

PREPARATION AND CHARACTERIZATION OF CONDUCTIVE CARBON BLACK/ POLYDIMETHYSILOXANE (PDMS) COMPOSITE

H. Jaafar¹, Nur Haziqah Abd Aziz¹, R. M. Sidek¹, M.N.Hamidon² and S. Shafie²

¹*Department of Electrical and Electronics, Faculty of Engineering,
Universiti Putra Malaysia, 43400 Serdang, Selangor, MALAYSIA*

²*Institute of Advanced Technology, Universiti Putra Malaysia
43400 Serdang, Selangor, MALAYSIA*

**Corresponding author: jhaslina@upm.edu.my*

ABSTRACT

This research comprises of preparation of carbon black nanoparticle and polymer for conductive composite and characterization of electrical properties for flexible electronic applications. Currently, conductive carbon nanotube-polymer composite is widely explored and recently applied in printed flexible and wearable sensors, RFID, optoelectronics circuit and solar cell. The carbon black-polymer conductive composite has good physical and electrical performance on flexible substrate and also low cost compared to other carbon materials. In this work, carbon black powder was mixed with Polydimethylsiloxane (PDMS) and the curing agent to create the conductive carbon composite. Mixture of 5%CB, 7.5%CB, 10% CB and 12.5%CB of the composite were prepared and cured in an oven at 80°C. Electrical conductivity and mechanical properties were measured and observed. Sample with 12.5%CB has higher conductivity compared to the other samples. The mechanical characterization also shows that the sample with 12.5%CB has the lowest resistance changes as the force applied increased. This conductive carbon-polymer composite is very useful as a sensing material of flexible biosensors and electronics circuit for biomedical other potential applications.

Keywords: carbon-based; carbon black; PDMS; conducting composite; flexible electronics

INTRODUCTION

The development in nanoparticle technology has been growing rapidly over the past few years. New researches and studies are demanding for developing the nanoparticles applications. Recently, increasing medical and biological interest in cheap disposable, analytical, and diagnostic devices has driven research towards the development and adaptation of low-cost electronic sensing devices. Carbon has proven to be a non-metal compound to serve metal's electrical properties. Carbon nanoparticles would also be a good, and cheaper source of nanoparticle with a wide range of applications compared to gold nanoparticles. Carbon-based conducting polymers developed for printing and flexible electronics could be on nanocomposites which made by mixing of metallic

nanoparticles with organic elastomers [1]. Carbon black, Carbon Nanotubes (CNT) and Graphene are widely explored recently to develop polymeric composite due to their high electrical properties.

The electrical properties of polymeric composites are highly dependent on volume, distribution, size, shape, phase orientation and interaction with the added conductive fillers [2]. The electric charges create electrical pathways and are a transition of electrically insulation to conductive. Thus, appropriate level for conductive fillers such as carbon black is needed to establish a compromise between desired physical and electrical properties. If the elastomer were highly loaded, the nano-material will become too hard and would exhibit lower elongation and tensile strength [3].

Amongst the list of metals paste practiced for printed electronics, silver (Ag) based pastes is the choice of most researchers due to its good physical and electrical performance on plastic substrates [1]. However, it cannot meet the purpose of low cost flexible electronic devices, which is the main purpose of screen printing technology. Polymer nanocomposite carbon and copper based pastes also show conductive properties for electronic and electrical applications. However, oxidation of copper based inks/pastes after printing is the main drawback of copper ink [4]. Thus, conductive carbon black-polymer composite is the solution due to nano-sized carbon particles has good electrical conductivity on flexible substrates.

Carbon black (CB) is comprised of nano-sized particles that have excellent electrical conductivity [5]. As a special grade of carbon black, conductive CB has an excellent electric conduction behavior which enables it to be used in various practical applications that require effective electrical conductivity, antistatic ability, antiradiation and electromagnetic interference (EMI) shielding [6]. CB has a fine conductivity which makes it good for sensor material and filler in thermally conductive composites.

Theoretically, as the amount of CB increase, the electrical resistivity of the polymer nano-composite will decrease and thus the thermal conductivity will be increased. In other words, if the CB is low, the electrical resistivity will be high due to the electron will have difficulty to move in low conductivity sample. Various polymers such as poly(methyl methacrylate) (PMMA), polycarbonate (PC), poly(ethylene) (PE), and others have been incorporated with carbon nanofillers. However, silicone-based elastomer polydimethylsiloxane (PDMS) is chosen in this work as it owns superior mechanical elasticity of tensile strain, making it an ideal choice for large-range strain sensing applications.

