Annealing effects on the charge transfer in metal/polymer contact

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***Abstract* - The experiments described in this paper have been prompted by some unusual charging results obtained from the annealing treatment of polytetrafluoroethylene (PTFE). Results from previous studies revealed that the surface treatment has profound effect on the charging properties of insulators. In this paper we report the effect of annealing on the charging properties of three polymers: Teflon (PTFE), nylon and polystyrene (PS).The results of charge transfer in metal/polymer contact show that the annealing of Teflon drastically reduced the charge measured to almost that of as-received sample whereas for nylon and PS annealing process does not influence the charge transfer measured.**

I. INTRODUCTION

The charging of insulators by contact or friction is a familiar effect which has been a subject of much research dating back to many decades. All the same, there is still no generally accepted explanation of the phenomenon. One major obstacle to the progress is the well known problem of irreproducibility of data from experiment. Researchers have observed large differences between the triboelectric behaviour of different samples of nominally the same material, and even a single piece of insulator may show place-to-place variation over its surface or its charging characteristics may change with time [1-4].The irreproducibility of the charge transferred has been interpreted in so many ways. For example it was proposed that the charge transfer to a particular sample of polymer might be determined by accidental impurity or surface contamination possibly during processing [1,5]. Many researchers however, found that the electrification of polymers is sensitive to “cleaning” or methods of preparing the sample’s surface [1,5 -7].

In this study, we have investigated charge transfer to three polymers as a result of their contact with metals using lapping as sample surface preparation and then followed by annealing in an argon environment.

II. EXPERIMENTAL METHODS

Contacts and charge measurement were carried out by an automated apparatus which is similar to that described in our previous study [3,8]. All metals made simple contact with the polymer surface with the same force of contact (≈ 5 N). It is also expected that the contact area should be the same for all contacts, except in so far as the hardness of different polymers may vary. The experiments were performed in liquid-nitrogen trapped environment of 10^{-5} or better to avoid the possibility of charge loss by gas discharge. The work functions of the metal contactor were measured without breaking the vacuum using Kelvin vibrating capacitor.

Metals: The metal contactors used in the experiment covered a wide range of work function. Some of the metals (e.g. Al, Mg, Cu) were machined and turned into a bullet shape (diameter ~ 6 mm), while others (Au, Pt, Sn) were made from soldering a molded metal foil on a brass sphere. The cleaning of the metals was done periodically by polishing them with a slurry of gamma grade aluminum powder and water after which they were cleaned in trichloroethylene and methanol (the methanol cleaning was omitted in the case of Mg because of rapid reaction between them) [8,9]. This method of cleaning has been used by previous investigators [10].

Polymers: The experiments were carried out using three different polymers: PTFE, Nylon and Polystyrene.

<u>Polytetrafluoroethylene</u> (PTFE): The PTFE used was a commercial sample supplied by TBA Industrial Products Ltd which is about 0.25 inch thick. Its surface was lapped on #600 SiC paper using water as lubricant and for final rinsing. The method has been previously employed as a surface preparation technique by other researchers [11]. The lapped sample was further subjected to heat treatment, i.e. annealing in a clean glass tube with a stream of argon gas flowing through. The annealing temperature was set to 320 ^{o}C and the treatment lasted for two hours. The cooling of the sample was also in the argon gas environment.

<u>Nylon 66</u>: The polymer sample was fabricated by injection mould and supplied by Polymer and Fibre Science Department at the University of Manchester. A one inch square was cut from the bulk and this was cleaned with detergent after which it was annealed in an argon gas environment at temperature 200 ^{o}C for about five hours. It was thereafter cooled to room temperature in the same argon gas environment.

<u>Polystyrene:</u> An approximate 0.2 inch thick PS was prepared by moulding (into sheet) through compression between two hot glass plates. The compression was done in an argon gas environment inside a glove box. The glass plates were cleaned with detergent and thoroughly rinsed with running hot water followed by cold water for a few hours. The samples were annealed at a temperature 140 ^{o}C in an argon environment for one hour after the initial charge transfer measurement on the lapped sample.

III. RESULTS AND DISCUSSION

A. *Contact Charging of PTFE*

The results of charge transfer to PTFE show that it is sensitive to surface preparation in agreement with some previous reports [1,5 -7]. It is clear that the charge transfer measured from Au/PTFE contact has increased as a result of lapping process as observed in Fig. 1 and Fig. 2. Our explanation for this observation is as follows: it is possible that the commercial sample used, which is from the manufacturer, is superficially contaminated by something which was not removed by cleaning with some solvent (trichloroethylene or methanol) which is now removed by lapping. On the other hand, it could be that the lapped surface charged strongly because it was “damaged”. For example, lapping will probably break the polymer chain and thus produce free radicals which might themselves be involved in contact charging.

