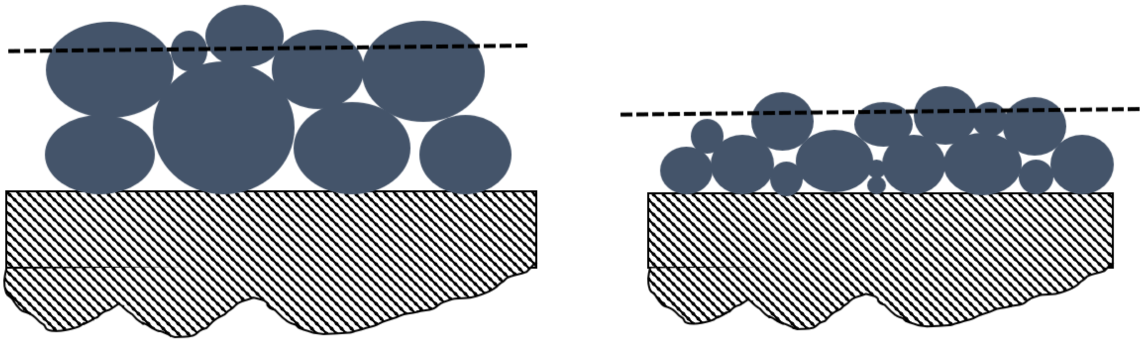


Figure 2.9 The film thickness of coarse powder coating (left) and fine powder coating (right) [49]

On the flip side, as briefed in 2.1.2, compared with coarse powders, fine powders are very hard to handle due to the increased effects of inter-particle forces. They become cohesive and agglomerate terribly, which makes it impossible to spray them using current coating equipment. So flow additives are essential for the use of fine coating powders.

2.5 The Powder Coating on Plastic Components

As introduced in 2.2.2, the mechanism of electrostatic spraying is to charge the coating powders in an intensive electric field known as corona zone generated by high voltages, the charged powder can adhere to the grounded substrate, so it requires the substrates to be conductive, that’s the reason why current powder coating applications are mainly with metals.

The biggest difficulty of powder coating on plastic components is that the substrate’s conductivity is rather low. When the charged powders deposit on the substrates, there are few opposite polarity electrons could flow through the workpiece to neutralize the surface charge. The accumulation of free electrons could rapidly form a repelling field, which would reject the further deposition of powders coming after. The insufficient coating would cause defects like “patchy” finish, pinholes and orange peels.

Many researches have been done to solve this problem. Generally, the methods could be divided into three kinds. The first kind of methods are using physical/chemical pretreatments of the workpieces [50], like plasma treatment, chemical oxidation and applying primers on the substrate surface to increase the adhesion. Another kind of methods focus on increasing the conductivity of substrates [51-57]. Conductive materials, like carbon fiber, metal backings or even charged water, were applied with the workpieces to increase conductivity. Takahashi et al [55] invented a primer with component including conductive materials such as conductive zinc, titanium and other surface active agents, which enable the coating efficiency. However, this method is restricted by the configurations of the plastic parts.

As for the last kind of methods, pre-heating method has been used by many researchers. The substrates are pre-heated up to certain temperature (70-140°C) before powder spray to melt the coating powders deposit on it, the results showed that the deposition of coating powders was enhanced.

Chapter 3 Development of the Classifier of Air Classifying Mill (ACM) for Reducing the Particle Size Distribution of Fine Coating Powders

3.1 Introduction

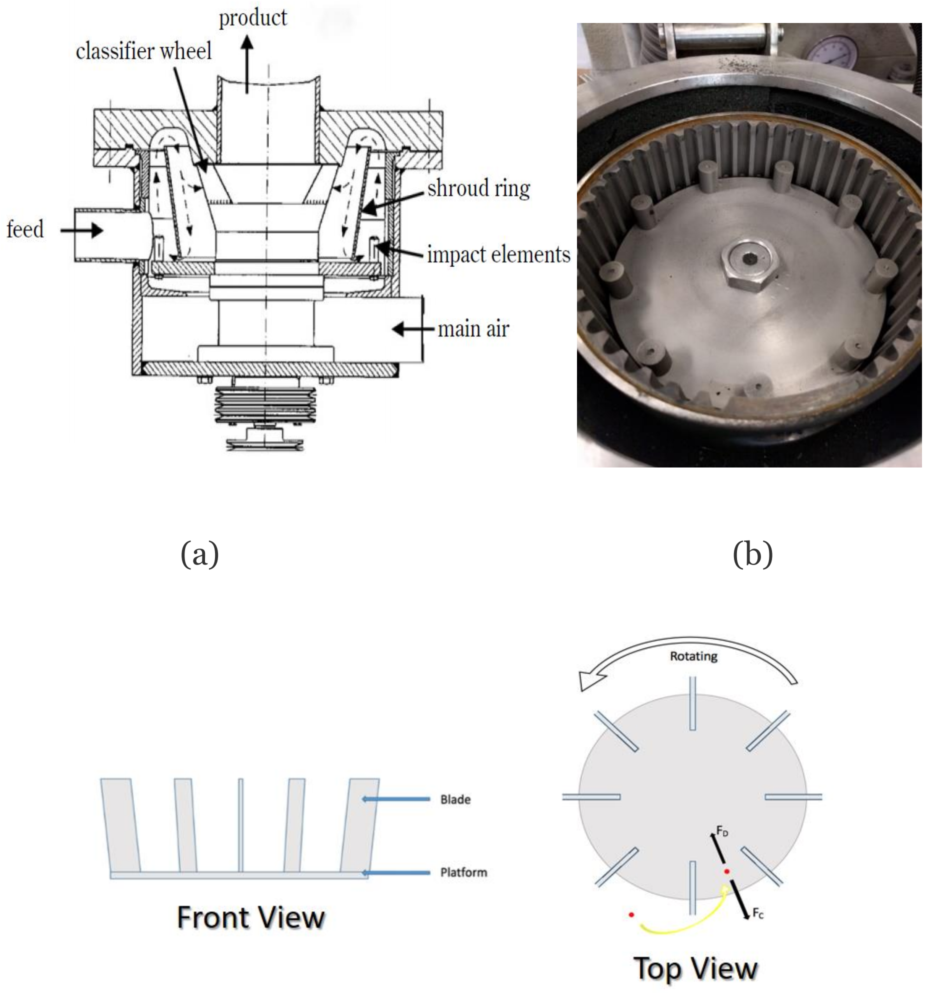
Air classifying mill (ACM) is one of the most wildly used grinding machines in powder coating, food products and pharmaceutical manufacturing fields. It integrates grinding and air classification into a single circuit (Figure 3.1 (a)). The main parts of air classifying mill include screw feeder, rotor (mill), air classifier and cyclone.

The rotor has two parts, a platform mounted in a horizontal position with several pins on it, and a gear wall surrounding it (Figure 3.1 (b)). The rotor is driven by a motor and has a round housing enclosing the internal classifier wheel, which has multiple fins (Figure 3.1 (c)).

The air classifier is a primary separator, which is designed to separate the particles larger than desirable size from the fine powder. The large particles would then be sent back to rotor to be further ground, while the fine powders are separated from air in the cyclone set behind and get collected as products. By applying the classifier between rotor and cyclone, it could reduce the burden of cyclone and narrow the particle size distribution of products. What’s more, by sending large particles back to rotor, instead of letting them directly arrive at cyclone and be blown out with air, the collection efficiency can be enhanced.

A shroud ring is located between the rotor and the classifier. The space between the rotor and shroud ring forms grinding zone, while the space between the shroud ring and classifier wheel forms the classifying zone.

The rotor, classifier and shroud ring forms the grinding chamber. A screw feeder is located at one side of the chamber, an air inlet is located beneath the rotor disc, and an air-and-product outlet is located above the classifier wheels.



(a) (b)

(c)

Figure 3.1 Schematic of air classifying mill (a), rotor (b) and classifier (c)

In the grinding process, the chips/coarse powders are fed in to the grinding zone by the screw feeder and stressed into fine powders by the pins located on the high-speed rotating rotor disc. Then they are blown up by the air flow and transported to the wheel classifier. The shroud ring separates grinding zone from classifying zone and leads the main air. Material which is fine enough could pass through the slots between classifier wheel's fins, and then flow out with air to cyclone through outlet located above the classifier. The coarse powders which are rejected by classifier would be sent back to the grinding zone by the internal circulation to be further milled (Figure 3.2).

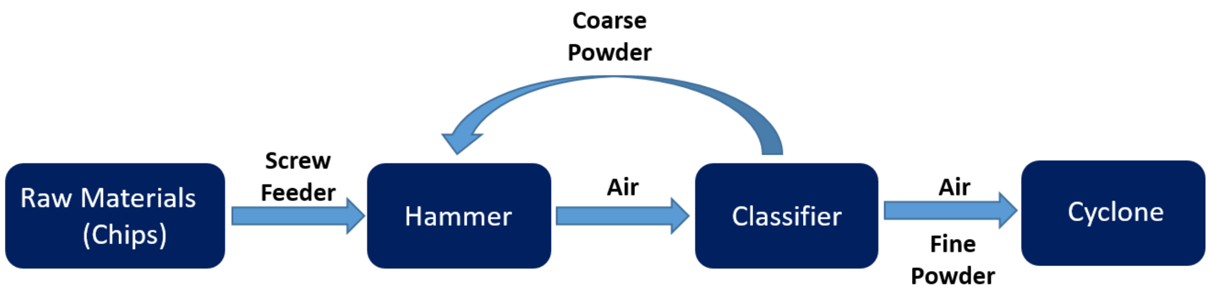


Figure 3.2 Sketch of grinding process

The basics of the classification principle can be seen in Figure 3.3. The cut size is determined by drag force (F_d) and centrifugal forces (F_c).

$$F_c = \pi \frac{d^3}{6} \rho_s \frac{v_\varphi^2}{r} \tag{1}$$

$$F_d = c_d\, Re \frac{\pi d^2}{4} \frac{\rho_a v_r^2}{2} \tag{2}$$

$$C_D = \frac{24}{Re} \tag{3}$$

then the cut size d can be calculated,

$$d = \sqrt{\frac{18}{\rho_s} \frac{v_r r}{v_\varphi^2}} \tag{4}$$

where the ρ_s stands for density of solids, v_φ stands for circumferential velocity, r stands for rotor radius, ρ_a is atmospheric density, v_r is radial velocity, c_d is drag efficiency, Re is Reynolds number.

In the ideal case, particles smaller than cut size could pass through the classifier and flow out with air to cyclone to be further classified, whereas the particles larger than cut size would be rejected and sent back to the grinding zone (Figure 3.3 left).

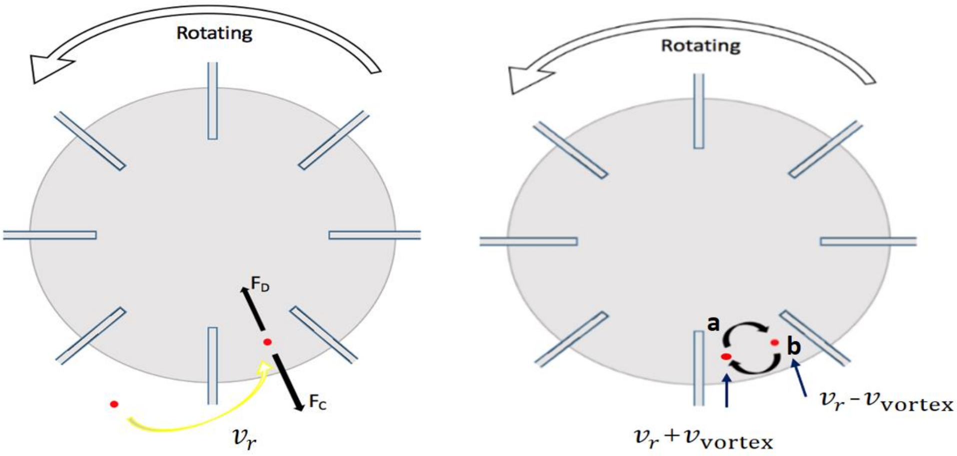


Figure 3.3 Principle of ideal classification (left) and undesirable case (right)

In practice, such an ideal cut cannot be realized due to several reasons, like the complex turbulent flow in the chamber (Figure 3.3 right).

Due to the internal vortex and eddies between the fins, the particles at point ***a*** have a higher speed than v_r, while the speed at point ***b*** is lower. This allows large particles pass through point ***a*** while fine particles at point ***b*** would be sent back to be further ground, which cause extra fine powders in the products.

Due to the undesirable classification, the particle size distributions of products are normally much broader than the anticipated results. According to the literatures and previous works of our group, narrow particle size distribution can benefit the powder flowability and the coating quality of powder coating film. This study is to revise the classifier of air classifying mill to narrow the particle size distribution of products.

The first idea of modifications was to increase the effective entrance area, which could lower the radial speed of air flow and reduce the eddies between fins. Moreover, the tooth extending into the air could pre-accelerate the particles in tangential direction at the rim of classifier, and the vortex can be greatly reduced.

3.2 Experimental Study

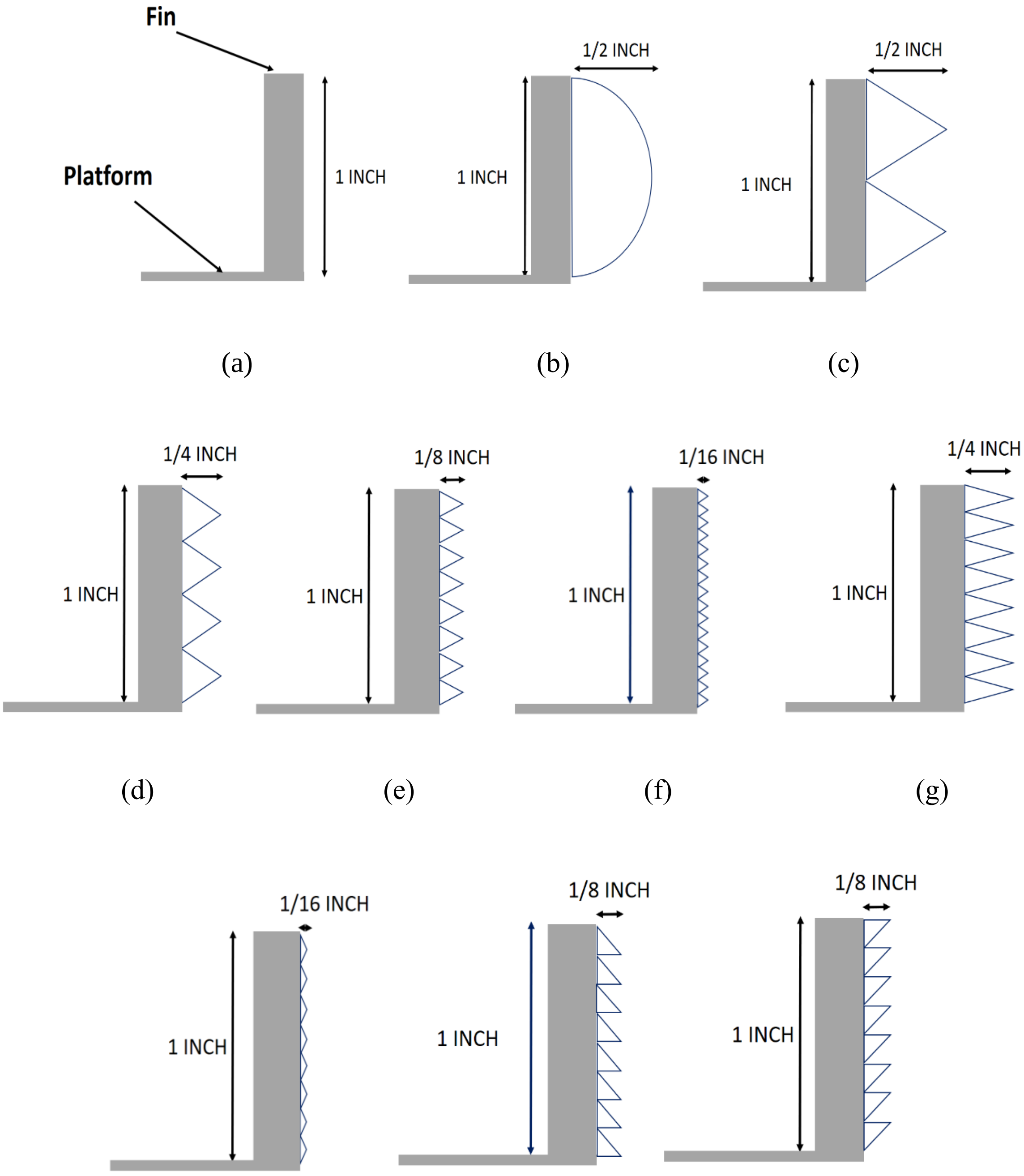
3.2.1 Experimental Design

In the study, plastic chips are cut into different shapes and are fixed on the fins of classifier wheel, which could either change the speed of air flow through classifier by adjusting the surface area or extending the radius of classifier wheel. The particle size distributions of products were compared to find the best modification.

3.2.2 Material and Methods

Modification of Classifier

The original classifier wheel has nine fins located on rim of it. Using hard plastics, nine different kinds of chips were made to modify the original fins of the classifier. For each kind of modifications, nine plastic chips were made and glued on the nine original fins. These plastic chips have different shapes, height and width of tooth (Figure 3.4-3.5). Including the original classifier, 10 different classifiers were investigated in the experiments in total.



