Effects of carbon nanotube aspect ratio on the functional properties of electrically conductive adhesive

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ABSTRACT – This project investigates the effect of carbon nanotubes aspect ratio on the functional properties of electrically conductive adhesive (ECA). Two types of multi walled carbon nanotubes (MWCNT) conductive filler are considered, with the same outer diameter but different length which have aspect ratios of 1750, termed high aspect ratio and 112.5, termed low aspect ratio and manually mixed with epoxy to produce the ECA. Results on the ECA using MWCNT of low aspect ratio on the electrical conductivity suggest that percolation threshold is reached at relatively high filler loading while the percolation threshold for high aspect ratio MWCNT is reached at lower filler loading. The results suggest that higher aspect ratio MWCNT has better conductivity as compared to low aspect ratio MWCNT.

1. INTRODUCTION

The effort to eliminate lead in solder have driven the electrical industries to two alternatives, that is lead-free metal solder alloys and polymer-based electrically conductive adhesive (ECA). There are two components in ECA which consists of resin or polymer matrix which can be either thermoplastic or thermosetting and a conductive filler typically based on metallic materials. The polymer matrix in electrically conductive adhesive (ECA) provides the mechanical properties such as mechanical strength, adhesion, and impact strength while the conductive filler provides the electrical properties.

In this study, the functional properties of MWCNT-ECA is studied with the aim to achieve good electrical conductivity, depending on the aspect ratio of MWCNT, by varying the length as well as using filler loading between 5 to 7 wt.%. A four-point probe test unit is used to determine the electrical conductivity of the MWCNT-filled ECA in terms of the sheet resistance value.

2. RESEARCH METHODOLOGY

2.1 Samples preparation

Three main substance is needed to formulate ECA which is, epoxy, hardener and conductive filler. Epoxy resin Araldite 506 is used as the polymer matrix and Polyetheramine Jeffamine D-230 is the hardener used which is thermoset hardener. MWCNT is used as the conductive filler with 2 different aspect ratio and different filler loading.

All the samples were prepared first by blending the epoxy Araldite 506 with Jeffamine D-230 Polyether amine which is the hardener. Before blending, the amount of epoxy used need to be measured using a weight balance. The MWCNT filler loading that are chosen for this research are 5 wt.%, 6 wt.%, and 7 wt.%. The rule of mixture formula is used to calculate the mixture amount needed. Table 2.1 below show the weight of each material used to formulate 5 g of ECA according to each filler loading.

Table 2.1 Formulation of 5g ECA

Filler loading (WT%)	**5**	**6**	**7**
Epoxy (g)	4.75	4.7	4.65
Hardener (g)	1.425	1.41	1.395
MWCNT (g)	0.25	0.3	0.35

Once the hardener is added to the epoxy, it was stirred for 1 minute with constant speed and rotation direction. Then, the required amount of MWCNT is added. The sample was then stirred for another 5 minutes to blend the mixture and MWCNT. The formulated ECA is then cured in a Memmert oven for 30 minutes with temperature of 100°C for curing.

2.2 Samples characterization

Six strips of the ECA was applied onto a 3-mm thick acrylic with dimensions of 45 mm (wide) and 88.9 mm (length) by using printing technique. Figure 2.2.1 shows the drawing illustration of the sample. The strip is 12.7 mm in length and 2 mm wide and were subjected to electrical test using a four-point probe test unit, with reference to ASTM F390-1.

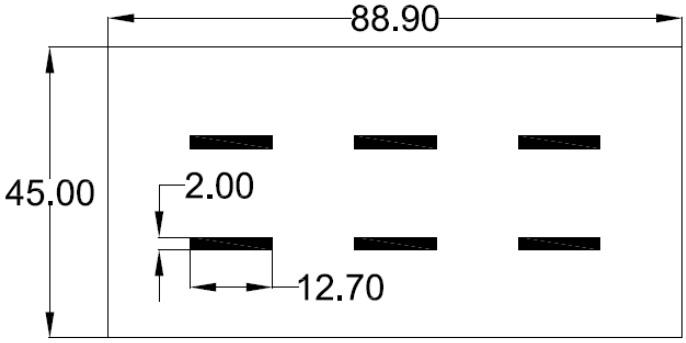


Figure 2.2.1 Drawing of electrical specimen.

3. RESULTS AND DISCUSSION

The results from the electrical test and scanning electron microscope (SEM) image MWCNT distribution in the ECA is discussed in this section. As the aspect ratio of filler increase, the conductivity generally increases. Excluded volume concept is used to describe this trend in which the volume around an object as the overlapping of two similar object is to be avoided when the center of the object is not allowed to enter. As the two MWCNT excluded volume overlapped, a conducting link may be formed. The percolation threshold decreases with decreasing excluded volume. This indicates that at lower filler loadings, better conductivity is achieved.

