Ife Journal of Science vol. 7, no. 2 (2005)

CHARGING CHARACTERISTICS OF POLYTETRAFLUOROETHYLENE (PTFE) BY SINGLE NON-SLIDING CONTACT WITH METALS

A.R. AKANDE

Department of Physics, University of Botswana, Private Bag 0022, Gaborone, Botswana.

(*Submitted*: 12 May 2005; *Accepted*: 21 October 2005)

Abstract

The charging characteristics of polytetrafluoroethylene (PTFE) have been investigated by a single non-sliding intermittent contact between metal and insulator in a vacuum environment. We observed that the method of sample preparation may affect the charging properties of the insulator. In particular, the charging of PTFE is governed by the mechanical damage and this can be reversed through annealing. The results also show that the charge transfer to PTFE is more or less the same for all metals which may imply that there is no strong variation of charge measured with the metal work function. The distribution of charge is not normal, which then corroborates our conclusion that the charge variation is a result of systematic changes in the properties of PTFE.

1. Introduction

Whenever two materials with different work functions come into intimate contact, an electric charge is transferred from one to the other thereby creating a double layer. The effect is industrially important because if one of the materials is a dielectric and the other is a metal then the potential difference between them, which is initially less than one volt, may rise to many kilovolts after they have been widely separated. The additional energy is of course derivable from the work done in separating the charges. This energy is often sufficient to initiate fire or explosion or to cause physiological shock and forces that may either interfere with the smooth running of a process or spoil it by the collection of dirt. All these considerations and other useful effects (not mentioned) have given rise to much theoretical and experimental work on static electrification of solids and liquids.

The contact electrification of polytetrafluoroethylene (PTFE) by metals in particular, had been reported by many workers (Wahlin and Backstrom, 1974; Davies 1969; 1972; Harper, 1967; Lowell, 1976; 1977; Akande and Lowell, 1985) nevertheless, there are still conflicting reports as to how the charge measured relates to the contacting metals as well as the distribution of the observed charges. For example Wahlin *et al* in their sliding experiment on Teflon and Davies (1969) on the repeated rolling contact on PTFE reported that the charge transfer is linearly related to the work function of the metal contactor. On the other hand, Lowell and some other colleagues (Lowell, 1976, 1977; Akande and Lowell, 1985, 1987) concluded that the measured charge transfer does not depend on the metal work function. Some workers (Wagner, 1956; Harper, 1967; Davies, 1969; Kornfield, 1969) also reported that charge transfer in a metal/polymer contact is sensitive to the method of cleaning or preparation of the sample surface.

This paper is an extension of our previous work (Akande and Lowell, 1985, 1987) in which we reported the contact electrification of PTFE along with other polymers. In the present paper, we shall give a detailed report of an extensive study of the contact charging of PTFE. We consider further study on the polymer to be essential, because of the properties of Teflon such as high electrical resistivity, low frictional coefficient and chemical inertness, among others which make the polymer very suitable for application in various electrical and mechanical appliances (Bailey and Bailey, 2000).

2. Experimental Method

We investigated the charge transfer between the polymer (PTFE) surface and the spherical metallic surfaces after they had come into contact and then separated. Each of the metal contactors makes 120 contacts to nominally the same 10 x 12 arrays of points on the polymer sample. The procedure that we used for measuring the contact charge exchange and the description of the contact equipment had been discussed in our earlier report (Akande and Lowell, 1985, 1987). The apparatus operates in a vacuum environment of about 10^{-4} Torr to exclude the possibility of air break down thereby causing error during measurement. During the experiment, nitrogen gas can be admitted into the vacuum chamber where it can be ionised by a source of alpha particle in order to neutralise any charge present on the sample surface at regular interval. The work functions of the metal contactors were measured by the conventional Kelvin technique to an accuracy of about 0.1 eV.

email:akandea@mopipi.ub.bw

It seems very likely therefore, that mechanical damage of the surface is responsible for the strong charging of the lapped PTFE sample. Different physical surface conditions are probably responsible for the variation in the charge transfer between one as–received PTFE sample and another.