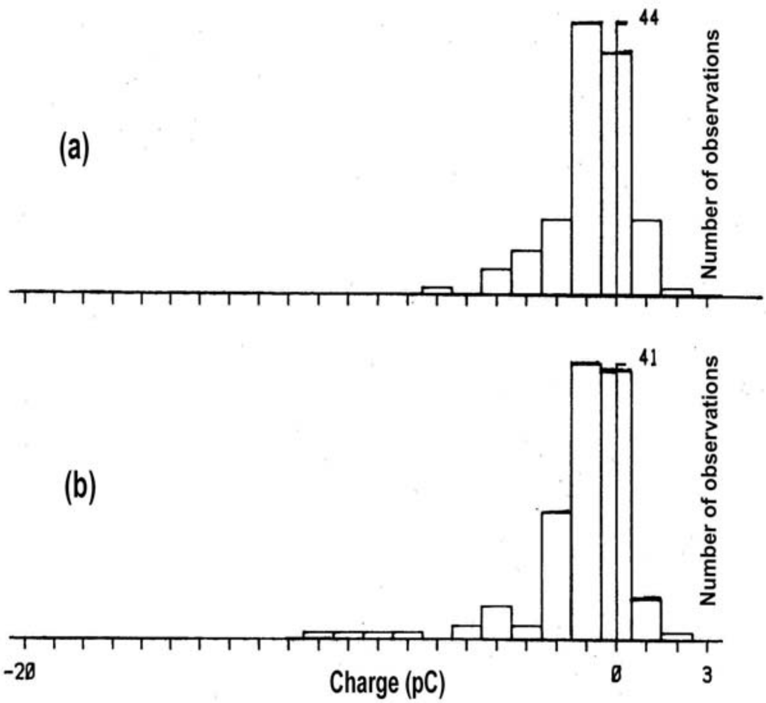

Fig. 1. Histogram showing charge transfer from Au to as-received PTFE (a) virgin material and (b) previously contacted by other metals prior to Au

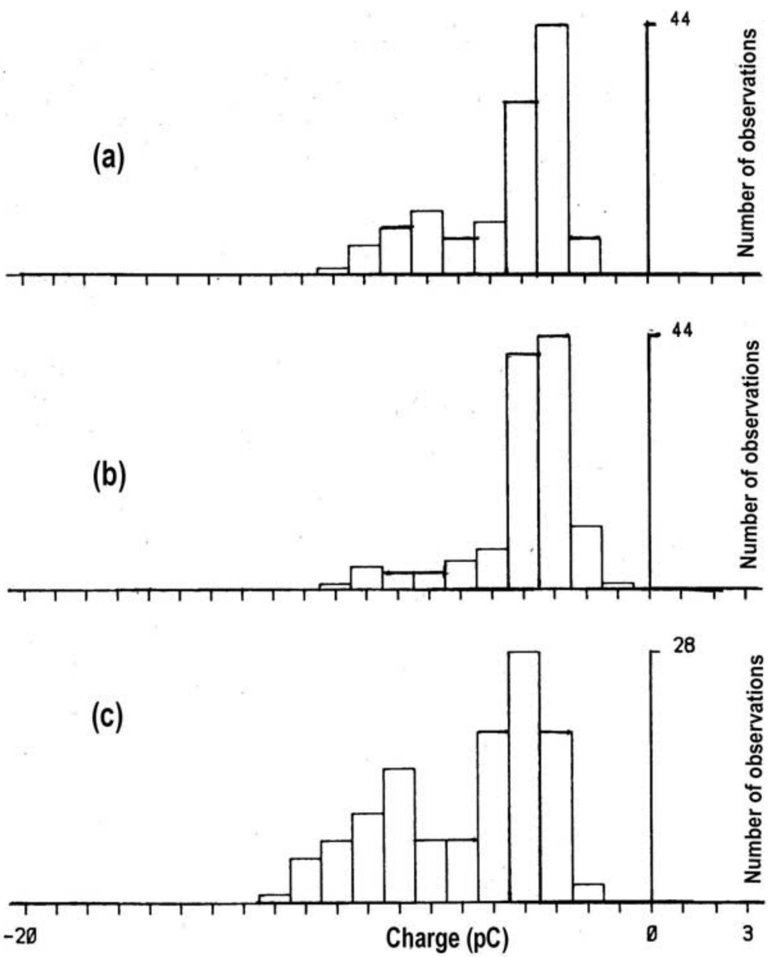

Fig. 2. Histogram showing charge transfer from Au to lapped PTFE (a) virgin sample, (b) & (c) previously contacted by other metals prior to Au

