Developing a Cost-Effective Composite Based on Electroless Nickel-Coated Cellulose Fibres for Electromagnetic Interference Shielding

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ABSTRACT: A series of composites based on polypropylene with different loadings of nickel-coated cellulose fibres (NCCF) were fabricated with the aim to create a composite suitable for EMI shielding and/or electrostatic discharge application. Various properties such as EMI shielding effectiveness, surface resistivity, volume resistivity and flexural strength were characterised according to ASTM standard. Both surface and volume resistivity suggested that the electrical conductivity of NCCF was not high enough and the composite remains electrically non-conducting up to 40 wt% loading of NCCF. However, nickel particles were still able to shield electromagnetic radiation regardless of their connectivity and conductivity. This was reinforced by EMI shielding measurement which showed that EMI shielding effectiveness of 6.5 dB was obtained by composite containing 40 wt% NCCF. Mechanical property characterisation showed that the NCCF composites have higher flexural strength than pure polypropylene. This is a positive effect as NCCF is now acting as a conducting reinforcing material rather than simply a conducting filler. Furthermore, the composites maintained approximately similar flexural strength regardless of the loading of NCCF.

KEYWORDS: EMI shielding composite, electroless nickel-coated cellulose fibres, EMI shielding effectiveness, surface resistivity, volume resistivity, flexure strength

1 INTRODUCTION

Electromagnetic interference (EMI) is an ongoing concern which causes degradation or malfunction of electronic systems and devices used in commercial products, military activities and space exploration. As electronic devices become more integrated and miniaturized, they become more susceptible to EMI [1]. Furthermore, Jang and Park have reported that prolonged exposure to electromagnetic radiation may cause symptoms of insomnia, nervousness and headache [2,3]. Hence, EMI shielding has become an increasingly important matter. One of the most effective, commercially available EMI shielding materials is conductive polymeric composite based on nickel-coated graphite fibres (NCGF) [4,5]. However, these EMI shielding composites are still quite expensive [6]. Therefore, the aim of this project is to develop a cost-effective EMI shielding composite using electroless nickel-plated fibres that are lighter, cheaper and from renewable sources.

Cellulose fibre is a cost-effective fibre substrate with many attractive properties such as high strength-to-weight ratio, ability to insulate heat and sound and able to control humidity [7,8]. Currently, there is no information available on nickel coating on cellulose fibres. Therefore, a technique reported by Li, Wang and Liu [9] (electroless nickel plating on wood veneer) was adapted and refined [10]. From there, a series of composites were developed and tested for their EMI shielding, electrical and mechanical properties according to ASTM standards.

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2 Experimental Procedures

2.1 Materials

The polymer matrix was polypropylene (PP) fibre (Atofina) with an undisclosed coupling agent provided by FiberVisions (Covington, Georgia, USA). The fibre dimensions were 23 μm wide and 5 mm long, with a melting point of approximately 165–166°C (by DSC). The filler in this case was NCCF reported previously [10].

2.2 Composite Preparation

Compression moulding was used as the composite fabrication technique to maintain aspect ratio of the NCCF because there are no damaging shear forces. A mixture of 100 g PP and NCCF were wet blended for approximately 10 minutes. Then the mixture was sieved and pressed with a tamper. The compressed pads were oven dried at 105°C for approximately 24 hours. Once dried, the pads were compression moulded at 170°C for 5 minutes. The dimensions of composite panels were approximately 150 mm × 150 mm × 3 mm.

A series of composites with varying amounts of NCCF were fabricated, as summarised in Table 1.

Table 1 Composition of composite panels.

	Set A	Set B	Set C	Set D	Set E
Wt. % of NCCF	40	30	25	20	10
Vol. % of NCCF	27	19	16	12	6
Number of Panels	3	3	3	3	3

2.3 Characterisation

The EMI shielding effectiveness of each composite panel was measured using the coaxial transmission line method according to ASTM D4935-99. The surface resistivity of each panel was determined by a megohmeter and guarded ring according to ASTM D257.

Following EMI shielding effectiveness and surface resistivity measurements, each panel was cut into strips of 15 mm x 135 mm x 3 mm. Volume resistivity measurements were carried out on each strip according to ASTM D4496. This gives the volume resistivity profile of each panel.

Finally, the mechanical properties of each strip were evaluated using the 3-point bending test according to ASTM D790 – 10. Furthermore, polished cross-section of composite strips were also analysed with SEM.

