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## Bare Conductive® role as filler in mechanical and electrical reinforcement of polyvinyl alcohol-based strain sensor

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# Bare Conductive® role as filler in mechanical and electrical reinforcement of polyvinyl alcohol-based strain sensor

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**Abstract.** Polyvinyl alcohol (PVA) is a water-soluble polymer typically suited for food and biomedical applications. However, its non-conductive properties limit PVA potential as material in electronic or sensor-based devices. In order to enhance the electrical as well as mechanical properties of PVA, Bare Conductive® (BC) paste was incorporated into PVA solution using solution intercalation method. It is discovered that the addition of BC could enhance the mechanical and electrical properties of PVA. The tensile test data showed that the presence of carbon black in BC had resulted in the tensile stress improvement at about 50-170 % as compared to that of the original value. On the other hand, the electrical conductivity of PVA/BC composite film at a higher wt% had demonstrated a significant increment in resistance/length ratio (1.86 kΩ/cm at 0.2 wt%BC).

## 1. Introduction

Polyvinyl alcohol (PVA) was firstly prepared in the year 1924 through polymerization of vinyl acetate and followed by hydrolysis of acetate groups [1]. Generally, PVA is regarded as one of the most typical polymer used in the industry, which explains the extremely large world production of PVA that can be achieved annually [2]. Because of its good chemical resistance and mechanical properties, there were wide ranges of application of PVA in different industries that can be seen in biomedical or pharmaceutical industries. Despite its popularity, a pristine PVA is known to have a lower tensile strength as compared to that of other polymers. Moreover, original PVA is considered as non-conductive and thus, limiting its application for various electronic devices. Hence, the addition of filler into the matrices is certainly a great idea to enhance the mechanical and electrical properties of PVA [3].

In this work, we propose that the application of commercial electrical paint with Bare Conductive® (BC) brand can be used to improve the mechanical and electrical properties of PVA [4]. This easily accessible conductive ink consisted of water, natural resin, conductive carbon, humectants and other unmentioned preservatives. Due to the high presence of carbon content in its chemical composition, it appears as black-opaque in color and is shown to have a sheet resistance of approximately at 55Ω/□ in value. Besides being economical, a highly solubility of BC in water is also one of the strong point for selection of BC as filler for water-friendly PVA. It is noticed that there were already a number of reported BC applications for prototyped electrical devices such as solder-less assembly for electronics (SAFE) [5], wearable radio frequency identification (RFID) [6] and sensors [7] with a reported resistivity range that



was varied between  $32\text{-}55\Omega/\square$ . To the best of our knowledge however, the application of commercial BC as filler for polymer has never been discussed in any literature until now.

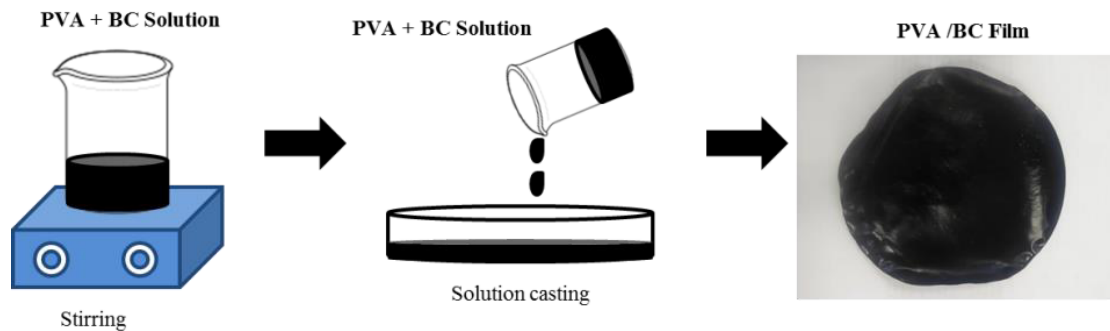
## 2. Method

### 2.1. Materials

Electric paint (Bare Conductive®) at 50 ml volume was obtained from retail store and was used as received. Meanwhile, polyvinyl alcohol (PVA) was supplied by Sigma Aldrich (Malaysia).

### 2.2. Solution casting of PVA/BC composite

A set of 0.25, 0.5, 0.75, and 1 g of BC mass were dissolved individually in 500 g PVA solution (0.1mg/ml) to get the desired weightage% ratio prior to the mixing for 15 minutes. Once completed, the resulted dispersion was poured into a petri dish and was left overnight to allow a drying process of PVA/BC composite film. A schematic illustration method is shown in Figure 1 for complete process of representation.