MATERIALS AND METHODS

Preparation of conductive carbon black-PDMS composite material

In the preparation of nano-composite material, 40 nm-particle size of carbon black is mixed with PDMS to obtain a conductive composite. Ratio of PDMS and the curing

agent is 1:10. The percentage of carbon is varied from 5 percent to 12.5 percent of composite for better conductivity. Mixture of carbon and PDMS is stirred in high rpm (2000-3000rpm) of speed mixer for few minutes. The mixture is then cured at 80°C in oven.

Table 1: The mass of PDMS, solvent and carbon black according to the percentage based on 7g-sample size

Sample	PDMS+solvent (g)	CB (g)	% CB
S1	4.75	0.25	5.0
S2	4.63	0.38	7.5
S3	4.50	0.50	10.0
S4	4.38	0.63	12.5

Characterization

The characterization of electrical properties included includes I-V plot to obtain the resistivity, conductivity, temperature effect and dielectric properties. The composite is not conductive if the carbon black concentration is too low. Electrical properties were measured using resistance meter. From measured resistance, resistivity (ρ) is then calculated based on equation (1) while conductivity (σ) is calculated using equation (2);

$$R = \frac{\rho L}{A} \quad \text{eq (1)}$$

$$\sigma = \frac{1}{R} \quad \text{eq (2)}$$

The mechanical characterization is determined by using tensile machine. The composite is clamped both sides at the machine and force will be applied to stretch the composites. Resistance changes over force applied will also be characterized using resistance meter. Elongation or strain of the composite is investigated for each of carbon compositions.

RESULTS AND DISCUSSION

Electrical Properties

The samples were tested for their resistance. Table 2 shows the details of resistivity and conductivity of four different samples with different percentages of carbon fillers. Figure1 shows that the conductivity of the CB-PDMS paste is increase as the percentage of carbon increase. This is because the electrical properties of carbon black filled create electrical pathways in the composite. Thus, appropriate weight and percent for conductive carbon fillers is needed to establish a compromise between desired physical and electrical properties. This result also proves the eq (2) above.

Table 2: Resistivity and conductivity of carbon black-polymer composite/paste samples

Sample	Resistivity (k Ω -mm)	Conductivity (S/mm)
S1-5%	19.91	0.0502
S2-7.5%	15.36	0.0651
S3-10.0%	1.55	0.6446
S4-12.5%	0.75	1.3303

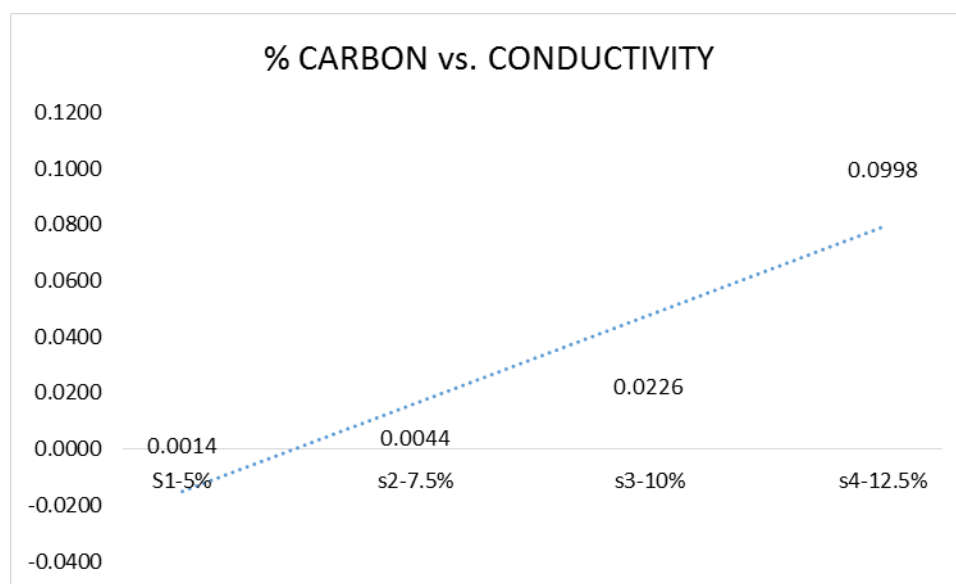


Figure 1: Percentage of carbon vs. conductivity for all samples

Mechanical Properties

The samples were also tested on mechanical properties and the changes in electrical properties. Resistance is measured using resistance meter while samples are stretched by force which consistently increased. This characterization is executed by Instron tensile machine. Thus, changes in resistance of all samples were measured while the samples are stretched. Results are as shown in Figure2 which shows resistance vs. extension of both samples, S3 (carbon10) and S4 (carbon12.5).