(a) (b) (c)

(d) (e) (f) (g)

(h) (i) (j)

Figure 3.4 Sketch of original fin (a) and modified fins (b-j)

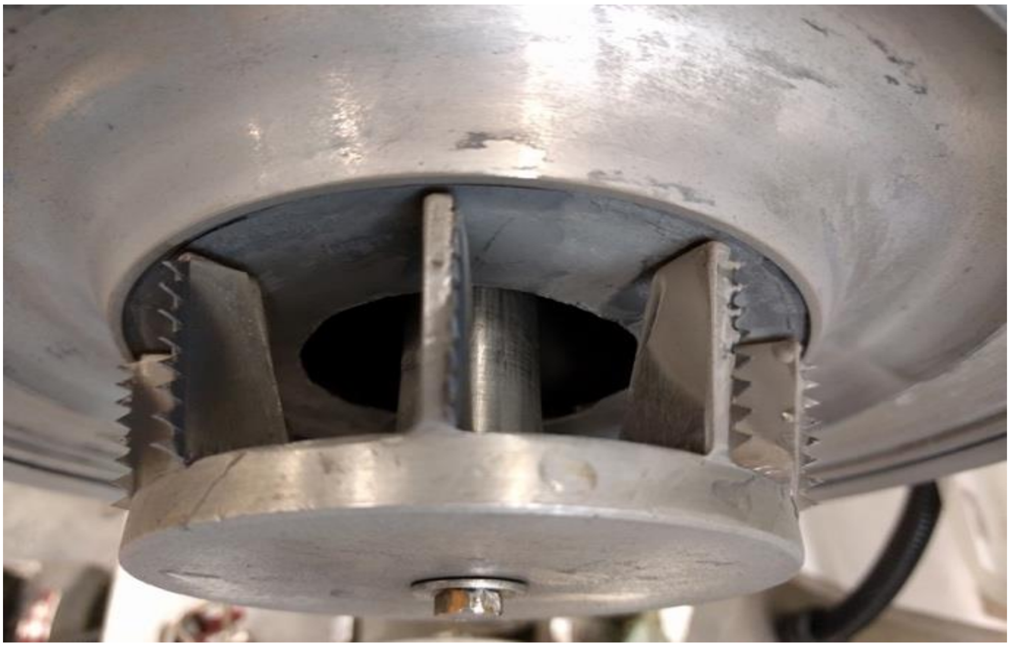


Figure 3.5 One kind of modified fins applied in experiments

The configuration of each kind of fins is listed in Table 3.1.

Table 3.1 The configuration of fins

Classifier	Shape of fins	Number of teeth on each fin	Height of tooth / Inch	Description of tooth
a				Original
b	Round	1	1/2	Semi-circle
c	Saw	2	1/2	Isosceles triangle
d	Saw	4	1/4	Isosceles triangle
e	Saw	8	1/8	Isosceles triangle
f	Saw	16	1/16	Isosceles triangle
g	Saw	8	1/4	Isosceles triangle
h	Saw	8	1/16	Isosceles triangle
i	Saw	8	1/8	Lower-side Vertical Right-angled triangle
j	Saw	8	1/8	Upper-side Vertica Right-angled triangle

Powder Grinding Process

The air classifying mill (ACM) used in the experiments was manufactured by Donghui Powder Processing Equipment Co., LTD. which is a smaller-scale of an industrial ACM (Figure 3.6).

Figure 3.6. Air classifying mill (ACM)

The raw materials of coating powders are polyester chips (TCI 9910-9000). For each kind of fins, the five different classifier speeds were applied in experiments to produce the coating powders with different sizes, while other parameters such as the speed of rotor and the speed of fan remained unchanged. The units of classifier speeds shown in the graphs behind are the variable frequency drive of classifier. The corresponding revolutions per minute are shown in the Table 3.2.

Under each condition, experiments were repeated for 3 times, so 150 samples were produced. For each sample run, 100g of polyester chips are put into the feeder.

Table 3.2 Corresponding revolutions of classifier per minute under different variable frequency drive

Speed of Classifier / Hz	Speed of Classifier / rpm
60	3320
50	2767
40	2213
30	1610
20	1107

Evaluation of Sample

The particle sizes and particle size distributions of products were tested by particle size analyzer (BT-9300S, Better Inc., China) shown in Figure 3.7.

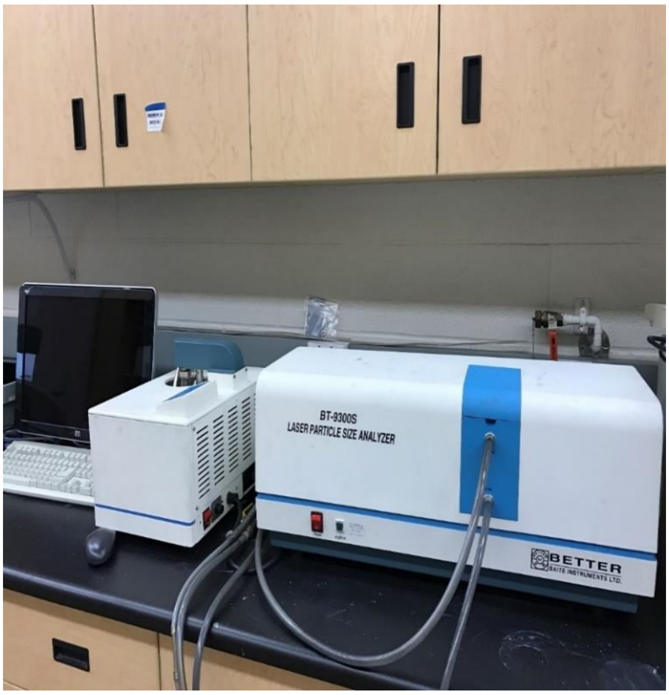


Figure 3.7 Particle size analyzer

To evaluate the effects of modification, for each sample, three critical parameters, the D_{50}, D_{10} and D_{90} were tested. These values indicate the particle sizes which below the corresponding weight percentage. For example, when D_{10} is 15μm, it means 10%wt powder in the sample is no larger than 15μm. In general, D_{50} is used to present the medium particle size of the powder, while the D_{10} and D_{90} are used to present the amount of small powder and large powder (Figure 3.8).

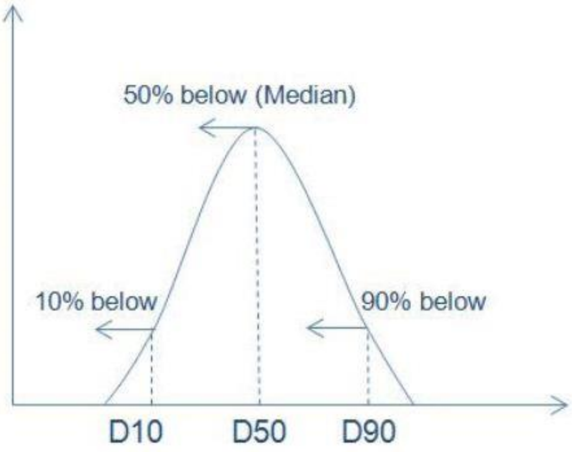


Figure 3.8 An example of particle size distribution

The span, which indicates the particle size distribution of powder, is determined by D_{50}, D_{10}, D_{90}

$$span = \frac{D_{90} - D_{10}}{D_{50}} \tag{4}$$

When D_{50} are the same, the product with higher D_{10} and/or lower D_{90} has a steeper curve of the particle size distribution (Figure 3.9), and the particles are more uniform. The span indicates the overall shape of the particle size distribution curve. Narrow particle size distribution/ low span is always desirable for coating powders, especially for the fine coating powders, since lower D_{90} leads to a better coating quality and higher D_{10} leads to improved powder flow properties.

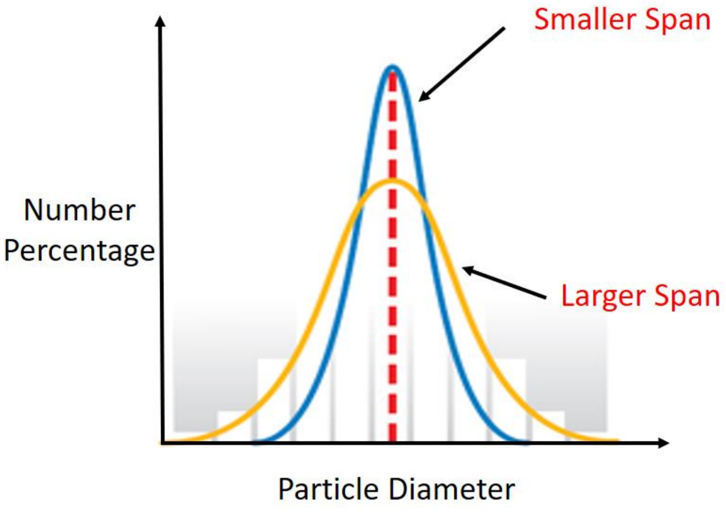
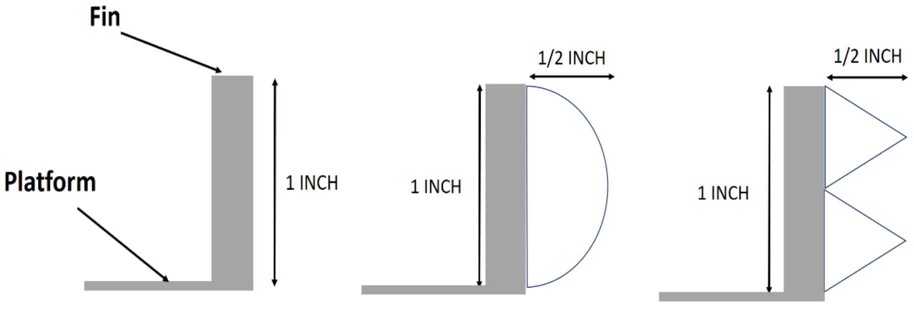


Figure 3.9 The particle size distributions with different span

3.3 Results and Discussion

In order to investigate the influences of fin's shape, height, surface area, number of tooth (density of tooth), 9 modified fins and the original classifier were divided into 4 groups.

3.3.1The Influences of Shape



(a) (b) (c)

Figure 3.10 The fins used to investigate the influences of fin's shape (a, b, c)

The experiments began with using the classifiers a, b, c (shown in Figure 3.10). The fins of classifier b and c are with the same height, while the shape of tooth are different. The tooth of classifier b are semi-circle while the tooth of classifier c are in the shape of saw. The results are illustrated in Figure 3.11-3.12.

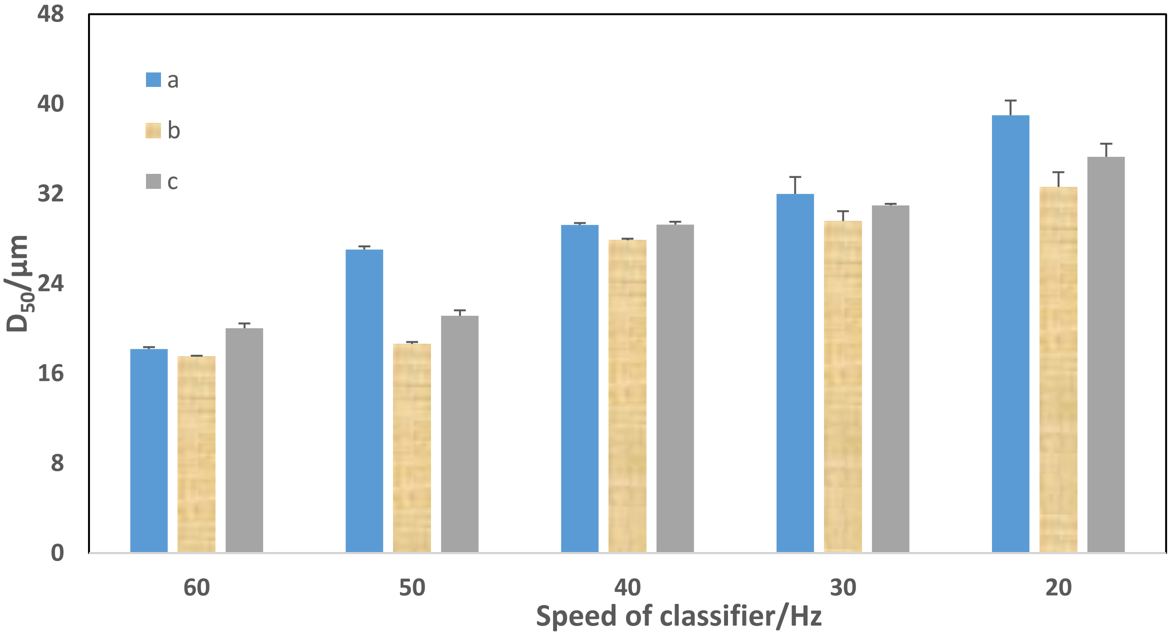


Figure 3.11 The D_{50} of each classifier at different classifier speeds

Figure 3.11 illustrates the average particle sizes of three classifiers at different speeds of classifier. It shows that for all three classifiers, by increasing the speed of classifier, the average particle sizes became smaller. It's suggested that increasing the speed of classifier is beneficial to producing fine powders.

For the classifier b, under the same classifier speed, it achieved the lowest D_{50}. Compared with the original classifier, the difference of D_{50} can be as high as 9μm, and the average difference is also over 3μm. So classifier b would be a good choice for producing fine powders without increasing the speed of classifier. As for classifier c, it's not as good as classifier b in reducing product's particle size. However, the overall performance is still better than the original classifier, especially at relatively low speed.

As for the influences on particle size distribution, the results are presented in Figure 3.12.

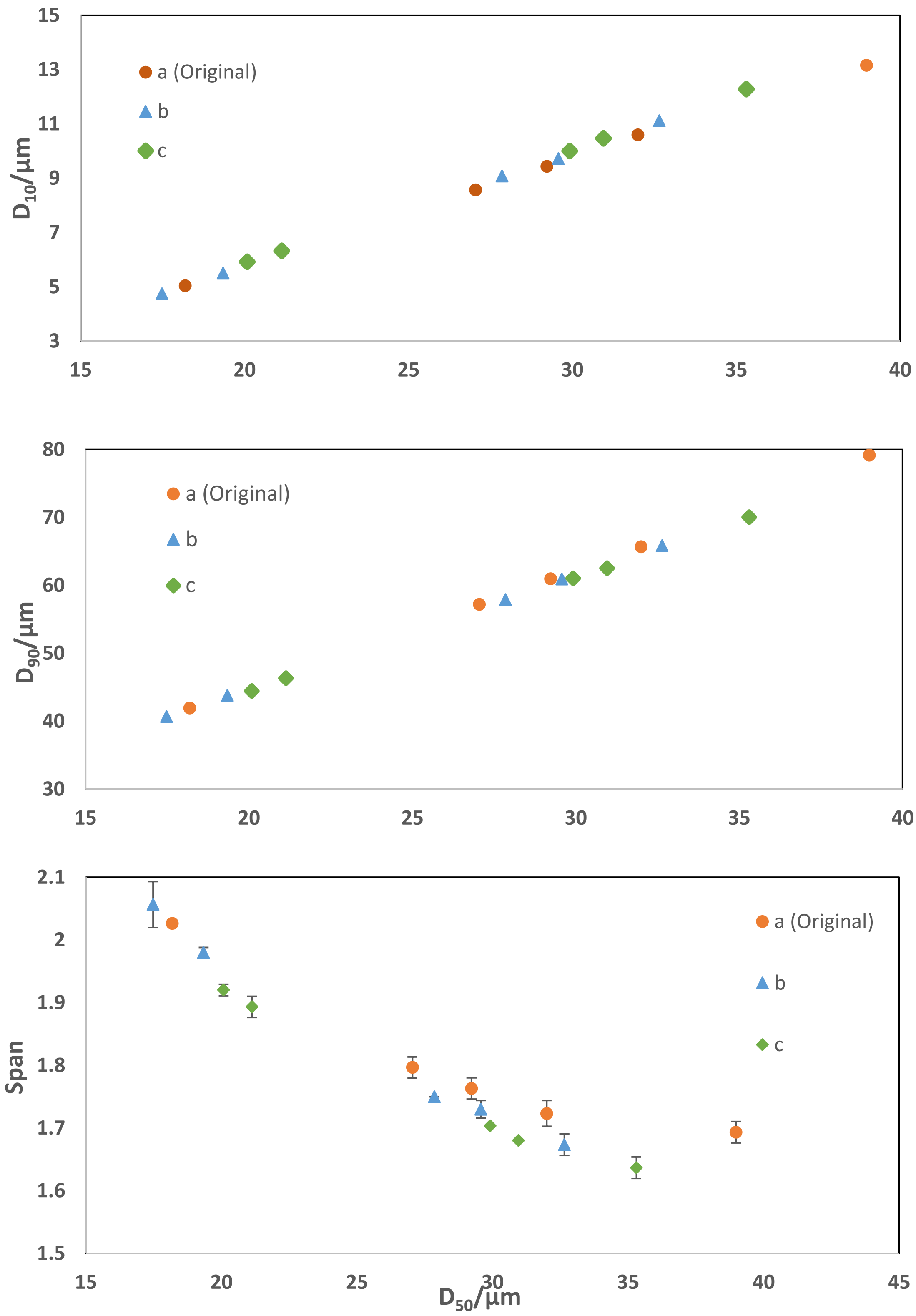


Figure 3.12 Comparisons of D_{10}, D_{90} and span with respect to D_{50} for different classifier fins (a, b, c)

In the figures, it shows that for all 3 kinds of classifiers, with the increase of D_{50}, the D_{10} and D_{90} increased correspondingly, while the span decreased with it. When the D_{50} was around 35μm, the span of powder was about 1.7; however, when D_{50} came to below 20μm, the span was as high as 2.1. This suggested that compared with producing coarse powder, producing fine powder with uniform particle size distribution is much more difficult.

