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Short communication

Influence of air-cooling time on physical properties of thermoplastic polyester powder coatings

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ABSTRACT

Properties such as the specular gloss, adhesive strength, viscoelasticity, and impact resistance of thermoplastic polyester powder coating film were studied as a function of air-cooling time. Thermoplastic polyester resin is known for the fact that the heating condition has an effect on the degree of crystallinity. We focused on the relationship between the air-cooling time employed in the film preparation process and the degree of crystallinity. The test pieces were dipped into a fluidized polyester powder vessel, and then cooled in air to form the film. We refer to this cooling time in air as the “air-cooling time”. It was found that the degree of crystallinity increased as the air-cooling time increased. As the degree of crystallinity increased, the specular gloss, adhesive strength, viscosity and impact resistance decreased. We therefore found that the improvement in film performance is related to the reduction in the air-cooling time. The importance of this phenomenon is considered in relation to the widespread use of thermoplastic polyester resin. Similar behavior is expected for other polyester powder coatings.

1. Introduction

Polymeric materials such as those used for coatings offer highly effective protection and have been developed and introduced in the industrial telecommunication field. For instance, solvent-based coatings have been applied to wireless steel towers and cable pipes. Conventional organic coatings usually include a wide variety of volatile organic compounds (VOCs), such as hydrocarbons (hexane, toluene, xylene), ketones (acetone, MEK, MIBK), alcohols (methanol, ethanol, cyclohexanol), and esters (ethyl acetate, butyl acetate, isobutyl acetate) [1]. However, even in the coating field, an awareness of the importance of being eco-friendly has been growing. This has led to an urgent need to reduce the use of VOCs [2]. One solution is to reduce the proportion of solvent in the coating ultimately to zero. So, we have developed and introduced a low-solvent coating for use in the telecommunication field. Another possible solution is to replace organic solvent with water. Water-based coatings have been in high demand, and thus we have been studying them with a view to protecting human health and the environment [3–7]. Another approach involves using powder coatings, which contain no solvent whatsoever. Such coatings represent the final destination along the road to VOC reduction. So we have developed and introduced a polyester powder coating for steel telephone poles and their related steel support materials that is both environmentally friendly and corrosion resistant and thus prevents damage caused by the natural environment [8–17]. Specifically, the bottom part of a steel telephone pole is exposed to more severe conditions than the rest of the pole. For instance, the bottom part of the pole comes into direct contact with the ground, mortar, and concrete, and therefore has the potential to be adversely affected by alkaline conditions. We have already studied the alkaline resistance of powder coatings [18–20].

With regard to powder coatings, there are two main coating systems, namely thermoplastic and thermosetting systems [21,22]. The thermoplastic coatings are typically polyethylene, polyamide, polyester, ethylene-vinyl alcohol copolymer, polyvinyl chloride, and polyvinylidene fluoride. The thermosetting coatings are epoxy resin, polyester resin, acrylate resin and glycidyl acrylate resin along with various hardeners. There are two distinct groups of powder coating application processes. The most widely used method for a thermoplastic system is the fluidized bed process. Here, a hot metal test piece is dipped into fluidized powder. The powder sinters, fuses and cures, thus forming a smooth polymer surface on the test piece. Another process for thermosetting products is predominately used with coating powders applied by electrostatic processes. In fact, we have selected a thermoplastic polyester

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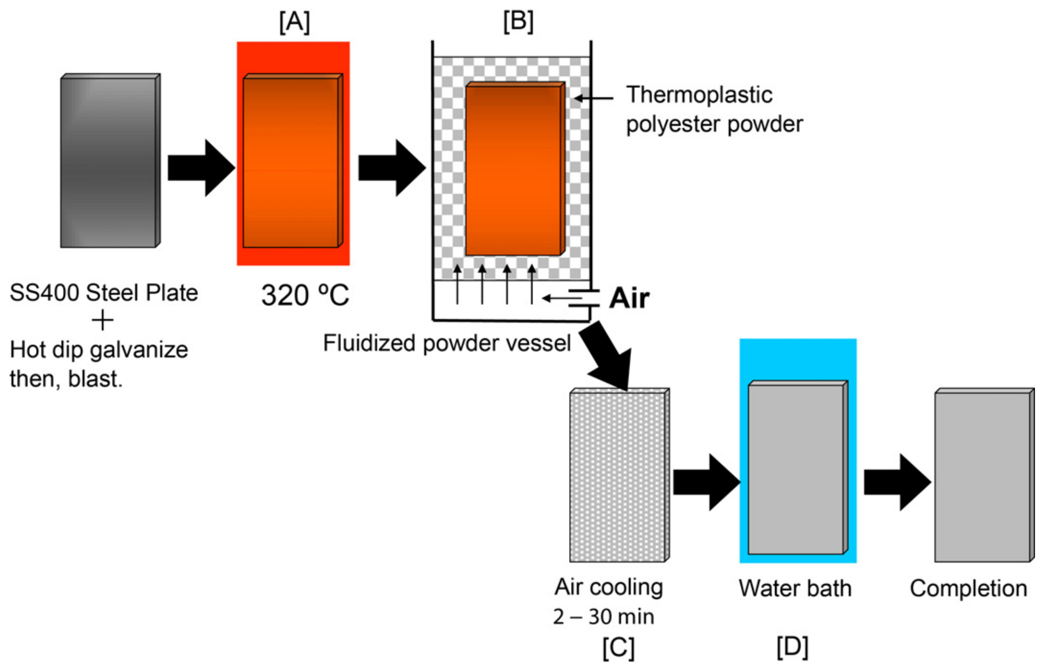