(d) Influence of previous contacts

For practical reasons, it is important to determine whether charge transfer is influenced by previous contacts to samples, assuming the charge deposited by these contacts to have been removed as described in the introductory section of the paper. If charge transfer does **not** depend on the previous contacts, it makes experiments much easier because the same sample can be used many times.

Some information on this can be found in Figure 2. The first histogram is for a virgin sample and the next two for samples previously contacted. It seems that there is no systematic difference between the two kinds of samples.

Figures 4a, b and c show that previous contacts have no appreciable effect on the contact electrification of as-received thin sheet, as-received thick material and lapped-and-annealed material. We conclude that previous contacts do not influence the contact electrification of PTFE. It is therefore legitimate for example to measure the charge transfer from (say) aluminium on the same sample already used to investigate charging by (say) gold.

(e) A comparison of charge transfer from Au and Al

An important question is "does the charge transfer varies with work function?" To answer it, we performed two kinds of experiment designed to complement each other. In one experiment, we made contacts with variety of metals to different parts of the PTFE surface. This kind of experiment is prone to systematic error due to the properties of the PTFE varying from one place to another; since different metals touch different areas it is to some extent difficult to decide whether an apparent difference between the charge from two metals is really caused by the metal being different or whether, instead it is a chance result of the variation in the properties of the PTFE. In order to offset these doubts we carried out experiments in which 120 contacts were made with Au and then with Al to the same region of the surface. Au and Al were chosen because they have quite different work functions. Nominally, the Al contacts touch the same 120 spots as the Au contacts but in practice the correspondence was probably not exact. Nevertheless, it remains true that the same region of the PTFE was used for the two metals so there is no question of any difference being due to the differences in the PTFE. These experiments are open to the objection that contacts to a previously-contacted surface might not give the same result as contact to a virgin surface. However, the results reported in section 3.4 show that there is little if any difference.

Figures 5a, b and c compare the charge transfer from Au to that for Al for the lapped, as-received thin sheet, and lapped-and-annealed material (in argon and air). In all these cases, there is rather little difference between the charge transferred from Au and from Al. A close examination shows that the charge from Al tends to be rather smaller than the charge from Au, except for the material annealed in air (for which there is no discernible difference). This impression is reinforced by considering the mean charge in each case. The mean for Al is always smaller (except for the case mentioned earlier); the difference is typically about the same as standard deviation of the distribution, i.e. about ten times the standard error of the mean. This is a very significant difference.

Thus, while to a first approximation Au and Al transfer the same charge to PTFE there seems to be a slight but probably significant difference, Au charging PTFE rather more than Al does. It seems unlikely that this difference is related to the difference in the work function, since for electron accepting insulator we should expect lower work function metal to transfer **more** charge. It is more likely to be a result of the Al being covered with a layer of oxide, whereas gold is not. But we observed that there is very little change in the work function of aluminium before and after the experiment hence there may be other reasons which account for the result.

(f) Charge transfer from various metals

In these experiments, contacts were made to PTFE with twelve different metals whose work function was measured before or after the charge transfer measurement. Ten contacts were made with each metal along a line on the PTFE surface. The plot of charge versus work function for the lapped PTFE is displayed in Figure 6 (i). The observed scatter is very large and well outside the errors, which shows clearly that the metal work function has little or no influence on the charge transfer. It seems that the charge transfer to a first approximation is constant for all metals and equal to 2.5 pC.

Figure 6 (ii) shows the result of the same experiment carried out on as-received thin sheet PTFE. We again observed considerable scatter well outside the errors hence, we conclude that the charge does not depend to a significant extent on the metal work function. The result shows that the charge tends to be smaller for low-work function metal but the scatter is too large to allow a firm conclusion.

