JOURNAL OF APPLIED SCIENCES RESEARCH

JOURNAL home page: http://www.aensiweb.com/jasr.html 2015 April; 11(5): pages 17-22.

Published Online: 27 January 2015. **Research Article**

The Properties of Recycled Copper Filled Epoxy Composites: The Comparison between Coarse and Fine Filler Particle

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Received: 25 November 2014; **Revised:** 26 December 2014; **Accepted:** 1 January 2015

ABSTRACT

The comparisons of filler particle size of recycled copper that are coarse and fine on mechanical, thermal, physical and mechanical were investigated. The recycled copper was collected as a waste from the milling machine and grinded into coarse (300-400 µm) and fine (10 µm) particle sizes. The recycled copper filled epoxy composite was fabricated using mechanical stirrer. The effect of volume fraction of recycled copper of the epoxy composites were also studied based on the flexural properties, coefficient of thermal analysis (CTE), hardness and density. Incorporation of recycled copper has decreased the CTE of the composites. The flexural properties, hardness and density of the composites increased with increasing of volume fraction and filler loading.

Keywords: Recycled copper; Particle size; Thermal; Electrical; Mechanical; Physical properties.

INTRODUCTION

The introduction of Conducting Polymer Composites (CPCs) has initiated the application of polymers in many fields of engineering especially in the electrical and electronic applications. Indeed, conducting polymer composites have shown its crucial importance in many useful and high end applications since few decades ago, and it continues to become choice of selection in various industries especially in electrical and electronic applications [1]. Conducting polymer composites involves incorporating conductive filler into the polymer matrix. These composites are produced from the blending of an insulating polymer matrix with electrical conductive fillers (carbon black, carbon fibre, metal particles) show many interesting features due to their electrical resistivity variation with thermal solicitations [2]. Polymer-based electrically conducting composites have several advantages over their pure metal counterparts including lower cost, ease of manufacture, high flexibility, reduced weight, mechanical shock absorption ability, corrosion resistance and conductivity control of many fields of engineering, such as for electromagnet interference (EMI) shielding, safe packaging, corrosion protection, electrostatic discharge (ESD) control, conductive adhesive and etc. [3].

Polymer composites filled with metal are of interest for used, one main parameter determining CPC properties is the conductive pathways structure, depending on many parameters such as filler content (φ), surface free energy of the filler and the matrix, crystallinity, reticulation and exclusion volume, i.e. zones where carbon black is concentrated [4]. The most general approach to describe the charge transport in conducting polymeric composites in relation to the content of conducting particles is provided by the percolation theory [5]. The percolation threshold is strongly influenced by the geometrical characteristics of the conductive filler, such as aspect ratio and particle size distribution, so that an increase in their value may dramatically drop the filler concentration required to achieve conduction in a given polymeric matrix [6]. The transfer conditions of the electric charge and heat flow determine the electrical and thermal conductivity level in the heterogeneous polymer-filler system, in which the conductive phase is formed by dispersed metallic or carbon filler [7]. Using recycled copper can save energy as copper extraction is very energy-consuming. Consequently, it can save landfills by reducing the amount of waste copper. In fact, there are many sources of recycled copper ranging from copper piping of the air conditioning units, scrap electrical wiring to door and window frames. In this study, recycled copper filled epoxy was characterized based on its mechanical, electrical and thermal properties. Testing such as particle size, flexural, coefficient of thermal expansion, electrical conductivity, hardness and density measurement were determined to study the properties of the composite.

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Materials and Methods

The recycled copper was milled into finer powder using different milling hours for 24 and 72 hours respectively. Meanwhile, the gel time of the epoxy was determined. Samples of epoxy composites filled with 0 vol. %, 10 vol. %, 20 vol. %, 30 vol. % and 40 vol. % of recycled copper were prepared. First, the epoxy resin with required weight was measured and poured into a mould. Then, the recycled copper filler was added and the mixture was stirred using mechanical stirrer until the mixture was homogeneous. Hardener of about 60phr by weight was added and the mixture was stirred again. The mixture was then poured into the mould and the composite was cured using air oven at 100 °C. The samples were polished using polishing machine to obtain samples with smooth surfaces prior to testing.