3 RESULTS AND DISCUSSIONS

3.1 Surface Resistivity, Volume Resistivity and SEM Images

In terms of surface resistivity, it can be seen from Figure 1 that the addition of NCCF only slightly

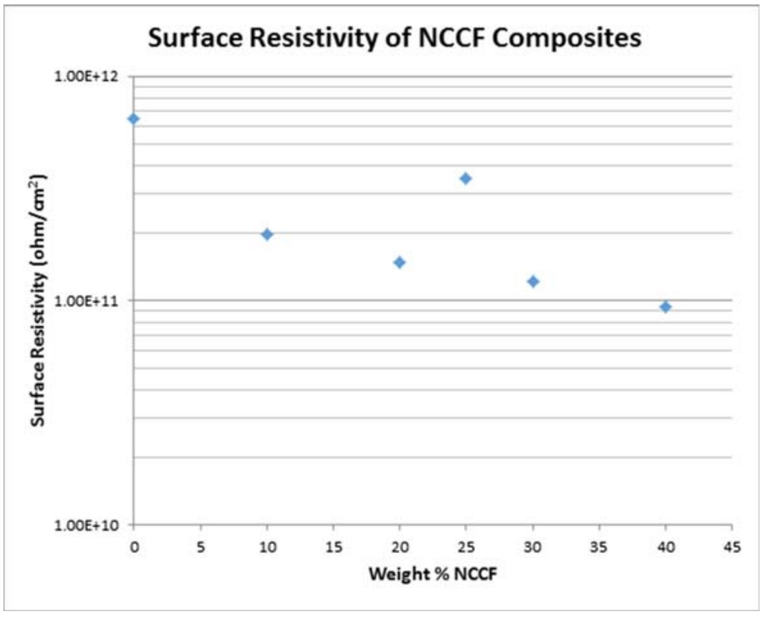

Figure 1 Surface resistivity of NCCF composites.

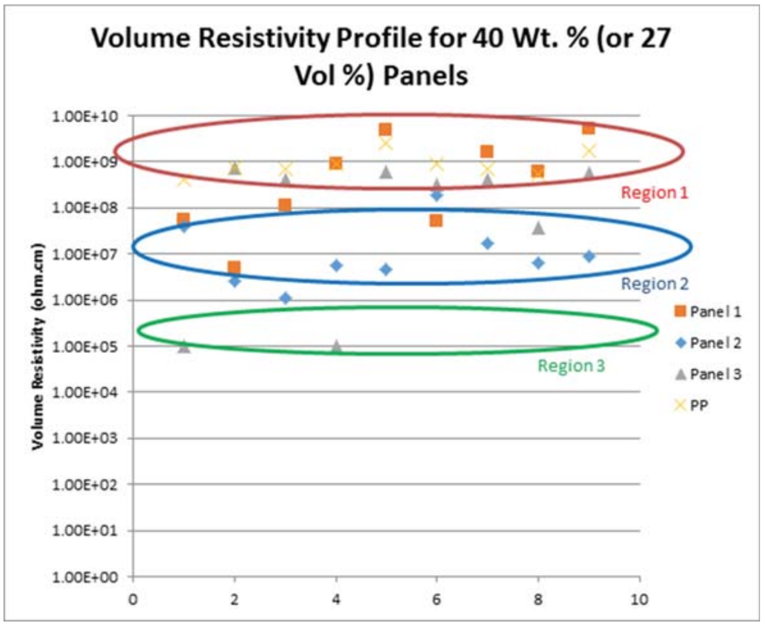

Figure 2 Volume resistivity profile of composite containing 40 wt% NCCF.

reduces the surface resistivity of the composite regardless of the amount that was added. The composite still remains electrically non-conducting.

In terms of volume resistivity, the following graph illustrates the volume resistivity profile for each panel. Figure 2 shows that, for 40 wt% panels, the range of volume resistivity value is quite large but it could be broken down into approximately 3 regions.

Region 1 is the non-conducting region, region 3 is the conducting region and region 2 is believed to be a mixture between region 1 and region 3. Due to the fact that only a few strips within a composite panel are electrically conducting, global conductivity could not be established throughout the composite and they will still remain electrically nonconducting, which is also in agreement with the surface resistivity measurement shown previously.

However, even if every strip were electrically conducting (in region 3 of Figure 2), the electrical conductivity would still not be high enough to achieve a minimum requirement (30–40 dB) of EMI shielding effectiveness for commercial application [11]. According to Kiaser, the volume resistivity should be at least 1 ohm.cm for EMI SE of 35 dB [12].

As a result, both surface and volume resistivity measurements have concluded that the electrical conductivity of NCCF was not high enough. The SEM image shown in Figure 3 also demonstrates that NCCF was randomly distributed within the polypropylene matrix with little evidence of porosity. This suggests that the composite has uniform morphology.

