Electrostatic Properties and Ions Elimination Effect of Polyvinyl Chloride (PVC) Adhesive Tape Manufacturing

Tatsanee Jenbanphue
Graduate program in safety engineering, Faculty of Engineering
Kasetsart University
50 Ngam Wong Wan Rd, Ladyao
Chatuchak, Bangkok, Thailand 10900
tatsanee.je@ku.th

Komsan Hongesombut
Department of Electrical Engineering, Faculty of Engineering
Kasetsart University
50 Ngam Wong Wan Rd, Ladyao,
Chatuchak, Bangkok, Thailand 10900
fengksh@ku.ac.th

Kulsawasd Jitkajornwanich
Department of Computer Science
Faculty of Science
King Mongkut's Institute of Technology Ladkrabang
Chalong Krung 1, Chalong Krung Road, Ladkrabang, Bangkok, Thailand 10520
kulsawasd.ji@kmitl.ac.th

Siwapon Srisonphan
Department of Electrical Engineering, Faculty of Engineering
Kasetsart University
50 Ngam Wong Wan Rd, Ladyao,
Chatuchak, Bangkok, Thailand 10900
fengspsr@ku.ac.th

2020 8th International Electrical Engineering Congress (iEECON) 978-1-7281-3076-7/20/$31.00 ©2020 IEEE 10.1109/iEECON48109.2020.229499

Abstract— **Electrostatic discharges (ESD) can release large amounts of energy to products and humans, causing product failure and pain, respectively. In this research, we elucidate the electrostatic charge generation, and discharge phenomena in real polyvinyl chloride (PVC) based electrical tape factory, which is primarily operated by the roll to roll manufacturing process. We perform the electrostatic potential measurement to identify the critical process of charge generation and to eliminate static charge at the source in order to prevent incidents caused by electrostatic discharge to operators or staff in the winding process. We also perform a numerical simulation-based finite element method (FEM) that provides modeling of an induced electric field, allowing the electrostatic discharge. The maximum potential is ~20 kV measured at 25 mm, indicating that the meter was induced by the electric field approximately ~0.8 MV/m, corresponding to surface charges density is ~ 10 μC/m^2. Therefore, we introduced the ionization emitter bar in this case because it is feasible to install to the current infrastructure of the tested factory. The ionization emitter appears to reduce the electrostatic charge deposited on the PVC surface ~ 30% of the original charges. Therefore, installing a charge-dissipation technology at a proper location or combining with other methods, the electrostatic charge generation can be minimized even in roll to roll process.**

Keywords—Electrostatic discharge, polyvinyl chloride, electrostatic potential, electric field, finite element method.

I. INTRODUCTION

Electrostatic discharge (ESD) has been received highly interested in many ways, including both its advantage and disadvantage. [1]–[4]. It typically occurs in the process involving in which two objects are in contact, causing electrons to transfer from one object to the other through the touched surface area. Once the objects are consequently separated, the electrons typically try to return to their initial objects. If the materials are an electrical conductor, the electrons can easily return to the original one. However, if either or both objects are insulation materials, Electrons may not be able to return to the original object. The transferred electrons were attached to the surface of the insulating material, causing both objects to have an unequal number of positive and negative charges on the surface. The intensity of electrostatic force depends on the types of charged materials, the surface area, the speed of the separation, and the surrounding humidity [1], [5], [6]. Although the electrostatic discharge has been intentionally used in various industrial applications such as paper copiers and painting [2], [3], the ESD can cause several problems in many industries such as electronics, textile, chemical, and the automotive industry [7]–[12]. Not only can ESD damage the product, but also affect the operator during working in the production process [7], [8], [10]–[13]. Moreover, if the work area contains volatile chemicals or fuels, it may cause a fire or explosion in the production process [10], [12]. Therefore, all industries should have proper protective measures to reduce or prevent electrostatic discharge exposure from machinery and the large insulating products that can store large amounts of electrical charges. Generally, workers employed many protective equipment's including grounding, bonding, humidity controller, ionizer, as well as wearing anti-static devices such as anti-static shoes, gloves, and anti-static wristbands to reduce ESD depending on the type of products [10]–[12], [14].