We ask the question, why is it the scatter in Figures 6 (i & ii) are so large compared to the standard error of the mean charge of the individual metal? The probable answer is that the triboelectric properties of PTFE tend to vary systematically as we move from

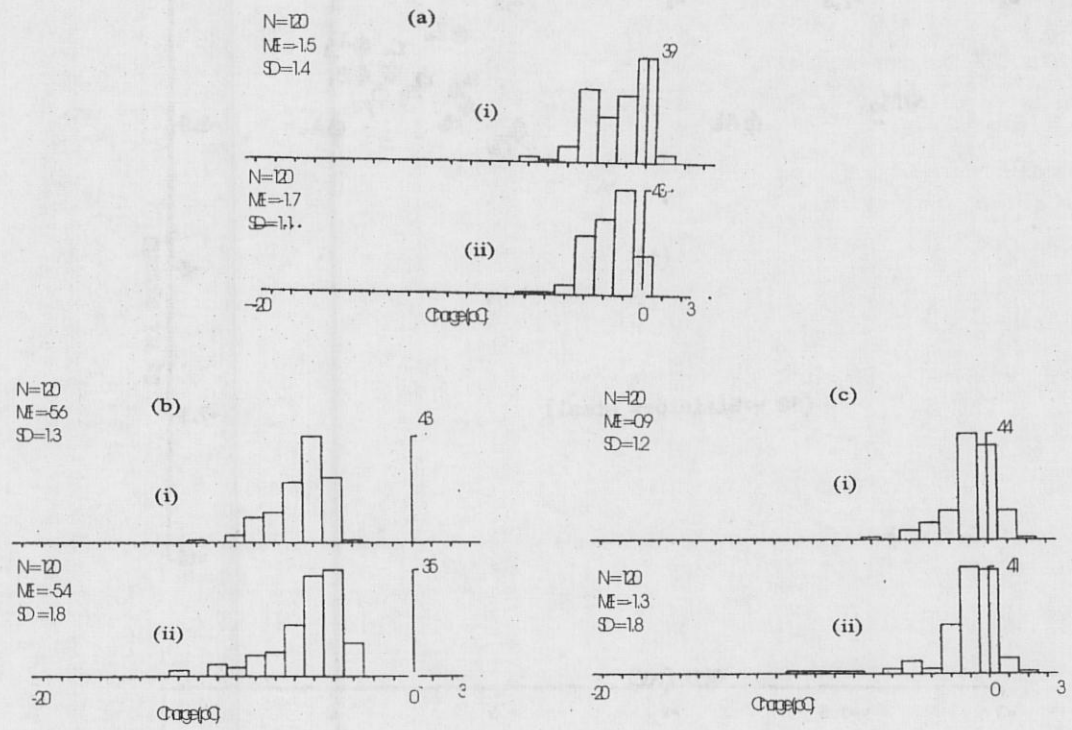

Figure 4: Effect of previous contact on the charging of PTFE by Au: (i) virgin sample and (ii) sample contacted previously by other metals and then by Au. (a) as-received thin hard sheet (b) as-received ¼ inch thick slab (c) lapped and annealed sample