Further investigation revealed that the electrical resistivity of nickel coating is directly proportional to the phosphorus content within the coating. According to Li, Wang and Liu, the electroless deposition of nickel on cellulose fibres will also impart phosphorus onto cellulose fibres due to the fact that sodium hypophosphite was used as the reducing agent [9]. Therefore, decreasing phosphorus content will increase electrical conductivity of NCCF. This will be investigated in the future.

For the 30, 25, 20 and 10 wt% composites there was only an electrically non-conducting region present, so

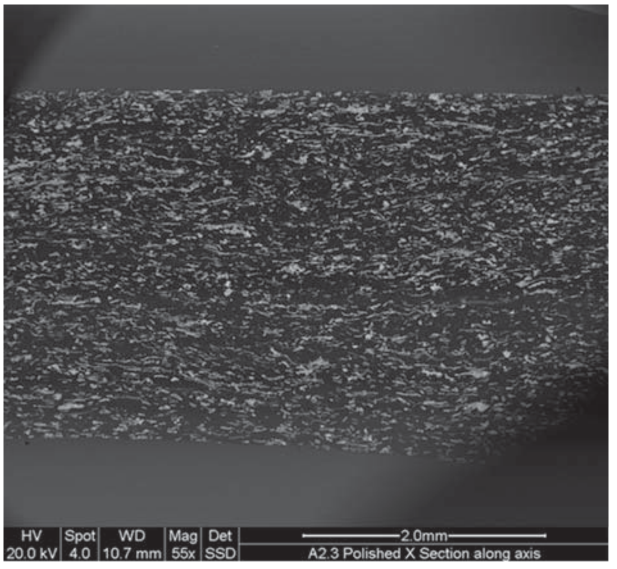

Figure 3 SEM image of polished cross-section of composite strip containing 40 wt% NCCF.

the composites are electrically non-conductive. The 20 wt% composite set was chosen as a representative sample, as shown in Figure 4.

3.2 EMI Shielding Effectiveness

In general, EMI SE increases with increased loading of NCCF as shown in Figure 5. The highest EMI SE shown on this graph is approximately 6.5 dB, which is obtained by the 40 wt% panels at 1.5 MHz. However, both surface and volume resistivity suggested that the composite panels are still not electrically conducting. According to Kaiser, EMI SE is 0 when volume resistivity is higher than 10^4 [11]. Therefore these NCCF composites should also possess similar EMI SE as pure PP. The reason that there is a certain degree of EMI shielding from NCCF composites maybe due to the fact that nickel particles are

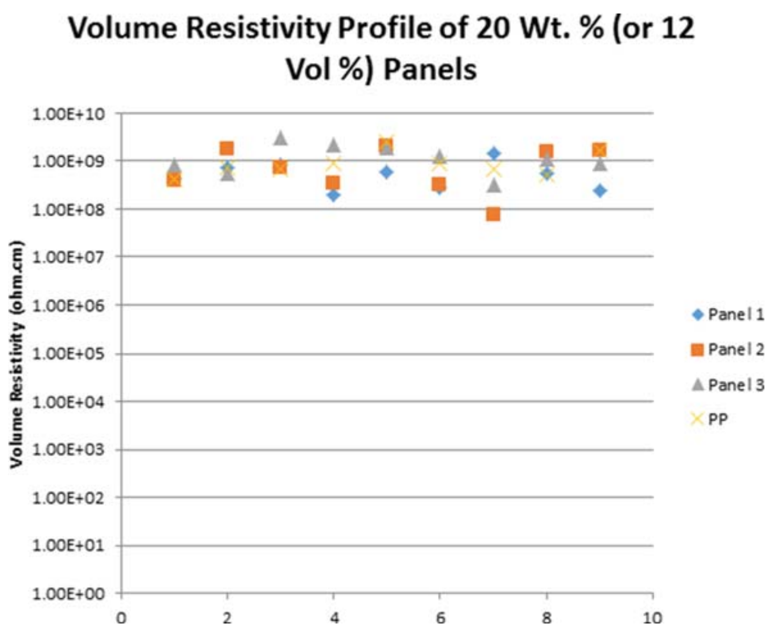

Figure 4 Volume resistivity profile of composite containing 20 wt% NCCF.

