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Low-Density Polyurethane-Based Antistatic Coating for PU Flexible Foam for Launch Vehicles

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Abstract

Polyurethane (PU) is a multi-functional polymer prepared by using more than two types of monomers. The unique properties of PU come from monomers, thus broadening the applicability of PU in many different sectors. Furthermore, the antistatic property of PU coatings can be improved by the addition of conductive fillers into the matrix, thus broadening their application in the manufacture of electronic products, aerospace systems, and daily necessities, and so on. The use of electrically conductive metal oxides as fillers makes it possible to reduce the resistivity of polymeric materials and slow down the flow of electric charges. In this study, a novel robust low-density antistatic polyurethane (APU) coating with titanium dioxide (TiO_2) and graphite as conductive fillers was specially designed for application on polyurethane flexible foam for reusable launch vehicles. For this purpose, the effective parameters on resin performance and surface resistivity of the synthesized coating were investigated and optimized. The surface resistivity of antistatic polyurethane coating containing 20–22 wt.% TiO_2 and graphite reached 10^5 Ω/sq and 10^9Ω/sq, respectively.

Keywords: Antistatic polyurethane (APU) coating, conductive fillers, titanium dioxide (TiO_2), graphite, surface resistivity

INTRODUCTION

Polyurethanes (PUs) are versatile polymers with properties that can vary between rubber-like elasticity and plastic-like toughness by varying the ratio of isocyanate to polyols, plasticizing conditions, and other factors [1, 2]. They are widely used to produce commercial adhesives and coatings for various substrates [3, 4]. However, these materials are insulative and can cause electrostatic discharge (ESD), which damages the contacted electronic devices [5–9]. Therefore, the surface resistivity must be reduced to values lower than 10^{11} Ω/sq [10] by adding conductive polymers/fillers, antistatic agents, etc.

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For antistatic agents, surfactants, conductive fillers, and polymers are commonly added as antistatic agents. Surfactants, small molecular-weight polymers, have hydrophilic groups that are incompatible with the resin. However, they contain lipophilic groups that are compatible with the resin [11]. The hydrophilic groups are arranged such that they face toward the air and absorb environmental moisture to form a conductive water film, thereby reducing the surface resistivity of the coating [12, 13]. The addition of antistatic agents, even though it improves the antistatic properties, drastically affects the mechanical and physical properties of resins.

Many types of conductive fillers are available, including polypyrroles, polyanilines, graphite, carbon nanotubes, carbon fibers, silver powders, copper powders, nickel powders, zinc oxides (ZnO), zirconium dioxide (ZrO_2), and TiO_2. When these are added, they form a conductive network structure in the matrix to dissipate the static charges [14, 15]. Compared with surfactants, conductive fillers are more stable because the antistatic property is maintained even when external forces are applied [16].

In this work, we have developed a low-density polyurethane (PU)-based antistatic coating with TiO_2 and graphite as conductive fillers for white (PU-White) and black antistatic coating (PU-Black), respectively. The objective of this study is to develop antistatic polyurethane coatings with good antistatic performance by adding a sufficient quantity of conductive fillers. Mechanical, thermal, and wind shear studies of polyurethane coatings on PU flexible foam were conducted to determine their suitability for reusable launch vehicles.

EXPERIMENTAL

Materials

Vitacol 1000 (hydroxyl value: 80–120 mg KOH/g), PVC powder (bulk density: 1.3–1.5 g/cc and particle size: 2–10 μ), antimony trioxide (95% min), tricresyl phosphate (specific gravity: 1.15–1.19), Olfex dry powder (bulk density: 0.55–0.65 g/cc and particle size: 40–60 μ), TiO_2 (95% min), graphite (true density: 2.1–2.1 g/cc), toluene (specific gravity: 0.83–0.89) and polymeric Methylene Diphenyl Diisocyanate (specific gravity: 1.2–1.23). All chemicals and materials were purchased in analytical grade and used as received.

Methods

Coating Density

To evaluate the density of the developed PU-White and PU-Black coatings, a PU flexible foam with dimensions of 150 mm × 150 mm × 15–20 mm was used. The foam thickness at various locations and the mass of the foam pad were measured before the application of the coatings. Two coatings, PU-Black and PU-White, were applied to the PU flexible foam using a painting brush. After 24 h of curing, the thickness of the coating along with the foam and mass was taken, from which the density was evaluated.

Water Absorption of the Coating

The water absorption capability of the coatings was determined by applying two coatings, PU-Black and PU-White, on a PU flexible foam with a cubic size of 50 mm. After curing for 24 h, the specimens were immersed in water for 24 h. The specimens were then removed from the water, and the surface water was removed without applying pressure using filter paper and weighed.