In order to determine whether the lapped surface charges strongly because it is “clean” or “damaged”, we investigated the effect of heat-treatment on the lapped surface. The heat treatment may be expected to remove physical damage by mobilizing the polymer chain. The contact charging of the annealed sample revealed that the heat treatment greatly reduces the charging to the same level before lapping the PTFE, i.e. as-received [Fig. 1. and Fig. 3.]. The results are strong evidence that it is the physical damage that enhances the contact charging of lapped PFTE and it can be reversed by heat treatment [3,9,12].

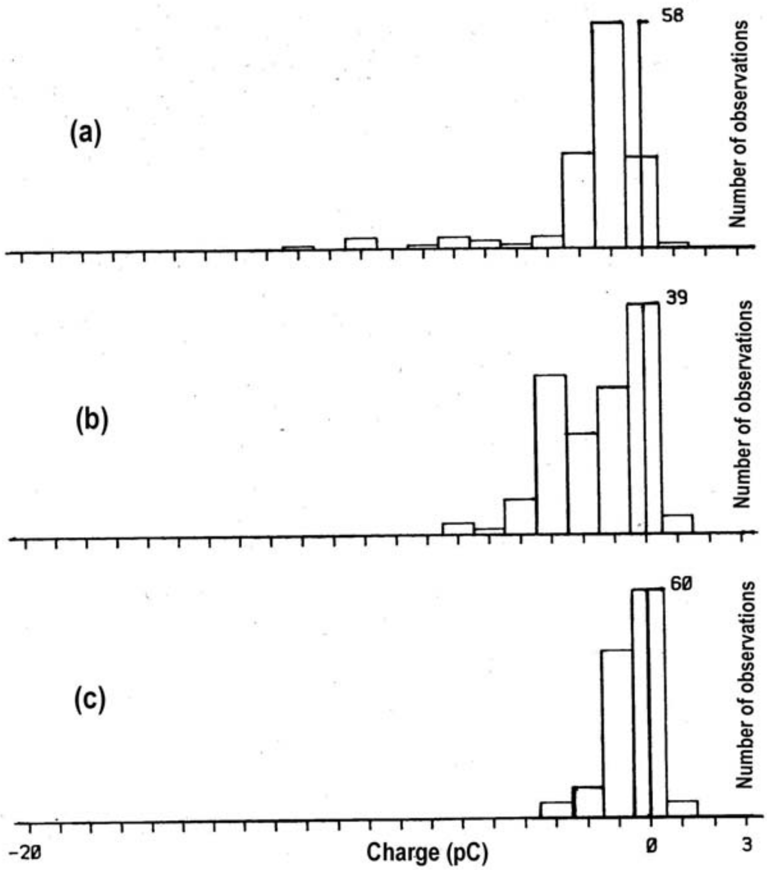

Fig. 3. Histogram showing charge transfer from Au to annealed PTFE sample in argon gas environment (a & b) and in air (c)

B. *Charge transfer to Nylon 66*

We have already seen that the electrification of PTFE by metals is sensitive to the method the sample surface is prepared with. In this regard we decided to investigate the effect of lapping followed by annealing on the charge transfer to Nylon by metals. The result from the study reveals that the contact charge measured is the same for both lapped and annealed nylon [Table 1]. The histogram of the Au/Nylon contact in Fig. 4 & Fig. 5 shows that the charge distribution for both treatments has the same spread with a tail towards the large positive charge.

