CARBON NANOTUBES BASED TEXTILE COATINGS FILLED WITH ALUMINIUM FLAKES FOR HIGH REFLECTIVITY HEATING AND LIGHTING APPLICATIONS

Filip GOVAERT, Myriam VANNESTE

Centexbel, Belgian Textile Research Centre, Technologiepark 7, B-9052 Gent, Belgium, fgo@centexbel.be, mv@centexbel.be

Abstract

Textile coatings based on polyacrylates and polyurethanes filled with carbon nanotubes (CNT) for electrical conductivity were functionalized with aluminium flakes for higher light and heat reflectivity. Electrical conductive textile coatings are presented with up to 15 wt% of CNT, based on the solid weight of the binder. Coating formulations with variable CNT concentrations were applied on polyester and cotton woven and knitted fabrics by different textile coating techniques: direct coating, transfer coating and screen printing. The coatings showed increasing electrical conductivity with increasing CNT concentration. The coatings can be regarded to be electrical conductive (sheet resistivity <103Ohm/sq) starting at 3 wt% CNT. The degree of dispersion of the carbon nanotubes particles inside the coating was visualized by scanning electron microscopy. The CNT particles form honeycomb structured networks in the coatings, proving a high degree of dispersion. This honeycomb structure of CNT particles is forming a conductive network in the coating leading to low resistivity values.

Additionally these CNT based coatings were functionalized with aluminium flakes for higher light and heat reflectivity. The compatibility of aluminium flakes in the binder material was investigated. Formulations with 1 wt% aluminium up to 5 wt% aluminium were prepared and applied. Reflectivity measurements prove the increasing light reflectivity with increasing aluminium content. Applications for this coating technology can be found in resistive heating textiles and base electrodes for flexible OLED lighting applications.

Keywords:

Carbon nanotubes, textile, coating, heating, lighting

1. INTRODUCTION

Smart textiles represent an exploding market with sustainable growth. Textile materials with integrated electrical conductivity make it possible to create intelligent articles with wide ranging applications in sports and work wear, healthcare and for technical applications. Nowadays, electrical conductive textile applications are made by weaving, knitting or attaching metal wires in the textile material [1, 2, 3]. The homogeneous distribution of the electric current over the total textile surface is pour and only located at the position of the metal wire. When metal wires and devices are present in this textile, very severe protection is necessary to avoid rapid degradation and corrosion of these materials. This protection is achieved by using insulation cabling, layered structures and more stiff and thick materials to limit bending and stretching [4, 5, 6].

Conductive coatings or finishes for textiles are used in application such as conductive mattress covers for surgical tables or fabrics with shielding for electromagnetic radiation for military applications or work wear. In that case high loading of carbon black is needed to provide sufficient electrical conductivity, but hampering the final textile properties [7]. Smooth, thin, flexible and stretchable textile coatings with high electrical conductivity offers the perspective in a new generation of high added value textile products with a huge variety of new applications such as heating, lighting and sensors.

The integration of carbon nanotubes (CNT) in coatings for textiles offer good perspectives to obtain electrical conductive textile materials without losing the basic properties of a textile, i.e. light weight, stretchable and flexible, comfortable and ease of use. Conductive textiles by incorporating CNT through a coating or dyeing process are already discussed [8, 9, 10]. This work assesses the usability of CNT in various textile materials and applications by investigating CNT as an additive in coatings for textiles. In this work, textile coatings with variable amounts of CNT were developed and applied by traditional textile application processes, i.e. direct coating and transfer coating. A high degree of dispersion of the CNT within the coating was observed over the entire concentration range and visualized by scanning electron microscopy. This study reveals the construction of a honeycomb conductive network of the CNT particles inside the coatings. Moreover, the aluminium powder increases the light reflectivity of this conductive CNT coating.