Results and Discussions

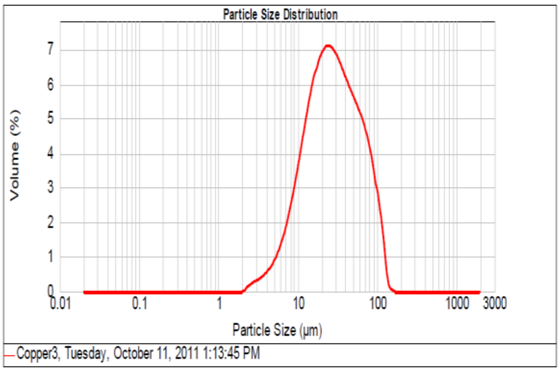
3.1 Recycled Copper Particle Size:

In this research, the recycled copper waste chips are collected from the milling machine were milled into powders for 2 sets of milling hours which are 24 hours and 72 hours. Table 1 shows the results of average powder particle sizes of the recycled copper for different milling time. It shows that when the milling time increases, finer powder of the recycled copper was obtained. During ball milling, powders were trapped between colliding balls and were subjected to high stress. Consequently, powders were subjected to a severe plastic deformation which exceeds their mechanical strength [8]. Thus, when the milling time or processing time was increased, the finer powders were obtained. Indeed, in most cases, the rate of particle refinement (i.e. particle size and, or crystallite size) is roughly logarithmic with the processing time or ball-to-powder ratio [8].

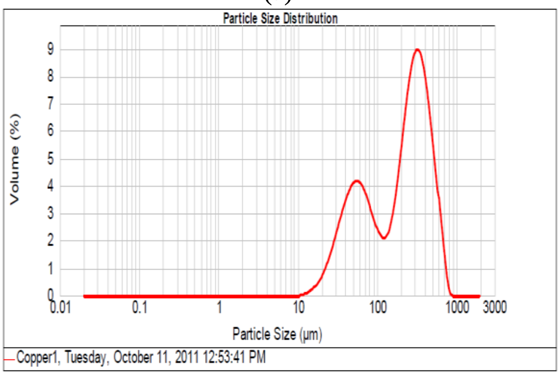
Figure 1 show the particle size distribution obtained through Malvern particle size analyser. When the powders were milled for longer hours, the multimodal distribution was gradually shifted to monomodal distribution, with a significant reduce of the volume percentage of coarser particles (around 350 μm). Owing to higher stressed subjected to the powders at longer milling hours, a more efficient milling operation was performed, changing the form of the powder from mixture of fine and coarse particles to completely fine particles.

Table 1: The particle sizes of the recycled copper powders.

Milling time (hours)	Particle size distribution	Average powder particle size of recycled copper (μm)
24	ladomiB	400-300
72	ladomonoM	10



(a)



(b)

Fig. 1: The particle size distribution for recycled copper powder which was milled for (a) 72 hours and (b) 24 hours respectively.

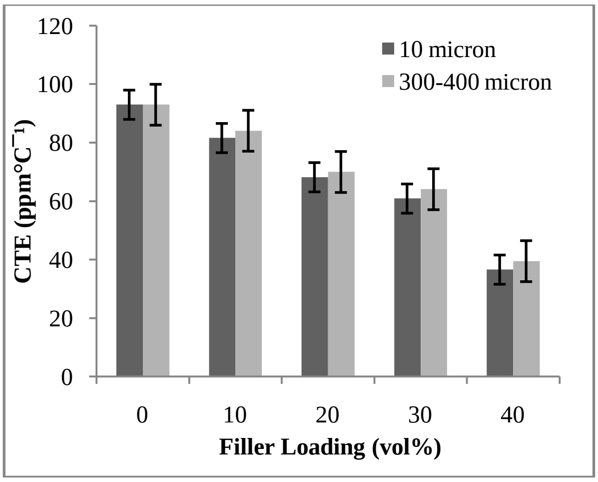


Fig. 2: Comparison of CTE of epoxy composites at different size with different recycled copper filler loading for average particle size of 10 and 300-400 micron.

