Inkjet Printed Electroadhesive pads on Rubber

A Project Report

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By

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Balbir Singh

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1. INTRODUCTION

1.1 Electroadhesion

There are many techniques, in which astriction between two surface can occur like, suction bonding, chemical bonding and electroadhesion. Among these, some techniques comes under controllable adhesion and electroadhesion is one of them [2]. It can create adhesive forces for different surfaces like wood, glass, plastic and other tough surfaces [4].

It is the phenomenon of attraction between two surfaces, which occurs when they interact through fringing electric field. Due to electric field of one surface, the other surface will undergo polarization as surface charges are induced on dielectrics [7].

1.2 Electroadhesive pads

The design of an electroadhesive pad and the type of substrate plays a vital role in strength of adhesive force generated by electroadhesion. Substrate can be elastomer, wood, glass, paper etc. Here, we used rubber as a substrate which is an elastomer [5]. The design of electroadhesive pad consists of two electrodes and an effective area where the fringing electric field is generated. Effective area should be high to have good adhesive forces. Increasing the length and the boundary area of electroadhesive pad are the ways to increase the effective area of pad. Dielectric between two electrodes also contributes to adhesive forces between surfaces. Different substrates have their own dielectric which is a parameter to choose them as a substrate for electroadheasive pad. In this project, we have fabricated an electroadhesive pads on rubber using inkjet printing and photographic process.

1.3 Applications

Electoadhesion is used in many areas, like for handling industrial material, electrostatic chucks and in soft robotics [1], [2], [4].

2. Review of Related literature

2.1 Printing Process

There are many technologies that can be used for printing purposes. Some of them are:-

- Offset lithography
- Flexography
- Inkjet Printing
- Screen Printing etc

Here for our project we have used desktop inkjet printer. This is the most economic method of printing. In this type of printer, image is created by droplets of ink which is present in cartridge. Ink is prompted from the small sized nozzles which are presented at bottom of cartridge [6]. A cartridge consists of a staggered silicon chip called dye in which nozzles are present. Scalability and high nozzle density are the key features for printing. Silicon chip is about 1inch long and have 4200 or less nozzles in it. Properties of ink also have an effect on the resolution of image. Ink contains a complex blend of pigments and dyes, which aids page retention and produces more accurate color.

The mechanism of thermal inkjet printing is based on the rapidly heating of ink which creates a bubble at the surface of heater. This causes a pressure pulse that access to place the ink droplets through the nozzle to any substrate. Heating of ink is done by the heating element with a tiny metal plate [6]. Electronic contact with printer is performed by the staggered silicon chip. As we give the print command from desktop, a small current starts to flow through the metal or resistor and thus the heating starts which leads the ink which is in contact with print head to vaporize into a tiny steam bubble inside the nozzle in the substrate. After this an ink droplet comes out of the nozzle onto the substrate. Time taken by this whole process is in the order of milliseconds [9].

There are many factors into which the quality of printing depends, like smooth flow of ink which is restricted if the ink begins to dry at print head, which is due to low level of ink in reservoir. This ink also acts as coolant to the metal plate or resistor which is being heated.

2.2 PHOTOGRAPHIC PROCESS

We have used traditional silver halide photographic process for fabrication of electroadhesive pad. This process consists of majorly four steps.

- Photographic Exposure
- Photographic development
- fixing
- Cleaning

In photographic exposure step, aim is to obtain silver clusters within silver halide (AgBr) crystals. After printing the electroadhesive pad, it is kept at a certain distance under halogen lamp for exposure for optimum time period [8].

After exposing the AgBr crystals, photographic development is done. Developer is basically strong reducing agent which leads to reduction of free moving silver ions present in silver halide crystals. We have used D-76 as a reducing agent which contains metol, borax, sodium sulphite and hydroquinone [1], [2], [3]. In development step, photographic film produces a visible image from a latent image. Sample must be exposed properly then only developer can reduce the free silver ions of silver halide film. Silver also show catalyst effect, it acts as electrode to accept electrons from developer and transferring them onto the conduction band of the unexposed crystals. The consequences of this leads to the reduction of one silver ion, and after certain number of reductions silver so produced would itself act as the catalyst.

Development step is followed by fixing where the unreacted silver ions are removed from the photographic film. After this film is just rinsed in water and allowed to dry under ambient condition.