In the electrical tape factory, however, electrostatic discharge is one of the significant problems because it is mainly manufactured from Polyvinyl chloride (PVC) plastic. This PVC tape has a very high insulating property resulting in a high possibility of accumulating electrical charges to its surface according to the lowest order of triboelectric effect [11], [15]. Notably, during the production process, Polyvinylchloride plastics have to pass through several friction contacts with the rollers or calenders to convey the melted plastic to form sheets, as presented in figure 1a. As a result, the mobile charges are transferring between the rollers and the tape. In the winding process, the adhesive PVC tape became a large roll and stored substantial electric charges, as well. In this work, we found that mostly, the electric charge will be transferred to the operator in the tape production

This work is supported by The Thailand Research Fund (TRF) and Kasetsart University (Grant No. RSA6280015).

process and the tape cutting process. When employees come in contact with statically charged products, the charge will transfer to the employees, causing distrust to the employees while working and causing damage to the product. Herein we elucidate the electrostatic charge generation in the production process and its electric field characteristic of the adhesive tape roll, including the factors that affect static electricity. Moreover, we demonstrate a way to prevent, control, and reduce the occurrence of the electrostatic force of the winding tape roll by using the ionization emitter in air, which is found to be feasible in the current factory.

II. RESULT AND DISCUSSION

A. *Process of polyvinylchloride (PVC) adhesive tape production.*

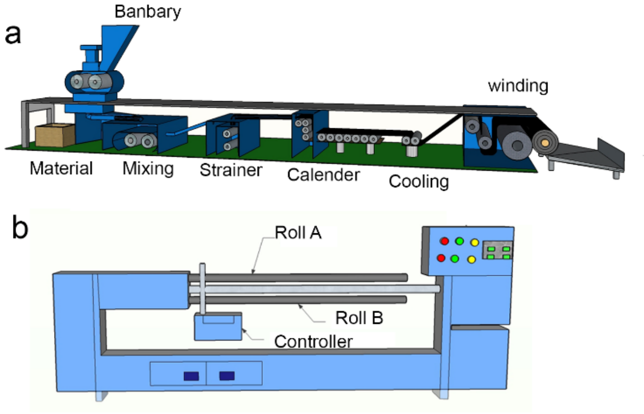

Fig. 1. Overall process of polyvinylchloride (PVC) adhesive tape production. (a) the PVC electrical tape production process and (b) The PVC tape cutting process.

In the PVC adhesive tape factory, the electrostatic discharge (ESD) to the operators has been reported in two main production processes, which are the duct tape production process (Figure 1a) and the tape cutting process (Figure 1b). The PVC tape production process typically began with the melting of polyvinylchloride (PVC) with the desired color (in the Banbary process) and sent it to the mixing rollers to mix all materials (in Mixing process) together. Consequently, the mixture was passed through the filtering strainer and rolled into sheets by the extrusion rollers at least four large rollers. After that, the duct tape will be cooled to reduce the temperature of the adhesive duct tape. In this process, the PVC tape went through ~20 rollers before rolled into the paper core (in the Winding process). Figure 1 shows that there are several contacts between the rollers and Polyvinyl chloride (PVC), causing electrostatic charge generation and accumulation on the surface of Polyvinyl chloride (PVC). During operation, the operators typically were exposed to electrostatic discharge when they come into contact with the PVC tape to push the tape over in the winding process, as presented in Figure 1a. Besides, Figure 2b shows the tape cutting process in which the machine consists of metal cores A and B. The operator will generally take a roll of PVC duct tape approximately ~100 cm in length into the metal core to cut the tape into the specified dimension. In this process, the operators usually experience electrostatic charges embedded in the tape that accumulated from the production process.

B. *The measurement of the electrostatic potential of PVC tape in winding stock roll.*

Figure 2b shows the measurement of the electrostatic potential at the winding stock roll in the PVC tape production process by using the ARMEKA Electrostatic Field Meter (AE-770).