3.2 Thermal Properties:

3.2.1 Coefficient Thermal Expansion (CTE):

The comparison of CTE between different coarse and fine particle size is shown in Figure 2. It shows that filler with 10 micron have slightly lower CTE than filler with 300-400 micron. Coarse filler in composites structure tend to have bigger gap in between them. It allows the composites to expand more when thermal was supplied. The properties of filler filled composites are determined by the characteristic of its components, composition, structure and interfacial interaction. Fine particle filler have better interaction since it have better orientation. Although filler content and filler size significantly influence the properties of polymer composites, any changes in polymer/filler interaction also have considerable effect on these properties. This effect depends both on the size of the contacting surfaces and on the strength of the interaction [9].

3.3 Mechanical Properties:

3.3.1 Flexural Strength:

Figure 3 shows the comparison of flexural strength for different particle size which is 10 micron and 300-400 micron in average particle size, respectively. From the graph, it shows that the particle size with 10 micron give higher flexural strength than 300-400 micron. The fine filler particle caused fewer voids in the composites structure. It was shown in earlier work that smaller particles are not desirable, for they require more polymers for effective binding, resulting in a lower flexural strength. Too large particles, on the other hand, act as discontinuities, again lowering the flexural strength. The difference between the size groups however, is most likely due to differences in packing density. Denser packing, i.e. a smaller composite porosity will result in a higher flexural strength [10].

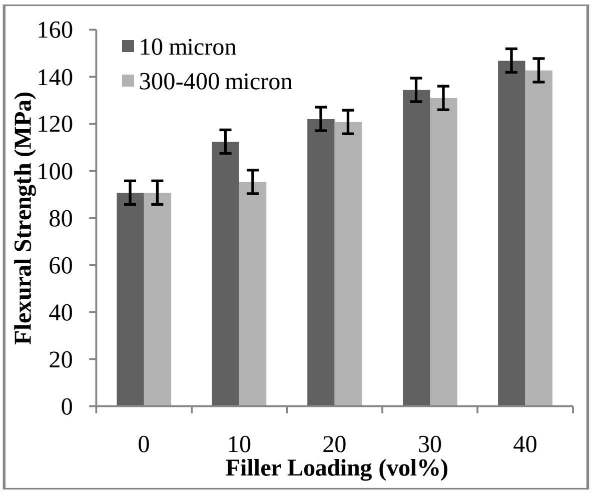


Fig. 3: Comparison of flexural strength of epoxy composites at different recycled copper filler loading for different average particle sizes.

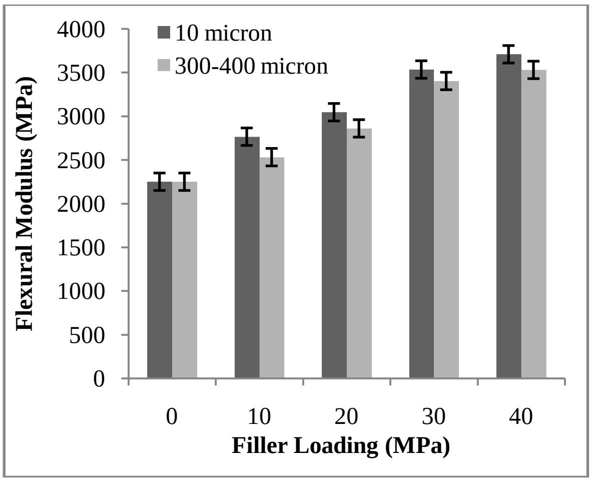


Fig. 4: Comparison of flexural modulus of epoxy composites at different recycled copper filler loading with different average particle sizes.

3.3.2 Flexural Modulus:

Figure 4 shows the comparison of flexural modulus of different recycled copper size which is 10 and 300-400 micron in average particle size, respectively. It shows that the particle size with 10 micron have higher flexural modulus than 300-400 micron. When the particle size increased the crack deflection, debonding and particle fracture are increased [11].