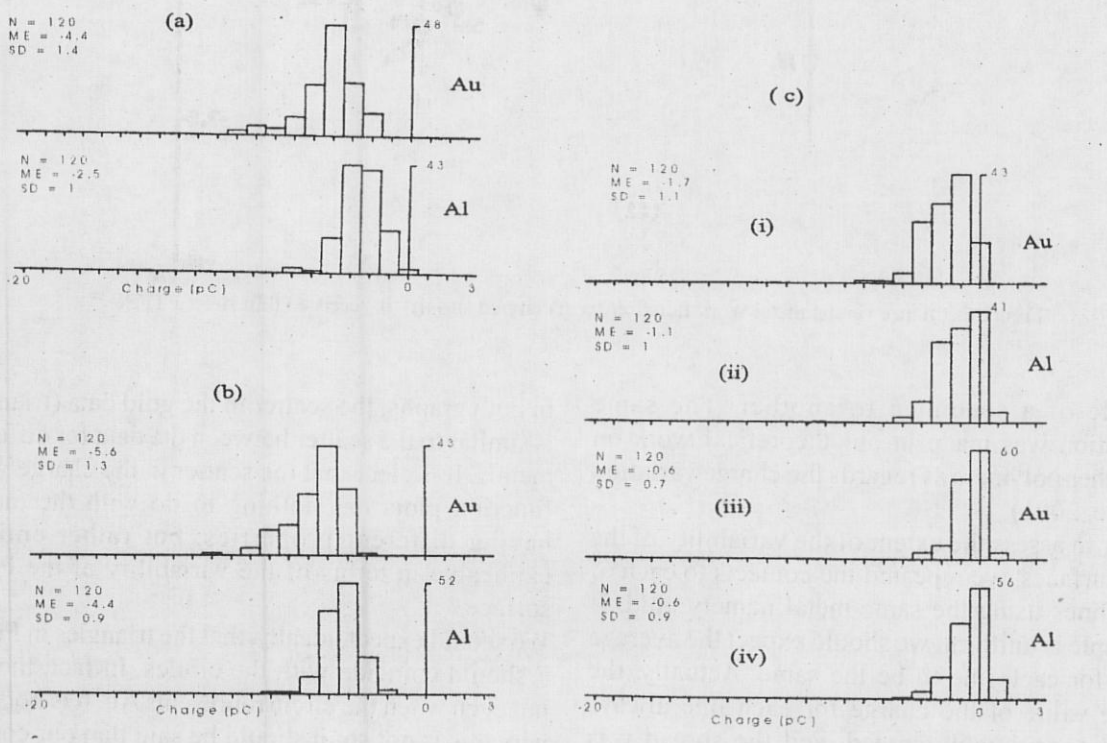

Figure 5: Comparison of charge transfer from Au and Al to PTFE
(a) lapped PTFE (b) as-received thin sheet PTFE (c) lapped PTFE i & ii annealed in argon gas iii & iv annealed in air