Silver is used in this process due to its conductivity, gold can be a replacement for silver but that is not economic.

Halides used for this process are Br and Cl, fluorides are not used because silver halide is hygroscopic in nature. Silver iodide is also rarely used as it is extremely insoluble in aqueous systems [3]. Silver bromide and chloride is generally used with a few per cent of iodide in photographic process.

3. Experimental Methods

3.1 Fabrication of electroadhesive pads

Several patterns can be used to fabricate electroadhesive pad, like interdigitated electrode, gecko structured pattern, concentric circles etc. Here we have printed an interdigitated electrode pattern. Firstly, for gaining confidence I have printed my electroadhesive pad on paper and then rubber. The Dimensions of pattern printed on paper and rubber are as follows:-

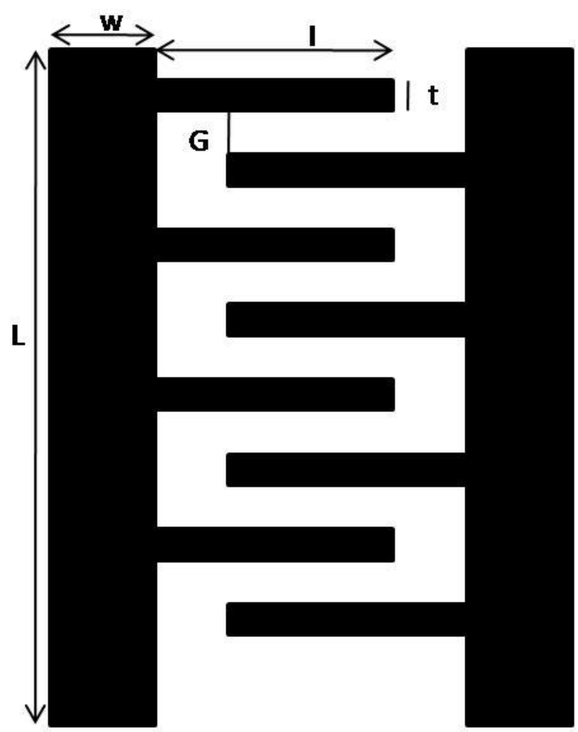


Figure1 Design for interdigitated electrode pattern

Dimension	Paper (cm)	Rubber (cm)
L	14.5	12
I	2	4.8
w	1	1
t	0.1	0.3
G	0.1	0.05

Table 1 Dimensions of pattern

The Printer setup used here is desktop inkjet printer (HP DeskJet 1010 series, Rs 2000). This setup is based on the thermal inkjet printing technology where chemicals are used in place of ink in cartridge. Chemicals used are:-

- Silver Nitrate (99.99%) was obtained from Sigma-Aldrich India
- Potassium iodide (99.0%) and
- Potassium bromide (99.0%) was obtained from SD fine-chem. Ltd. India.

Initially 0.5M solution of silver nitrate and 1M solution of mixture of KCl and KI (Cl:I::95:5%$_w$), KBr and KI (Cl:I::95:5%$_w$) were used. All the solutions were made in DI (dionised) water. Different cartridge is used for different solution. Two different patterns were printed on paper using KCl and KBr by printing alternate layers of potassium halide and silver nitrate. In case of rubber, the pattern is printed using potassium bromide. Cartridge is cleaned with propan-2-ol after printing each layer of Silver nitrate and potassium halide.

Printing a pattern in rubber is a challenging role. We have used butyl rubber as a substrate for electroadhesive pad which is hydrophobic in nature, to deal with this problem; we have increased the roughness of the rubber by rubbing its surface with sand paper and tissue paper. To obtain uniform printing, maximum DPI (droplets per inch) on rubber, printer settings were adjusted as speciality paper, best quality. By doing this, print head will move only above the printing pattern resulting into minimum spreading of solutions and maximum DPI. Appearance of greenish tint on the substrate confirms the formation of silver bromide. Pattern is kept for drying up to optimum time after printing each layer. Pattern printed on paper is dried under fan and the pattern in which rubber is used as substrate, is dried under ambient condition.

