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An analysis of starburst defects in wrinkled powder coatings

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ABSTRACT

Starbursts are defects in wrinkled powder coatings wherein the typical random orientation of the wrinkles is disrupted. Instead, wrinkles orient radially around a central point creating a star-like pattern. The origin of the starburst defect was investigated by mechanical profilometry and elemental analysis by energy dispersive X-ray spectroscopy (EDS). Topographical measurements demonstrated that the centers of the stars almost always are at a higher elevation compared to their surroundings, suggesting the presence of non-dispersed extender particles or external impurities at the center. EDS analysis of the center of the stars confirmed the presence of external particles or impurities. Radial orientation of the wrinkles around the external particles can be explained by preferential pattern orientation due to directional stress relief.

1. Introduction

Powder coatings with a wrinkle appearance have found widespread use in coatings for office furniture, laboratory equipment and vehicle parts. These coatings have an aesthetically pleasing, textured surface in which the visual gloss can be high or low. Due to the wrinkled surface structure of the coating, light is reflected in many directions giving a “sparkle” look when viewed in sunlight. One drawback of wrinkle coatings is the well-known propensity of the coating to develop starburst type defects. As shown in Fig. 1, a starburst is a defect on wrinkled coating surfaces where the normal, randomly oriented wrinkle pattern is disrupted and the wrinkles are oriented radially around a central point. These defects appear as randomly placed stars on the wrinkled coating surface with diameters varying from a fraction of a millimeter to a few millimeters.

Starburst defects appear in all types of wrinkle powder coatings, regardless of coating chemistry (epoxy or polyester). Jacobs et al. [1] reported formation of starburst defects in polyester-based powder coatings. By inspection of photomicrographs, they speculated that the centers of the stars do not have holes, and the stars are meeting points of several wrinkles. It is generally accepted in the industry that reduced starburst formation is achieved by high intensity pre-mixing and compounding of components, and lower pigment and extender loadings. Uneven rates of heating due to poor airflow in the cure oven, lower catalyst loadings and in general slower curing rates promote the formation of starbursts. Coating applicators have learned that surfaces to be coated must be clean, compressed air must be free of water and grease, and airborne contaminants must be kept to a minimum to assure starburst-free wrinkle finishes. However, even the most vigilant coater can experience random starburst defects and can spend a significant amount of time and money cleaning and reworking parts. Therefore, an understanding of what causes starburst defects and how to reduce the appearance of such defects would be of great value to the industry.

Several researchers have investigated the formation of wrinkles in powder coatings [2–6], but the formation of starburst defects in such coatings is not well understood. This paper, therefore, investigates the formation of starburst defects in wrinkled coatings by topographical measurements and elemental analysis. Mechanical profilometry was used to generate topographical data on the stars. Energy dispersive X-ray spectroscopy (EDS) was used to compare elemental distribution at the center of the stars to that of a control area on the wrinkled surface. From the topographical measurements, it was found that the center of the star is almost always at a higher elevation compared to its surroundings, suggesting the presence of non-dispersed extender particles or of an external contaminant at the center. Elemental analysis of the center of the star confirmed the presence of external particles or impurities. These external particles provide a point stress release in an otherwise

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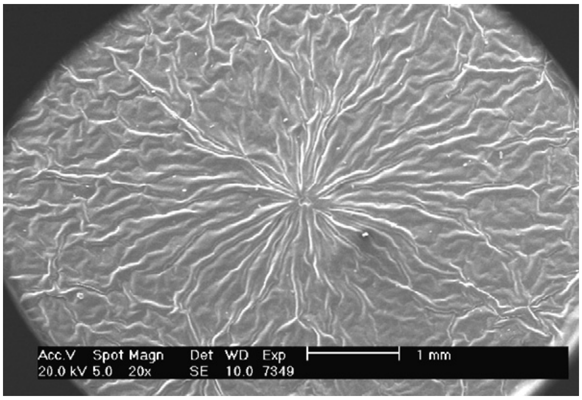

Fig. 1. SEM micrograph of a starburst defect.

in-plane isotropic stress field, which cause the wrinkles to orient radially around the particle to create a star-like pattern.

2. Experimental

In an effort to understand the starburst phenomenon, five wrinkling coating powders covering two coating chemistries were obtained from four powder coating manufacturers. The basic chemistries of the coating samples are presented in Table 1. The powders were coated onto either aluminum or cold rolled steel Q-panels in a controlled laboratory environment by a conical tip Nordson Versa Spray gun operating at a 60 kV potential difference. The coatings were cured at 375 °F for 15 min in a forced convection electric oven (Blue M, Blue Island, IL). The cured thicknesses of the samples are also presented in Table 1.