2. MATERIALS AND METHODS

2.1 Materials

The CNT's were supplied by Nanocyl (Belgium) as an aqueous dispersion of 3% by weight. This dispersion is commercially available under the name of Aquacyl. The aluminium pigments were obtained from Eckart (Germany) as a powder IReflex 5000 White. As binders, polyacrylate dispersions under the commercial name Lurapret from BASF (Germany) were used. Lurapret dispersions are used to make coatings for home and technical textiles and characterized by a good wash and chemical resistance and a long life time. Furthermore pigment stabilizing agents based on alkoxylated surfactants were used to improve the dispersion of the CNT particles in the formulation. The textile materials used in this study are polyester knitted and woven fabrics from various suppliers. For transfer coating process, release paper from ArjoWiggins, UK (Primacast Mirror) was used.

2.2 Methods

Coating formulations were prepared by mixing different amounts of the CNT dispersion, aluminium powder and binder dispersion with a laboratory overhead stirrer (IKA, Germany). First the CNT dispersion is added to a mixture of the binder and the surfactants in small amounts to avoid high viscosity increase due to the CNT particles. Small amounts of water are added as well to counter this thickening effect. Next high speed mixing and a short ultrasonic treatment are used to obtain a homogeneous dispersed CNT coating formulation. The aluminium powder is added during the final formulation phase and this in small amounts of 1%, 3% and 5% based on the solid weight of the coating formulation. Finally, the vessel was placed in a desiccator and subjected to a vacuum process for 30 min with a maximum vacuum of -1 bar. This was done to avoid the introduction of air bubbles in the coating formulation and afterwards in the coating on the fabric.

For the application of the coatings, a labcoater LTE-S from Mathis (Switzerland) was used. This labcoater is a combination of an applicator and drying unit. For the direct coating applications, the coatings were applied in a three layered structure. First, a basecoat was applied with the technique of knife-in-air. In this way, a thin layer is applied that covers all pores and holes of the fabric. The coating was immediately dried during 3 min at 150°C. Next, two layers were applied by the technique of knife-on-roll. The knife gap was set at 200 μm. After application the coating is dried in two steps: first during 2 min at 80°C and next during 2 min at 150°C. This was done to have gradual evaporation of water and to avoid the formation of air bubbles in the coating. Coated fabrics of 300 x 400 mm were obtained after the application and curing processes. Several samples were prepared for conductivity measurements, characterization and further testing. For the transfer coating applications, two layers of a CNT based coating were applied on transfer paper and subsequently transferred to the textile material with a tie-coat. This tie-coat is based on a polyurethane dispersion. Drying is done in the same two step procedure as described above for the direct coatings.

Morphology analysis of surface and layer structure was carried out by means of an optical microscope, LV100POL (Nikon, Japan) equipped with digital imaging camera and software, DS-Fi1 (Nikon, Japan). Scanning electron microscopy (SEM) was used to visualize the CNT particles in the coatings and to evaluate the degree of dispersion of CNT. An ultra-high resolution field emission scanning electron microscope was used, Jeol JSM-7600F (Jeol, Japan). Reflection spectra were measured using a spectrophotometer UltrascanPRO (geometry: d/0) with Hunterlab EasyMatchQC software. Spot size opening is 19,8 mm.

3. RESULTS AND DISCUSSION

3.1 Coating application

The 15 different coating formulations, containing 1 wt% of CNT up to 15 wt% were applied by the direct knife on roll coating process in a 3 layered structure as explained in the Materials and Methods section. The coatings for evaluating the sheet resistance were prepared by this direct knife coating procedure. A picture of a 3 layered coating system produced on a roll-to-roll coating equipment is shown in figure 1 together with a microscopic image of the cross section of this system.

Fig. 1 Black acrylate-based coating containing 10 wt% CNT on a white polyester fabric: as produced (left) and microscopic image of a cross section (right)

The binders used for this type of coatings are high quality polyacrylates for textile coating with good film forming properties, high adhesion, good flexibility and scratch resistance. These properties are reflected in the coatings containing CNT. The irregularities observed on the surface can be explained by the roughness of the textile substrate. This can be seen on the image of the cross-section where the waviness of the coating is following the structure of the woven fabric.