Table 3.1 Sheet resistance of high and low aspect ratio MWCNT ECA with respect to their filler loading.

Filler Loading	**Sheet Resistance (kΩ/sq.)**	
	High aspect ratio	**Low aspect ratio**
5	10.66 ± 3.19	180.87 ± 48.70
6	3.79 ± 1.89	143.40 ± 45.84
7	1.367 ± 0.49	77.33 ± 51.15

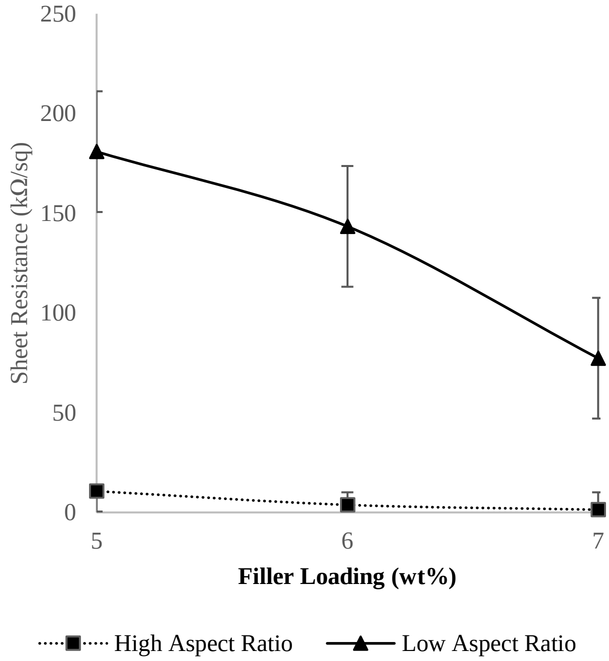
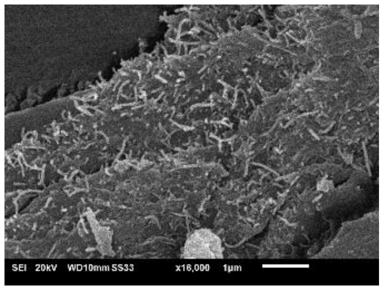
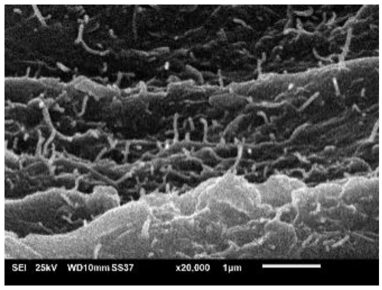


Figure 3.1 Sheet Resistance of different aspect ratio and filler loading of MWCNT ECA

Figure 3.1 shows the sheet resistance of the MWCNT of different aspect ratio and filler loading. The high aspect ratio MWCNT filled ECA has a lower sheet resistance as compared to low aspect ratio MWCNT filled ECA with respect to the filler loading used in this research. Thus, the percolation threshold of high aspect ratio MWCNT filled ECA occurred at lower filler loading compared to low aspect ratio MWCNT filled ECA. This may due to the agglomeration of the MWCNT and the conductive path created by the MWCNT in the ECA. Figure 3.2 (a) and (b) show the distribution of high aspect ratio MWCNT in the ECA for 5 wt.% and 7 wt.% where for 7 wt.% the agglomeration of MWCNT is observe in Figure 3.2 (b) due to the non-uniformity of the MWCNT filler.



(a)



(b)

Figure 3.2 SEM image of high aspect ratio MWCNT distribution with (a) 5 wt.% (b) 7 wt.%

4. CONCLUSION

MWCNT with different aspect ratio is used to formulate the ECA and characterized in terms of electrical performance with respect to different filler loading. From the result obtained, high aspect ratio MWCNT-filled ECA yield in better conductivity as compared to the ECA with low aspect ratio MWCNT filler. Moreover, the electrical conductivity suggests that percolation threshold of ECA mixed with MWCNT is achieved at relatively low filler loading due to the continuity of conductive path created by the MWCNT in the ECA.

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REFERENCES

[1] Nash, C., Spiesschaert, Y., Amarandei, G., Stoeva, Z., Tomov, R. I., Tonchev, D., & Glowacki, B. A. (2015). A Comparative Study on the Conductive Properties of Coated and Printed Silver Layers on a Paper Substrate. *Journal of Electronic Materials*, 44(1), 497.

[2] Kazani, I. (2012). Study of screen-printed electroconductive textile materials (Doctoral dissertation, Ghent University).

[3] Kim, D., & Moon, J. (2005). Highly conductive ink jet printed films of nanosilver particles for printable electronics. *Electrochemical and Solid-State Letters*, 8(11), J30-J33.

[4] Kamyshny, A., Steinke, J., & Magdassi, S. (2011). Metal-based inkjet inks for printed electronics. *The Open Applied Physics Journal*, 4(1).