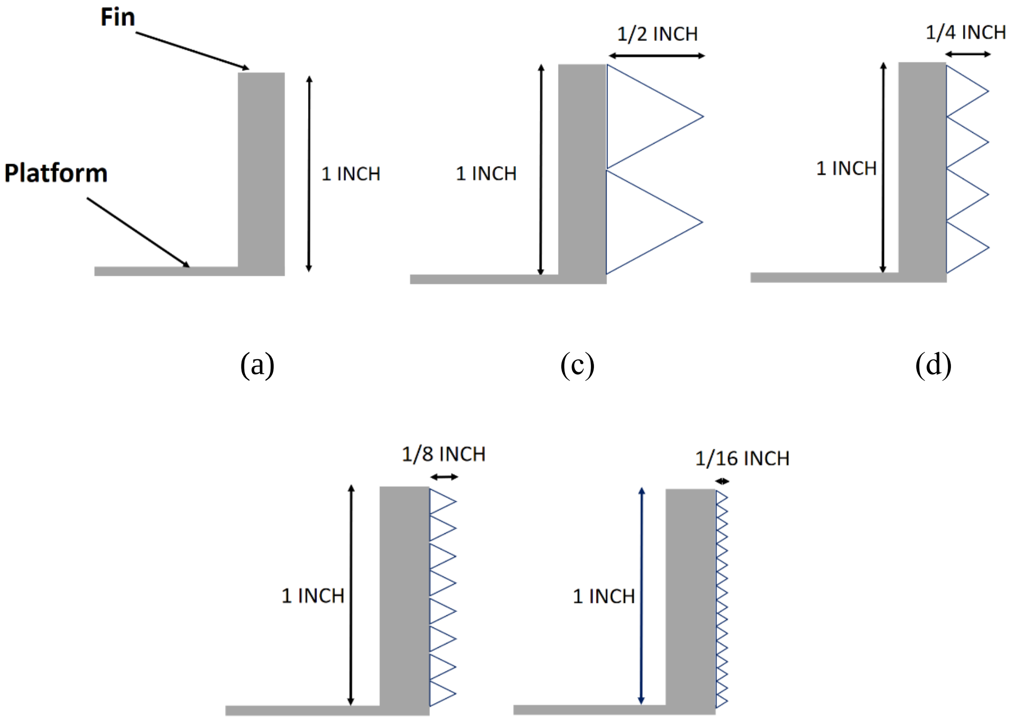
In comparison with original classifier, the two modified classifiers both showed better performance regarding the D_{10}, D_{90} and span, proving that the modifications did work. When D_{50} were the same, the sample produced by classifier c showed the best results, which had the largest D_{10} and smallest d_{90}, and in this way, the span of classifier c was also the lowest. Compared with the original classifier, the span of classifier c was decreased by about 0.05. The performance of classifier b was also better than the original one, but not as good as classifier c. It can be concluded that when the extend length of fins are same, the fins with saw-shape teeth have better performance than the fins with round tooth.

The reason for this decrease of span might due to the increase of peripheral length, which lowerd the air speed through classifier and enhanced the classifying efficiency.

Overall, both modifications performed with better results than the original classifier, both in reducing the particle size and narrowing the particle size distribution. For classifier b, it works the best in reducing average particle under the same speed of classifier, while classifier c worked better in lowering the span of products.

Because the main purpose of this study was about narrowing particle size distribution, in the consecutive experiments, the fins with saw-shape teeth were applied, which were the same as classifier c.

The Influences of the Number of Tooth



(a) (c) (d)

(e) (f)

Figure 3.13 The fins used to investigate the influences of the number of tooth (a, c, d, e, f)

In order to investigate the influences of the number of tooth, combined with the original classifier (a), classifier c, d, e, f were tested in the experiments. These modified fins had the same peripheral length, while the number of tooth were different. The more tooth a fin had, the smaller the height was. The results are shown in Figure 3.14-3.15.

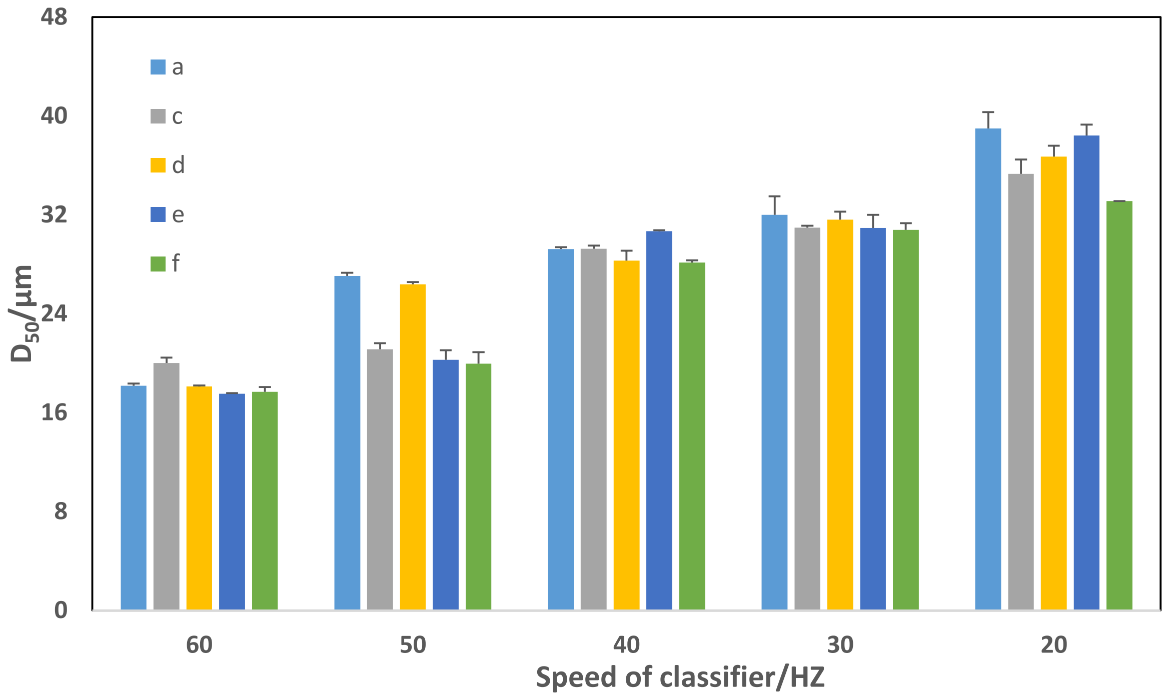


Figure 3.14 The D_{50} of each classifier at different classifier speeds

Figure 3.14 illustrates the average particle sizes of five classifiers at different speeds of classifier. Although original classifier did show better results than some classifiers at a few speeds, the overall performance of all four modified classifiers were better than the original classifier in reducing particle sizes. For modified classifiers, the differences of D_{50} were not significant compared with the original classifier at higher speeds, the differences were within 1μm, classifier c even showed higher D_{50} than the original classifier. However, at lower speeds, the D_{50} differences with original classifier were more significant, especially when the speeds were 50 and 20. Among all modified classifiers, classifier f showed the best results at all speeds in reducing the average particle sizes of products.

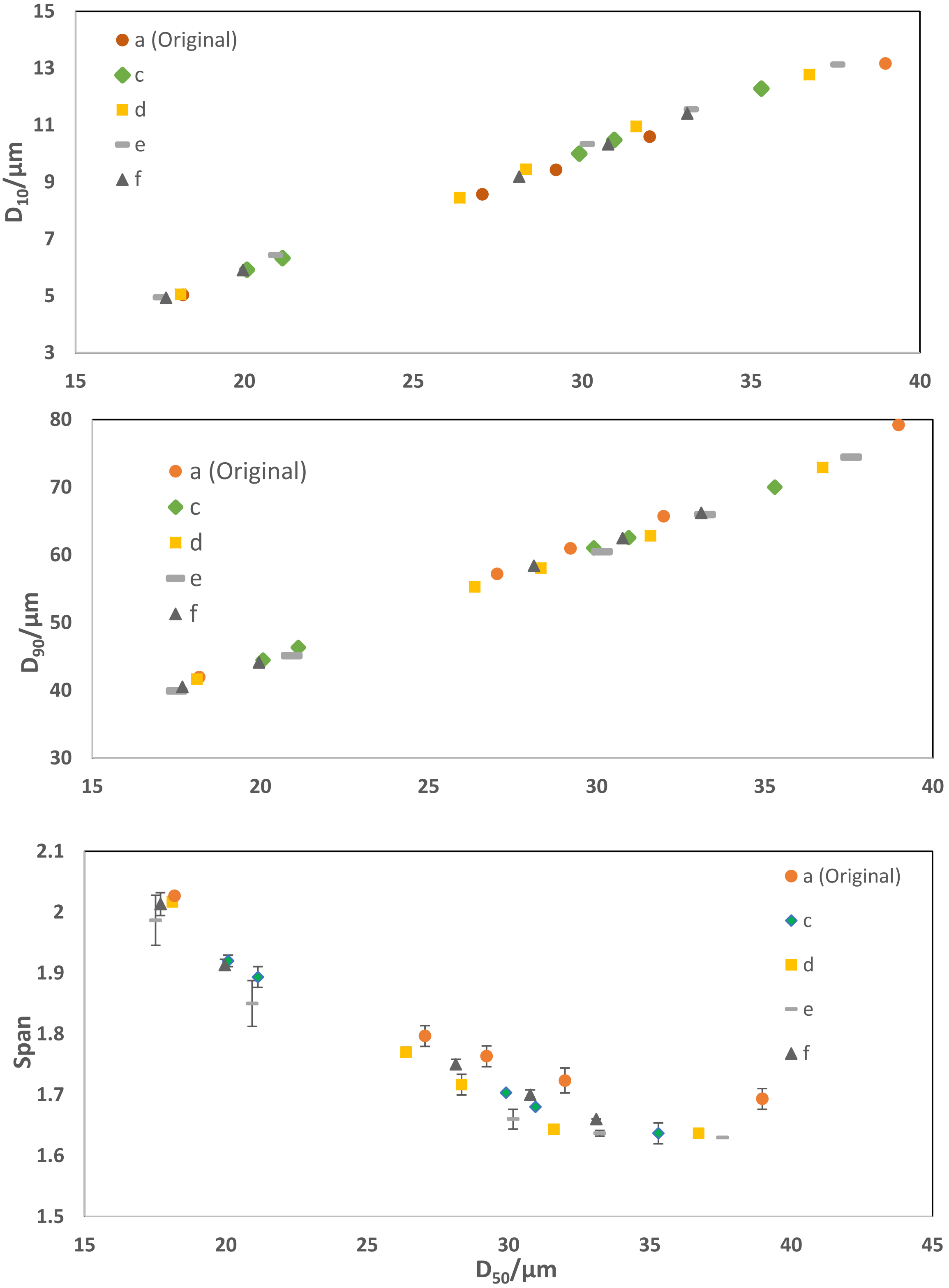


Figure 3.15 Comparisons of D_{10}, D_{90} and span with respect to D_{50} for different classifier fins (a, c, d, e, f)

As shown in Figure 3.15, regarding D_{10}, D_{90} and span, all modified classifiers showed better results than the original classifier. So the modifications did work in narrowing the particle size distributions of products.

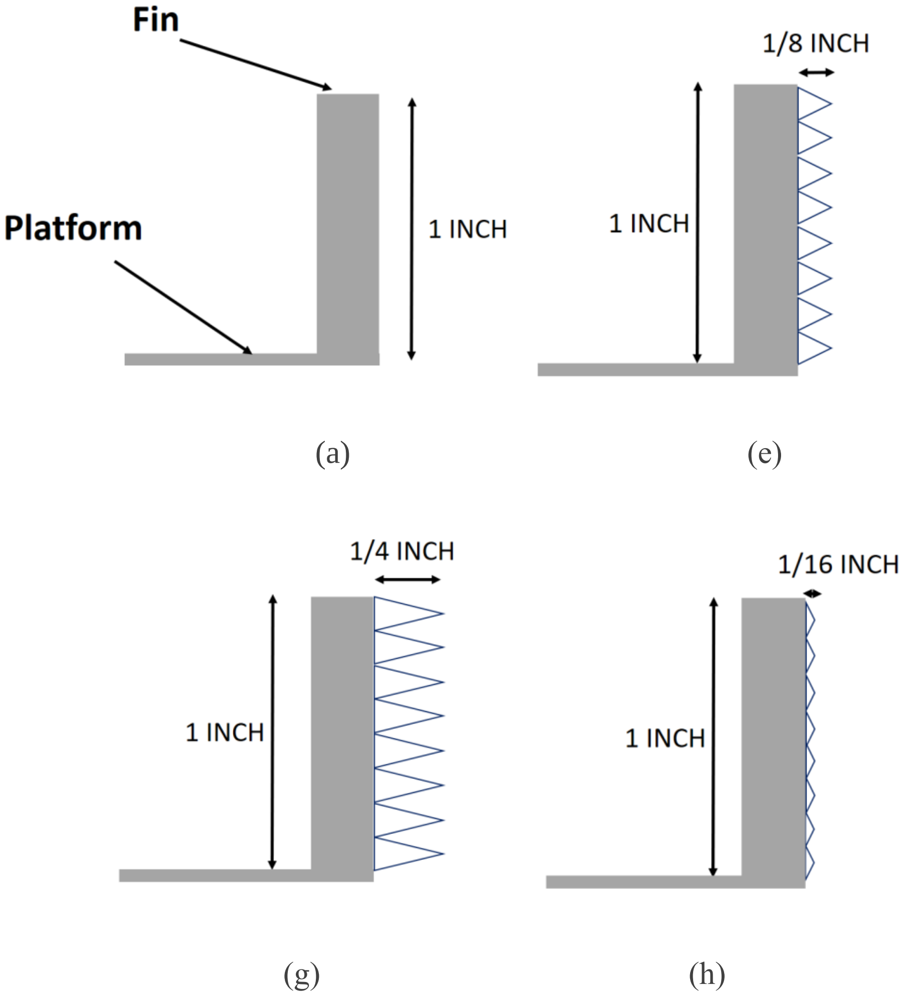
From classifier c to e, when the peripheral lengths were the same, the increase of the number of tooth and the decrease the height contributed to higher D_{10}, lower D_{90} and span under same D_{50}. It means the denser the tooth, the better the performance. One possible explanation is when the peripheral length stays the same, making height shorter could decrease the vortex flow between the fins.

However, the performance became worse when further increase the number of tooth and decrease the height, although it’s still better than the original classifier. The cause might be that further increasing the number of tooth made the height too small and caused marginal effects.

From the figures, it can also be concluded that, when the D_{50} was smaller than 30μm, the differences of performance among modified classifiers were significant, however, when the D_{50} was larger than 30μm, the difference of D_{10}, D_{90} and span among them became smaller, although the difference with original classifier stayed significant. It indicates that the main difference of modified classifiers fell in fine powder manufacturing part.

Overall, all modified classifiers showed generally better results than original classifier both on reducing D_{50} and decreasing span. Among all four modified classifiers which had the same peripheral length, regarding the D_{50}, classifier f showed the best results in reducing particle size at the same speeds of classifier. However, classifier e showed the best results in narrowing the particle size distribution than others. Compared with original classifier, the span can be significantly decreased by more than 0.1. So in the consecutive experiments, the number of tooth used was the same as classifier e.

3.3.3 The Influences of Height



(a) (e)

(g) (h)

Figure 3.16 The fins used to investigate the influences of height (a, e, g, h)

In order to further investigate the influences of height, combined with the original classifier, classifier e, g and h were applied in the experiments, which had same number of tooth on each fin while the height were different. Results are compared with the original classifier and shown in Figure 3.17-3.18.

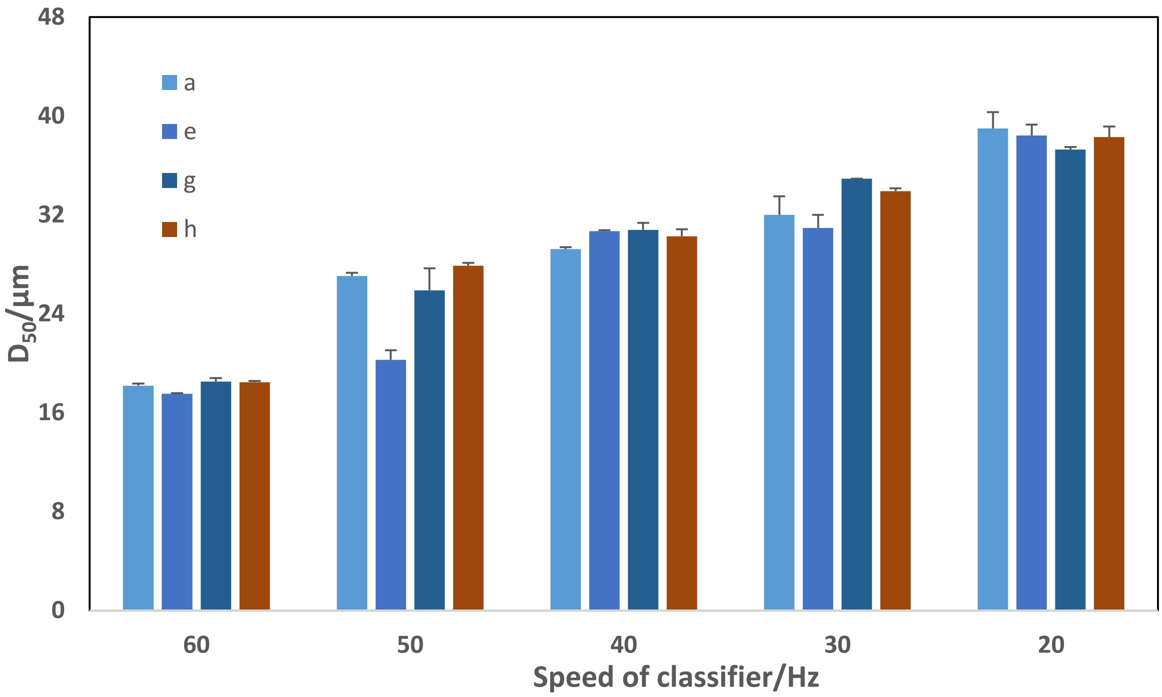


Figure 3.17 The D_{50} of each classifier at different classifier speeds

Figure 3.17 illustrates the average particle sizes of four classifiers at different speeds of classifier. When the speeds of classifier were low (20, 30, 40), the modified classifier didn't show good performance on reducing average particle sizes, compared with original classifier, the D_{50} was either higher or with no significant difference. However, when the speed of classifier increased to 50, the modified classifiers showed much better results, which indicates that these three modified worked better in reducing particle size at high speeds.