The sheet resistance of the 15 different coatings was measured directly on the coated samples with a four probe sheet resistance measurement. The results obtained for an acrylic-based textile coating are shown in figure 2. There is a direct relationship between the concentration of CNT in the coating and the sheet resistance as expected: increasing the amount of CNT in the coating decreases the sheet resistance. A sheet resistance down to 60 Ω/sq was measured at 10 wt% CNT. it can be seen that percolation starts between 3 and 4 wt%. The coatings can be regarded to be electrical conductive (sheet resistivity <103Ohm/sq) starting at 3 wt% CNT. For industrial use, it is important to see that a broad range of electrical conductivity levels can be obtained by simply changing the amount of CNT in the coating. Above a concentration of 10 wt% CNT, no significant decrease of sheet resistance is measured.

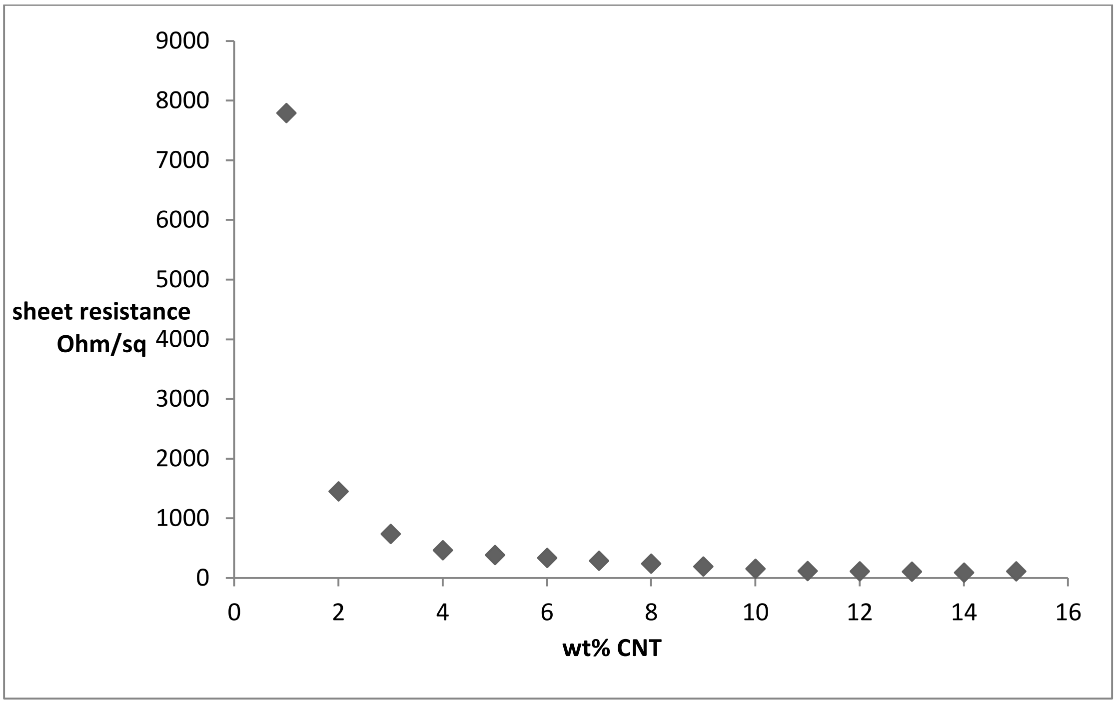

Fig. 2 Sheet resistance of an acrylic-based textile coatings with different CNT loading (wt%)