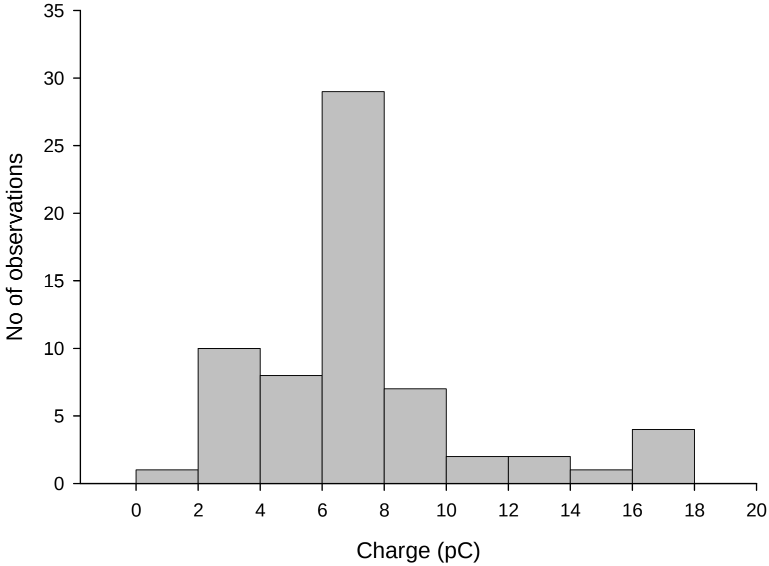

Fig. 4. Histogram showing charge transfer from Au to lapped Nylon

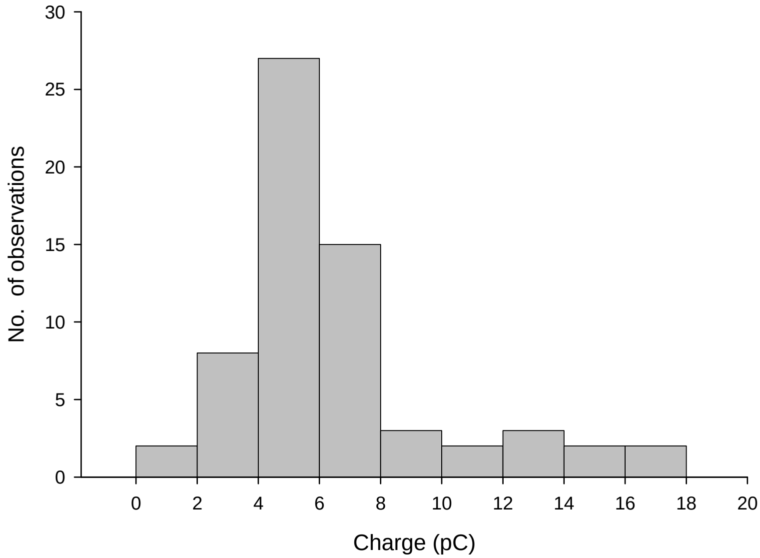

Fig. 5. Histogram showing charge transfer from Au to annealed Nylon

C. *Charge transfer to Polystyrene*

In this section we report the charge transferred to polystyrene prepared by compression mould. We measured contact charge from Au to both lapped and annealed samples. The sample was annealed for two different reasons: (i) to reduce the sample to a charge neutral surface according to Fabish et al [13] and (ii) to observe its effect on the charge transferred to the sample.

The contact charging of lapped sample is not significantly different from the original sample (i.e. compressed mould followed by cleaning with organic solvent). The average charge calculated for sixty-four Au/virgin PS and Au/lapped PS contacts are 0.81 ±0.20 pC and 0.75 ±0.13 pC respectively. The annealing of the mould sample does not affect the charge transfer; the average charge for Au/annealed PS contacts is 0.72 ±0.13 pC. The distributions of the charge measured for both lapped and annealed are shown in Fig. 6 & Fig. 7. Both histograms have the same width with a tail towards the large positive charge.