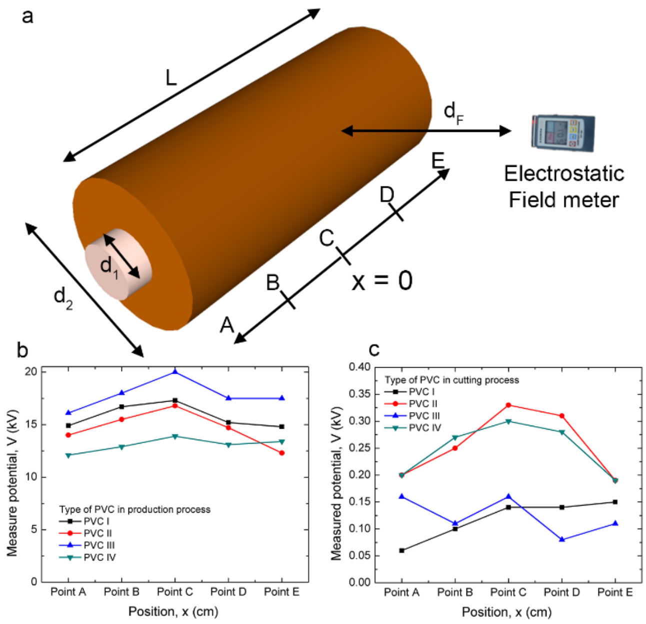

Fig. 2. The measurement of the electrostatic potential of PVC tape in winding stock roll in the production process and in the cutting process. (a) the electrostatic measurement setup and positioned along the PVC tape. The measured electrostatic potential of (b) PVC winding stock roll and (c) PVC tape roll in the cutting process.

Although the electrostatic potential measurement is an indirect inspection to observe the amount of charge that occurs in the PVC tape production [15], [16], with this simple method, we can identify the processes that cause the electrostatic charge generation and also estimate the electrostatic charge distribution on the PVC duct tape surface. We thus performed the electrostatic measurement of 4 types of polyvinyl chloride (PVC) tape under the real production Prepare Your Paper Before Styling in which the winding roll has the size approximately ~100 centimeters in length (L) and ~60 centimeters diameter (d2), whereas the paper core in the center of the tape roll is ~120 centimeters in length and approximately ~10 centimeters diameter (d1). Regarding the design of the ARMEKA Electrostatic Field Meter, the distance of the electrostatic field meter should be ~25 mm away from the winding stock roll as calibration by the its factory. By performing the potential measurement along the length of winding stocked roll as presented in points A, B, C, D, and E, which is ~20 cm spacing between each spot (Figure 2a). The results show that there is similar induced electrostatic potential of all four polyvinyl chlorides (PVC) tape in winding stock roll which is averagely ~16 kV and the maximum potential is ~20 kV, as shown in Figure 2b. During the measurement, the temperature and humidity were measured by Hygrometer MHT-381SD which is ~32.5 degrees Celsius and 60% humidity, respectively. The result suggests that the humidity level is not the main factor for electrostatic generation in this PVC tape manufacturing [1], [5], [6]. Therefore, the electrostatic charges produced in the duct tape production process is, mainly due to the friction of the duct tape and metal and rubber rollers [11], [15]. Besides, Figure

2c demonstrates electrostatic potential measurement of the four polyvinyl chlorides (PVC) in cutting processes. The electrostatic potential is only up to ~0.33 kV. Similar to the winding stock roll, the highest electrostatic voltage is in the middle of the duct tape and gradually decreases to the edge. The measured temperature was s about ~24 degrees Celsius, and the humidity is ~52%. The overall result suggests that the electrostatic potential of the PVC tape production process was higher than the cutting tape process because the production process provides more friction between the PVC tape and metal/rubber rollers. Moreover, the size of the winding stock tape is relatively large, causing a huge accumulation of electrostatic charge in the roll. Therefore, the electrostatic discharge of the duct tape, especially in the production process (up to ~20 kV), can cause the microscale electrical current flows through the operators once they come too close to the roll.