3.2. Dispersion of carbon nanotubes

By a controlled preparation of CNT based formulations – slow addition of the CNT dispersion, counter the effect of viscosity increase by the addition of small amounts of water – a high degree of dispersion of the CNT in the binder matrix can be obtained. Mixtures of alkoxylates improve strongly the rheology of the formulation. Moreover by adding these alkoxylated surfactants to the formulation, the CNT orientate during the coating drying process in a way that they form a honeycomb structure inside the binder matrix. This structure can be visualized by scanning electron microscopy images of applied coatings, depicted in figure 3 (left). The electrically conductive CNTs are highlighted during imaging and a structured network is visible. This structure forms a continuous network inside the coating at a concentration of 10 wt% of CNT, based on the solid content. At lower CNT content, this network is inside the coating as well, but not homogeneously present over de complete surface. At a concentration above 10 wt% of CNT in the coating, this network is in some areas overloaded with CNT. The SEM analysis shows that a high degree of dispersion of carbon nanotubes can be observed. A network structure appears together with a high value of conductivity. From 3 wt% CNT the first network structure appears. This is also the concentration where a more linear relation between concentration and resistivity starts. The most clear network structure can be observed at 10 and 11 wt%. The origin of this network can be explained by the fact that the CNT particles are homogeneously present in the acrylate binder dispersion. During the drying process of the wet coating, all the water evaporates and the acrylate particles move together surrounded by the CNT particles. The CNT particles settle between the acrylate particles forming a honeycomb structured network. In the SEM picture in figure 3 (right) one can observe the surface of an acrylate based coating. This coating was completely dried at 30°C to avoid fusion of the acrylate particles at high temperature. In this picture the individual acrylate particles can be observed. The particles have an average particles size of approx. 180 nm. This size corresponds to CNT honeycomb cell size that can be observed in figure 3 (left). Measurements show that these CNT cells have sizes between 160 and 230 nm. The most perfect CNT honeycomb cells have a diameter of approx. 180 nm.

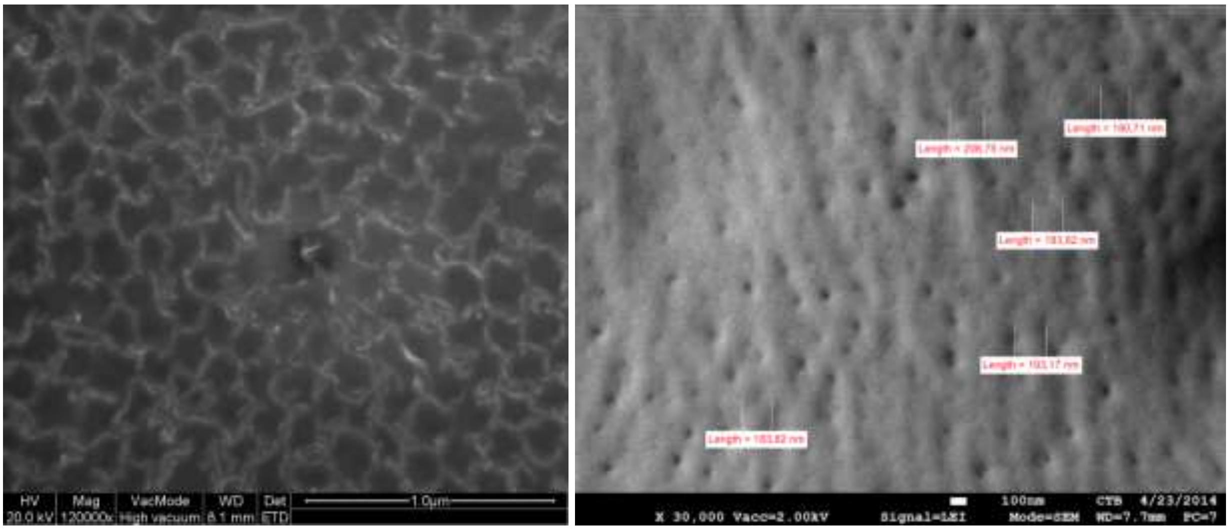

Fig. 3 Scanning electron microscopy images of the surface of an acrylate-based coating containing 10 wt% CNT (left) and without CNT (right)

3.3. Improving reflectivity

CNT based coatings are black, even at very low concentration of CNT. For heating and lighting applications an improved heat and light reflectivity would be beneficial. For this reason, aluminium powder was introduced into a high conductive 10 wt% CNT coating formulation at concentration levels of 1% and 5% of weight based on the solid content of the coating. The aluminium powder shows no compatibility problem when added to the CNT containing formulation. The additional thickening effect due to the aluminium powder must again be countered by the addition of a small amount of water. Reflectivity spectra of coatings without and with aluminium (Al) powder were measured with a spectrophotometer. The results are depicted in figure 4. The reflectivity of the coating increased with increasing aluminium content. Applications for this coating technology can be found in resistive heating textiles and base electrodes for flexible OLED lighting applications. Now-a-days silver based electrodes are used for this purpose. With resistivity value down to 60 Ω/sq and an improved reflectivity, these flexible coatings are investigated to replace silver and to introduce lighting and heating elements into textiles.

