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A mechanistic study of the effect of pigment loading on the appearance of powder coatings
The effect of surface topography on the optical properties of powder coatings: Modelling and experimental results

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ABSTRACT

Gloss is a critical property for many powder coating applications and is related to the amount of light reflected by the coating layer on a substrate. Gloss of powder coatings can, depending on the composition, vary from excellent to matt. It is well known in the powder coatings industry that increasing loadings of pigment, especially TiO_2, causes a detrimental loss of gloss. In order to understand the cause of this phenomenon two questions have to be addressed: firstly, what is the relation between the optical properties and the surface topography of the powder coating and, secondly, how do the powder coating composition and curing conditions affect the surface topography? In order to answer the first question, the typical features of the surface of a cured powder coating have been studied in detail. Using a white light interferometer, it has been shown that the surface topography consists of both short wave and long wave patterns. Each of these patterns could be described by using two statistical parameters only, the root mean square height of the roughness and its correlation length. The effect of both the short and long wave roughness on the gloss has been simulated with a single wave pattern model, based on an approximation of the Kirchoff scattering theory [9]. These simulations illustrated that neither the short nor the long wave roughness on itself determines the optical properties. In order to quantify the combined effect of the long and short wave surface features a two-scale modelling approach was followed. The predictions of this model were in good agreement with experimental gloss data of coatings containing different amounts and types of pigments.

1. Introduction

Appearance and especially gloss is a critical property for powder coatings [1]. Gloss is known to be negatively affected by pigment loading. Many studies have been performed in this area [2–5] and references therein. In a study of the parameters affecting the performance of powder coatings, Reck et al. [3] have shown that the gloss of a cured powder coating is highly dependent on the layer thickness and the powder particle size. For layer thicknesses below 40–50 μm a sharp loss of gloss occur. By reducing the powder particle size this can be improved. It was also shown that pigment loading (titanium dioxide only or in combination with a $BaSO_4$ extender) has a large influence, with a sharp drop of the gloss for loadings exceeding a weight fraction of about 45%. The gloss of a coating is a perception by the human eye, which finds its origin in a combination of physical effects. As discussed in detail by Simpson [4], different aspects of gloss are specular gloss, absence of bloom gloss, distinctness of image gloss and surface uniformity gloss. In most powder coating studies it is the specular gloss, the direct reflection of light under its angle of incidence, that is studied – often in combination with the diffuse scattering or 'haze' as a measure for the distinctness of image. Experimentally, gloss and haze determination are standardized via ASTM and ISO methods and usually performed with commercially available instruments [3,5]. In a recent report by Juckel [5] the effects of the level of pigment loading on the 20° loss were reported, showing a serious reduction of the gloss at loadings exceeding 50 wt%. It was also shown that this gloss reduction can be avoided by the use of process additives that affect the pigment dispersion during extrusion of the powder coating formulation. Similar results have been reported by Duivenvoorde et al. [6,7] on the use of blockcopolymers as pigment stabilizers in powder coating. In this work it is considered that pigment flocculation has on the one hand an effect on the appearance of the coatings whereas on the other hand it also affects the flow and levelling of the coating. Both phenomena seem to be interrelated

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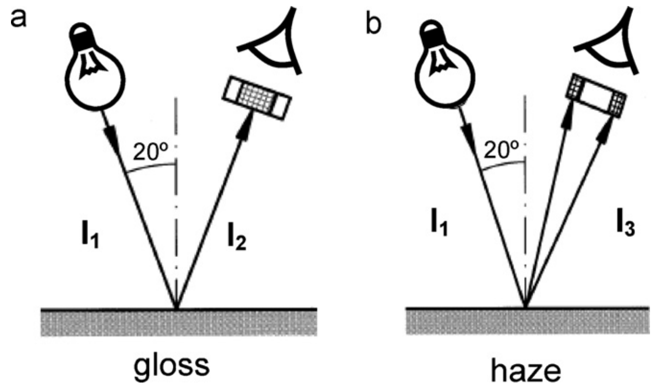

Fig. 1. Schematic representation of the measurement of (a) the 20° gloss property and (b) the haze property.