C. The electrostatic potential measurement with and without ionization bar in electrical tape production process.

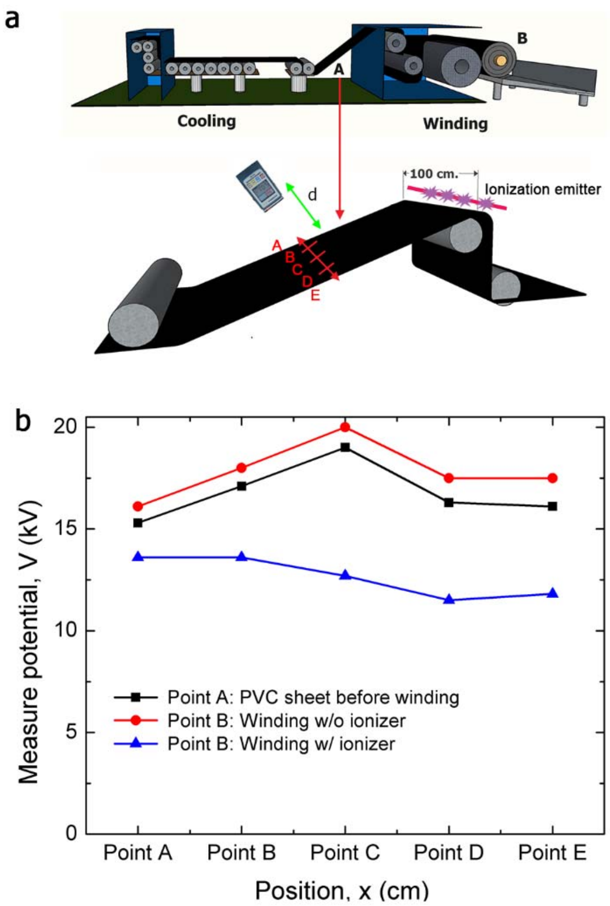

Fig. 3. The electrostatic potential measurement on a single layer of sheet tape and the entire winding roll with and without ionization bar. (a) Experiment setup and (b) The graph comparison of measured potential

After experiencing many friction contacts between the PVC and ~40 metal/rubber rollers, it can cause electrostatic charges generation and the accumulation on the surface of the PVC tape. Therefore, in order to study and identify the primary electrostatic charge generation in the PVC duct tape production process, we directly measured the surface potential of the Polyvinyl chloride (PVC) sheet at before (Figure 3a point A) and after (Figure 3a point A) entering the winding process. As present in Figure 3a -bottom, the surface potential of a sheet of duct tape with a width of 100 cm was measured for 5 points as A, B, C, D, and E. The distance between the electrostatic potential meter and a single layer of sheet tape is about 25 mm as required from factory calibration. The electrostatic potential of polyvinyl chlorides (PVC) sheet at Figure 3a-point A demonstrates the maximum potential at ~18 kV, which is at the center of PVC roll and gradually decreases to ~15 kV at the edge (Figure 2b- black line). After that, we also measured the induced potential of winding stock roll. The electrostatic potential of winding duct tape was ~19 kV, which is very close to a measurement of a single layer of PVC sheet (Figure 3b-red line). Therefore, it can be concluded that the electrostatic charge was generated and accumulated on the PVC sheet before winding.

D. The distribution and direction of the electric field radiated from the PVC tape roll.

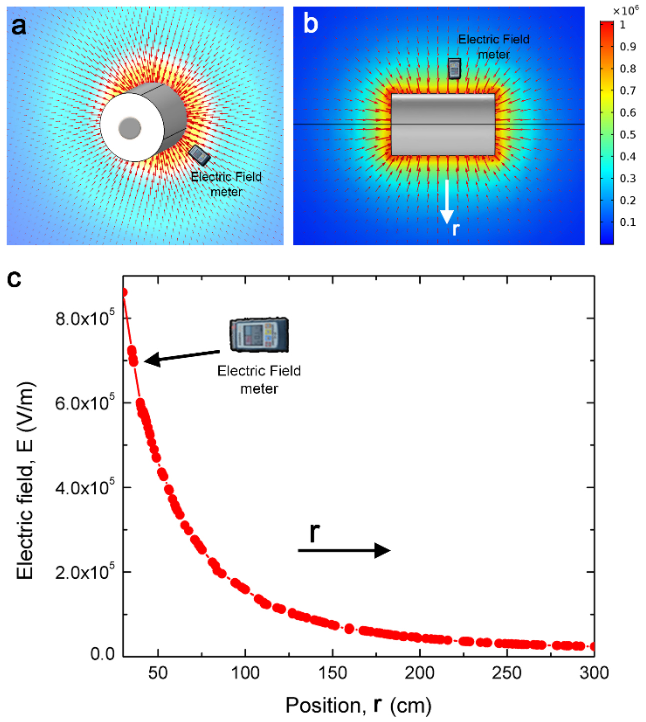

Fig. 4. The distribution and direction of the electric field radiated from the PVC tape roll. (a) the FEM simulation based on Poisson's equation and (b) displaying the electric field force radially out ward from PVC rod. (c) the electric field along the radial path from the PVC tape surface.