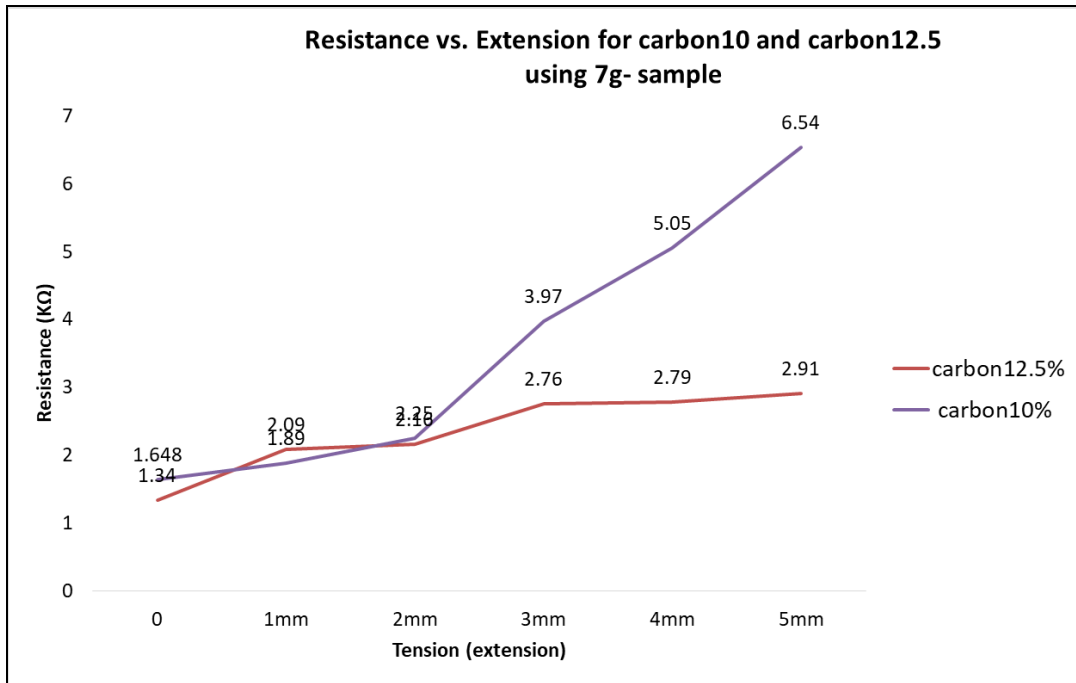


Figure 2: Resistance vs extension of (S3) carbon10 and (S4) carbon12.5

Figure 2 shows that carbon with 12.5%CB has lower resistance at most of all conditions compared to carbon with 10%CB while being stretched. The low value in resistance means higher conductivity which proves the equation (1). The relationship also shows the stretchability of the carbon composite due to the linear graphs obtained. In this work, force applied is limited due to samples slipped off from the clamped as the force increased. Fig 3 (a) and (b) shows the resistance changes over force applied for both S3 and S4. Resistance values are increase with increased force for both samples. However, the difference in resistance values are obviously seen as the resistance for S4 is very much lower (almost ten times) than S3.