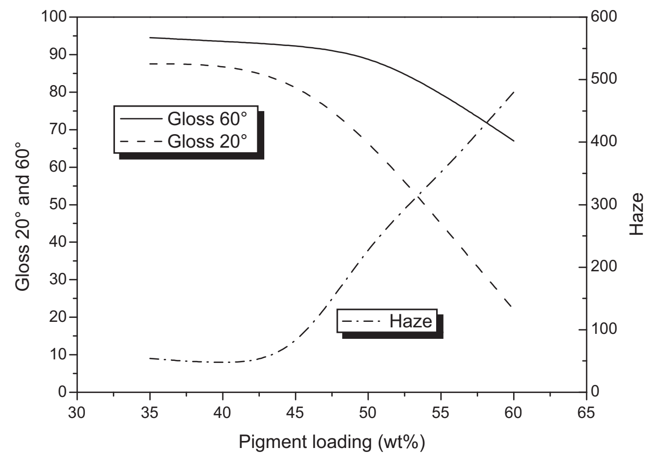

Fig. 2. Gloss and haze as a function of the pigment loading of a TiO_2 (K2160) pigmented powder coating based on the Uralac P865 (a product of DSM Powder Coating Resins, The Netherlands) polyester resin.

and have an effect on the texture of the cured coating. However, pigment flocculation is known to cause surface features on a submicron to micron scale [8], whereas insufficient levelling results in features on the size scale of the powder paint particles or larger (up to millimeters). The latter long wave length features are also the cause of visible texture or human observable roughness of the coating. Both features are expected to have an effect on the gloss of the coating, though these effects will be different due to the significantly different length scales. This prompted us to an in-depth study on the effect of pigment loading on the texture and the resulting appearance, especially the gloss, of titanium dioxide containing powder coatings.

2. Gloss and haze

Gloss is generally defined as the amount of light that is reflected in the specular direction (i.e. the same angle at which the light incidents). This is schematically illustrated in Fig. 1a. The haze is given by the ratio of the scattered intensity at an angle off the specular direction to that of a reference surface (Fig. 1b). Important to note here is that commercial gloss meters have a detector with finite dimensions in the order of 1–10 mm^2. This implies that the bundle of light measured during a gloss measurement with a standard gloss meter will also contain some scattered light and will not only consist of purely specular reflected light [9].

When a beam of light is incident upon a surface, some of the light is reflected while the rest is transmitted into the object, where it is absorbed, refracted or scattered. In this work the main focus is on specularly reflected and diffusely scattered light. Contributions of adsorbed, refracted and subsurface scattered light, as detailed by Trezza and Krochta [10], are being neglected here.

For many applications a high gloss coating, defined as a coating with a gloss at 20° larger than 90% and a haze value smaller than 50, is required. As discussed in the introduction, it is generally accepted that above a critical pigment concentration, the optical properties of a powder coating deteriorate dramatically. This is further illustrated in Fig. 2, which shows gloss and haze data for a standard polyester based powder coating containing different amounts of titanium dioxide pigment.

The critical pigment concentration beyond which the gloss drops is approximately 40 wt%, which corresponds to a volume concentration of about 20%. According to the theory of non-interacting spheres the maximum packing volume concentration of spherical particles is approximately 63%, thus the observed critical pigment concentration is far from a maximum volumetric loading of the pigment particles. Finding the cause of this critical loading will be a first step towards enabling powder coatings with much higher pigment loading, and thus better colour strength, while maintaining high gloss values.

3. Materials and methods

3.1. Materials

Surface topography measurements were performed on standard aluminium sample plates onto which the powder coating had been applied. After spraying, the coating was cured for 10 min at 200 °C in a convection oven. The typical coating thickness was approximately 50 μm. Two sets of samples were investigated: (1) a series of proprietary calibration plates used at DSM powder coating resins as an internal standard for optical appearance. (2) A series of indoor powder coating samples based on carboxylic functional polyester (Uralac P5070), with different amounts of TiO_2 pigment (33–55 wt% K2310 from Kronos) and 32 wt% Araldite epoxy crosslinker GT7004.

3.2. Methods

The surface topography was studied optically with a white light interferometer (NT1100 from Veeco Instruments). This device is able to rapidly measure a 3D scan of a large surface area (e.g. $2 \times 2\,mm^2$ with a single scan) with a height resolution of a few nanometers and a lateral resolution of 600 nm. By using an automatic XY table and appropriate stitching software, the interferometer is able to measure even much larger samples (e.g. $10 \times 2\,mm^2$). Furthermore, the software of this instrument (Vision 2.1) allows data treatment, such as e.g. Gaussian low and high frequency filtering in order to extract short and long wave features.

4. Characterization of the surface topography of a powder coating

The most frequently used parameter to characterize the surface topography is the root mean square (rms) roughness R_q. In order to incorporate the lateral distribution of the roughness into the description of a surface, a surface height correlation function has to be introduced. This function, often Gaussian or exponential, describes how the surface heights are distributed in the lateral direction over the surface. In the simplest cases the correlation function has a single characteristic length L, the so-called correlation length. This correlation length roughly corresponds to the