More importantly, the results indicate that the electrostatic discharges to the operator come from the outermost layer of the PVC sheet of the tape roll. Therefore, if we can neutralize the attached charges on the PVC layer, the PVC roll will be safe for the operator to touch the product. Note that the measurement of surface potential was designed to directly sense to electric field from a simple plane with fixed potential source and informing the reader with measured potential at a given distance. Regarding the maximum measured potential ~20 kV measured at 25 mm, thus, the electrostatic meter experiences the electric field ~0.8 MV/m. Besides, by using the famous Maxwell's Equation for the electric field generated by a distribution of electric charges, we can approximate a surface electrostatic charge density of PVC roll surface as :

$$\oint E \cdot dA = \frac{q_{enc}}{\varepsilon} \quad (1)$$

where the electric field E through any infinitesimal Gaussian surface, A equal to the net charge enclosed (q_{enc}) divided by the permittivity of free space (ϵ) : Therefore, the surface charges density is ~ 10 μC/m^2. This result shows good agreement with finite element methods (FEM), which were used to elucidate the distribution and direction of the electric field radiated from the PVC tape roll. As shown in Figure 4, The commercial software based on FEM, COMSOL, was implemented can calculate based on Poisson's equation and displaying the entirely electric field force entire PVC rod [17]. The simulation result, as presented in Figure 4, is generated from the surface charge density is ~8 μC/m^2. Figure 4a and Figure 4b demonstrate that the electric is radially outward from the PVC roll and significantly high up to 1 MV/m at around the edge of PVC. Note that if there is any ground or conducting material such as humans come to very close to the PVC roll, it can influence the electric field distribution causing the electrostatic discharge to the operator. Therefore, the fringe field allows the most possible of electrical discharge through the air known as corona [18]–[20]. Therefore, it is necessary to reduce the electrostatic charge as much as possible before touching them. However, because of the glue involvement and the sophisticated process, it is too difficult to install or add any dissipation charge into the system. After surveying the environment, we decided to add the ionization bar in order to observe the feasibility of reducing the electrostatic charge in the duct tape production process without touching any product. The KEYENCE ionizer bar was introduced and installed before winding, as presented in Figure 3a-bottom. A single ionization emitter bar was created by corona discharge to provide many ions with positive and negative polarity to reduce the accumulation charges on top of the PVC sheet before winding [20], [21]. The result shows that we can reduce ~7 kV electrostatic potential per installed single ionization bar at this manufacturing (from ~20 kV to ~12.5 kV surface potential at the center of roll). Therefore, the electrostatic surface charge density is reduced from ~8 μC/m^2 to ~5 μC/m^2. As to the current situation, we may need to add at least three more ionization emitter bars to sufficiently compensate the electrostatic charge deposited on the PVC tape surface in the production line.

III. Conclusion

In roll to roll manufacturing operations, electrostatic issues are usually caused by tribocharging effect between two chemically dissimilar materials. The non-contact electrostatic field meters can be used to indicate the main cause of static problems. In the current PVC tape factory, the ionization emitter becomes effective methods to neutralize the electrostatic charge on the PVC layer after accumulated from multiple contacts. Eliminating static charge at the source is the most cost-effective solution to static problems.

Acknowledgment

This work is supported by The Thailand Research Fund (TRF) and Kasetsart University (Grant No. RSA6280015).

References

[1] .K. J. Boelter and J. H. Davidson, "Ozone generation by indoor, electrostatic air cleaners," Aerosol Sci. Technol., vol. 27, no. 6, pp. 689–708, Jan. 1997.

[2] T. F. Hayne, "Screen Controlled Corona Device (Scorotron) for Charging in a Xerographic Copier," IEEE Trans. Ind. Appl., vol. IA-12, no. 1, pp. 63–67, 1976.

[3] G. M. LaPorte, "The Use of an Electrostatic Detection Device to Identify Individual and Class Characteristics on Documents Produced by Printers and Copiers—A Preliminary Study," J. Forensic Sci., vol. 49, no. 3, pp. 1–11, 2004.

