

Antistatic Performance and Improvement Strategies of Polymers

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Abstract. Electrostatic discharge poses significant threats to industrial production. These hazards include explosions, electronic malfunctions and equipment damage. In order to address the issue, this study focuses on mechanisms of formation of electrostatic discharge, how antistatic properties work, and feasible tactics to enhance antistatic performances of polymers. This study focuses on the electrostatic electrification mechanism which can be quantified using tunneling effect and core antistatic mechanisms including hydrophilic conductive mechanism alongside conductive network mechanism. Furthermore, related methods tackling this problem including but not limited to conductive fillers blending with bulk polymers are discussed. Electrostatic electrification mechanism is explained in terms of electron transfer, ion transfer and mechanical reactions plus material transfer. Key mechanisms, especially hydrophilic conductive mechanism and conductive network mechanism, contribute to enhanced antistatic properties of materials. This article discusses the two main solutions in detail, analyzing their pros and cons to show their effectiveness and customizable modification. Meanwhile, the challenges in durability and other aspects are also discussed. This provides valuable insights into industrializing efficient and green new means of improving antistatic properties.

Keywords: Polymers, antistatic, conductive fillers.

1. Introduction

Modern industries show great dependency on the application of polymer materials, because of their versatile properties such as being economical, light weight, and anticorrosion. But on the other side, static electricity can be triggered by inherent insulation properties of most majority of polymer materials, which is one of the greatest causes of concern. Static electricity may cause dust absorption in medical apparatus [1]. Therefore, constantly enhancing their performance in antistatic is a target for many researchers. By now, the mostly used methods for antistatic packaging for electronics are metallized polymeric materials, the blends with antistatic agents and the compounding with carbon materials [2].

Some researchers have started exploring the possibility of surface modification by free radical reactions to improve antistatic properties. Till now, many approaches have been explored to enhance the antistatic properties of polymers, including grafting with hydrophilic or conductive materials onto polymer materials, producing polymer by copolymerizing antistatic monomers, and treating polymer materials surface with antistatic coating.

In this article, the enhancement strategies of antistatic properties in polymers are focused on. It is well known that all these strategies are based on the good understanding of electrostatic electrification mechanism and antistatic mechanism [3]. Therefore, electrostatic electrification mechanism and antistatic mechanism is discussed in this work. Furthermore, this article will also summarize the key different strategies of antistatic polymers preparation with their advantages and disadvantages.

2. Electrostatic Electrification Mechanism

It is widely regarded that static electrification is mainly triggered by contact friction. When two objects with the same chemical state or the different chemical states but different physical states are in contact or being rubbed with each other, electrons will escape from one surface thus being transferred to the other. In this case, each object may have excessive positive or negative charges. If

the materials are conductive, the charge can equalize itself by the backflow of electrons instantly after the objects are separated. However, most polymeric materials are insulators, in which electrons are held in rigid lattice thus they cannot flow freely. These charges cannot be released in time. Thus, there will be accumulation of charges on the surface.

A consensus can be reached that there are mainly three ways of mechanism of charge being transferred, electron, ion and material, with electron transfer being the most omnipresent one. Electron transfer has been at a dominating place on certain occasions. Fermi energy level and electronic energy state of materials are important factors when determining the direction of electron transfer, and electrons flowing from high level to low level is the case at all times. Factors, for instance, surface properties, as well as chemical reactions of various materials can determine may contribute to friction electrification taking place between different polymers. Therefore, the transfers of electron and material may take place simultaneously. It is often the case that, when an ionomer or polymer alongside the surface molecular salt is in contact with other materials, ion transfer takes place. It is widely regarded that strong bound ion carrying polar charge and loosely bound ion carrying opposite polar charge are two kinds of ions in charge of the ion transfer for electrification. These two kinds of ions could establish a balance between each other. As they touched the other surface, ions from the loosely bound ions could be transferred to the other surface, causing the previous surface to lose electrons thus carry positive net charge of strong bound ions [1].