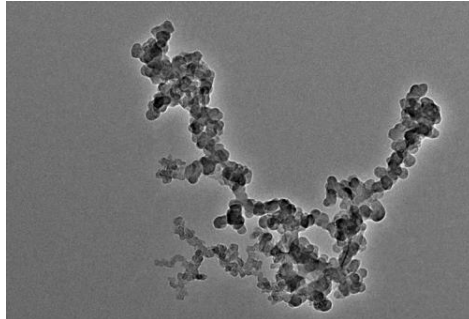
**Figure 1.** PVA/BC composite films preparation is graphically presented

### 2.3. Characterizations

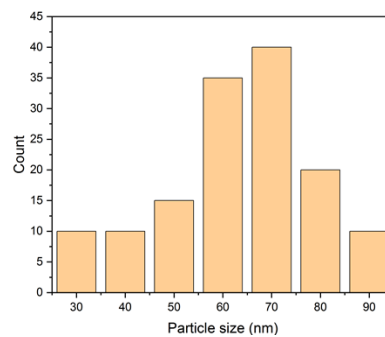
Morphological and structural analysis of BC and the resulted PVA/BC composite film was investigated using TEM and SEM. In order to determine the film conductivity, the mean resistance for each casted film of PVA/BC composites with different wt% was measured using two-probe method (Victor 86B). Later, the same samples were used for tensile test measurement, whereas three strips with dimension of  $1\text{ cm} \times 5\text{ cm}$  each were cut out from the film. A universal testing machine (INSTRON) with a designated load cell of 250 N was employed for measurement of the strips with extension rate of  $5\text{ mm min}^{-1}$ . The ambient temperature during the test was recorded at  $26^\circ\text{C}$ .

## 3. Results and discussion

The TEM image shown in Figure 2 indicates agglomerated state of carbon black in Bare Conductive® ink. We measured the particles size and noted that the recorded dimension from 140 particles measurements was ranged between 30 to 90 nm in values (see Figure 3).