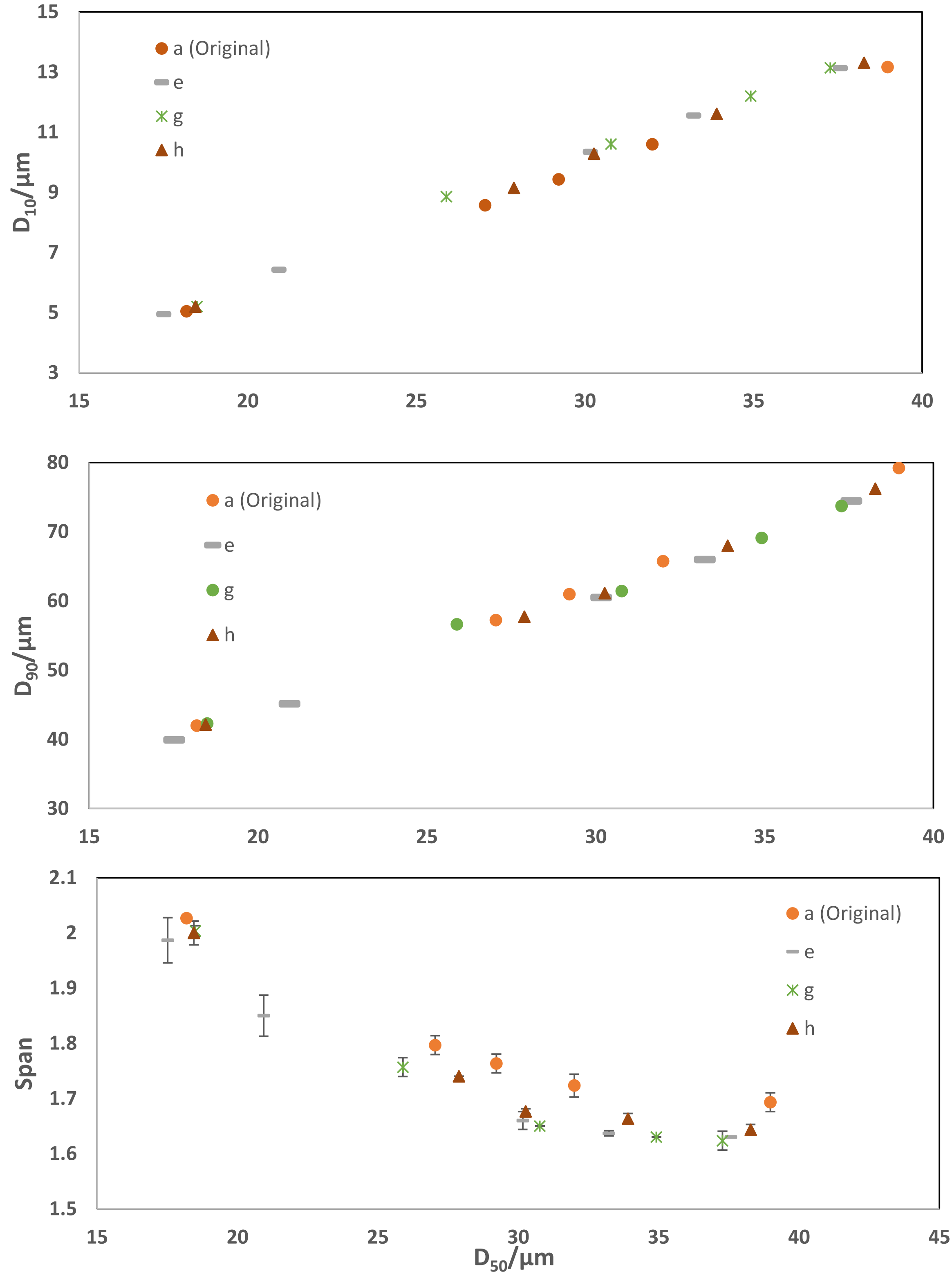


Figure 3.18 Comparisons of D_{10}, D_{90} and span with respect to D_{50} for different classifier fins (a, e, g, h)

As shown in Figure 3.18, compared with the original classifier, three kinds of modified classifier all showed better performances, regarding the D_{10}, D_{90} and the span. Among three groups, the performance of classifer h was the worst, whose tooth height was smallest.

Compared with classifier h, classifier g showed better results, one reason might be that by extending the height, the total peripheral length of fin can be raised, which determined the speed of air flow. When certain amount of air is passing through classifier at the same time, the bigger the peripheral length, the lower the air speed is, which would contribute to the enhance of classifying efficiency.

According to the comparison between classifer e and g, although the classifier g had bigger height, the overall performance was not as good as classifier e.

One possilbe explaination is that extending the height might create complex internal vortex between fins (Figure 3.19), which gives the particles with undesirable sizes a higher chance to pass the classifier. However, when D_{50} was higher than 30μm, classifier g had comparable performance in reducing span.

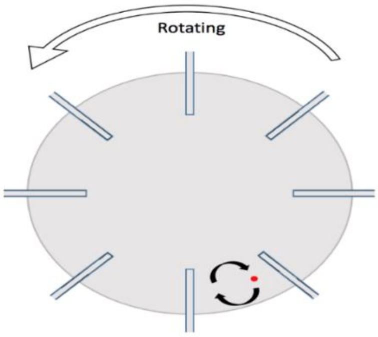
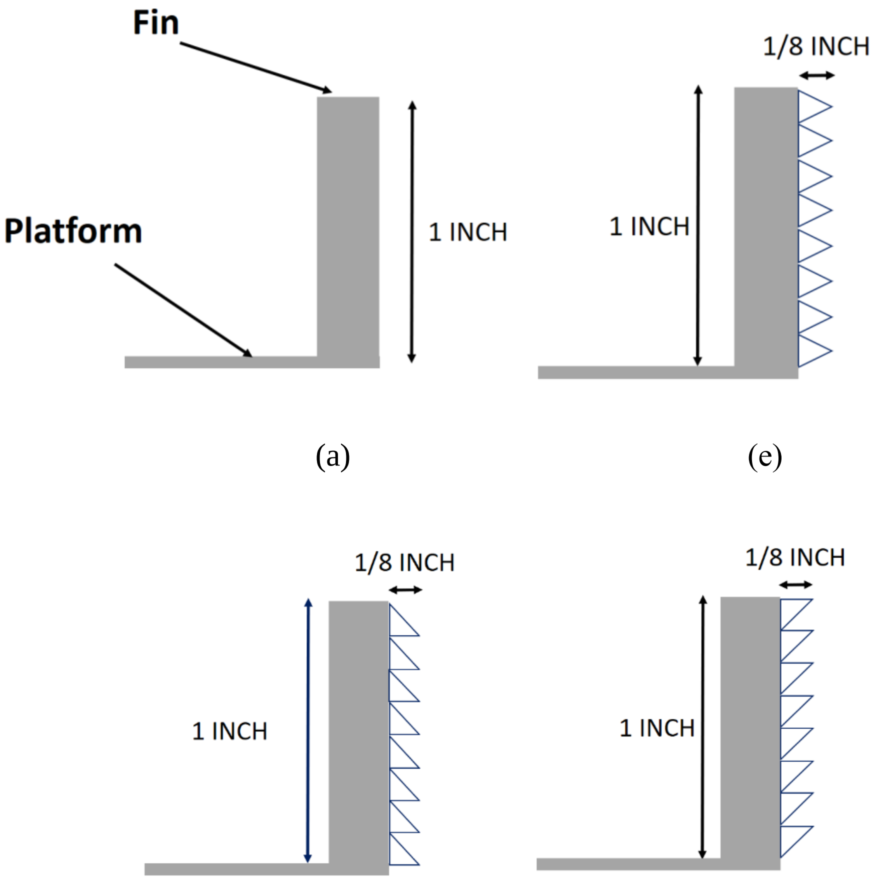


Figure 3.19. The internal vortex between fins

In summary, the height of tooth had an optimum number. Increasing height to certain extend can improve the performance of classifier. However, further increase of height could cause the loss of classify efficiency as well.

3.3.4 The Influences of the Shape of Tooth



(a) (e)

(i) (j)

Figure 3.20 The fins used to investigate the influences of height (a, e, i, j)

The experiments continued with classifier i and j, which had same height and number of tooth with classifier e, and the results were compared with the original classifier (Figure 3.21-3.22).

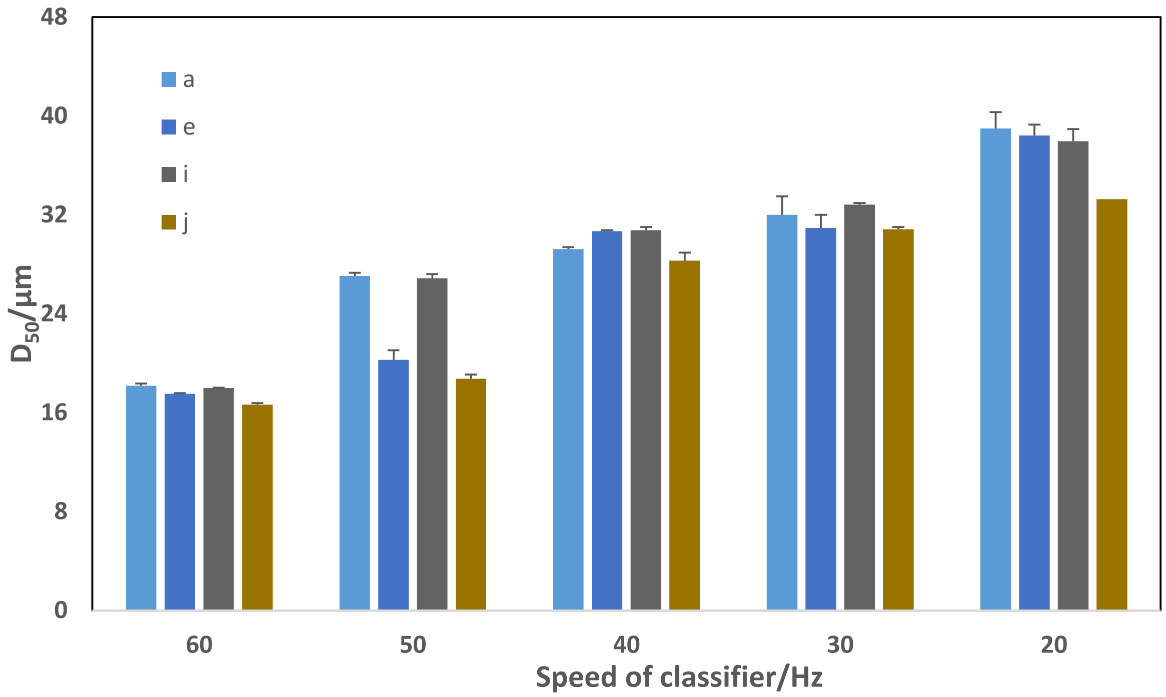


Figure 3.21 The D_{50} of each classifier at different classifier speeds

Figure 3.21 shows the average particle sizes of 4 classifiers at different speeds of classifier. Although original classifier showed slightly better results than classifier e and classifier i at 30 and 40, the overall performance of all three modified classifiers were better than the original classifier in reducing particle sizes. Especially, classifier j showed very good performance in reducing particle size compared with original classifier, at both high speeds and low speeds. When the speed of classifier were 50 and 20, the D_{50} can be decreased by about 9µm and 5µm respectively, at other speeds, the average differences were also above 1µm.

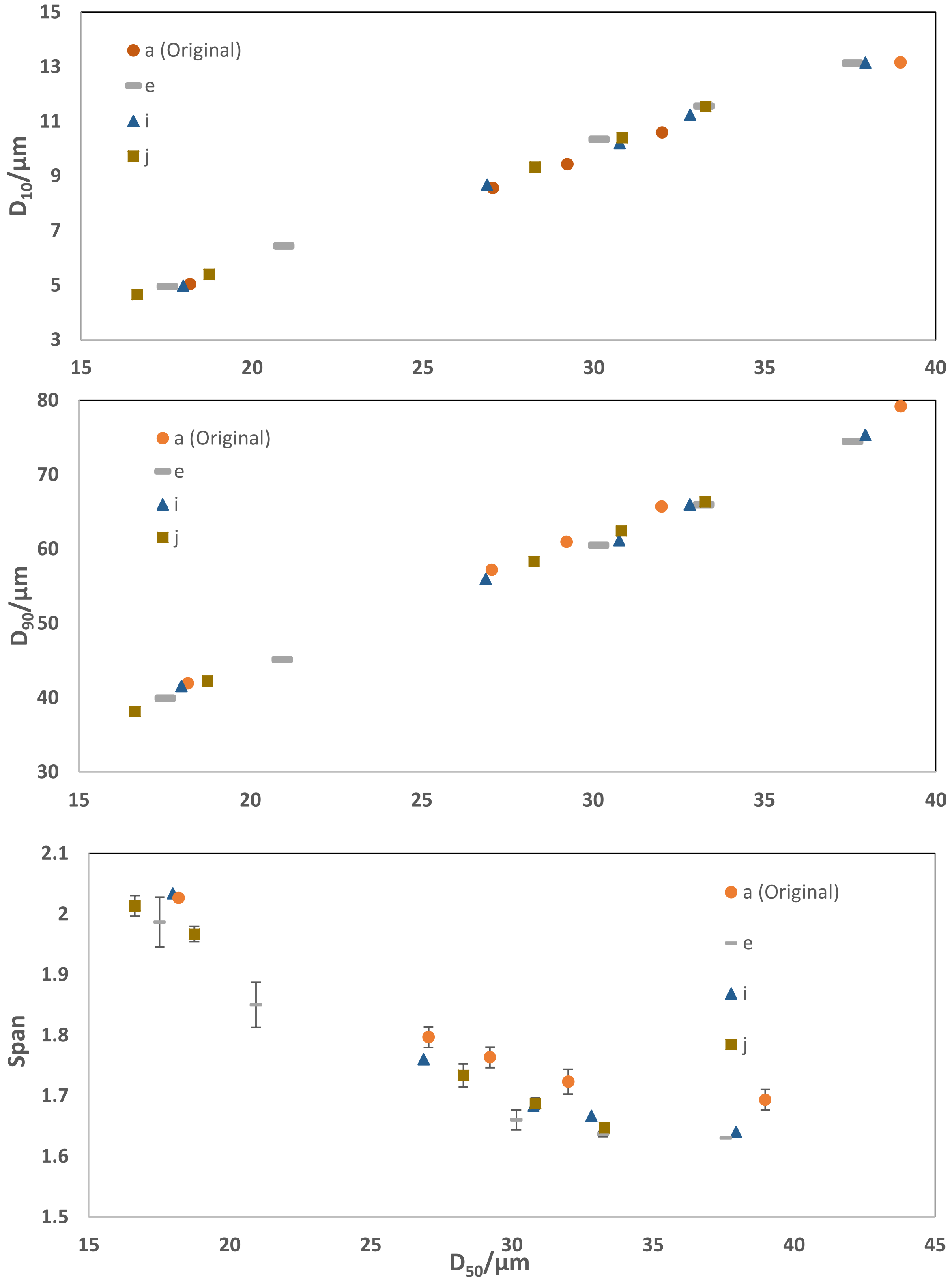


Figure 3.16 Comparisons of D_{10}, D_{90} and span with respect to D_{50} for different classifier fins (a, e, i, j)

As shown in Figure 3.16, the two new fins showd better results compared the original classifier, the span can be decreased by about 0.04. Also, the classifier j showed slightly better results than classifier i in increasing D_{10} and decreasing span than classifier i. This reason might be that the particles from grinding chamber came from the top of classifier, and a upperside-vertical teeth had more direct effects on the particles.

However, compared with classifier e, the two new fins showed no better results, which indicates that when the number of tooth and height were the same, the fins with isosceles-triangle-shape tooth worked better than right-angled-triangle fins.

In summary, classifier j showed very good performance in reducing average particle sizes. However, the two classifiers with right-angled-triangle fins didn't work as well as classifier e on narrowing the particle size distribution.

3.3.5 The Influences on Collection Efficiency

In the experiments, 100g of powder coating chips were fed into the ACM for each sample run. The output was recorded each time, and the average output was calculated. The results showed that under the same grinding conditions, there was no significant difference among different fins, so the reduction of span was achieved without sacrificing the collection efficiency. When the speed of classifier changed, the collection efficiency would change with it. The average collection efficiencies under different speeds of classifier are listed in Table 3.2. It showed that as the speed of classifier increased, the collection efficiency would decrease, because a higher speed would result in a smaller particle size of product, and in this way, more powder would be blown away with air in the cyclone, causing the loss of collection efficiency.

Table 3.3 The collection efficiencies under different speeds of classifier

Speed of Classifier	60	50	40	30	20
Average collection efficiency of original classifier/%	89.50	93.71	95.45	96.34	97.27
Average collection efficiency of classifier d/%	90.30	94.09	95.38	96.71	97.53

3.4 Chapter Summary

The modifications of classifier of ACM were to provide improvement of classification for coating powder grinding process. Nine kinds of fins were used to modify the classier, which have different shapes, heights, number of tooth and so on. The influences on the product' particle sizes and particle size distributions are investigated.

Concluded from the results, classifier j showed the best results on reducing the particle sizes when the speeds of classifier are fixed. At the same speed, the D_{50} can be decreased by as much as 9μm compared with the original classifier. Classifier f also showed very good performance in this part,

As for particle size distribution, all nine modified classifiers showed better results than the original classifier. When D_{50} stays the same, the increase of D_{10}, decrease of D_{90} and span can be seen. Among the modified classifiers, classifier e worked the best in narrowing the particle size distribution. Compared with original classifier, the span can be decreased by over 0.1 at the same D_{50}. And according to the results of output, this span difference was achieved without compromising the collection efficiency.

Chapter 4 Study of Fine Powder Coating on Plastic Component

4.1 Introduction

Powder coating techniques has been applied in automotive industry since early 1970s. At first, the powder coating applications were mainly with metal components, for instance, the hubs of cars. Nowadays, in order to enhance the fuel efficiency, there is an increasing demand for the automotive industries to reduce the total weight of vehicles. In this way, the necessity of applying lighter parts, like plastic parts, in the vehicles has kept increasing [59]. Therefore, powder coating on plastic components has become a real need.