Calculation: Water absorption, % by volume $= \frac{M2-M1}{\rho \, x \, V}$

Surface Resistivity

To measure the surface resistivity of the developed PU-Black and PU-White coatings, three PU flexible foams of size 100 mm × 100 mm × 25 mm (min) were required. The thickness and weights of three foam specimens were measured.

Flexible foam specimens were coated with PU-Black and PU-White using a painting brush. After curing for 24 h at room temperature (RT), the surface resistivity of the cured coatings was measured using a surface resistivity meter (SRM).

Lap Shear Strength of Coatings

For the lap shear strength of PU-Black and PU-White with PU flexible foam, 3nos (min) of aluminum strips with dimensions of 100 mm (l) × 1 inch (w) are required. Over the strips, 1 inch has to be marked, and the marked surface wiped properly with a cotton cloth dipped in acetone/toluene. Bond PU flexible foam of size 1 inch × 5 mm thickness on a marked area on aluminum strips using adhesive. Two strips bonded with flexible foam were bonded together using either PU-Black or PU-White and wrapped tightly using cellophane tape. The mixture was cured for 24 h.

Thermal Cycling

The temperature-withstanding abilities of the PU-White and PU-Black coated foam specimens were evaluated through a thermal cycling test. Five cycles were carried out, in which one cycle consisted of 23 min soak at 0°C and 23 min soak at +60°C. PU flexible foam with dimensions of 150 mm × 150 mm, 15–20 mm was coated with PU-Black or PU-White and exposed to the aforementioned conditions.

Wind Shear Test

For launch vehicles, the maximum flight speed is Mach <0.7, aerodynamic heating is negligible, and only aerodynamic shear occurs. The maximum expected shear pressure was 250 Pa. Hence, the suitability of PU-Black and PU-White was tested in an open jet facility (OJF) (Figure 1) by applying the maximum shear stress on the specimen. Specimens of different thicknesses were subjected to a wind shear test.

Preparation of Antistatic Coating Premix

Typically, the base premix was prepared by mixing 30–32 g Vitacol 1000, 4–5 g PVC, 8–9 g antimony trioxide, 4–5 g Tricresyl Phosphate (TCP), and 25–26 g Olfex dry powder using a mechanical stirrer (2/3 HP, 5000 rpm) for approximately 5 min. This can be considered a premix and stored in a closed container under ambient conditions.

Preparation of PU-Black and PU-White Coating

The curable composition was prepared by mixing the prepared premix with conductive fillers, solvent, and curing agent, as shown in Table 1. Initially, conductive fillers and toluene were added to the prepared premix and mixed well with a glass rod, followed by a mechanical stirrer (2/3 HP, 3000 rpm) for 1 min. The curing agent, MDI, was then added and mixed for approximately 10–20 s.

Coating Method

Coating studies were conducted on PU flexible foam with a density of 50–60 kg/m^{3,} which was molded using a metallic mold. The prepared antistatic polyurethane coating, as per the composition listed in Table 1, was applied using a brush. The thickness of the polyurethane coating was maintained at ~ 1 mm. Finally, the coated specimens were cured for 20–24 h.

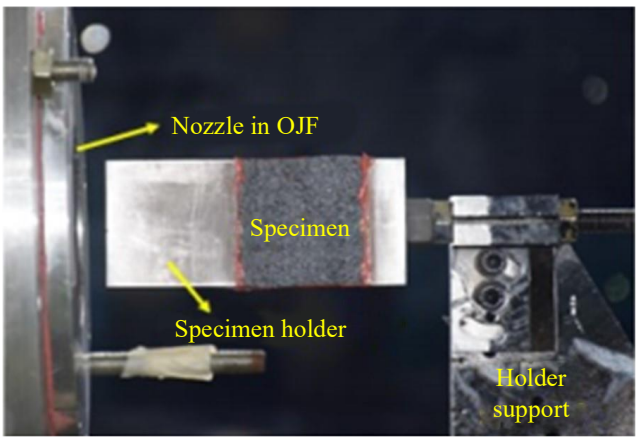

Figure 1. Specimen in the olfex joint facility (OJF).

Table 1. Composition for preparing an antistatic polyurethane coating.

S.N.	Raw material	Quantity, g
1	Antistatic coating premix	30–35
2	Conductive filler (TiO_2 or Graphite)	7–8
3	Toluene	6–6.5
4	Polymeric MDI	8–9

RESULTS AND DISCUSSION

Coating Density

Figure 2 shows the PU flexible foam coated with PU-Black and PU-White (i.e., Polyurethane White coating). The densities of the coatings obtained were in the range of 0.6–0.8 g/cc.