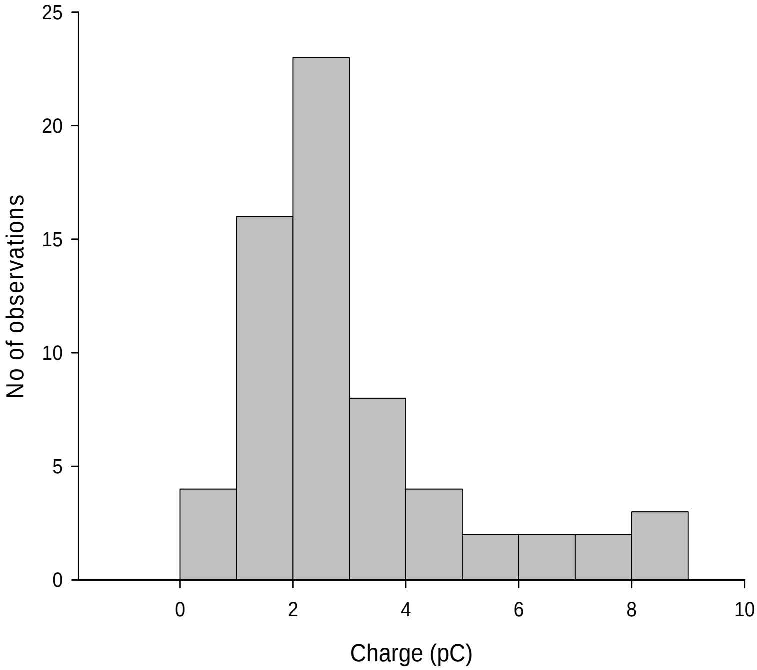

Fig. 6. Histogram showing charge transfer from Au to lapped PS

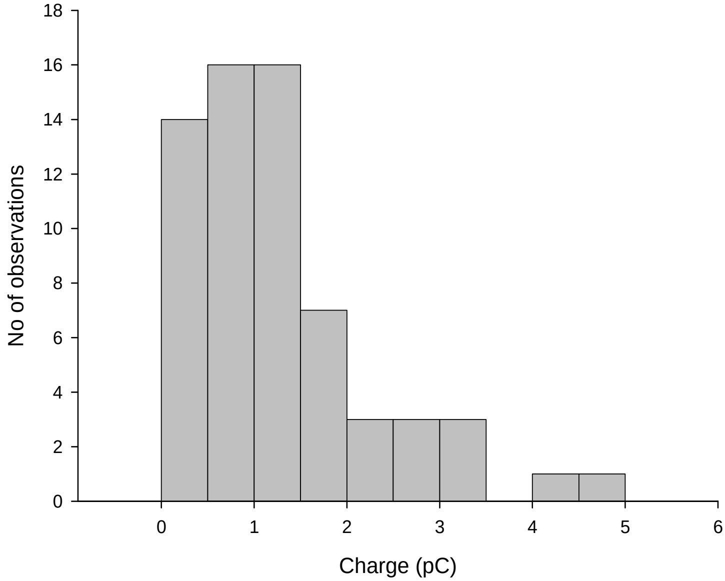

Fig. 7. Histogram showing charge transfer from Au to annealed PS

D. *The effect of the annealing*

In Table 1 we compare the charge transfer from metals to both lapped and annealed samples for the three polymers investigated. We observed that the annealing has significant effects on the charging of PTFE while there is no noticeable effect on the charge measured on Nylon and PS for all the metal contactors. In our earlier studies we reported that the charging of nylon is insensitive to the method of surface preparation while the purification of the solution- cast PS does not affect its charging characteristics [9].

TABLE 1: CHARGE TRANSFER FROM METALS TO LAPPED AND ANNEALED POLYMER SAMPLES

Sample	Type	Au (pC)	Al (pC)	Pt (pC)	Zn (pC)	Mg (pC)
PTFE	lapped	-2.59 ±0.30	-2.57 ±0.23	-1.62 ±0.19	-0.98 ±0.16	-2.13 ±0.23
PTFE	annealed	-0.88 ±0.31	-0.84 ± 0.35	-0.56 ±0.29	-0.49 ±0.03	-0.92 ±0.28
Nylon	lapped	7.34 ±0.45	0.97 ±0.11	6.61 ±0.39	1.83 ±0.21	-2.29 ±0.09
Nylon	annealed	6.44 ±0.43	0.92 ± 0.26	5.50 ±0.41	-4.10 ±0.24	-4.72 ±0.22
PS	lapped	0.75 ±0.13	-1.26 ±0.12	-0.88 ±0.12	-0.39 ±0.05	-0.88 ±0.11
PS	annealed	0.72 ±0.13	-1.88 ±0.25	-1.78 ±0.21	-1.71 ±0.23	-0.87 ±013

IV. SUMMARY AND CONCLUSION

The experiment we have discussed shows that the methods of preparation have different effect on the samples investigated. The charge transferred to PTFE by metals, for example increased markedly by lapping but becomes small again if the sample is annealed. The charge transferred for both lapped and annealed samples is independent of the metal used [Table 1]. This means that the metal work function has very little effect on the charge measured after contact and separation.

Unlike the observation made in the case of PTFE, the charge transferred to nylon from metals is insensitive to the method of preparation and it is clear that annealing has no effect on the lapped samples. The metal workfunction seems to affect the charge transfer for both treatments which is in agreement with our previous study on nylon [8]

Charge transferred to PS seems to be independent of preparation method; the average contact charge calculated for both lapped and annealed sample are almost equal for the same metal. The metal work function influences the charge transfer to polystyrene because the measured charge from low work function metal (Mg) is always negative whereas charge from the high work function metal (Au) is always positive.

In summary, the effect of sample preparation on the contact charge is not the same for all polymers. It is evident that there is no justification to conclude that the contact charge transfer to polymers is dependent on its surface cleaning. In one of our works we reported that the purification of solution cast PS sample [9] has no effect on the charge measured.

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