The purpose of powder coating on plastics is not only for esthetics but also for the purpose of better chemical resistance and/or impact protection [60]. By powder coating, good resistances to abrasion or corrosion of the plastic components can be achieved. However, compared with the powder coating on metal parts, powder coating with plastic substrates has not been successful using the conventional electrostatic coating techniques. One reason is that in the curing process, high temperature (over 190℃) is needed. However, at this temperature, plastic substrates would get warped or distorted. Also, compared with metals, plastic substrates are more likely to absorb moisture from air. At the high temperature in curing process, the moisture would evaporate out from the substrates and cause pinholes on coating film, known as "popping", which is another problem for powder coatings to form smooth surface.

The biggest difficulty for electrostatic spraying on plastic targets is that a plastic surface is non/low-conductive. The principle of conventional electrostatic spray is to apply high voltage to form an intense electric field near the spray gun, so that the powders can be charged during the spray process. The charged particles then would be adhered to a grounded substrate. So it is a basic requirement for the substrates to have good conductivity. For the plastic substrates, due to the low-conductivity, longer charge relaxation time is needed for plastic substrates compared with metals [51-53]. Plastic substrate becomes charged quickly when the charged particles deposit on surface and there is no way to neutralize it. The accumulation of free electrons could form a repelling field, which hinders the coming powders from further deposition, resulting in insufficient coating. This phenomenon is known as “back-ionization”, as illustrated Figure 4.1 (left). The insufficient and non-uniform powder coverage could also form “patchy” surface [51] as shown in Figure 4.1 (right). So conventional electrostatic spray alone is not doable for coating on plastic component.

Figure4.1 Surface defects of the powder coating on plastic substrate

According to the previous work of our group, pre-heating method has been proven to be effective (Figure 4.2). There are two main advantages of preheating the thermoplastics substrate. Firstly, by preheating the substrate, the moistures can be greatly reduced, which could avoid the form of “popping” during the curing process. Secondly, first-pass coating powders transferred to the substrate would be melted by the heat, making it much easier for the powder coming after to deposit on the substrate surface. The results showed that using pre-heating method, sufficient and uniform powder film could be achieved.

Figure 4.2 Coating on plastic component using pre- heating method

However, in the previous work, what applied in experiments was coarse powder ($D_{50}>25\mu m$). In this study, in order to further enhance surface quality, fine powder ($D_{50}\leq 25\mu m$) was used in experiments. The influence of D_{50} was investigated, and when D_{50} are same, the influence of particle size distribution was also investigated.

Besides, due to the low transfer efficiency of fine powder during spray process, voltages were applied in spray processes as a supplementary method in assisting pre-heating method. In addition, considering the poor flowability of fine powder, flow additives were added into the fine powders. The influences of additives were investigated, both on powder flowability and surface quality.

4.2 Experimental Study

4.2.1 Experiment Design

In this experiment, the influences of particle size and particle size distribution on two kinds of commonly-used coating powders were first investigated. In addition, considering the poor flowability of fine powder, different amounts of additives were added into coating powders. Moreover, because of the low transfer efficiency, voltages were applied during the spray processes. The influences of voltages and flow additives were then investigated.

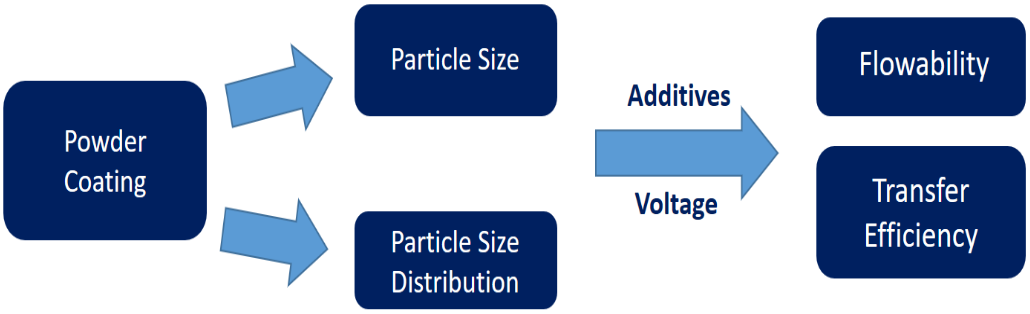


Figure 4.3 The Schematic of experiments

4.2.2 Material and Method

Powder coating materials

The substrate panels are made from polyamide laminate co-moulded with 20%wt of glass fibers (Ultramid 8202 HS, JM886 Fraunhofer Institute for Chemical Technology ICT) with same size (5cm×7cm).

Two different commonly-used commercial coating powders were applied in experiments, namely, polyester (TCI 9910-9000) and epoxy (TCI 7830-9000). The original coating powders were further milled by air classifying mill (ACM) into different sizes with different particle size distributions. The particle sizes and particle size distributions after milling are listed in Table 4.1-4.2.

Table 4.1 The D_{50} and span of polyester coating powders applied in experiments

Group	D_{50}/µm	Size Span
A	17	2.10
B	17	1.94
C	17	1.86
D	20	1.92
E	20	1.80
F	40	1.71
G	40	1.63

Table 4.2The D_{50} and span of epoxy coating powders applied in experiments

Group	D_{50}/µm	Size Span
a	39	1.78
b	27	1.52
c	27	1.4
d	25	1.4
e	20	1.78

Additives

Two commercial nano-scale additives, AEROSIL ® 972 (CAS-No. 68611-44-9, Evonik Industries AG) and AEROXIDE® Alu C (CAS-No. 1344-28-1, Evonik Industries AG), were added into fine powder as flow additives. The amount of additives added into fine powder are listed in Table 4.3.

Table 4.3 The amount of additives added into fine powders for both polyester and epoxy experiments

Group	Aerosil 972/ wt%	Aluminum C/ wt%
I	0.05	0.05
II	0.1	0.1
III	0.2	0.2

To mix the additives into coating powders, manually pre-mixing method was firstly used. After that, to make sure the additives are well dispersed with coating powders, the pre-mixed samples were sieved by the ultrasonic-vibration sifter (KET-C, Branson).

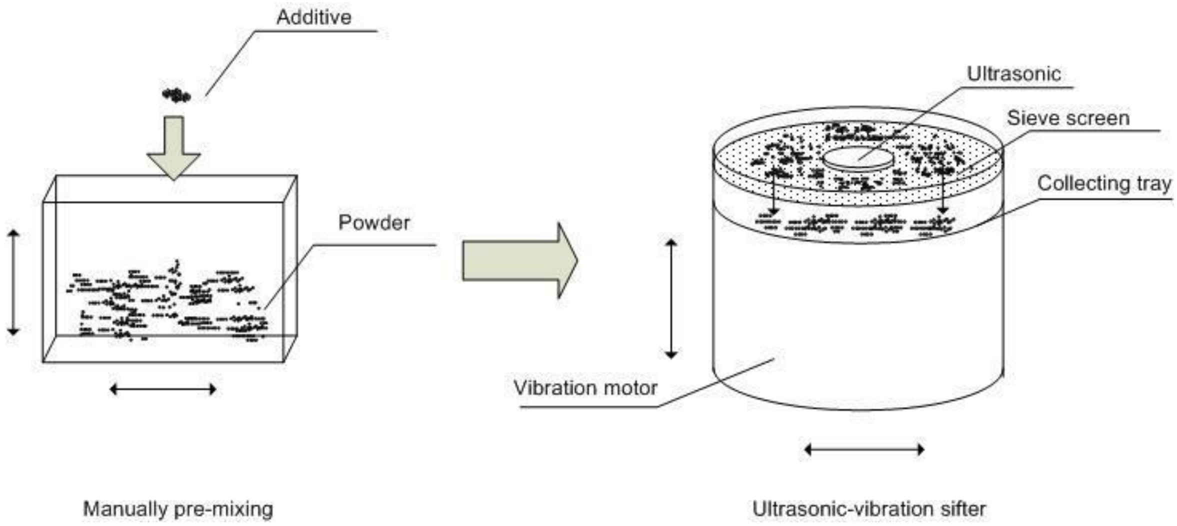


Figure 4.4 Schematic of mixing

As shown in Figure 4.4, the coating powders and preciously-weighted additives were put into a sealed plastic bag for manual pre-mixing. After shaking for 30 times, the pre-mixed sample was then transferred to the ultrasonic-vibration sieve with a 45µm screen to be further sieved.

There are two purposes of applying ultrasonic-sieving in this experiments. The first reason was that compared with manual mixing, the ultrasonic-sieving can ensure a better dispersion of additives in the coating powders. The second one was because of the agglomeration of additives. Due to the nano-scale particle sizes. The relative magnitude of the inter-particle forces among additives are very high, so the additives tend to agglomerate together. This could result in the inconstant distribution of additives in coating powders and cause surface defects like seeds. Using the ultrasonic sieving, the vibration could break the agglomerated additives. Moreover, the 45µm-sieve could make sure that there is no agglomeration larger than 45µm appear in the sieved coating powders.

To ensure a precise addition of additives, a large amount of sample (500g) was produced, although only less than 100g of coating powders were needed for each sample.

Spraying method

Figure 4.5 Nordson 902 Powder Coating Booth

The spraying process was conducted in the lab-scale spray booth (Nordson, USA) and the coating powders were sprayed using Gema OptiFlex spray gun (Gema, Switzerland). Three different voltages were applied in spraying process with polyester, namely, 15 kV, 30kV and 45kV, while two different voltages were applied in the epoxy experiments, which are 30kV and 45kV.

Coating procedures

As shown is Figure 4.6, a plastic panel was firstly pre-heated for 15 minutes to the set temperature (same as the curing temperature) in a convection oven. Then it was removed from oven to the spray booth quickly. After spraying, the panel was returned to convection oven, heated for 15 min under the curing temperature. The average temperature loss before spraying was about 20°C.

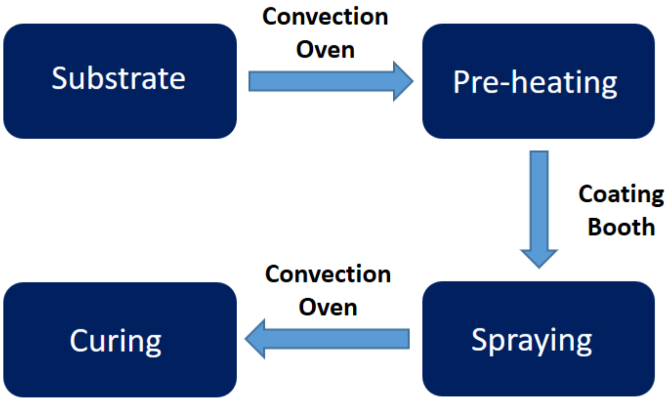


Figure 4.6 Schematic of spraying process

According to the previous researches, the pre-heating temperature was suggested to be higher than the melting temperature of coating powders but was below the melting point of the plastic. 160°C was determined as the upper limit for both pre-heating and curing.

4.3.3 Measurement Techniques

Evaluation of surface finish

Film Thickness

The film thickness of the coating film was measured by digital micrometer. For each panel, four measurements were taken at four set locations as shown in Figure 4.7. The coating film thickness was obtained by the overall thickness difference before and after coating.

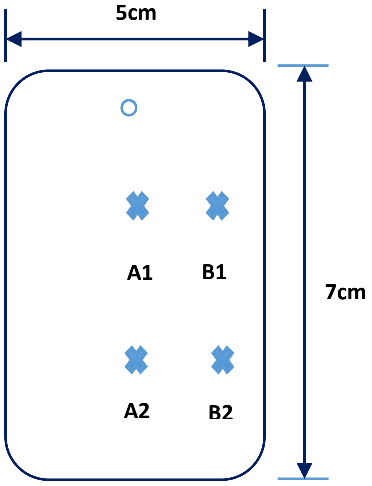


Figure 4.7 Schematic of the measuring points for film thickness

Gloss

Gloss is an optical property which indicates how well a surface reflects light in a specular (mirror-like) direction. It is one of important parameters that are used to describe the visual appearance of an object. The factors that affect gloss are the refractive index of the material, the angle of incident light and the surface topography.

Gloss 60°, Gloss 20° and Gloss 85°are commonly used. When Gloss 60° is higher than 80, the surface can be defined as high gloss, then Gloss 20° is needed to further evaluate the surface quality, while Gloss 85° is used to evaluate low-gloss surface.

In experiments, gloss was tested using Rhopoint IQ Gloss Meter (A6000-002, Rhopoint Instruments).

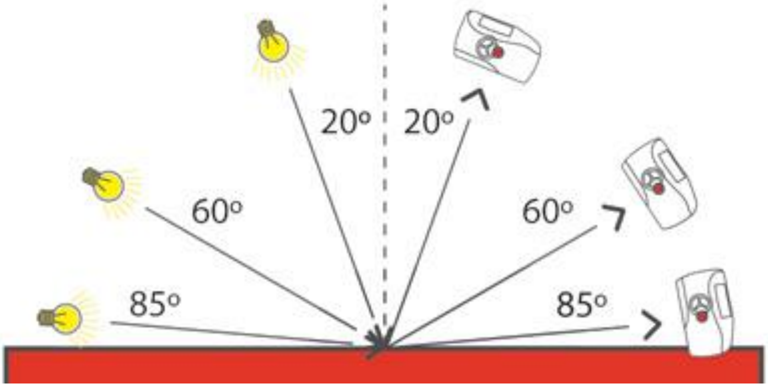


Figure4.8 The schematic of gloss measurement

DOI

Distinctness of image (DOI) characterizes the sharpness of a reflected image when viewed in a surface. Surfaces with textures such as orange peel distort reflected images and hen have a lower DOI. Perfectly smooth surfaces have a DOI of 100. Viscosity and flow characteristics, particle size distribution, flake alignment, improper application parameters and techniques can all cause the loss of DOI.

Haze

Reflection haze is scattered light caused by micro texture and is measured adjacent to the main gloss component. High quality glossy surfaces have a clear, brilliant finish (HU=0).

Evaluation of flowability of coating powders

To evaluate the flowability of coating powders with different amounts of additives, the avalanche angle (AVA) of each coating powders was tested by Revolution Analyzer (Mercury Scientific Inc., Sandy Hook, CT, US). In the test, 120ml of coating powders were put into a cylindrical-drum container with two transparent sides. The container was put into the analyzer and be kept rolling slowly. During the testing process, a light was put on one side of the container while a camera was put on the other side, monitoring the behavior of powder in this rolling process (Figure 4.9). The analyzer could calculate the maximum angle of power prior to the start of the power avalanche occurrence (Figure 4.10). This angle is the avalanche angle. To ensure the accuracy of testing, avalanche angle of each coating powders was tested for 200 times to take the average number.

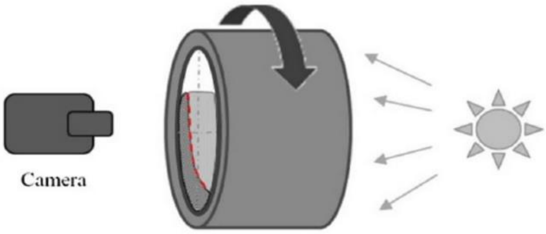


Figure 4.9 The Schematic of AVA measurement

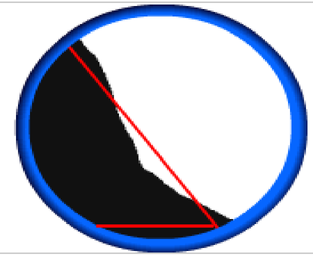


Figure 4.10 The Schematic of avalanche angle of powder

Evaluation of transfer efficiency

To evaluate the transfer efficiency in spray process, for each panel, the weight before and after coating was tested, so the amount of powder transferred to the panel can be calculated.

To investigate the influence of applied voltages on transfer efficiency, in the polyester experiments, 12g of polyester coating powder was loaded into spray gun for each spray, the amount of powder transferred to powder was used to evaluate transfer efficiency. In the epoxy experiments, the amount of coating powders transferred to each panel was preciously controlled to 0.8g, so the loading amount of epoxy each time is used to evaluate transfer efficiency.

4.3 Results and Discussion

4.3.1 Polyester Coating

The influences of particle size

Figure 4.11-4.13 show the surface quality under different D_0. As the D_{50} decreases, Gloss 60° and distinctness of image (DOI) increase correspondingly, which indicate better surface quality. However, the D_{50} has no significant influence on Haze. In general, according to the evaluation of gloss, DOI and Haze, it can be concluded that by reducing particle sizes, better surface finish can be achieved.