[4] D. Zajfman et al., "Electrostatic bottle for long-time storage of fast ion beams," Phys. Rev. A - At. Mol. Opt. Phys., vol. 55, no. 3, pp. R1577–R1580, 1997.

[5] B. Tabti, M. R. Mekideche, M. C. Plopeanu, L. M. Dumitran, A. Antoniu, and L. Dascalescu, "Factors that influence the decay rate of the potential at the surface of nonwoven fabrics after negative corona discharge deposition," IEEE Trans. Ind. Appl., vol. 46, no. 4, pp. 1586–1592, Jul. 2010.

[6] M. Abdel-Salam, "Influence of humidity on charge density and electric field in electrostatic precipitators," J. Phys. D. Appl. Phys., vol. 25, no. 9, pp. 1318–1322, Sep. 1992.

[7] P. T. Krein, "Electrostatic discharge issues in electric vehicles," IEEE Trans. Ind. Appl., vol. 32, no. 6, pp. 1278–1284, 1996.

[8] H. L. Floyd, "Prevention is better than a cure: Electric shock injuries from static electricity discharges," IEEE Ind. Appl. Mag., vol. 18, no. 3, pp. 57–60, May 2012.

[9] K. B. Cheng, T. H. Ueng, and G. Dixon, "Electrostatic Discharge Properties of Stainless Steel/Polyester Woven Fabrics," Text. Res. J., vol. 71, no. 8, pp. 732–738, 2001.

[10] E. S. Udoetok and A. N. Nguyen, "Grounding resistance for control of static electricity ignition hazards," J. Electrostat., vol. 69, no. 1, pp. 23–29, Feb. 2011.

[11] K. Robinson and W. Durkin, "Electrostatic issues in roll-to-roll manufacturing operations," IEEE Trans. Ind. Appl., vol. 46, no. 6, pp. 2172–2178, Nov. 2010.

[12] L. G. Britton, Avoiding Static Ignition Hazards in Chemical Operations. Wiley, 1999.

[13] J. Paasi, "Assessment of ESD threats to electronic components," J. Electrostat., vol. 63, no. 6–10, pp. 589–596, Jun. 2005.

[14] E. M. Charlson, E. J. Charlson, S. Burkett, and H. K. Yasuda, "Study of the Contact Electrification of Polymers using Contact and Separation Current," IEEE Trans. Electr. Insul., vol. 27, no. 6, pp. 1144–1151, 1992.

[15] W. H. Hsing, J. H. Lin, and K. T. Kao, "The investigation of fiber carding performance with the application of static electricity to carded nonwoven fabric process," J. Mater. Process. Technol., vol. 192–193, pp. 543–548, Oct. 2007.

[16] A. Fatihou, L. Dascalescu, N. Zouzou, M. B. Neagoe, A. Reguig, and L. M. Dumitran, "Measurement of surface potential of non-uniformly charged insulating materials using a non-contact electrostatic voltmeter," IEEE Trans. Dielectr. Electr. Insul., vol. 23, no. 4, pp. 2377–2384, Aug. 2016.

[17] C. Multiphysics and C. Multiphysics, "COMSOL Multiphysics ® 4.3a," COMSOL Multiphysics ® 4.3a, 2013.

[18] S. Srisonphan, "Hybrid Graphene–Si-Based Nanoscale Vacuum Field Effect Phototransistors," ACS Photonics, vol. 3, no. 10, pp. 1799–1808, Oct. 2016.

[19] S. Srisonphan, "Tuning Surface Wettability through Hot Carrier Initiated Impact Ionization in Cold Plasma," ACS Appl. Mater. Interfaces, vol. 10, no. 13, pp. 11297–11304, Apr. 2018.

[20] S. Srisonphan and K. Jitkajornwanich, "Nearly Ballistic Electron Transport in an Out-of-Plane Nanoscale Defect-Void Channel," IEEE Trans. Electron Devices, vol. 65, no. 6, pp. 2601–2606, Jun. 2018.

[21] N. Teerakawanich, V. Kasemsuwan, K. Jitkajornwanich, W. Kanokbannakorn, and S. Srisonphan, "Microcorona Discharge-Mediated Nonthermal Atmospheric Plasma for Seed Surface Modification," Plasma Chem. Plasma Process., vol. 38, no. 4, pp. 817–830, Jul. 2018. 6.