Contact electrification of polymeric surfaces

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Contact electrification between nylon and polytetrafluoroethylene (PTFE) flat surfaces conducted under controlled environment of different temperature and relative humidity reveals that charge generated on PTFE increases as the contact force increases from 11 N to 17 N. This can be explained by the fact that the contact area increases as the contact force increases. Contact electrification is also studied for four different materials against each other. It is found that the tribo-electric series for those four materials are nylon (+), stainless steel, polypropylene (PP), and PTFE (-). The absolute value of charge generated on nylon is found to be much lower than that on PP or PTFE. In addition, it is also found that the charge generated on one surface cannot represent the charge generated on the other surface which is contacted.

Keywords: Contact electrification, Contact force, Electrostatic generation, Electrostatic dissipation, Polymeric surface, Tribo-electric series

1 Introduction

Synthetic polymers are widely used because they offer excellent properties. However, most of the synthetic polymers have a common drawback, that the electrostatic charge is easy to generate but hard to dissipate, causing problems in industry. For example, in textiles, charge can be generated on synthetic films/fibres/filaments when they are processed across rollers and guides. The generated charge may cause the films/fibres/filaments to cling on parts of the machine and therefore cause the production line to stop, which results in the irregularity of products and low manufacturing efficiency. More severely, the charge may be sufficient to cause sparks and lead to fires and explosions in the plants. Therefore, it is extremely important to understand the mechanism of static behavior of synthetic polymers, so that efforts can be made to minimize its negative impact.

The static generation can be classified into contact electrification (charging by contact and separation of two different surfaces) and frictional electrification (charging by dynamic rubbing of two surfaces). Compared to the frictional electrification, the contact electrification is simpler for analysis since there is no concern about the rubbing speed and its interactions with other factors (e.g. temperature and contact area) on the static generation. There have been several studies on the contact electrification of polymeric plates. It has been revealed that charge increases as the number of contacts increases. However, the rate of increase of charge is decreased as the number of contacts increases and a saturation value appears after many cycles of contacts. There is no universally agreed explanation on the issue why the charge increases with number of contacts. One of the important factors influencing the charge generation is the contact area between two contacted surfaces. Coste and Pechery and Ohara indicated that charge increases as the surface roughness decreases. The reason lies in that the increase of the real contact area would provide more electrons or ions to participate in the charge transfer. In addition to the effect of contact area, researchers have attempted to understand the influence of environmental conditions and surface finishes on contact electrification. However, it is evident that in some cases the reported observations are in contradiction with each other. For example, Sereda and Feldman and Medley pointed out that charge would increase as the relative humidity (RH) is increased. After the charge reaches a maximum value, it decreases rapidly due to the increase in RH. Ohara found that charge attains a maximum value and then decreases as the temperature is increased. However, Greason found that charge keeps on decreasing as the RH and the temperature increase. Possible reasons for this disparity could be attributed to the differences

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in experimental procedures coupled with the accuracy of systems used.

In order to gain a better understanding of the static behaviour of polymers, this study examines the contact electrification of flat polymeric surfaces that are commonly used in industry. PTFE, nylon 6,6 and PP are tested for static charging under different levels of contact force, relative humidity, and temperature.

2 Materials and Methods

2.1 Materials and Sample Preparation

The device (Fig. 1) used to measure the amount of electrostatic charge generated on a movable contact head after contacting a fixed contact plate (polymeric or metal) has been described elsewhere\(^\text{15}\). In this work, finish free nylon, polypropylene (PP), polytetrafluoroethylene (PTFE), and stainless steel rods were machined to the required shape of contact head, which is cylinder of 6.35 mm diameter (Fig. 2). One end of the contact was drilled for mounting onto a driving rod. The other end of the contact head was flat surface, which would contact and separate with the fixed contact plate. After the initial machining, each contact head was smoothed by sand paper (grit size of 2000 µm) and water to reduce their surface roughness. Additionally, nylon, PP, PTFE and stainless steel plates were cut into dimension of 10 cm x 10 cm, to be used as the fixed contact plates. The nylon, PP, and PTFE were acquired from Industrial Plastic Supply, Inc. and the stainless steel was Mirror-Like #8 ordered from McMaster-Carr.