Water Absorption of the Coating

Generally, PU flexible foam, owing to its high open-cell content, is highly water-absorbing in nature. The PU-Black and PU-White coated PU flexible foams showed a drastic reduction in their water absorption capability. The details are presented in Table 2.

Lap Shear Strength of PU Antistatic Coating

The shear strength requirement for a reusable launch vehicle is 250 Pa (0.0025 ksc). The test results show that cohesive failure occurred with good adhesion strength with PU-Black and PU-White with flexible foam. Table 3 presents the results.

Antistatic Properties

The high resistivity of PU causes electrostatic discharge damage in sensitive electronic devices during manufacture, packing, shipping, and usage [17, 18]. The surface resistivity is directly linked to the moisture-absorbing capability of the coating. The hygroscopicity of the coating is mainly due to the presence of polar groups such as hydroxyl groups, which dissipate static electricity, thereby reducing the surface resistivity of the coating. In addition, water molecules can be adsorbed to form a water film by Olfex on the surface of the coating, which leads to a reduction in the surface resistivity. In addition, the addition of fillers such as TiO_2 and graphite reduced the surface resistivity to $10^5\Omega$/sq and $10^9\Omega$/sq, respectively.

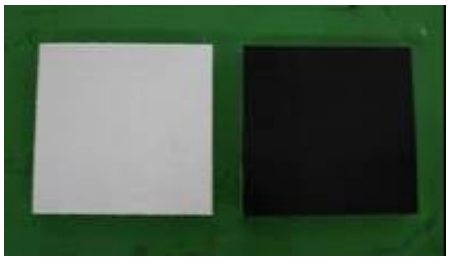

Figure 2. PU flexible foam coated with PU-White and PU-Black coating.

Table 2. Water absorption results.

S.N.	Specimen details	% Water absorption after 24 hrs.' immersion
1	Bare foam (without coating), %	6.25, 4.57, 4.21
2	PU flexible foam with white coating, %	0.17, 0.23, 0.20
3	PU flexible foam with black coating, %	0.16, 0.20, 0.22

Table 3. LSS of PU-Black and PU-White with PU flexible foam.

Sample No.	LSS of PU-White coating with PU flexible foam, ksc	LSS of PU-Black coating with PU flexible foam, ksc
1	0.7	0.6
2	0.5	0.6
3	0.6	0.6
4	0.8	0.7
5	0.7	0.7

LSS, lap shear strength

Figure 3. Test specimen after wind shear test with low thickness (a) PU-Black, and (b) PU-White.

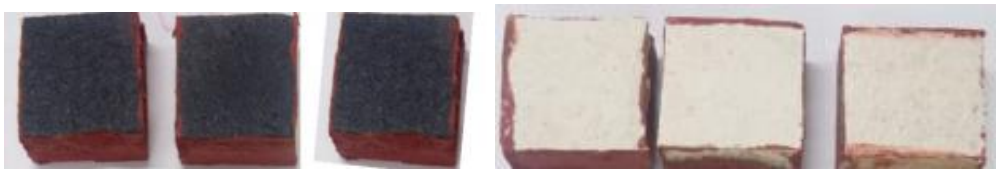

Figure 4. Test specimen for wind shear test (a) PU-Black coated on flexible foam, and (b) PU-White coated on flexible foam.

Thermal Cycling

The PU flexible foam coated with PU-Black and PU-White coatings was exposed to thermal cycling conditions. No debonding cracks or bulging were observed in the specimen, which clearly indicates that the developed system withstands the temperature variations that reusable launch vehicles can experience.

Wind Shear Test

PU flexible foams coated with different thicknesses of PU-Black and PU-White (0.2, 0.4, 0.6, 0.8, and 1 mm) were subjected to wind shear tests. The PU coating with a thickness of less than 1 mm showed peeling off of the coating from the foam surface. The details are shown in Figure 3. However, the coating with a thickness greater than 1 mm was perfectly intact after the wind shear test, as shown in Figure 4.

CONCLUSION

In summary, a black-and-white PU coating was developed that satisfies the requirements for reusable launch vehicles. The PU antistatic coatings thus obtained by the addition of TiO_2 and graphite as antistatic agents showed excellent antistatic properties, thermal stability, and higher lap shear strength. The wind shear test of the foam surveyed the ability of the coating at flight speeds of $Ma<0.7$ and shear of 250 Pa. This novel method of preparation of PU antistatic coatings with improved mechanical and antistatic properties provides a beneficial pathway towards the development of antistatic surfaces to prevent dust accumulation or electrical insulation.

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