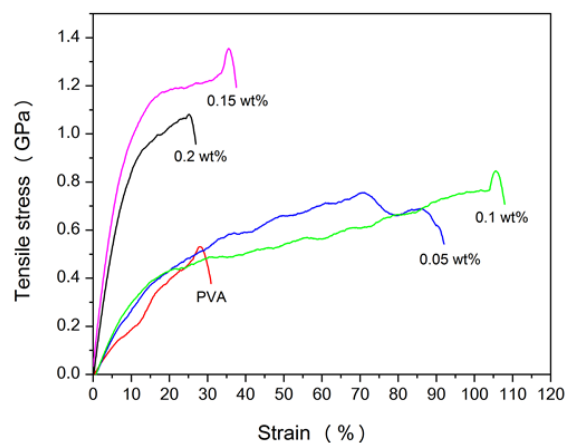


**Figure 2.** TEM image of agglomerated carbon black for Bare Conductive® ink



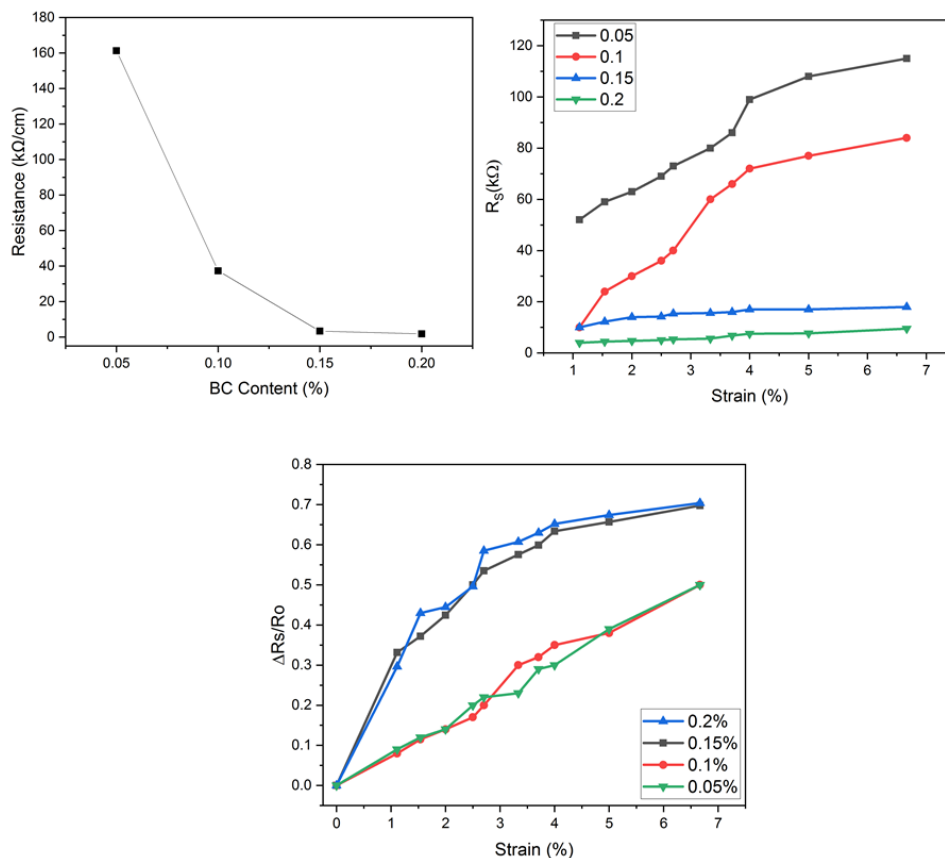
**Figure 3.** Particle size distribution for Bare Conductive® ink

Figure 4 shows stress-strain plot of PVA and PVA/BC films after addition of BC at varying mass. We noted that there is an increment for tensile stress from 0.5 GPa (pure PVA) to 1.35 GPa after incorporation of 0.15wt.% BC. However, further addition of BC in PVA matrices (0.2wt.%) would decrease the mechanical performance of PVA/BC composite due to the possible agglomeration and weakened interfacial interaction between filler and polymer matrix [8].



**Figure 4** Typical stress-strain plot for PVA and PVA/BC composite

In the resistance analysis for PVA/BC composite (see Figure 5a), it is observed that the increment of BC mass would improve the electrical conductivity and reduce the resistance values further. The addition of conductive BC into the insulating matrices is suggested to increase the number of conductive network in the matrices, which plausibly explain a significant decrement of resistance even at a smaller BC mass. Meanwhile, for details investigation of strain sensing performance against varied strains magnitude (1.1%–6.7%) for PVA/BC composite with 0.05wt.%, 0.1wt.%, 0.15wt. % and 0.2wt. % mass, the resulted resistance changes ( $R_s$ ) were plotted as a function of strain and further presented in **Figure 5b**. Generally, the subjected strain ( $\varepsilon$ ) on a thin film sensor can be calculate by considering  $\varepsilon$  as the ratio of substrate thickness, ( $t$ ) and bending diameter ( $D$ ) [9]. In this paper, the value of  $t$  was taken as 100  $\mu\text{m}$  with bending diameter  $D$  was taken between 1.5 and 9 cm.



**Figure 5.** Characterization of electrical and strain sensing ability of PVA/BC composite film

It is clear that the increment of BC content from 0.15% to 0.2% in the PVA matrix would contribute to a resulted smaller value of  $R_s$ . We also notice that the sensitivity ( $\Delta R_s/R_0$ ) of our PVA/BC composite was enhanced with almost 0.7 at the maximum strain of 6.7% for sample with 0.2wt.% BC (see Figure 5c), while a much lower BC content could only produced sensitivity that could up only to 0.5 even at similarly applied strain. Therefore, we conclude that the presence of BC ink is crucial for strain sensing ability of PVA/BC composite film since the addition of 0.2wt.% ink did not impede the sensitivity of film towards strain despite has been observed to produce poorer mechanical characteristic.

## Conclusion

In conclusion, it has been proven that the addition of conductive ink with Bare Conductive® brand into PVA matrices could enhance mechanical with the resulted maximum tensile stress of 1.35 GPa and tensile stress improvement at about 50-170 % as compared to that of the original value. Beside mechanical enhancement, it is shown that the resistance of PVA/BC composite film at a higher addition of BC ink would decrease significantly and resulting into a better strain sensing performance (70%) for the composite film. With such a simple preparation method and economical value of BC ink, a prospect of low-cost strain-sensitive PVA/BC composite film while remains competitive in the sensing performance certainly is attractive.

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