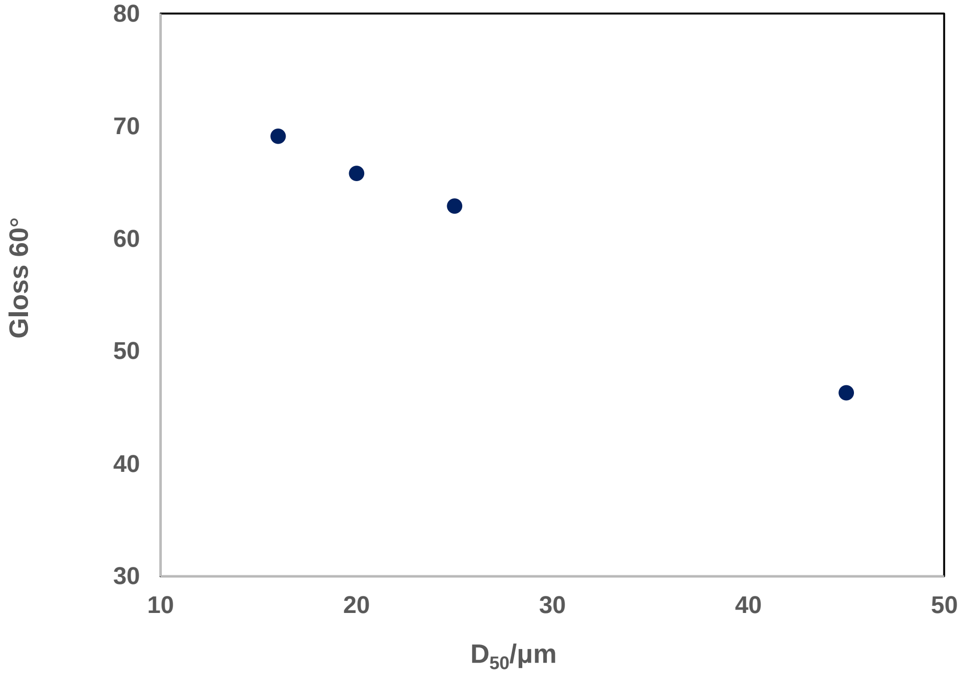


Figure 4.11 The influence of D_{50} on Gloss 60° (140℃)

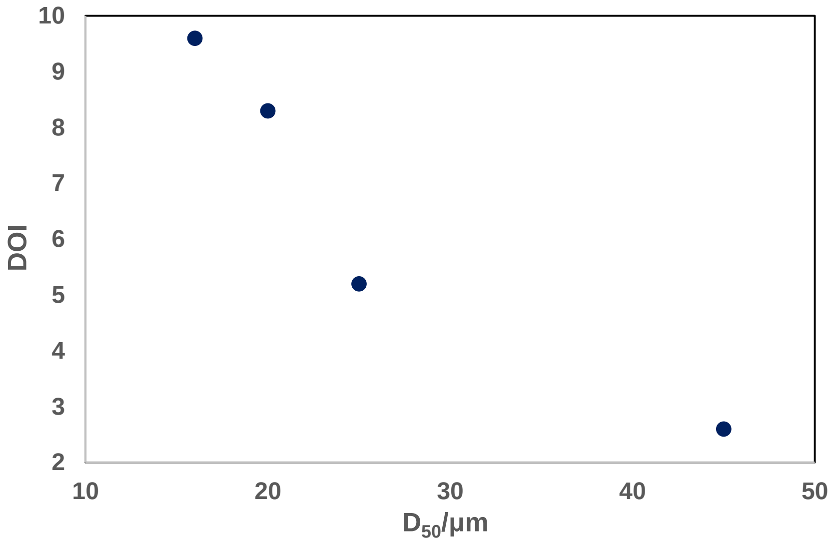


Figure 4.12 The influence of D_{50} on DOI (140°C)

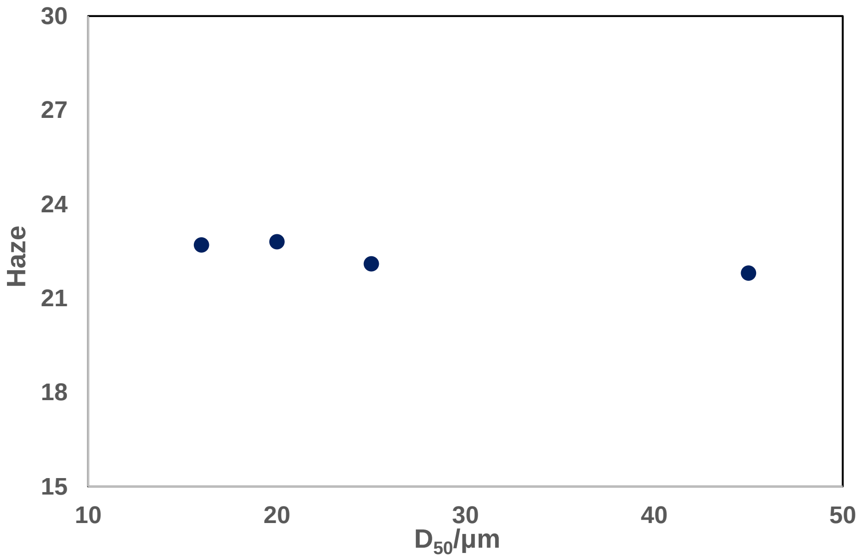


Figure 4.13 The influence of D_{50} on Haze (140°C)

The influence of particle size distribution

The influences of span on Gloss 60°, distinctness of image (DOI) and Haze under 140°C and 160°C are shown in Figure 4.14-4.19.

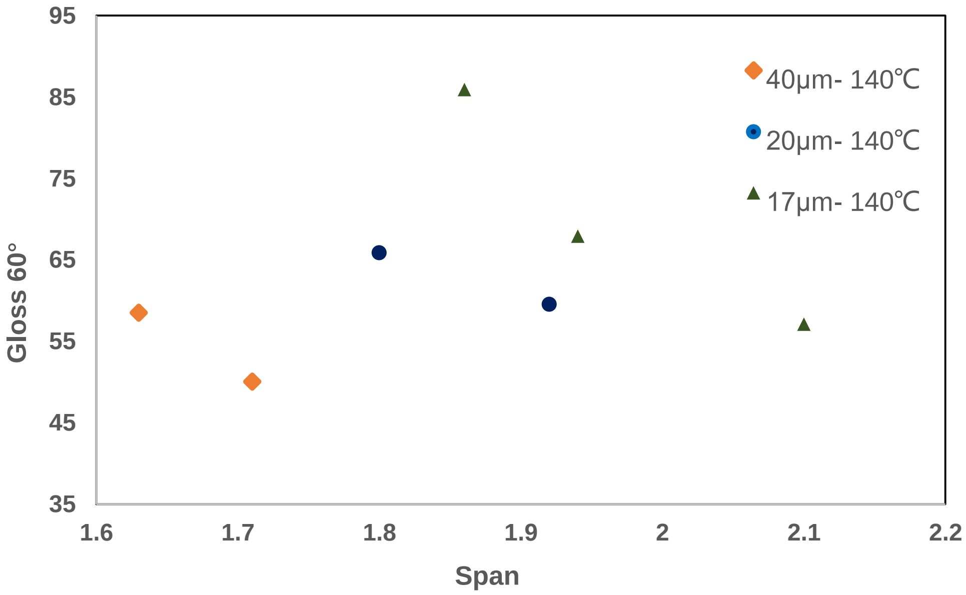


Figure 4.14 The influence of span on Gloss 60° (140°C)

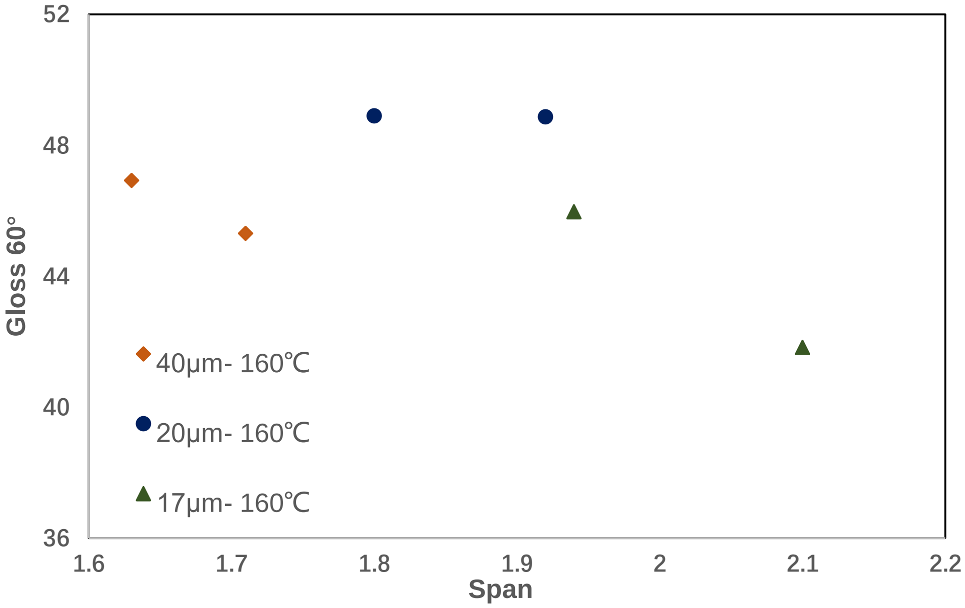


Figure 4.15 The influence of span on Gloss 60° (160°C)

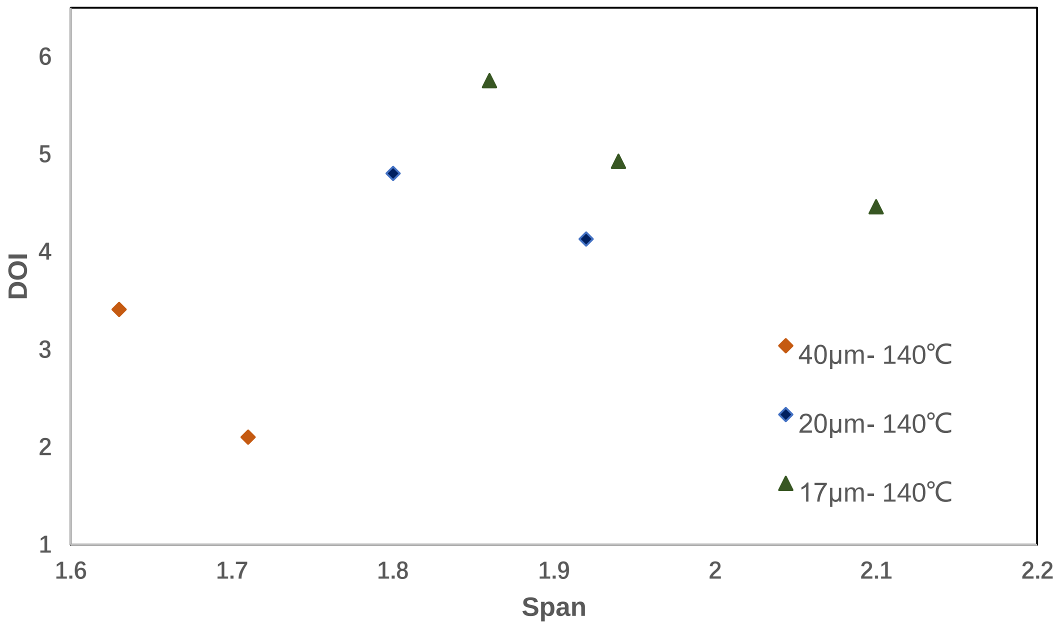


Figure 4.16 The influence of span on DOI (140℃)

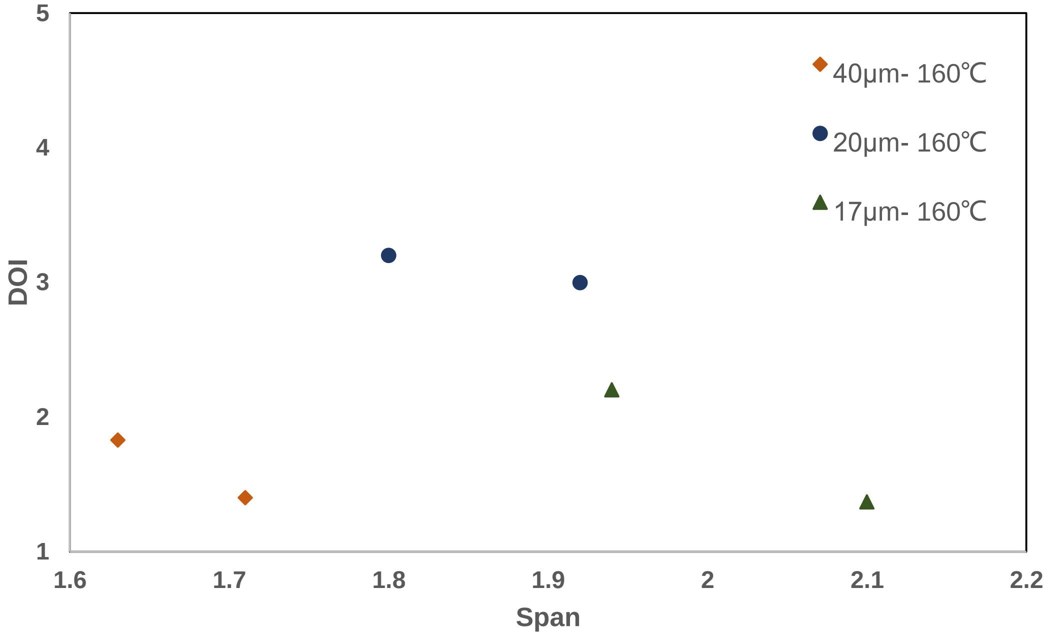


Figure 4.17 The influence of span on DOI (160℃)

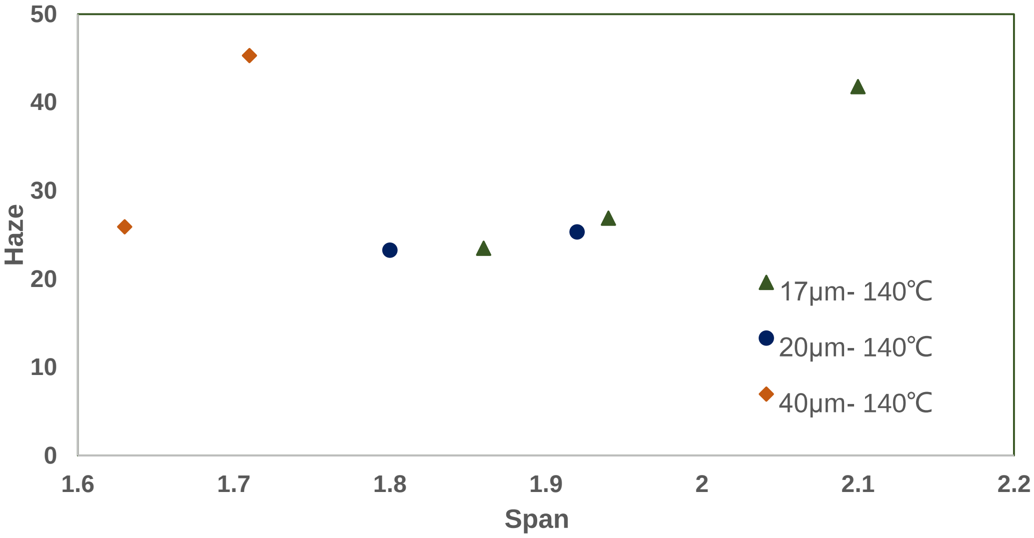


Figure 4.18 The influence of span on Haze (140°C)

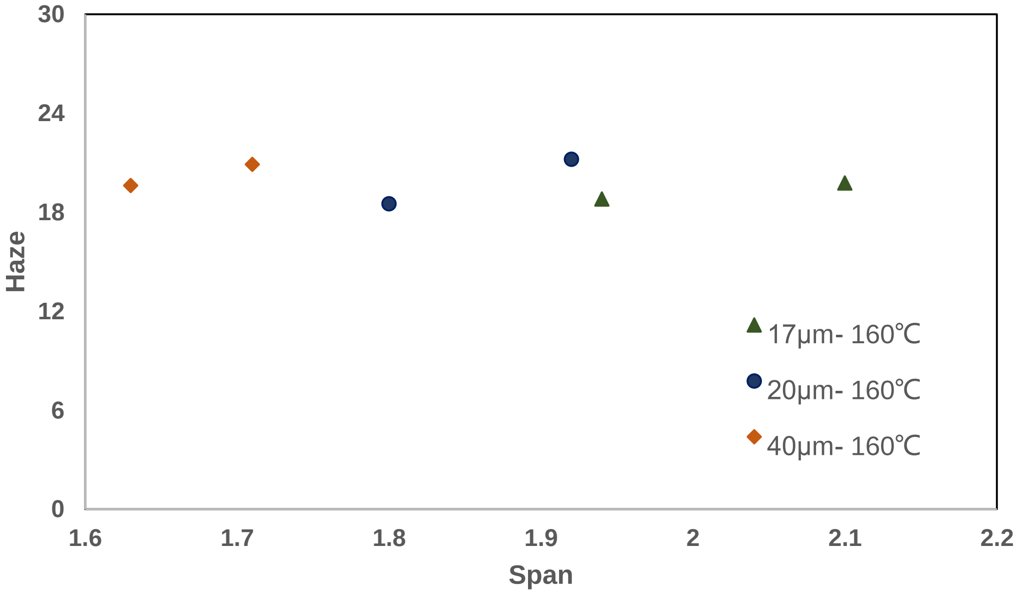


Figure 4.19 The influence of span on Haze (160°C)

As shown in these figures, under both 140℃ and 160℃, when the D_{50} were the same, the coating powders with lower span showed higher Gloss 60° and DOI. While as the span decreases, the haze decreased correspondingly. It indicated that when D_{50} stays the same, lowering the span of coating powders is beneficial to obtaining more uniform films and better surface conditions.

The benefits of lowering span might due to the removal of small particles, which increased the flowability of coating powders and made it easier to form a smooth surface.

The influences of additives on the flowability of fine powder

To further investigate the influences of additives, group A (D_{50}≈17μm, span=2.10) was used to mix up with different amounts of flow additives (shown in Table 3). After mixing, the avalanche angle of each group of coating powders was tested and was compared with the result of non-additives coating powder. The results are shown in Figure 4.20.