3. Key Mechanisms Explaining Antistatic Properties

3.1. Hydrophilic Conductive Mechanism

Thin molecular membrane of water can be made by the process of applying antistatic agent to the polymer surface absorbing water vapour through its hydrophilic groups (eg. -OH, -COOH, -NH₂, -SO₃H). This makes a thin water membrane, and antistatic agent would ionize greatly. Then the anions and cation are generated to neutralize static charges on the surface. The antistatic agent would also absorb ionizable impurities to make ion concentration higher and improve conducting ability to give off static charges. Additionally, a physical barrier between the polymer and other objects can be produced by antistatic agent on polymer surface. It can minimize the chance of frictions and reduce the possibility of triboelectrification [1].

3.2. Conductive Network Mechanism

Researchers believe that the conductive particles in the polymer can form conductive channels to trigger the enhancement of the conductivity in the polymer.

Those isolated conductive particles were densely packed, with simply a thin resin film separating them. Attributing to thermal vibration, electrons get activated thus being able to leap over the thin resin interface layer and jump to the neighboring conductive particles to create a tunnel current.

It is indicated by field emission theory that the strong internal electric field between conductive particles could cause electrons to jump over the resin interfacial layer barriers to reach the neighboring conductive particles, causing a field emission current [1].

4. Antistatic Polymer Research Roadmap

4.1. Novel Antistatic Agent

Surfactants and ionic liquids, like the first generation of antistatic agents, have been widely used because they are cheap and easy to access. They should be compatible with the matrix polymer to a certain extent, which will guarantee the appropriate migration to the surface to be functional. However, their durability needs to be taken into consideration. Because the quick migration to the surface from the inner matrix can reduce such effect. Besides, performances of surfactant type antistatic agents largely depends on the environmental humidity. Under dry conditions, if antistatic

agents cannot absorb enough moisture to form water molecular film on polymer surface, its antistatic performance will deteriorate seriously.

Traditional antistatic agents have many drawbacks such as not long-lasting and being overly dependent on the external environment. Besides, the additional amounts are large, generally 15~25%, which is costly. Therefore, new varieties should be developed based on existing ones to meet increasing demand for antistatic agents in industrial uses.

In recent years, researchers have developed a large number of new polymer conductive antistatic agents. Composite with poly (ionic liquid) nylon composite (P[MTMA]BF₄/Nylon 6) was prepared and investigated [1]. Tested results show that 2 wt% addition of the novel polyionic liquid (PIL) can provide some scrub resistance and durable excellent antistatic effect. Additionally, it is proved that this novel antistatic agent can efficiently enhance the elongation at break and aging resistance [3].

There is another accessible alternative, a novel polymeric antistatic agent, poly (1, 2-dihydro-2, 2, 4-trimethyl-quinoline) (TMQ) with great antistatic performance, economical, and ideal compatibility with polypropylene (PP), being made from isopentenyl polyoxymethylene ether (TPEG), maleic anhydride (MAH) as well as homemade quaternary ammonium salt (QAS) [4].

Moreover, aminomethyl acrylamide could be made through reaction between acrylamide, formaldehyde and dimethylamine. After that, the resultant product produced with dimethyl sulfate and polymerized to obtain an antistatic agent poly (acrylamide quaternary ammonium). When the polymer antistatic agent was applied in solution form at the concentration of 1.44% to polyester fabric, it rendered the fabric better antistatic property and fair washing durability [5].

Therefore, as study on this method deepens continuously, there is great possibility in future development.

