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The electrification of polymers by metals through repeated non-sliding and sliding contact

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Abstract-**The charge transfer between metals and polymers using repeated non-sliding and sliding mode of contact has been investigated. The reports from the previous researchers indicated that charge transfer between metal/polymer contact depend on the mode of contact; but the result from our present investigation shows that the charge transfer from the sliding contact is not qualitatively different from single non-sliding contact. In the repeated contact, we found that charge increases when contact are repeated but does not approach asymptotic or equilibrium value.**

I. INTRODUCTION

The measured charge transfer in a metal/polymer contact has been linked to the method of contact. The information from the literature informed us that that different investigators have employed different kind of contact between their metal and polymer samples e.g. a single simple contact [1,2,3] sliding contact [4] and repeated rolling contact [5]. It is conceivable that different mechanisims of charge transfer might be involved with this mode of contact. The mode of contact can partly account for the difference between theory and experimental result especially as it relates to charge measured and the metal contact work function. For example sliding contacts cause frictional heating; they may also alter the metal surface by rubing away its oxide or they may promote transfer of polymer materials to the metal surface. These or other effects may alter the charge transfer.

We report in this study an attempt to resolve some of the uncertainties and ambiguities relating to contact electrification using different modes of contact. We therefore investigated the role of metal work function in sliding and repeated contacts. Repeated contacts are known to increase charge transfer [1,6,7] and it is not implausible that the charge resulting from a large number of contacts might depend on work function in a different way to the charge transferred by a single contact.

II. EXPERIMENTAL METHOD

A. Apparatus

We investigated the charge transferred between plane polymer surfaces and spherical metallic surfaces after they had had been touched together and separated. The apparatus used were similar to the one used in our earlier study [3]. The metal samples (about 4mm radius) were either machined from the bulk metal or machined from brass and then plated. All the metal samples were polished to a mirror finish. The work functions of the metal samples were measured by Kelvin technique to an accuracy of about 0.1 eV. Samples of Mg, Zn, Sn, Pb, Ni, Cu, Au and Pt were used in the experiment.

The polymer samples investigated were solution-cast polyvinyl chloride (PVC), lapped polytetrafluoroethylene (PTFE), solution-cast polystyrene (PS), polyvinyl alcohol (PVOH) and lapped nylon. The details of cleaning the samples (metals and polymers) are contained in our earlier work [3].

B. Measurement

The experimental procedure used in our earlier study (single non-sliding) was easily adapted to the study of the sliding contacts. It was only necessary to lower the metal contactor on to the polymer sample, move its support carriage to the required distance, lift the metal sample again and measure the charge. We caused each metal sample to slide a short distance (1mm) at various places scattered across the surface of the polymer. The sliding tracks of each metal were intermingled (but not overlapping) so that each metal sampled the whole of the polymer surface rather than a particular region.

The study of repeated contacts was aimed at finding out whether the rate of charge accumulation depended on the metal work function, i.e. whether the accumulated charge after many contacts depends on the work function in a different way to the charge transfer from a single contact. We also need to allow for place-to-place variation not only the magnitude of charge transferred but also its rate of accumulation may vary from place to place. To average such variations we proceed as follows: for a given metal, we made 30 contacts to a fixed place on the sample surface measuring the charge after each contact. This was repeated at 19 other places scattered over the polymer surface and from the 20 sets of data we calculated the *average* charge Q_1 after the final contact, the average Q_2 after the second contact and so on up to 30th contact. The same measurements were repeated for other metals, interspersing the contact position so that each metal sampled the whole of the surface.

C. *Observation*

The charge measured for sliding contacts as shown in Figure 1 is not qualitatively, different from charge transferred in a single non-sliding contact as reported in our earlier study [8]. For example, the charge measured caused by metals sliding over PVC and PTFE shows no dependence on the metal work function, whereas in the case of nylon and polystyrene the charge transfer tends to increase from negative to positive values as the work function increases. We observed that the scatter in the Figure 1 is quite large; sliding 20 mm is equivalent (in total charge transfer) to making about 200 single contacts hence in our previous where in which we made an average of 64 contacts; they show less scatter than the sliding contacts. This unexpected large scatter suggests that sliding may introduce some complicating factor such as material transfer.

In the repeated contacts, we find that charge increases when contact are repeated. The result is in agreement with the findings reported by previous studies [1,2,6]. It is natural to expect that the charge should eventually approach some asymptotic value and this “equilibrium” value might depend on the metal work function while the initial rate of charge accumulation does not. However previous work [1] indicated that there may be no such asymptotic value for the charge. We find that the rate of charge accumulation diminishes as number of contacts increases but the charge does *not* approach a constant value. Instead, it continues to increase apparently indefinitely, varying roughly as the *logarithm* of the number of contacts as shown in the present study (Figure 2). In the same figure, it is clear that no “saturation” or “equilibrium” can be defined on the basis of our observation. However, we can conclude from Figure 2 that the fractional increase in charge for any number of contacts up to 30 is not dependent on the work function. This is certainly so for PTFE and PVC; for PVOH and nylon different metals do not accumulate charge at the same rate but there is no *systematic* effect of the work function. For this study, our interest was on PTFE and PVC because we had earlier that in a *single non-sliding contact* charge transfer is independent of the work function. The result in Figure 2, therefore confirm the same conclusion that in a *multiple* contact charge transfer is independent of the work function which means repeating the contact increases the charge by the same factor for all metals. This conclusion or observation is only strictly valid only for a number of contacts within the range investigated i.e. 1 – 30 (Figure 2). It is significant in this connection that the accumulated charge is proportional to the logarithm of the number of contacts, so that a very large number of repeated contacts would be required to increase the charge much more than that achieved for 30 contacts. It is therefore unlikely in *practice* that the charge transfer to PTFE or PVC will depend on the work function for any *achievable* number of contacts.