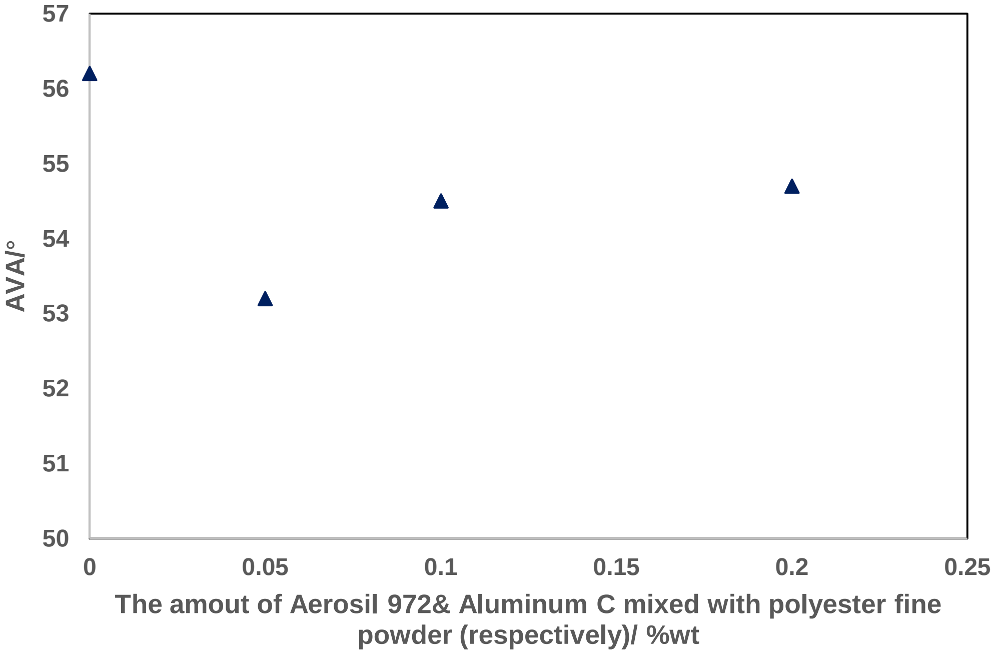


Figure 4.20 The influence of the amount of additives on the flowability of polyester fine powder

As shown in Figure 4.20, by adding 0.05%wt Aerosil 972 and 0.05%wt and Aluminum C, the avalanche angle (AVA) of polyester fine powder was decreased by more than 3°, which indicates the improvement of flowability. However, further addition of additives could cause the increase of AVA. The reason was that by adding certain amount of additives, the nano additives can act like lubricant among the micron-scale powder (Figure 20 left). However, if too much additives were added into coating powder, the coating powders would have more nature of nano particles, whose flowability is extremely poor (Figure 20 right). In summary, the best flowability can be obtained by adding 0.05%wt Aerosil 972 and 0.05%wt and Aluminum C.

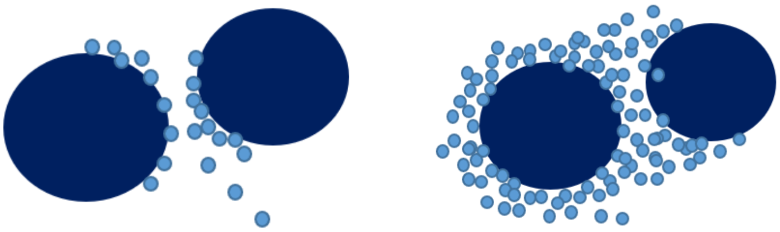


Figure 4.21 The desirable amount of additives (left) and undesirable amount of additives (right)

The influence of voltage

As is shown in Figure 4.22, for all three groups of coating powders, when 12g of coating powder was loaded into the spray gun for each spray, more amount of powder transferred to panel as the voltage increases. This indicated that for fine powder, applying voltage could be an effective supplementary method in assisting preheating to get more powders deposit on the substrate.

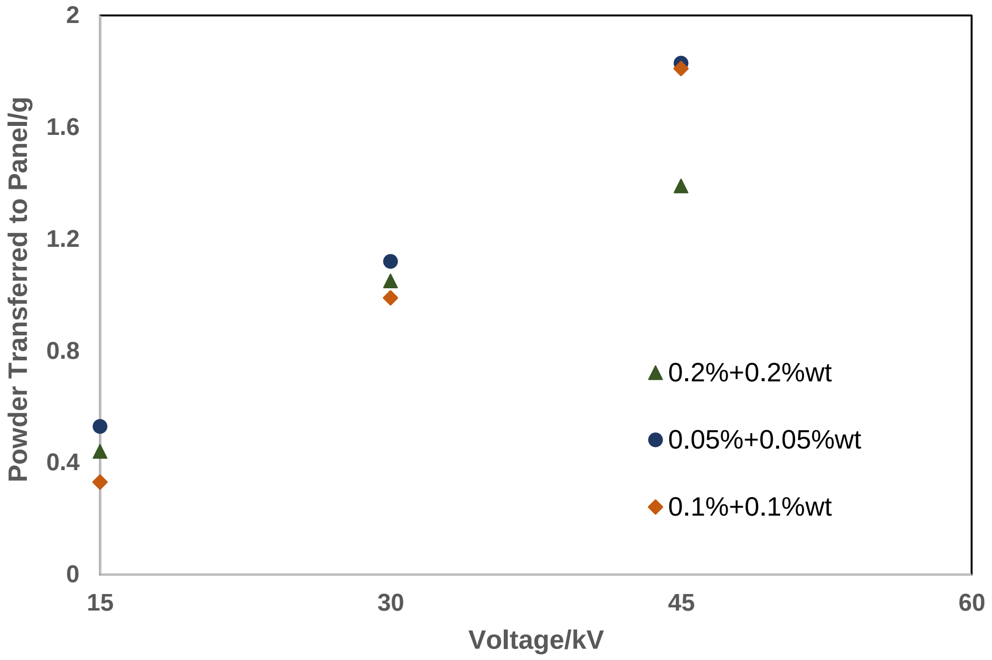


Figure 4.22 The influence of voltage on transfer efficiency

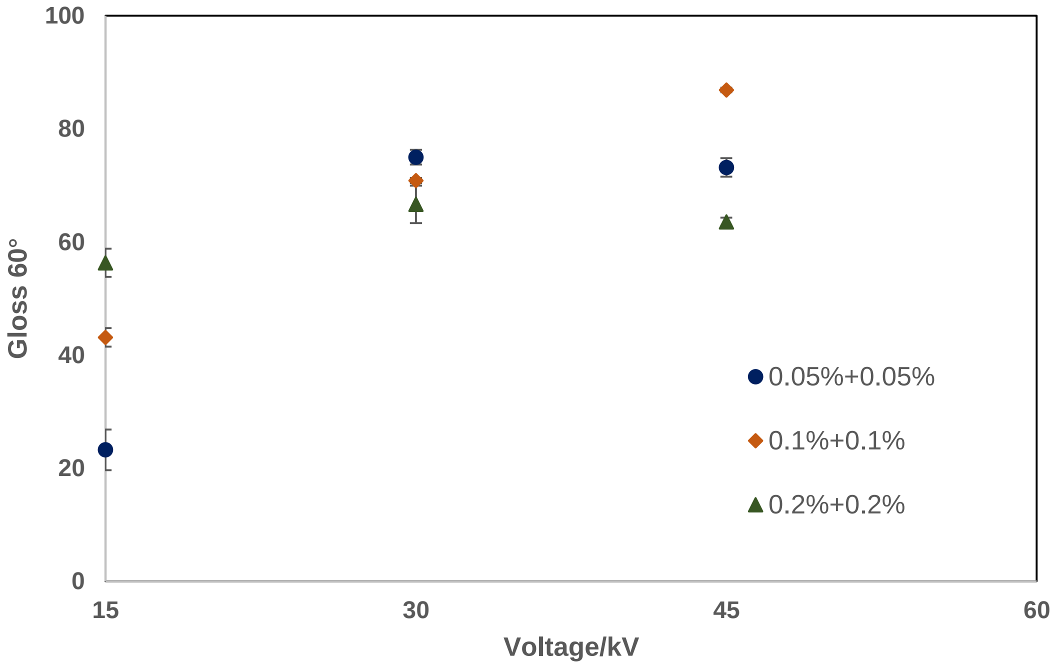


Figure 4.23 The influence of voltage on Gloss 60°

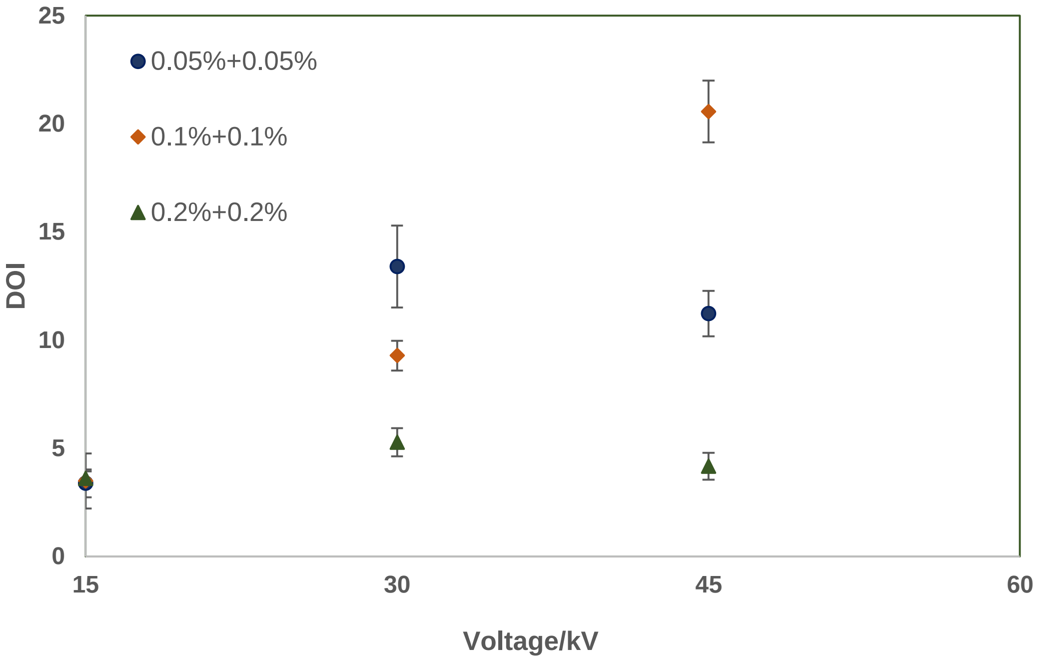


Figure 4.24 The influence of voltage on DOI

In Figure 4.23-4.24, it is shown that for polyester coating powder which had 0.05%wt Aerosil 972 and 0.05%wt Aluminum C,0.2%wt Aerosil 972 and 0.2%wt Aluminum C, increasing voltage from 15kV to 30kV, higher Gloss 60°and DOI can be achieved. However, keeping increasing voltage to 45kV would causes the decrease of Gloss 60°and DOI. On the other hand, for the coating powder which had 0.1%wt Aerosil 972 and 0.1%wt Aluminum C, both Gloss 60°and DOI had an increasing trend as voltage increases. One possible explanation of this phenomenon was that the amount of powder transferred to panel was different, resulting from the difference of transfer efficiency among groups. Insufficient coating could cause low gloss and surface defects, like orange peel. On the other hand, if too much powder was transferred to panel, the film thickness would be too high, which could also cause surface defects like pinholes.

The film thickness was around 110μm when the voltage was 15kV, while film thickness became 150μm when the voltage went up to 30kV, which mainly due to higher transfer efficiency.

When adjusting voltage to 45kV, the film thickness of all three groups of coating powder was above 200µm, which is too thick for coating. Considering both surface quality and film thickness, 15kV and 45kV are not suggested for practical use. In this way, as demonstrated by the above results, when voltage is 30kV, it showed that as the more amount of additives, the surface condition became worse as the poorer Gloss and DOI obtained.

4.3.2 Epoxy Coating

The influence of particle size and particle size distribution

The epoxy experiments were also carried out under the same experimental procedure, and the results are shown in Figure 4.25-4.28.

As shown in Figure 4.25, Gloss 60° are all higher than 80, so Gloss 20° is used to further evaluate surface quality. By comparing point a with point e or point c with point d, we can see that when spans were the same, the coating powder with lower D_{50} has higher Gloss 20°. Comparing point b with point c which have same D_{50}, it's shown that the coating powder with lower span also showed higher Gloss 20°.

Similar trend can also be observed in Figure 4.26, indicating that by lowering D_{50} and span, higher DOI can be obtained, which mean better surface quality. Same conclusion can also be concluded from the results of Haze, as shown in Figure 4.27.

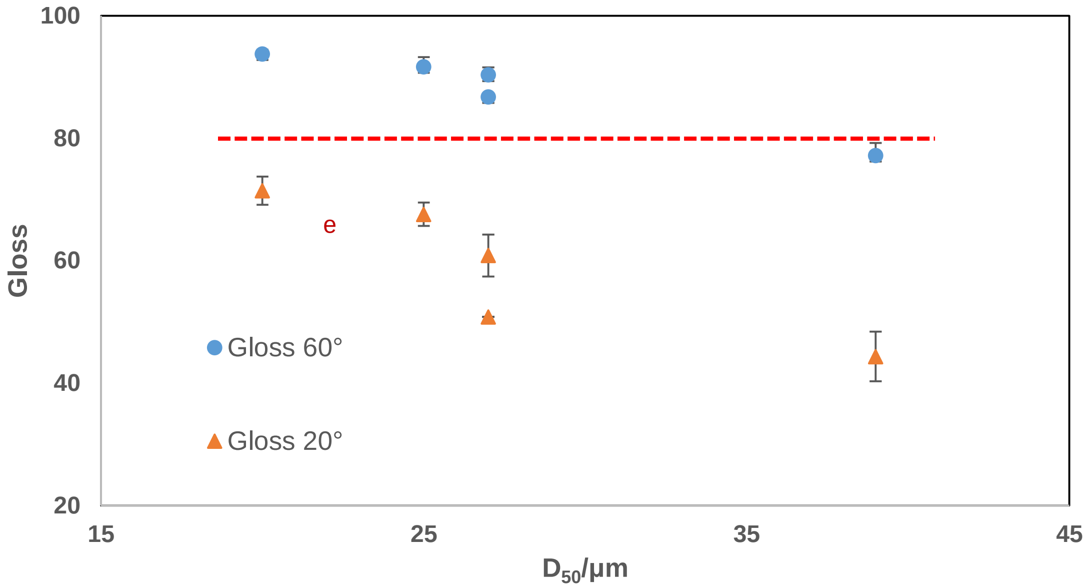


Figure 4.25 The influences of D_{50} and span on Gloss

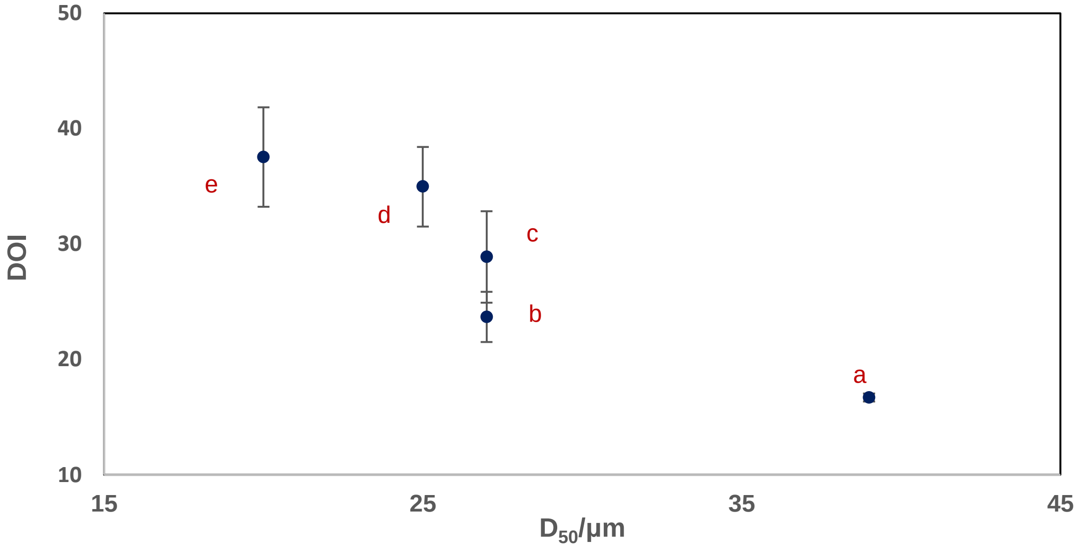


Figure 4.26 The influences of D_{50} and span on DOI

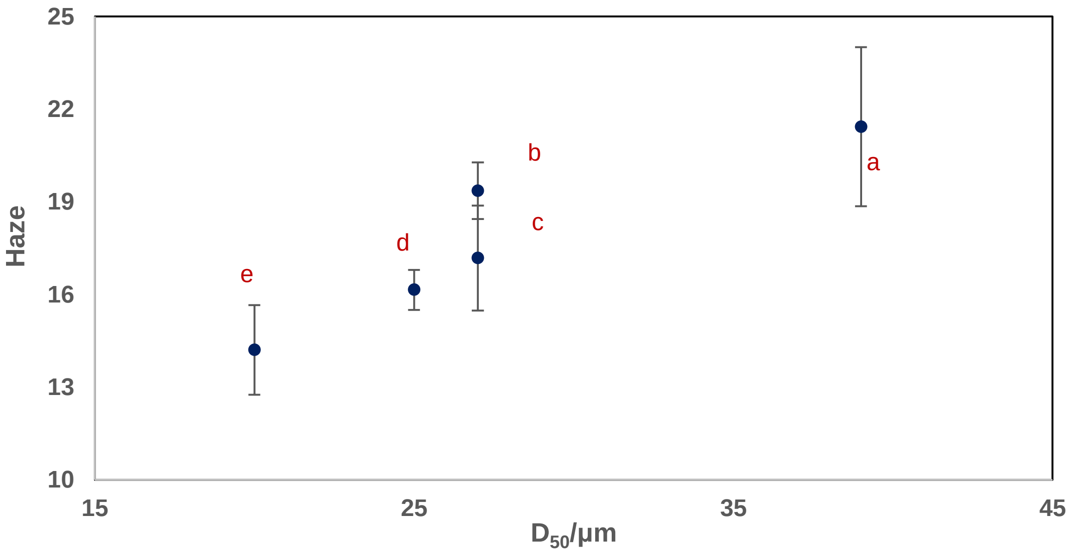
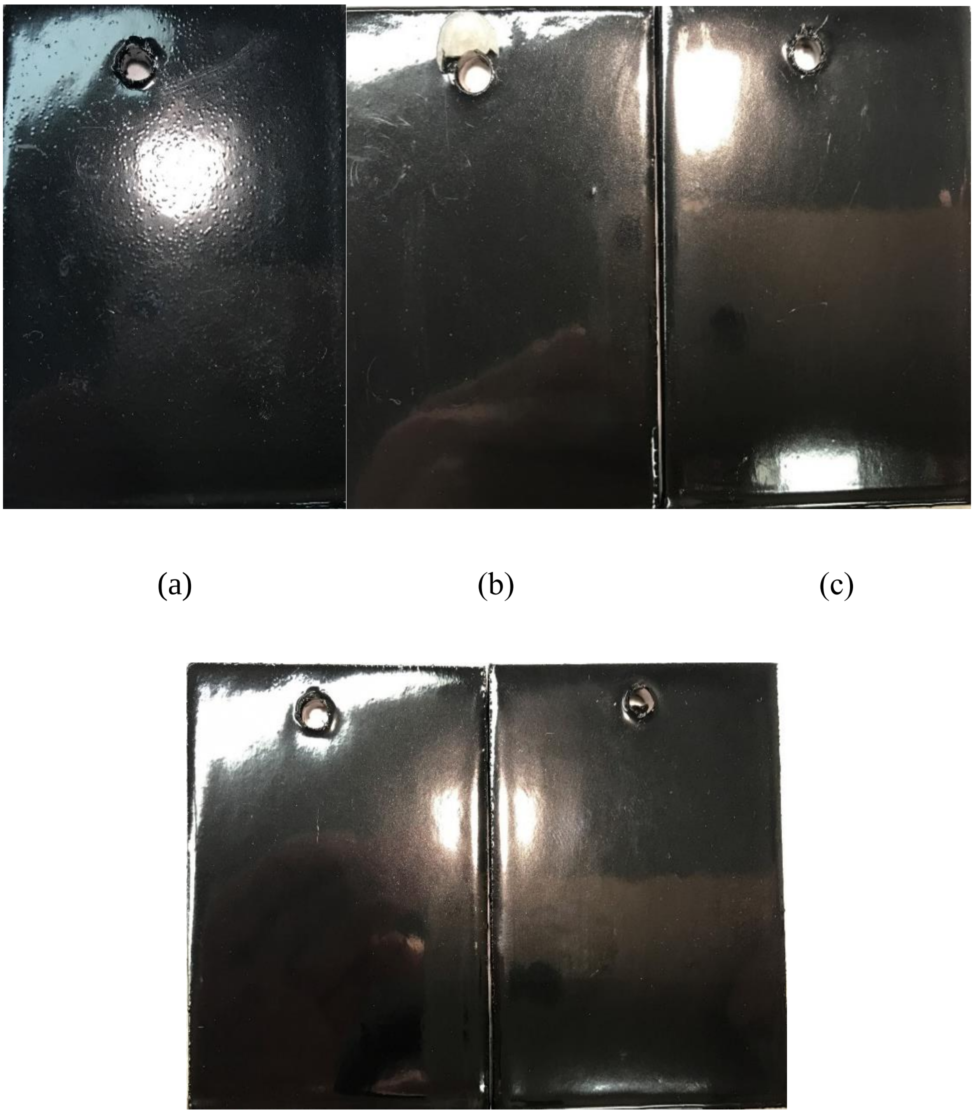