After printing, the patterns were exposed to light through a conventionally used halogen lamp (500W) for 20 minutes in case of paper and 30 minutes for rubber substrate. We have also done a study on the optimum distance at which the rubber pattern is kept under halogen lamp for exposure. After exposing, patterns were dipped in a photographic developer, D-76 for 10 min. in case of paper and overnight development is done for the pattern printed on rubber. Composition of developer is as follows:-

- 20 g sodium sulphite
- 0.4 g metol

- 1.0 g hydroquinone
- 0.4 g borax
- 200 ml dionised water.

Then, the pattern is rinsed in water for 10 minutes and change in the color of pattern is noticed. Subsequently, the pattern is allowed to dry for 3 to 4 hrs in ambient conditions.

4. Results and discussions

4.1 Study of exposure distance from halogen lamp

A study has been carried out on, effect of distance at which rubber pattern was placed from halogen lamp for exposure. We have taken three similar printed pattern on rubber in which two layers of each solution was printed. The results were obtained as follows:-

Sample	Distance From halogen lamp (cm)	Exposure Time (minutes)	Development time (hrs)	Resistance (Ώ,ohm)
1	22	30	3	243
2	35	30	3	120
3	55	30	3	110

Table 2 Study on optimum distance from halogen lamp

According to results obtained, pattern which is placed at maximum distance from halogen lamp during exposure has the maximum conductivity. When we place our pattern near to lamp, smell of burning of rubber confirms that, The substrate is getting attached with silver halide crystals which hinder the growth of silver clusters around them and this whole will lead to increase in the resistance of pattern. Pattern should be placed at sufficient distance during exposure process so that silver crystals cannot get destroyed and have sufficient energy to form its clusters.

4.2 Study of Potassium halide and drying time

We have printed two similar patterns using different potassium halides; KCl and KBr. Pattern which is printed using KBr have some conductivity while another pattern does not shows conductive nature. This may due to, in case of KCl, silver nanoparticles will form and formation of silver nanowires will take place in case of KBr. Silver nanoparticles may not have uniform distribution and distance between two consecutive particles is not able to conduct the electricity through them. But silver nanowires are continous through which smooth flow of electrons occur on applying sufficient voltage across electrodes.

Drying after printing each layer is another key factor which contributes to conductivity of pattern. We have printed two similar patterns on paper substrate using KBr and kept for drying up to 3 minutes and 8 minutes under fan. The pattern which is dried for 3 minutes does not have conductivity, but the pattern which is dried up to 8 min. shows some value of resistance as measured using a multimeter. This may be because of that the reactants are not getting sufficient time for conversion.

In case of rubber substrate, if the pattern is kept for drying horizontally, it has uniform conductivity throughout its surface, which is not observed in the pattern which is kept slightly at any angle or vertical position. This may be because of the movement of silver halide crystals from top to bottom of pattern due to which more no. of silver nanowires will form at the bottom, which leads to higher conductivity at that point.

4.3 Shielding of wires

To obtain uniform printed pattern on paper and rubber, we have covered the wire which is connects the laptop and printer with aluminium foil. In laboratory, there are many computer systems, high voltage equipments are present (control panel). They generate their own electric field which may interact with electric field of printer wire. The shielding of the wires with an Aluminium foil acts as an insulating layer for the electric field of the equipments which may disturb the electric signals of printer wire.