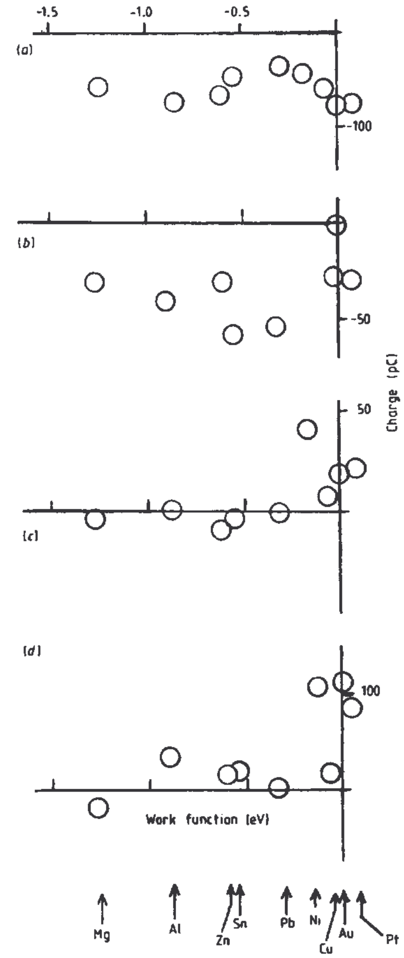

Fig. 1. Charge transfer in sliding contacts to (a) solution-cast polyvinyl chloride; (b) lapped PTFE; (c) solution-cast polystyrene and, (d) lapped nylon. The charge per mm of the sliding movement is plotted against the work function.

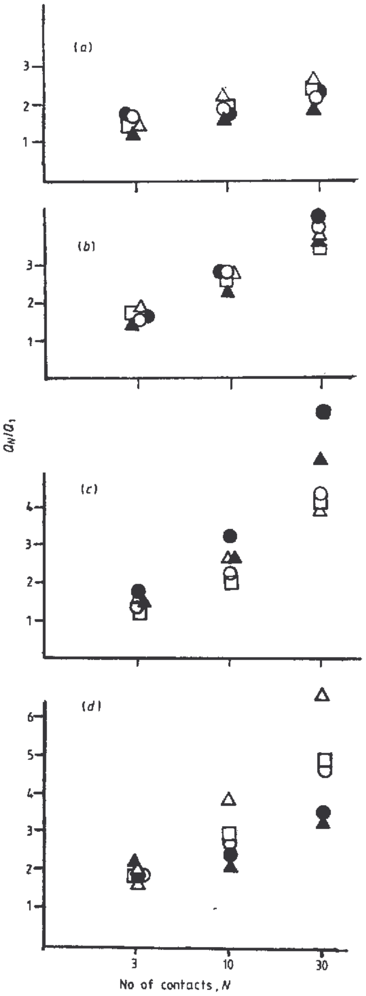

Fig. 2. Charge accumulation in repeated contacts to (a) lapped PTFE; (b) solution-cast PVC; (c) solution-cast PVOH and (d), lapped nylon. The charge after N contacts Q_N (normalized by dividing by Q_1, the charge on the first contact) is plotted against N (log scale). Each point represents the mean of 20 trials. The contacting metals are Au (open circles); Al (open triangles); Pt (open squares); Mg (full circles) and Zn (full triangles).

III. SUMMARY AND CONCLUSION

The reason for charge accumulation in a repeated contact remains obscure. Homewood et al [2] suggested that the accumulation of charge that occurs in repeated contact can be due to insulator being slightly conducting so that charge can flow away from region of contact but this is not the case of highly insulating polymer like PTFE, PVC and polyethylene (PE). Fabish et al [9] reported the steady charge level reached after repeated contact between polystyrene film and metal in term of electron injection from metal into polystyrene. Lowell [1] proposed that the accumulation of charge is a result of displacement of polymer molecules. The present study can neither confirm nor refute the hypothesis.

The importance of our observation in the context of the present work is that we may conclude that the relationship between the charge and the work function which we found for the single contact is not a special effect of a single mode of contact, but obtains also in repeated (and in sliding) contact. The apparent discrepancy between our observation and previous studies in for example PTFE cannot be attributed to different contact modes. We cannot definitely account for these discrepancies but in some cases they may be illusory.

Based on the present study and observation, we can conclude that:

(i) The charge/work function relationship seem to be essentially the same for different modes of contact – single, repeated and sliding contact.

(ii) For the repeated contact, we found that charge increases when contact are repeated as reported by previous work but does not approach equilibrium value.

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