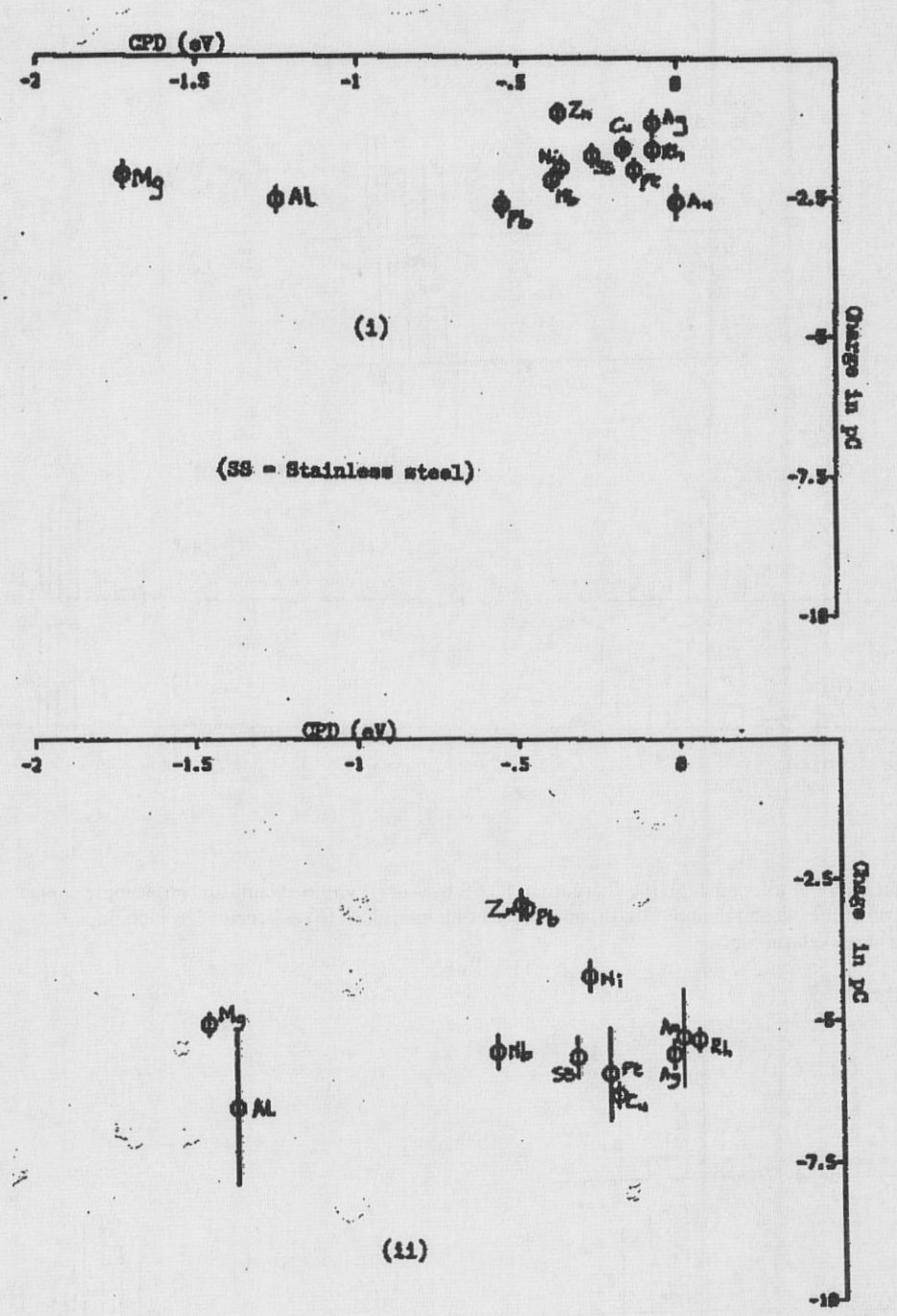

Figure 6: Charge versus metal work function for (i) lapped and (ii) as-received thin sheet PTFE

one side of a specimen to another. The same observation was made in our theoretical work on some other polymers as regards the charge variation (Akande, 2001).

In order to assess the extent of the variability of the PTFE surfaces, we repeated the contacts to each of the 12 lines using the same metal namely gold. If the sample is uniform, we should expect the average charge for each line to be the same. Actually, the average value of the charge for each line always showed considerable spread, and the spread was always comparable to that exhibited by different metals. In order to assess the sample variability, gold contacts on the graph of charge versus work function are plotted in Figures 7 (i & ii).

In both graphs, the scatter in the gold data (triangle) is similar to the scatter between the data for different metals. It is clear that the scatter in the charge/work function plots has nothing to do with the metals having different properties, but rather entirely explicable in terms of the variability of the PTFE surface.

We should expect, ideally, that the triangles in Figure 7 should coincide with the circles. In fact, they do not even when the circle represents Au. It is not clear why this is not so; it should be said that our contact equipment was not designed to relocate a given position very accurately, so that the gold contacts were probably not made to exactly the same place