The panels were visually inspected for defects, and one starburst defect on each sample was chosen for further characterization. The topographical measurements of the selected stars were obtained by a stylus-based mechanical profilometer (Tencor P-10 surface profiler, KLA-Tencor, San Jose, CA). The coating surfaces were scanned in straight lines using a 5 μm radius hemispherical tip carbide stylus. A contact force of 1 mg was used for this purpose. Several such 1D straight line scans, each placed 10 μm apart, were taken to construct interpolated 2D and 3D images of the starburst defects.

The defects were analyzed using a scanning electron microscope (SEM) fitted with an energy dispersive X-ray attachment (Philips XL30 with an EDAX DX4). The backscattered-electron mode was used to produce SEM micrographs of the starburst defects. For EDS analysis, a control area where no defects were present was chosen for each sample. The elements present in this area were identified using energy dispersive X-ray spectroscopy. The starburst defect area was analyzed in a similar manner. The elements present in each area were then compared.

3. Results and discussion

The starburst phenomenon can be described as a radial convergence of the wrinkle patterns with a well-defined center (see Fig. 1). The stars have a radially symmetric order compared to the rest of the coatings area where patterns are oriented randomly. Fig. 2 presents both 2D and 3D mechanical profilometry traces of typical starburst defects obtained from Samples 2 and 4. Fig. 2 also presents color coded topographical measurements of the stars. From the mechanical profilometry traces and topographical measurements, it is evident that the center of the star is at a higher elevation than its surroundings. The higher elevation of the center was observed for all the stars investigated in all five samples. Based on these observations, it was hypothesized that unmelted powder particles, extender or external impurity present at the center of the star is responsible for the formation of the starburst defects.

Fig. 3 shows SEM micrographs of stars from Samples 2 and 4. The figure also shows images at higher magnification of the centers of these stars on which the EDS analysis was carried out. It is evident from Fig. 3A1 and B1 that in Sample 2, higher concentrations of bright second phase particles are present at the center of the star compared to other areas of the coating surface. Higher atomic weight elements appear brighter in these figures. However, a similar claim cannot be made for Sample 4 from Fig. 3A2 and B2. SEM micrographs of some of the remaining samples showed clusters of second phase particles at the center of the stars, whereas others did not. In order to conclusively determine whether any extraneous particles or impurities were present at the center of the stars, elemental compositions of the center of the stars were compared to those of the control coating samples.

Typical polyester-based powder coatings contain a hydroxyl functional polyester resin, a multi-functional cross-linking agent such as tetramethoxymethyl glycoluril, blocked acid catalyst, organic and/or inorganic pigments, extenders such as calcium carbonate and barium sulfate and post-blend additives like fumed silica or alumina [1]. Typical epoxy-based powder coatings contain bisphenol-A type epoxy resin, methylene disalicylic acid, amine blocked Lewis acid catalyst, pigments, extenders and post-blend additives [3]. However, the exact compositions of the coatings and choice of additives differ between manufacturers. This is evident from the elemental analysis of the control samples of polyester- and epoxy-based powder coatings from different manufacturers (see Table 2).

Table 2 compares elemental compositions measured by EDS at the center of the starburst defects to that of control areas of the coating samples. In Sample 1, iron and calcium, elements foreign to the coating, are present at the center of the defect. In Sample 2, barium and sulphur are absent from the center of the defect and titanium is present. There is also a relatively high percentage of calcium and silicon present in the center of the defect. These observations indicate the presence of a calcium metasilicate particle at the center of the star, which might have been used as a mineral extender alongside barium sulfate. In Sample 3, again barium and sulphur are absent in the center of the defect, while there is a larger amount of aluminum as compared to the control area. This could be due to the presence of undispersed aluminum oxide, which is used as a post-blend additive by some powder manufacturers. Chlorine, calcium and titanium are also present as elements foreign to the coating. In Sample 4, a high quantity of aluminum is present at the center of the defect, which may be due to the presence of undispersed post-blend dry flow additive; aluminum oxide. In Sample 5, sodium, chlorine, potassium and silicon are present as elements foreign to the coating. In general, potassium, chlorine, iron and sodium at the center of the defect indicate the presence of extraneous dirt particles. However, titanium appears to be a contaminant from another coating powder.

EDS analysis conclusively shows that the center of the defect contains significantly different elemental composition compared to the control area of the coating. The significant difference in ele-

Table 1
Chemistry and cured coating thicknesses of the samples

Sample ID	Chemistry	Coating thickness (Mils)	Manufacturer
1	Epoxy	4.5–4.7	A
2	Polyester	2.2–3.2	B
3	Polyester	5.0–5.5	C
4	Polyester	2.8–3.5	D
5	Epoxy	2.5–4.0	D