Figure 4.27 The influences of D_{50} and span on Haze

The visual inspections are presented in Figure 4.28. From the graph, it can be seen that the panel coated with lower-D_{50} and lower-span coating powders showed much higher gloss, the surfaces are also much smoother than the panel using original coating powders.

In summary, by lowering D_{50} and span, better surface finish can be achieved.

The reason is similar to the one in polyester experiments. The coating powders with lower span have very little amount of extra small powders, making it much easier to form a smooth surface with few defacts.



(a) (b) (c)

(d) (e)

Figure 4.28. Visual inspections of samples coated with coating powders having different particle sizes and particle distributions

The influence of voltage on transfer efficiency

To evaluate the transfer efficiency of epoxy under two different voltages, the amount of coating powders transferred to panel was preciously controlled to 0.8g, and the amount of coating powder which was needed to be loaded into spray gun therefore can be used to evaluate transfer efficiency. The results indicated that when the voltage was 30kV, 12g of coating powder is needed, while 10g of powder loading was proper for 45kV. The above results suggested that increasing voltage supply in spray process could efficiency enhance transfer effectively. The film thickness was around 140µm.

The influences of additives on flowability

To further investigate the influences of the amount of additives, group e (D_{50}≈20µm, span=1.78) was used to mix up with different amounts of flow additives (shown in Table 4.3). After mixing, the avalanche angle of each group of coating powders was tested and be compared with the result of non-additives coating powder. The results are shown in Figure 4.29.

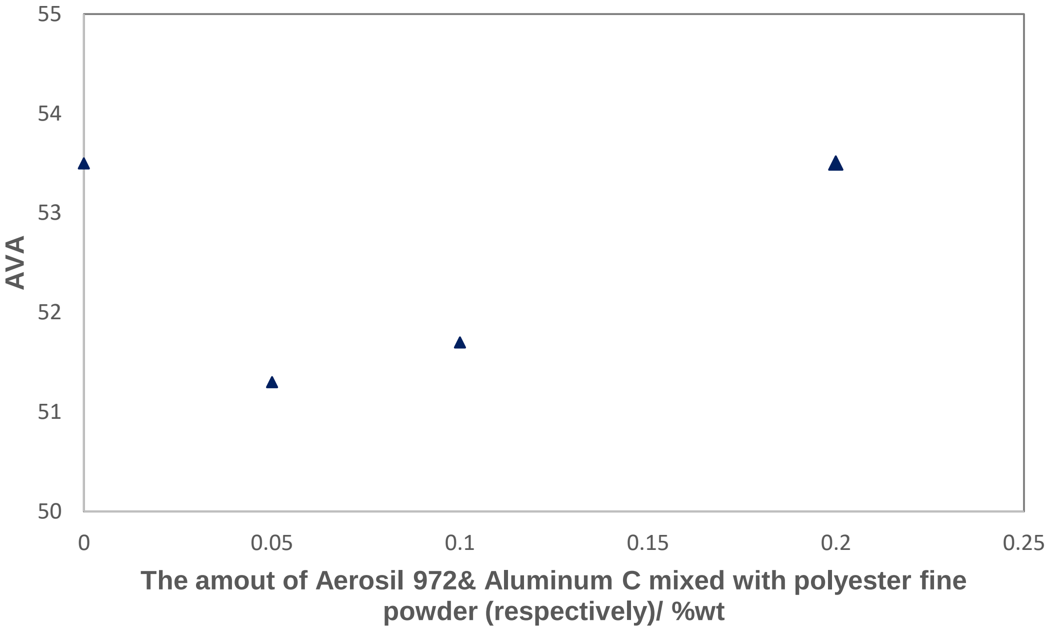


Figure 4.29 The influence of the amount of additives on the flowability of epoxy fine powder

From Figure 4.29, by adding 0.05%wt Aerosil 972 and 0.05%wt Aluminum C, the avalanche angle of fine powder can be decreased by more than 2°. However, further addition of additives could cause the increase of avalanche angle. The explanation was the same as the one in polyester experiments: too much additives in the powder coating may deteriorate the flowability as the powder behave more like nano particle. In summary, by adding 0.05%wt Aerosil 972 and 0.05%wt and Aluminum C, best flowability can be achieved.

The influences of additives on surface quality

From Figure 4.30, it is shown that under both 30kV and 45kV, the Gloss 60°of all three groups of coating powders are all higher than 80, so Gloss 20° is used to further evaluate the Gloss. Under both two different voltages, the Gloss 20° decreases with more additives existing, indicating the use of additives causes the loss of gloss.

Figure 4.31 suggested that the difference of DOI among three groups is not significant under 30kV. When the voltage increased to 45kV, the less DOI can be obtained due to more amount of additives.

As is shown in Figure 4.32, under both voltages, the increase of the amount of additives result in the increase of Haze. From Figure 4.30-4.32, it can be concluded that the use of additives would compromise the surface quality, considering Gloss, DOI and Haze.

It can also be observed that with same film thickness, Gloss and DOI are higher under higher voltage. The reason for this phenomenon was mainly due to that when applying higher voltage in spray process, the powder transferred panel is more compact, which makes it easier for powders to flow after melting and form smooth surface before curing.

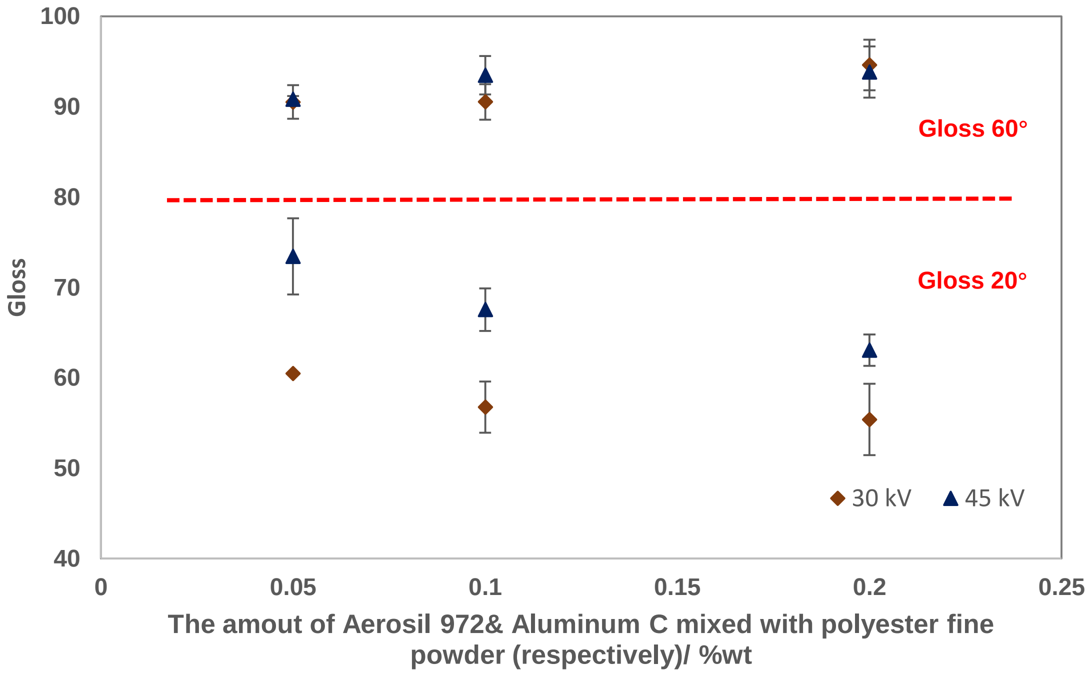


Figure 4.30 The influence of the amount of additives on Gloss

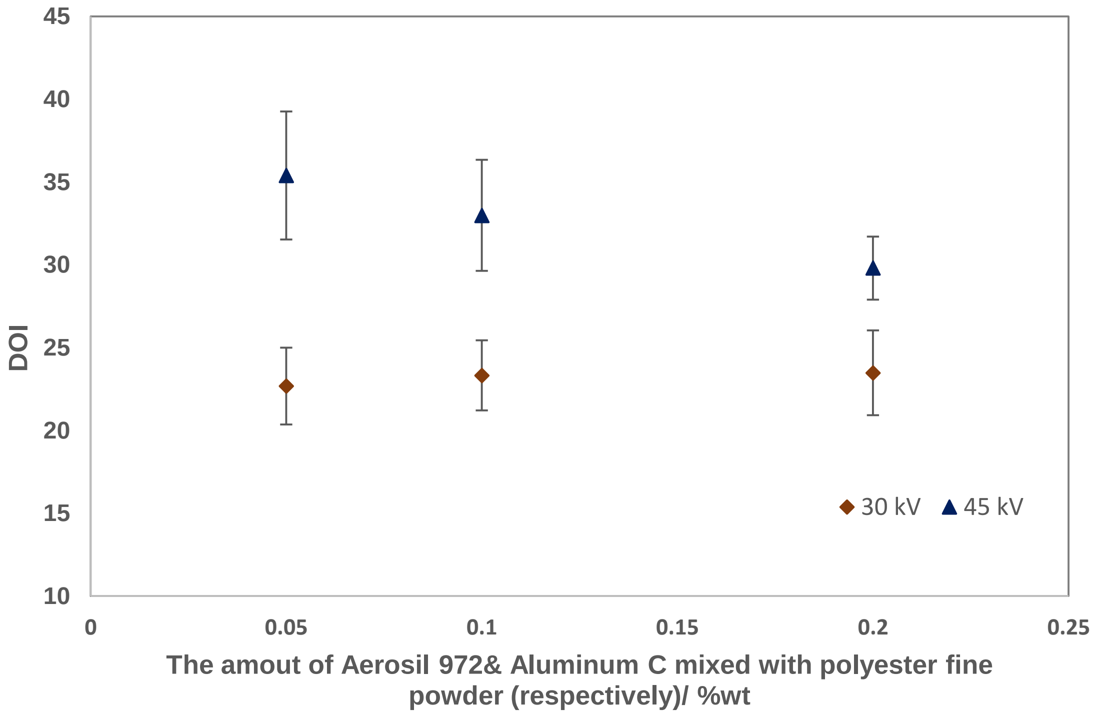


Figure 4.31 The influence of the amount of additives on DOI

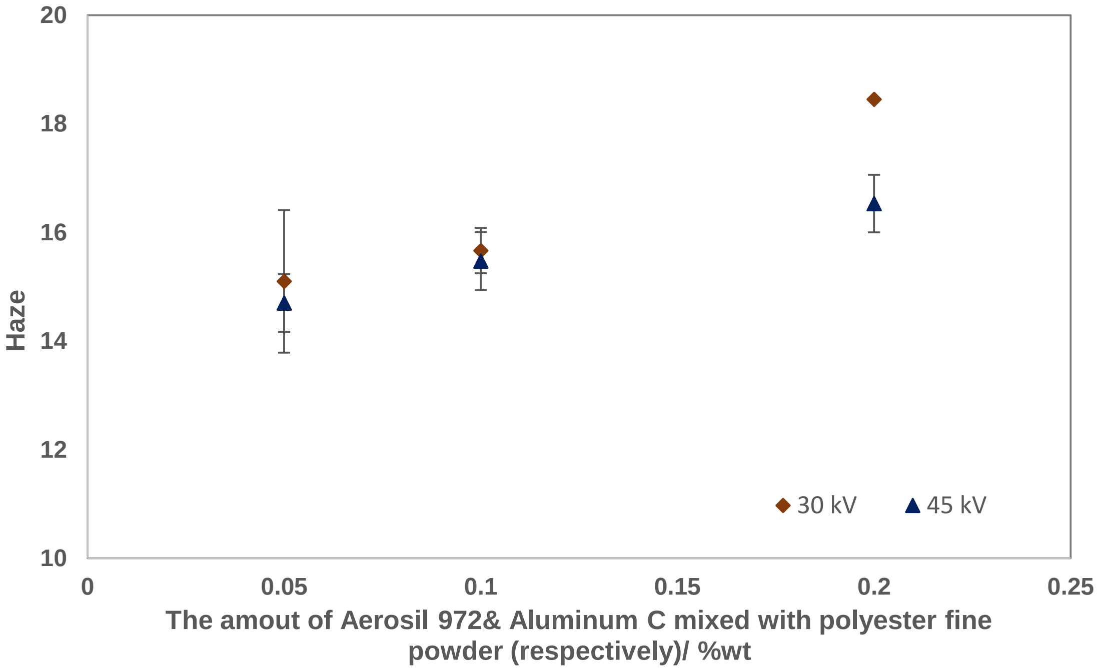


Figure 4.32 The influence of the amount of additives on Haze

4.4 Chapter Summary

In this chapter, experiments were conducted using polyester and epoxy coating powders. The influences of particle size and particle size distribution were first investigated. The results showed that by decreasing particle size, higher Gloss & DOI and lower Haze value were presented, indicating better surface conditions of fine powder could be achieved compared with using coarse powder. Furthermore, when D_{50} were the same, better surface finish can be obtained by lowering span, which indicated that narrowing particle size distributions was an effective way to get better surface quality.

In addition, considering of the poor flowability of the fine powder, Aerosil 972 and Aluminum C were added into fine powder to improve flowability. For both polyester and epoxy, by adding 0.05%wt Aerosil 972 and 0.05%wt Aluminum C, best flowability can be achieved. Besides, under acceptable film thickness, as the amount of additives increases, Gloss & DOI decrease while the Haze increases, indicating the use of additives would compromise surface quality.

Due to the low transfer efficiency of fine powder, voltages were applied in spray process as a supplementary method to increase transfer efficiency in aiding the pre-heating method. The results showed that increasing the voltage would effectively improve transfer efficiency in using polyester and epoxy.

Chapter 5 Conclusions and Recommendations

5.1 Conclusions

In order to narrow the particle size distribution of powder products, nine modifications on the classifier of air classifying mill (ACM) were investigated. Another project is to investigate the influences of particle sizes, particle size distributions, flow additives and voltages with two commercial coating powders on non-conductive plastics.

5.1.1 The Modification of Classifier of ACM

In this study, three critical parameters of the products, D_{10}, D_{90} and size span, were used to evaluate the effects of the modifications. Concluded from the results of 150 samples, under the same D_{50}, the products by modified classifiers all showed higher D_{10}, lower D_{90} and lower span than the product from original classifier, indicating the modifications was effective. The most significant span reduction was over 0.1. This was achieved using the fins in the shape of saw, with eight 1/8-inch-long tooth on each. According to the results of the collection efficiency, no product was compromised due to modifications.

5.1.2 The Powder Coating with Plastic Components

The results suggested that compared with coarse powder, fine powder could contribute to better surface finish. When the particle sizes were the same, using the coating powders with lower span resulted in better surface quality.

Due to the poor flowability, two flow additives were added into fine coating powders. The results revealed that by adding certain amount of additives, the avalanche angle (AVA) can be significantly reduced, which suggested the improvement on flowability. However, the use of additives could result in worse surface finishes. Considering both flowability and surface quality, 0.1%wt total amount of additives were suggested.

Moreover, applying voltages during the spray processes was proven to be effective as a complementary method assisting pre-heating to increase transfer efficiency.

5.2 Recommendations

For future work, the following recommendations are given.

- Only the modifications on classifier were conducted in this study, the modifications on pulverizing disc are suggested to further reduce the particle size distributions of products.
- Two nano additives, Aerosil 972 and Aluminum C, were applied to increase the flowability of fine powders. Other nano additives, like the UWO low-cure catalysts produced by Powder Technology Research Center, could also be used, which might function as flow additives and low-cure catalyst at the same time.

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