Before conducting a static charge experiment, each contact head and contact plate was cleaned by ethanol, deionizing water, and deionizing gas, and then kept inside an environmental room under required condition of temperature and relative humidity (RH) for at least 24 h. The target was to clean the materials and dissipate the static charges that may have been generated due to handling. Before each test, the initial charge on the contact head and the contact plate was measured and if it was not zero, the cleaning and deionizing procedure was repeated.

2.2 Design of Experiment

Two sets of experiments were conducted. The first dealt with the evaluation of static generation on PTFE contact head after contacting against nylon contact plate under different contact forces (11, 14 and 17 N) in controlled environment of temperature (21, 25 and 30°C) and RH (43, 55 and 65%) with the total runs of 3 x 3 x 3 = 27. Each run was replicated 3 times and a total of 81 (3 x 3 x 3 x 3) observations were made for each response.

The second experiment addressed static generation on nylon, PTFE, stainless steel and PP surfaces when they are in contact against each other under two levels of temperatures (21 °C and 30 °C) and two levels of RH (43 and 65%) with the total runs of 2 x 2 x 4 x 4 = 64. Each run was replicated 3 times and a total of 192 (2 x 2 x 4 x 4 x 3) observations were made for each response. Both contact head and contact plate materials were the same.

The fixed parameters for the first experiment were contact head of PTFE; nylon fixed plate; contact frequency of 72 cycles/min; data collection rate of 17 points/s. The responses considered for this experiment were charge generated on the PTFE contact head after the first contact, 50 contacts, 100 contacts, and 120 contacts.

The fixed parameters for the second experiment were contact force of 14 N; contact frequency of 72 cycles/min; data collection rate of 17 points/s. The response considered for this experiment was charge generated on the contact head after 50 contacts.

The data of the measured dependent parameters (responses) were processed using the multi-factor...
analysis of variance (multi-way ANOVA) to reveal the influence of the main parameters and their interactions on the responses listed above at confidence level of 95% (or p-value of 5% or 0.05).

3 Results and Discussion

3.1 Experimental Design I

The ANOVA indicates that the effect of contact force on charge generated after the first, 50, 100, and 120 cycles of contact is significant. The p-value is 0.0094 for the response of charge generated after the first contact, 0.0008 for charge generated after 50 contacts, 0.0003 for charge generated after 100 contacts, and 0.0004 for charge generated after 120 contacts. Figure 3 shows the average charge generated on PTFE after 50 contacts against nylon for all 27 runs. Each value in the figure represents the mean of 3 replications. Although there are a few exceptions (charge generated under 25°C and 43% RH and under 25°C and 65% RH), the absolute charge generated increases with the contact force. For all runs the average charge generated increases when the contact force is changed from 11 N to 17 N, regardless of the level of temperature and relative humidity. This can be explained by the fact that with higher force the contact area between the nylon and PTFE surfaces increases. The increase in contact area allows greater transfer of electrons from the nylon to the PTFE, which causes more negative charge generated on the PTFE.

Figure 4 shows typical curves of charge build up with repeated contacts under the three levels of contact force at 30°C and 30% RH. The results indicate that the charge saturation, occurred when the charge reached its maximum value, in most runs is reached after 50-100 contacts. After such number of contacts, the charge generation and the charge dissipation are equal.

In Fig. 4, the sample subjected to 17 N contact force generates higher charge after the initial contact (the first contact) compared to the samples subjected to 10 and 14 N contact force. This is because the real contact area is larger under 17 N force than the other two levels of contact force, which provides more electrons and ions to participate into the charge exchange between the two surfaces. Furthermore, charge on sample subjected to 17 N force increases faster (almost linearly for the first 5 contacts) than the other two samples subjected to 10 N and 14 N contact force. This could be related to rapid increase in the rate of contact area caused by the high contact force of 17 N that causes proportional increase in the rate of charge generation.