3.4 Electrical Properties:

3.4.1 Electrical Conductivity:

Figure 5 shows that the comparison of electrical conductivity of epoxy composites at different size with different recycled copper filler loading. From the figure, recycled copper with 10 micron in average particle size have higher electrical conductivity than recycled copper with 300-400 micron in average particle size. The fine filler will have a compact structure compared to coarse particle. Therefore, the percolation threshold effect is about to happened. The electrical performance of matrix-conductive filler composites is sufficient affected by the size of the inclusions [12].

3.5 Physical Properties:

3.5.1 Vickers Hardness:

Figure 6 shows the comparison of Vickers hardness of epoxy composites at different average particle sizes with different recycled copper filler loading. From the figure, it indicates that the recycled copper with 10 micron in average particle size have slightly higher hardness than recycled copper with 300-400 micron in average particle size. Fine filler caused the composites to have fewer voids since it will pack the structure [13]. Packed composites will strengthen the composites and therefore have high Vickers hardness value. Fine filler will tend to collide more frequently, leading to less easiness to be subjected to plastic deformation as it resistance to higher stress applied is higher.

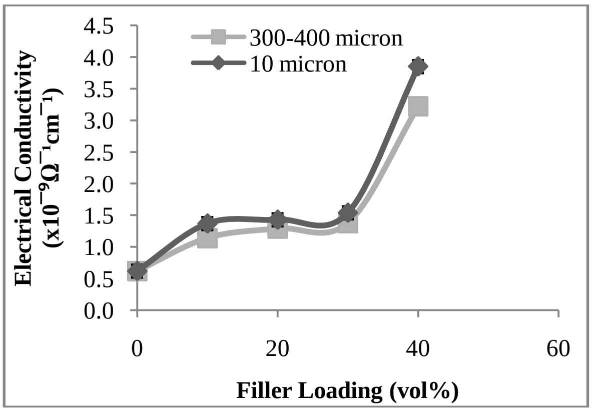


Fig. 5: Comparison of electrical conductivity of epoxy composites at different average particle sizes with different recycled copper filler loading.

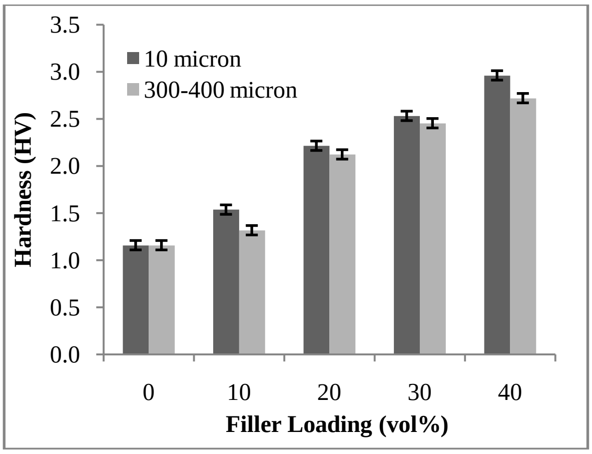


Fig. 6: Comparison of Vickers hardness of epoxycomposites filled with fine particle size at different recycled copper filler loading.

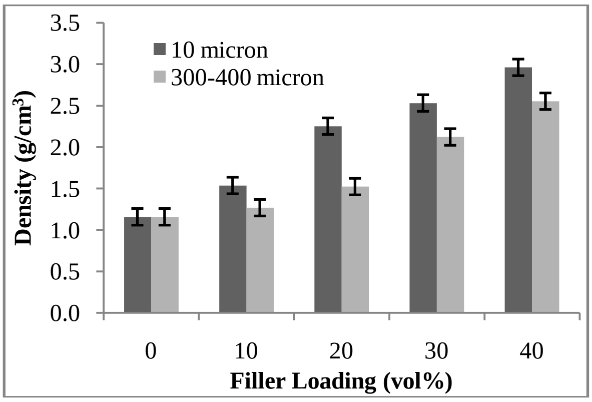


Fig. 7: Comparison of density of epoxy composites at different average particle size with different recycled copper filler loading.