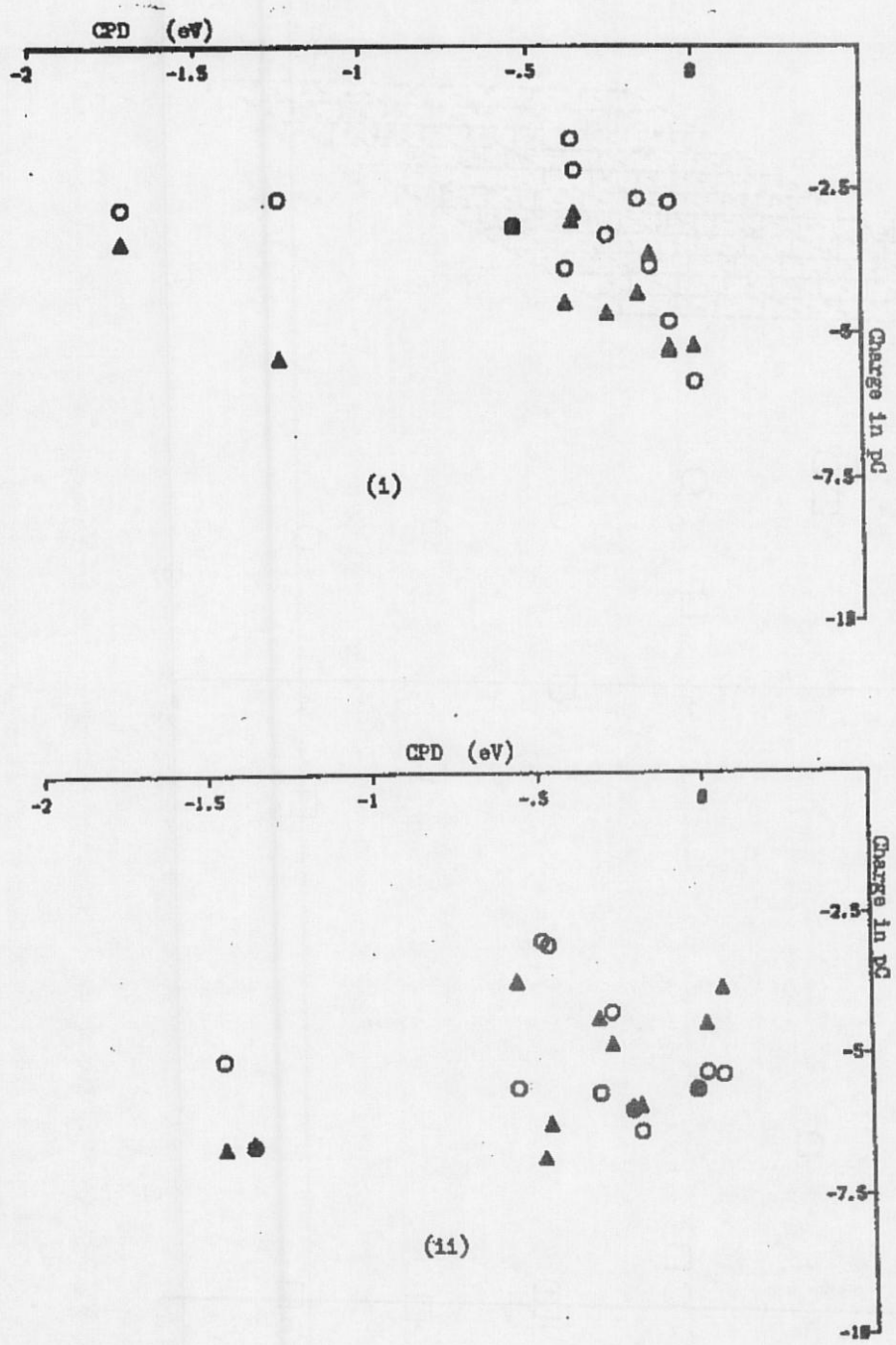

Figure 7: Charge transfer by Au plotted against work function together with charge transfer by other metals (the triangles show charge from Au contact to the same region of PTFE as the metal whose abscissae they share) (i) lapped and (ii) as-received thin sheet PTFE.