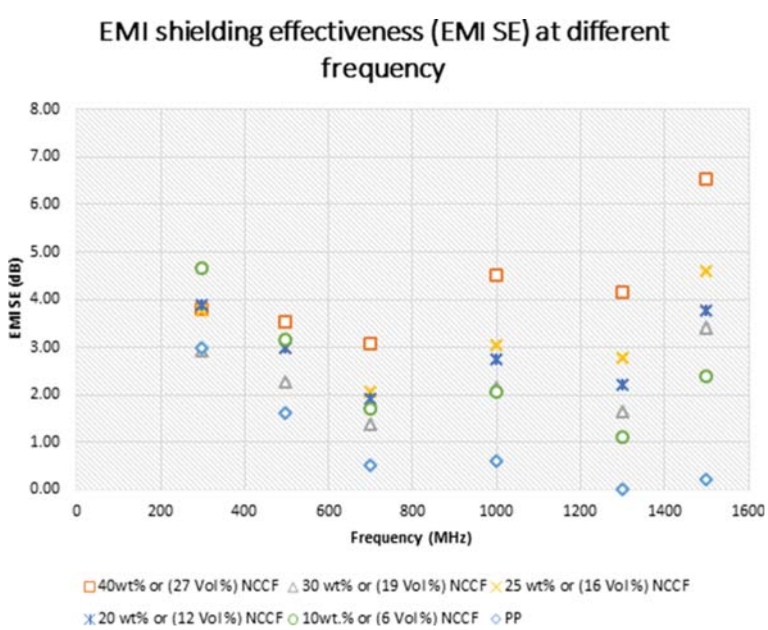

Figure 5 EMI SE of NCCF composites at different frequencies.

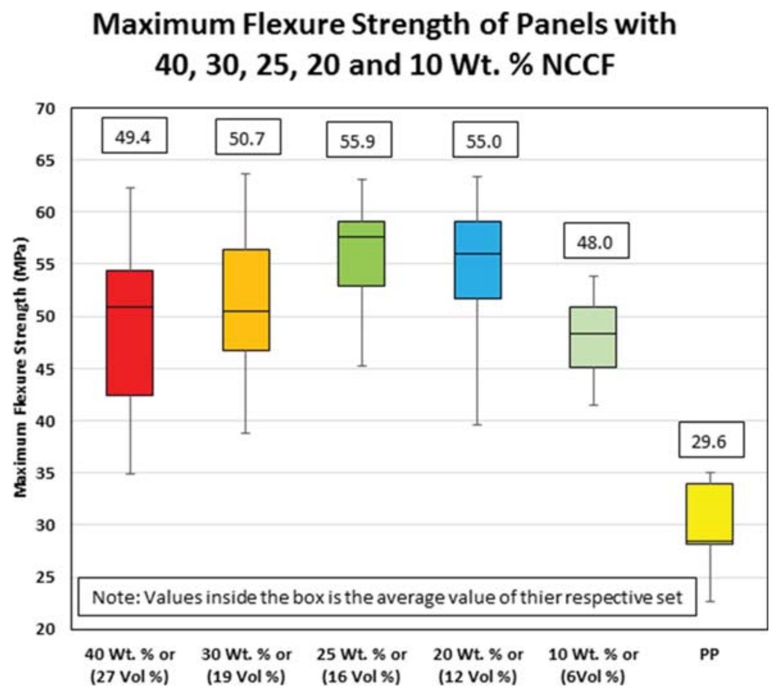

Figure 6 Maximum flexural strength of composite with different loadings of NCCF.

still able to shield EMI to a certain extent regardless of their connectivity and conductivity. Unfortunately, this is still not good enough as the minimum requirement of EMI SE for commercial material is between 30–40 dB [11].

3.3 Flexural Strength

Figure 6 illustrates the flexural strength of the composite strips. It can be seen from Figure 6 that, on average, adding NCCF into PP increases the flexural strength of the composite. This can be attributed to the fact that the presence of the coupling agent effectively binds PP with NCCF, resulting in the improvement in mechanical property. Furthermore, it can be seen that there is no significant difference in terms of flexural strength between the 40, 30, 25, 20 and 10 wt% panels.

4 CONCLUSIONS

It can be concluded that a series of dense and compact composites with varying amounts of NCCF have been successfully fabricated and extensive material characterisation such as EMI shielding effectiveness, surface resistivity, volume resistivity and mechanical properties based on ATSM standards have been fully conducted. Both surface and volume resistivity measurements have suggested that the electrical conductivity of NCCF was not high enough. Further optimisation of electroless nickel plating parameters is required in order to reduce the phosphorus content of nickel coating. This will then increase the electrical conductivity of NCCF. However, even though both surface and volume resistivity measurements suggested that the composite was not electrically conducting, NCCF composites still possess the ability to shield electromagnetic radiation. This could possibly be due to the fact that nickel particles are still able to shield electromagnetic radiation regardless of their connectivity and conductivity. For future work, in addition to the optimisation of electroless nickel plating parameters, the fabrication of composites based on standard EMI shielding stainless steel fibres will also be carried out in order to establish a comparable baseline with NCCF composite. Mechanical property characterisation has shown that the NCCF composites have higher flexural strength than pure polypropylene. This is a positive effect as NCCF is now acting as a conducting reinforcing material rather than simply a conducting filler. Furthermore, the composites maintained approximately similar flexural strength regardless of the loading of NCCF.

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