3.5.2 Density:

Figure 7 illustrates the comparison of density of epoxy composites at different size with different recycled copper filler loading. The addition of fine filler causing the composites to have better distribution since particles distribute all around the composites. From the figure, it indicates that recycled copper with smaller average particle size which is 10 micron have higher density than recycled copper with 300-400 in size. This difference proves that the optimal gradation factor is affected by the balanced distribution of the filler particles in the mixture achieving a maximal packing [14].

2. Conclusion:

When the milling hours increased, the particles size distribution of recycled copper changed gradually from bimodal (24 milling hours) particle size distribution to monomodal particle size distribution (72 milling hours). In overall, epoxy composites filled with fine recycled copper content showed the best performance in term of overall properties, because had lowest CTE value and highest flexural properties, electrical conductivity, hardness and density value respectively.

Acknowledgement

The financial support of Fundamental Research Grant Scheme (FRGS) grant no: 9003-00280 is gratefully acknowledged.

References

1. Ramasubramaniam, R., J. Chen, H. Liu, 2003. Homogeneous carbon nanotube/polymer composites for electrical applications. *Applied Physics Letters*, 83: 2928-2930.
2. Li, C., L. Zhang, L. Ding, H. Ren, H. Cui, 2011. Effect of conductive polymers coated anode on the performance of microbial fuel cells (MFCs) and its biodiversity analysis. *Biosensors and Bioelectronics*, 26: 4169-4176.
3. The, P.L., H.T. Ng, C.K. Yeoh, 2011. Recycled Copper as the Conductive Filler in Polyester Composites. *Malaysian Polymer Journal*, 6: 98-108.

4. Gazotti, Jr. W.A., G. Casalbore-Miceli, S. Mitzakoff, A. Geri, M.C. Gallazz, M.A. De Paoli, 1999. Conductive polymer blends as electrochromic materials. *Electrochimica Acta*, 44(12): 1965-1971.
5. Battisti, A., A.A. Skordos, I.K. Partridge, 2010. Percolation threshold of carbon nanotubes filled unsaturated polyesters. *Composites Science and Technology*, 70(4): 600-637.
6. Rupprecht, L., (Eds). 1999. *Conductive polymers and plastics*. Norwich, NY: Plastic Design Library.
7. Jaafar @ Mustapha M., 2008. Conductive Polymer Composite for Electronic Packaging.
8. Xu, X., J.H. Kim, W.K. Yeoh, Y. Zhang, S.X. Dou, 2006. Improved Jc of MgB_2 superconductor by ball milling using different media. *Superconductor Science and Technology*, 19: 47-50.
9. Erika, F., B.P. Janosmoczo, 2004. Determination of surface characteristics of particulate fillers by inverse gas chromatography at infinite dilution: a critical approach. *Journal of Colloid and Interface Science*, 269: 143-152.
10. Wong, D.W.Y., L. Lin, P.T. McGrail, T. Peijs, P.J. Hogg, 2010. Improved fracture toughness of carbon fibre/epoxy composite laminates using dissolvable thermoplastic fibres. *Composites: Part A.*, 41: 759-767.
11. Kitey, R., H.V. Tippur, 2005. Role of particle size and filler-matrix adhesion on dynamic fracture of glass-filled epoxy: i. micromeasurement. *Actamaterialia*, 53: 1153-1165.
12. Psarras, G.C., 2006. Hopping conductivity in polymer matrix-metal particles composites. *Composites: Part A*., 37: 1545-1553.
13. Suriati, G., M. Mariatti, A. Azizan, 2011. Effects of filler shape and size on the properties of silver filled epoxy composite for electronic applications. *Journal of Materials Science: Materials in Electronics*, 22: 56-63.
14. Sided, A., Y.R. Holdengrabe, A. Buchman, 1992. Fundamental model for prediction of optimal particulate composite properties. *Composites*, 24: 355-360.