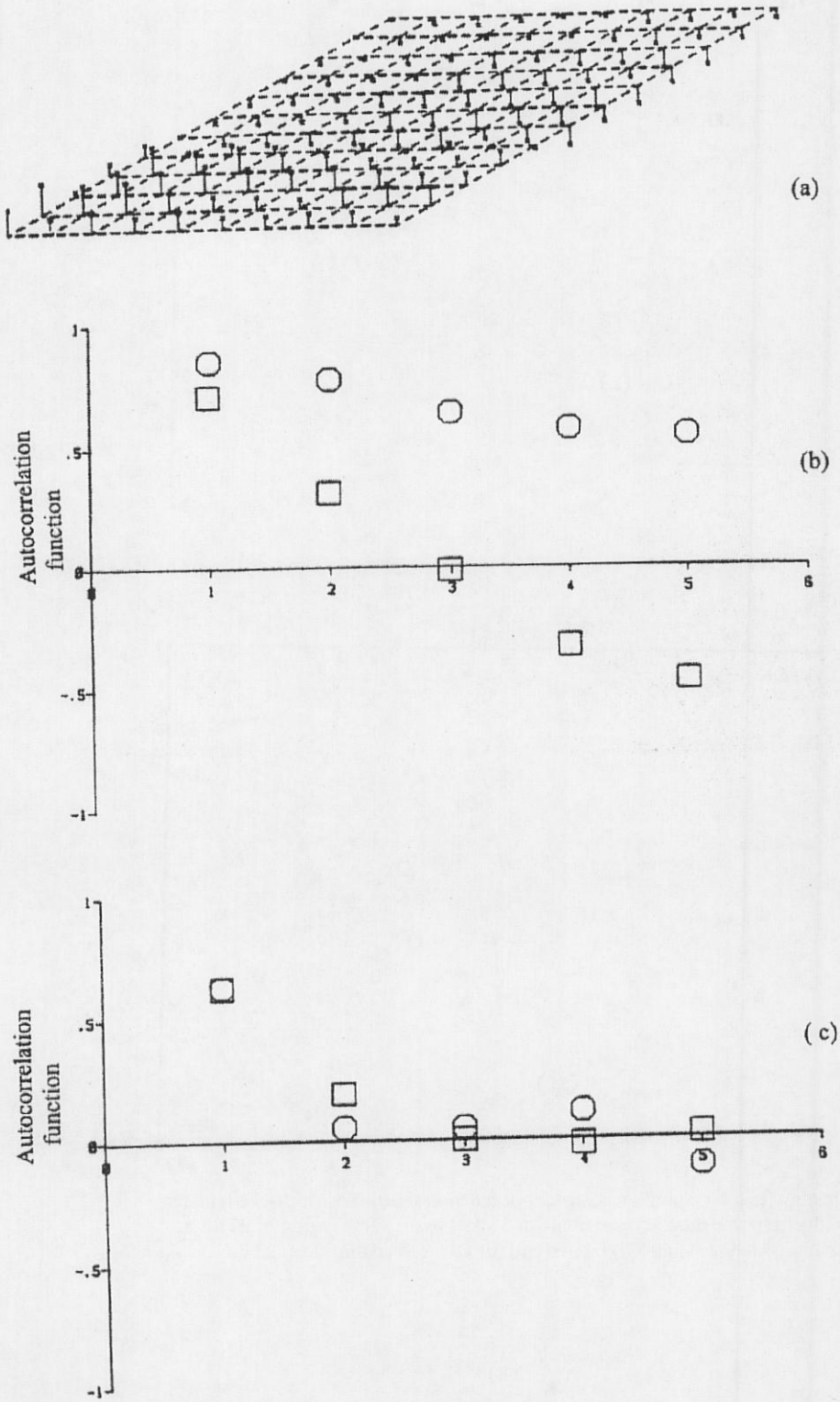

Figure 8: (a) Charge transfer from Au to lapped PTFE as a function of position on the sample i.e. charge "map".
(b) Autocorrelation function of sample 7(a) plotted as a function of distance in two grid directions.
(c) Autocorrelation function versus distance for two samples of lapped PTFE.

as the contacts with the corresponding metal. Nevertheless, the extent of the difference is surprising. It is true, however that the charge from Au tends to be similar to that of the corresponding metal in Figure 7 (i) for example, the triangles tend to follow the circles, with couple of glaring exceptions (notably Al, at CPD = -1.25 eV). An interesting example of this is shown in Figure 7 (ii); if low work function metals (Au and Mg) had been omitted from this study it might have been concluded (from the circle alone) that the charge was a strong function of the metal work function. However, Au data (triangles) clearly show that the apparent work function dependence is a spurious consequence of non-uniformity of the PTFE surface.