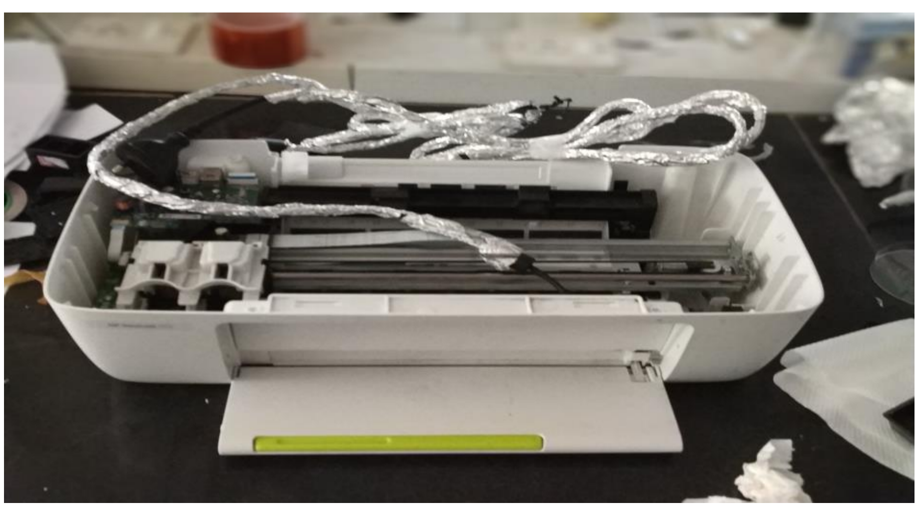
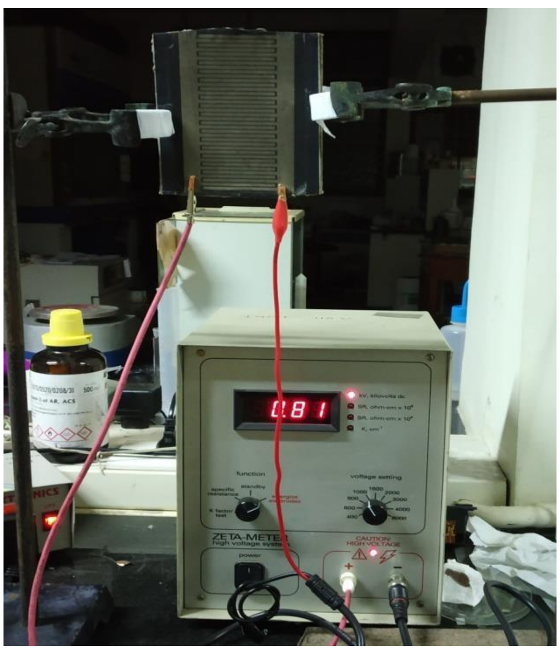


Figure 2 Shielding of printer wire with Aluminium foil.

4.4 Electroadhesive load test

Electroadhesive load test was carried out using a set-up shown in figure 2. The paper and rubber substrates were clamped onto a cardboard base for ensuring mechanical rigidity and electrical insulation. High voltage was applied onto both rubber and paper pattern. Voltage is increased in steps upto 4kV. The effective area of paper pattern was 23 cm^2 and that of rubber pattern was 55 cm^2. Both paper and rubber based electrodes were covered with thin 20µm polyethylene terephthalate sheet to enhance the electric field generated by electrodes and protection of pattern from dust. PET sheet acts as a dielectric which enhances the fringing electric field between electrodes. High voltage is applied and setup is kept undisturbed for 15 min for paper pattern and 2 hrs for rubber pattern for stabilization. After achieving stable voltage, a glass slide of known weight is adhered on the surface of both patterns. Additional weights were hung on the paper substrate pattern.

Figure 3 Digital photograph of set-up



The paper printed pattern was able to sustain a load of 100 g at 1.5 kV. After applying voltage above 2kV, sparking occurs which deteriorates the pattern as silver nanowires was getting destroyed and finally failure occurs. When higher voltage is applied change in texture and color of pattern will occur. We have observed that a brownish color had penetrated into the pores of paper and the printed pattern was also visible from the backside of the paper. This can be due to electro migration of excess salts left behind after development. Migration of electrons takes place from negative to positive electrodes which increase the width of positive electrode and decrease in the width of negative electrode.

In case of rubber, high voltage is applied and set-up is kept undisturbed for 10 hrs stabilization. Initially, voltage is increases with a very slow rate up to 800V after that it again starts to decrease. Pattern is sustaining a load of 6.1g at 400V. Above 3kV, sparking starts to occur and which will deteriorate our pattern. Brownish colour near the boundaries of pattern confirms the occurrence of electro migration. We have conducted electroadhesive load test on same rubber substrate sample for consecutive three days and observed that the pattern has negligible change in its conductivity. On the other hand, paper substrate gets deteriorate rapidly as compared to this one, which means rubber substrate can sustain for longer time period.

Conclusion

In conclusion, the print-expose-develop process has been used to fabricate an electroadhesive pad on rubber, using an office inkjet printer and silver halide photographic process. The paper sample has sustained a load of 100g at 1.5 kV and rubber sample sustained a load of 6.1 g at 400V. But we have observed that rubber pattern has a better life as compared to paper substrate pattern. This confirms that in place of paper, rubber can be used in future for fabricating electroadhesive pads.

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