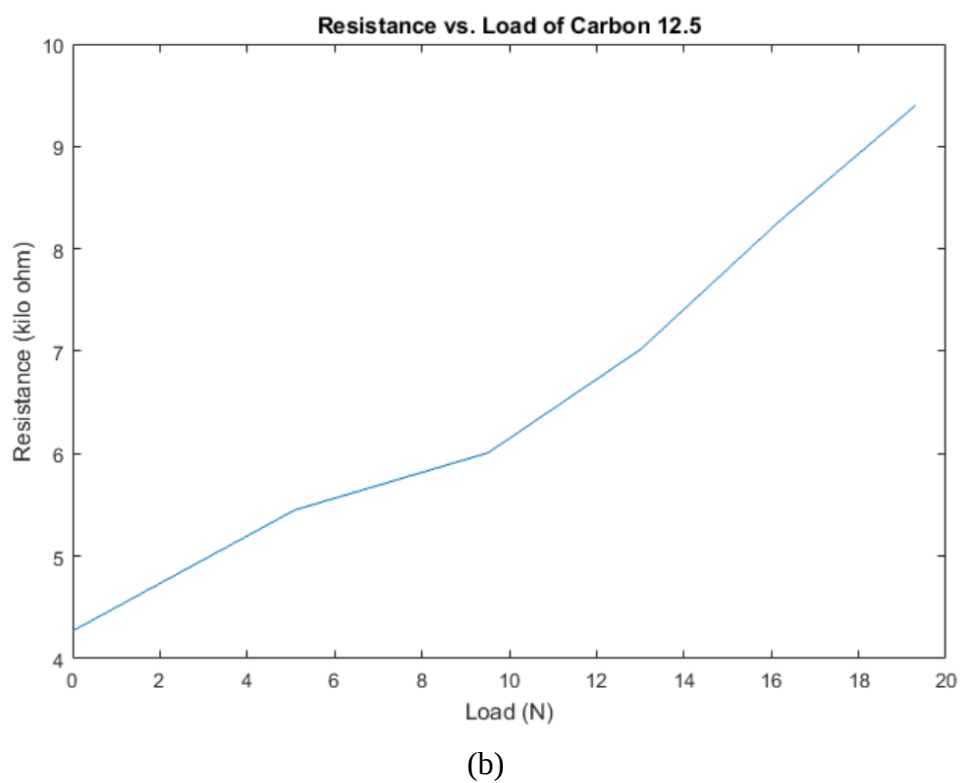
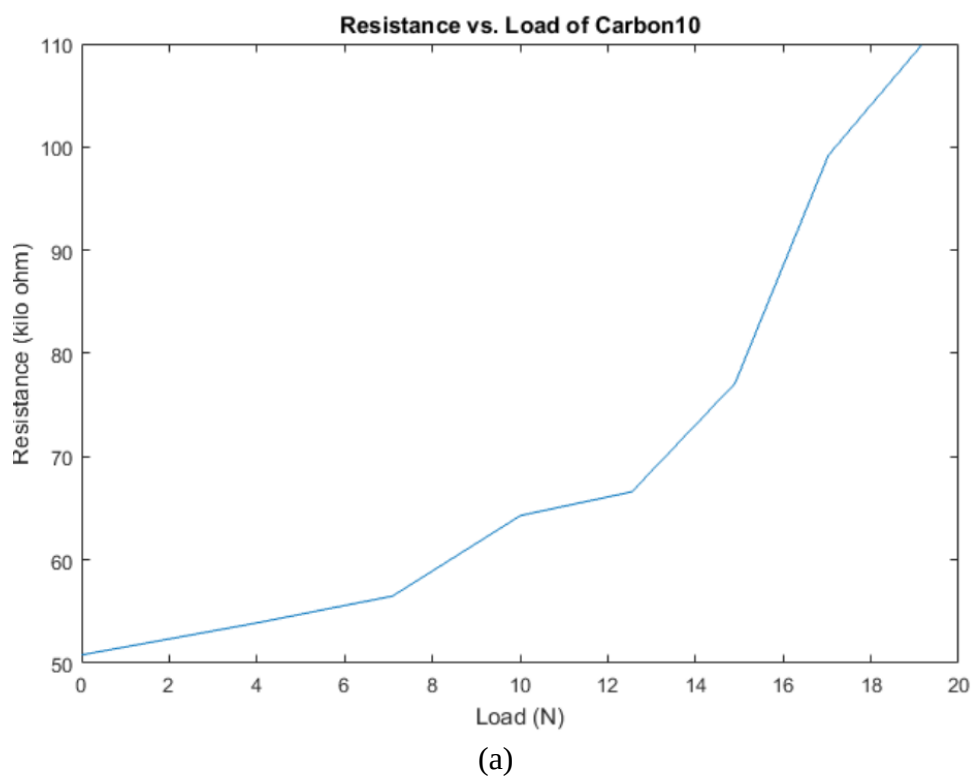


Figure 2: Resistance vs. Force Applied for (a) S3 and (b) S4 samples

CONCLUSION

As a conclusion, the conductive carbon black- PDMS composite is prepared in four percentages of carbon black to compare the electrical properties. Conductivity is linearly proportional with the percentage of carbon black. This, the highest percentage of carbon fillers in the polymer (12.5%) shows the highest conductivity. Mechanical properties of the composite also shows linear relationship which the resistance is increased with the extension and force. Thus, the conductive paste is a stretchable material. However, the tensile force is limited as discussed earlier to observe the nonlinear behavior.

REFERENCES

- [1] Saleem Khan, Leandro Lorenzelli, and Ravinder S. Dahiya *IEEE Sensors Journal*, **15** (6) 3164-3185 (2015)
- [2] Müller, K., Bugnicourt, E., Latorre, M., Jorda, M., Echegoyen Sanz, Y., Lagaron, J. M., Schmid, M. *Automotive and Solar Energy Fields. Nanomaterials*, **7** (4) 74 (2017)
- [3] Yamada, T.; Hayamizu, Y.; Yamamoto, Y.; Yomogida, Y.; Izadi-Najafabadi, A.; Futaba, D. N.; Hata, K. *Nat. Nanotechnol.* **6** 296–301 (2011)
- [4] D. S. Kim, A. Khan, K. Rahman, S. Khan, H. C. Kim, and K. H. Choi, *Mater. Manuf. Process.*, **26** (9) 1196–1201 (2011)
- [5] Lee, D.; Hong, H. P.; Lee, M. J.; Park, C. W. *Sens. Actuators, A* **180** 120–126 (2012)
- [6] Cohen, D. J.; Mitra, D.; Peterson, K.; Maharbiz, M. M. *Nano Lett.* **12** 1821–1825 (2012)