4.2. Conductive Fillers Blending with Bulk Polymers

Conductive particulate inclusions within a continuous insulating matrix generally result in a steep reduction in electric resistivity, starting at a threshold volume fraction that has great dependency on spatial distribution and shape of the filler particles. Different dimensional conductive fillers with sphere shape, glass fiber, nanotubes, graphene nanoflakes as well as three-dimensional tetrapod. The target of the related researches is to improve antistatic properties of polymer materials and get some synergy on other performance improvement like mechanical property, scratch resistance, thermal stability, corrosion resistance, or anti-bacterium properties. Qingyan Shang et al. used rare earth modified BaTiO₃ powder as conductive fillers instead of traditional metal particles with epoxy resin, together with dispersant, curing agent to prepare antistatic coating, and achieved surface resistance of $1.18 \times 10^{10} \Omega$, with better corrosion resistance.

Designing core-shell structures offers another approach to enhance the conductivity of polymers. An ultrathin conductive layer can be coated onto the surface of polymer microspheres. By this way, the cost can be reduced while maintaining a high conductivity. Weng et al. mixed dodecyl benzenesulfonic acid (DBSA) doped SiO₂@PANI (SP) core-shell microspheres with commercial polystyrene (PS) as coating. It is demonstrated that the antistatic and corrosion protection effects were promoted, simultaneously. Antistatic properties of the PS/SP composite coating may result from the interconnection of conducting phase (SP core-shell sphere) in non-conducting matrix (PS), creating a conducting path along the matrix. Fig. 1 illustrates the mechanism of this new strategy. The enhancement of the corrosion protection efficiency of PS/SP composites coated on the cold roll steel (CRS) electrode could be due to the following two reasons. Firstly, the SP core-shell microspheres provide a form of anodic protection that significantly reduces the corrosion rate. Secondly, the well-dispersed SP core-shell microspheres in the PS matrix may enhance the gas barrier properties of the composites, which results in a remarkably increased torsion of the diffusion pathways for O₂, N₂ and H₂O, which significantly improve its corrosion resistance performance.

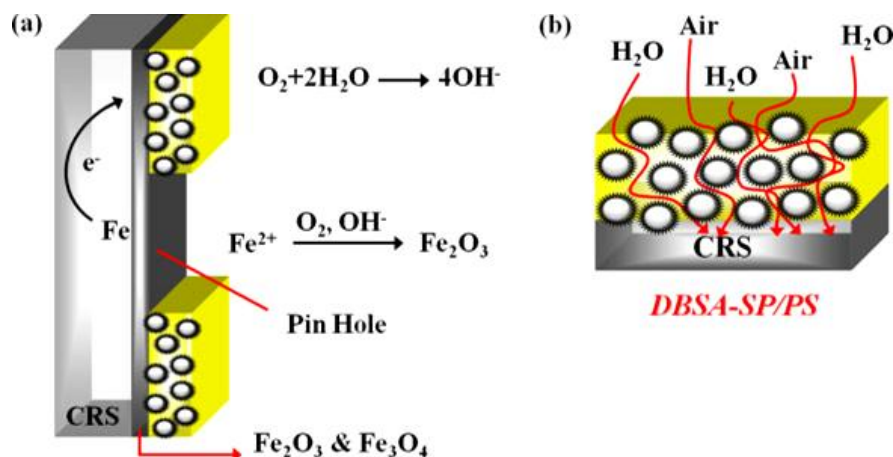


Figure 1. Schematic diagram of performance improvement mechanism [1]

There will be more possibilities for antistatic properties in the future, and even 3D printing can be a starting point, A novel polymerizable antistatic agent (DES) and polyurethane acrylate (PUA-B) developed from the glycolysis products of waste PET were prepared. A is an expected solution.

5. Conclusion

Polymers have wide applications in different industries due to their comprehensive properties. The inherent insulation properties of the material severely limit its performance and safety due to static electricity issues. Therefore, this study investigated tactics for improving the antistatic performance of polymers through multiple means. Through the analysis of electrostatic electrification mechanism including electron, ion and material transfer, conductive network formation and hydrophilic conduction are proved to effectively reduce surface resistivity. This study also introduced novel antistatic agent and the conductive filler blending method. The study provides information and probabilities for the future development of antistatic polymer materials with satisfying performance.

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