In conclusion, it is well established that for the samples studied here, the charge transfer to PTFE is more or less the same for all the metals investigated. There is no strong variation of charge with work function. The experiments with many metals do not refute the conclusion in the last section that Al transfers slightly less charge than Au.

(g) Variation in charge

The work described above has shown that the charge transfer to PTFE is well defined and reproducible in the sense that different samples of the same kind of material yield the same charge and roughly the same spread about the mean. However, this spread about the mean is considerable and presents obstacle to further progress in determining the contact charging properties of PTFE. For example, it makes it difficult to establish whether or not the charge transfer exhibits a slight decrease as the metal work function is reduced. It is therefore worthwhile to try to find out more about why the charge is variable. In particular, it would be useful to know whether the variation is random (in space) or systematic, and whether or not it is normally distributed.

We can obtain useful information about the spatial variation of the contact charge from the charge "map" as shown in Figure 8a. Here the sample surface is represented by the doted grid and a charge at a given position is represented by a cross. The vertical distance above or below the plane is proportional to the deviation of the measured charge above the mean. It is observed that in one direction of the grid, the charge shows a steady change from above-average to below average values whereas in the other direction there is no pronounced systematic variation. In order to supplement the qualitative information obtained from charge map, we calculate the autocorrelation function of the charge transfer. The results are plotted in Figures 8b and 8c. From the plots, we observed a tendency of charge transfer to one point to be correlated the charge transferred at another point with a distance x from it. A steady change of autocorrelation function with distance may imply a systematic variation in triboelectric properties of the polymer. We see that autocorrelation data confirm the qualitative impression we got from the charge map (Figure 8a).

For the majority of the samples studied, we found that the autocorrelation function behaved in a qualitatively similar way to Figure 8b i.e. it varied steadily over long distances. The charge was not always monotonic; sometimes for example the autocorrelation function decreased and increased again, showing a tendency for the charge to be smaller in the centre of the sample and larger at the edges. We conclude that observed spread in the contact-charge measurement is usually caused by large-scale variation in the properties of the material. This observation agrees very well with our theoretical work on the variation of charge transfer for other polymers (Akande, 2001).

We observed from the histogram plots in Figures 1 and 2 that the distribution is not normal (i.e. not gaussian) because they often exhibit a pronounced asymmetry. Quantitative information can be derived from cumulative distribution plots as shown in Figures 9a & b. From the plots it is obvious that the distribution is not gaussian because if it were, the points would lie on the 45° line. To a fair approximation the plot seems to consist of two straight line sections, which is consistent with the hypothesis that the data can be described by two gaussian distributions each with its own mean and standard deviation.

This might tempt one to postulate two independent charging mechanisms but to do so would be a rush; we have already established that the variation of charge is not random but systematic and in the light of this conclusion it is not surprising that the data do not follow a gaussian distribution.

4. Summary and Conclusion

As we had said in the introduction, a major motivation for this work was to resolve the apparent conflicts and uncertainties about the charging characteristics of PTFE. On the basis of our investigations and observations, we now give the following summaries.

(i) Charge transfer to PTFE in different forms or different sources can differ widely.

ii) The magnitude of the charge seems to be governed by mechanical damage. The charge transfer increased markedly by lapping, but becomes small again if the sample is annealed.

(iii) Metal work function has very little effect on the charge transfer. To a first approximation the charge transfer is the same for all metals.

(iv) However, there is evidence that charge from Al is consistently less than the charge from Au. This is opposite to what one would expect from the work function; the reason may be due to the Al being coated with oxide.