Fig. 1. Schematic diagram of powder coating process.

powder coating for steel telephone poles and related materials because stable 300 μm to 1 mm thick film products with no pinholes are likely to be obtained for protecting outdoor plant [8–17]. In this case, the fluidized powder bed method is used for the coating process as described above.

The thermal history and aging time could certainly affect the coating film performance, and there have been many excellent studies on the effect of thermal history and aging on polymer films [23–26] including polyethylene [27,28], epoxy [29–31], PMMA [32–34], polyester [35,36], poly(vinyl acetate) [37], powder coatings [38–46], and organic coatings [47–53]. Specifically, in relation to the crystallinity and aging effect of polyester resin, Todoki has published a series of notable research papers reporting DSC and XRD measurements performed on polyester samples that had been exposed for over 16 years [54–57]. Because the polyester resin is partly crystallized, the effect on powder coating film performance, and especially the mechanical properties, cannot be ignored in industrial applications. In addition, an inexpensive coating process is required. However, other than Thames et al. [40] and Zhang et al. [44] there have been few reports on the exact relationship between the degree of crystallinity and the mechanical performance of thermoplastic powder coating, despite it being crucially important for such applications as steel poles. A certain optimum condition should be established for each application field.

Here, we focused on the effects of the air-cooling time during quenching from above T_m in the coating process by using a fluidized powder vessel as a steel pole. The coating film properties such as specular gloss, adhesive strength, viscoelasticity and impact resistance are very important and are possibly easily influenced by film crystallinity. Thus, the objectives of this study are (1) to investigate the relationship between the air-cooling time employed during quenching from above T_m in the film preparation process and the degree of crystallinity, (2) to determine the effect of the crystallinity on film performance in terms of specular gloss, adhesive strength, viscoelasticity and impact resistance, and (3) finally to develop an efficient novel powder coating process with minimum energy consumption. A preliminary report on this powder coating has already been published by our laboratory [17].

2. Experimental procedures

2.1. Powder coating process

The base substrate was an SS400 steel plate (50 mm × 100 mm × 3.2 mm) that was galvanized and sweep-blasted. We used thermoplastic polyester powder (SAPOE 5000, NTT-AT, Tokyo, Japan) called PET, and its hue was N-7 gray. The glass transition temperature was around 72 °C, and the melting temperature was 230–240 °C. The molecular weight was around 50,000, and the particle size was 90 ± 10 μm. The coating process is shown schematically in Fig. 1. We first heated the test pieces at around 320 °C (A in Fig. 1) and then dipped them into a fluidized polyester powder vessel for 5 s (B in Fig. 1). The test pieces were subsequently removed and kept in static air (20 °C) for 2–30 min in a vertical position to ensure that the powder coating materials on the surface had completely melted (C in Fig. 1). Finally they were immersed in water to cool (D in Fig. 1), and test specimens were obtained. Here, we refer to this cooling time in air as the "air-cooling time" (C in Fig. 1). Obviously, the heat capacity could affect the formation of film, however, in this study we used SS400 steel with a uniform thickness, and so we ignored the effect of heat capacity. The surface temperature of the test specimens was measured with a thermometer (TEMPERATURE HiTESTER 3442, HIOKI, Nagano, Japan and IR-TA, CHINO, Tokyo, Japan).

2.2. Measurement of mass, thickness and 60° specular gloss

Before coating, we measured the mass and thickness of the galvanized steel pieces. After coating, we measured the mass, coating thickness and 60° specular gloss. To determine the coating thickness and 60° specular gloss, we used an Elcometer (Elcometer 345, Elcometer Inc., Michigan, USA) and a Digital Variable Gloss Meter (UGV-5, Suga Test Instruments, Tokyo, Japan), respectively.

2.3. Determining crystallinity

The samples were cooled by immersing them in a liquid N_2 bath, and the coating film was peeled from the test specimen by using a