The ANOVA also indicates that when the data are collectively analysed, the effects of RH, temperature, and their interaction on charge generation are significant, irrespective of the number of contacts (p-values are smaller than 0.05). To better understand the effects of temperature and RH, the values of charge generated after 50 contacts (Fig. 3) are sorted by relative humidity and temperature (Fig. 5). This figure shows no specific trend in terms of effect of RH and temperature on charge generated. However, in the two cases the charge generated at 21°C and 30°C with 55% RH and 17 N contact force is noticeably high. This means that there is second order interaction among the parameters such as contact force, temperature and RH.

3.2 Experimental Design II

In experimental design II, the nylon, PP, stainless steel and PTFE surfaces are contacted against each other. It is found that the PTFE is always negatively charged and the nylon is always positively charged after contacting the other three materials (Fig. 6). PP is negatively charged against nylon and stainless steel, while it is positively charged against the
PTFE. According to these observations, the tribo-electric series for these four materials can be summarized in the order of nylon (+), stainless steel, PP, and PTFE (-). The material close to the positive end of the series is positively charged when contacted against materials close to the negative end of the series. This agrees with findings of other researchers' tribo-electric series.

In Fig. 6, there is no general trend exhibited for the effect of RH on charge generated. However, it shows that the higher charge is generated at the higher temperature, irrespective of the humidity value. This could be the combined results of following two different effects:

(i) Usually, if the relative humidity is kept constant, the water content in the air increases as the temperature increases. For example, when the RH is kept at 43%, there is about 12 g of water per kilogram of air at 21°C. At the same RH (43%), increase in temperature to 30°C causes the amount of water per kilogram of air to increase to 20 g. Although the polymeric surfaces used in this experiment are hydrophobic, water in the air can still be adsorbed on their surface. Those water molecules adsorbed on polymeric surface may perform in two different ways:

(a) Charging—water (ions) performs like media for charge transfer, and thus potentially increase charging and

(b) Dissipation—water acts as conductor, which may help the charge moving/dissipating along the surface or into the bulk. In this work, the effect of charging might exceed the effect of dissipation when temperature is increased, therefore, charge generated at 30°C is higher than that generated at 21°C.

(ii) The mobility of polymer surface molecules increases as the temperature increases. This can promote the charge transfer between two surfaces. Meanwhile, the mobility of molecules in the air increases as the temperature increases, which may promote the charge dissipation through the air. The charging effect might exceed the dissipation effect, thus results in higher charge generated at 30°C than that at 21°C.

Figure 6 shows the charge generated on PTFE after 50 cycles of contacts against other materials. The charge generated on PTFE after contacting nylon is found to be highest, while the charge generated on PTFE after contacting PP varies with temperature and humidity; however no clear trend is evident. It is interesting to note that the charge generated on PTFE after contacting nylon is higher than on contacting other materials, however, the charge observed on nylon after contacting other materials is always very low (< 15 pC). Additionally, no charge is observed on the stainless steel contact head, which is expected from a good conductor.

It is evident from these results that the charge measured on the contact head cannot be used to infer the charge on the contact plate. Indeed when the
polymer used for contact plate and contact head are interchanged very different results can be found. For example, PP generates a significant charge when contacted against the PTFE plate, but PTFE contact head only generates a small charge when contacted against the PP plate.

4 Conclusion
Two sets of experiments have been conducted to gain a better understanding of the static behaviour of polymers surfaces after simple contact and separation for repeated number of cycles. In the first experiment the static generation of finish free PTFE and nylon surfaces is determined for a range of parameters namely contact force, temperature and RH. It is found that the charge (- ve) generated on the PTFE surface increases significantly with the contact force. No specific trend of the charge generated in terms of temperature or RH is found.

In the second experiment four different materials (nylon, stainless steel, PP, and PTFE) are tested to determine their static generation properties. The tribo-electric series of the four different materials is investigated by contacting against each other. It is found that their tribo-electric series is nylon (+), stainless steel, PP, and PTFE (-), which is in agreement with previous research findings. The absolute charge generated on nylon is much lower than that generated on PP or PTFE. Additionally, it is also found that charge generated on one surface cannot represent the charge on the other surface by which it is contacted.

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