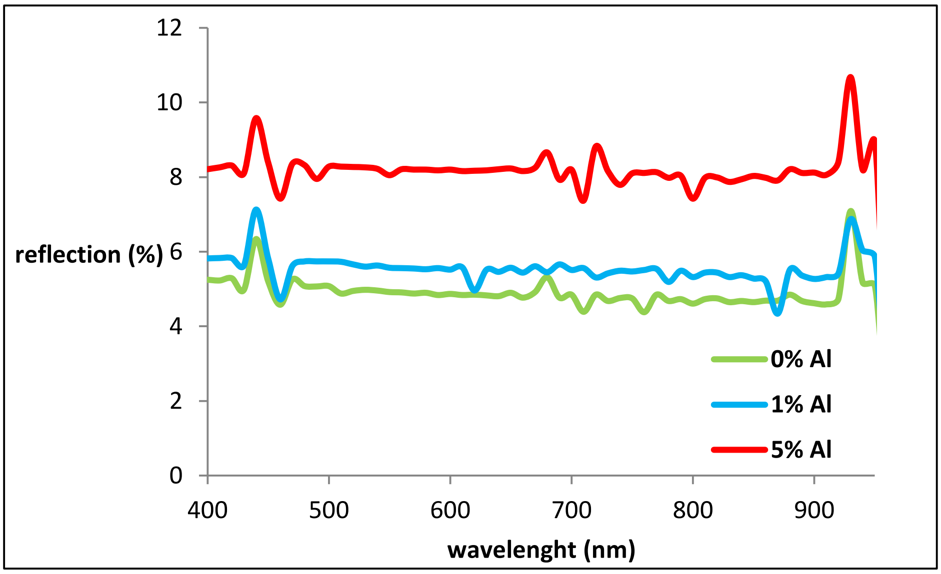

Fig. 4 Reflection spectra of 10 wt% CNT based coatings with and without aluminium (Al)

Conclusions

This work describes the introduction of electrical conductivity in textile materials by the use of textile coatings filled with carbon nanotubes. The preparation of coating formulations of water based acrylic binders with CNT as the active filler material is demonstrated. The application of these coating formulations was demonstrated by direct coating and transfer coating. The level of conductivity of these layers can be defined by the coating composition. By varying the amount of CNT in the coating formulation, the range of conductivity can be tuned from anti-static (1 wt% CNT) up to high conductivity (10 wt% CNT). The high level of conductivity (low resistivity) was explained by a high degree of dispersion of the CNT particles in the coating. A network of honeycomb structured CNTs can be visualized by scanning electron microscopy. The CNT network can be explained by the fact that the CNT particles are homogeneously present in the acrylate binder dispersion. The cell size of this CNT network corresponds to the size of the acrylate particles. Additionally these black CNT based coatings were functionalized with aluminium flakes to improve the reflectivity. With a low resistivity value of 60 Ω/sq at 10 wt% CNT and an improved reflectivity, these flexible coatings are investigated to replace silver and to introduce lighting and heating elements into textiles.

ACKNOWLEDGEMENTS

The research results presented in this paper have been obtained in the research project IWT-120629, with the financial support of the Flemish government agency for Innovation by Science and Technology. F. Govaert and M. Vanneste are grateful to Nanocyl for providing the CNT material, for the fruitful discussions and collaboration.

REFERENCES

[1] R.F. Service, *Science* 301 (2003) 909

[2] M. Catrysse, R. Puers, C. Hertleer, L. Van Langenhove, H. Van Egmond, D. Matthys, *Sens. Actuators* A 114 (2004) 302

[3] I. Locher, T. Kirstein, G. Tröster, *Proceedings of the First International Scientific Conference Ambience 2005*, Tampere, Finland, 2005

[4] E.R. Post, M. Orth, P.R. Russo, N. Gershenfeld, *IBM System Journal* 39 (2000) 840

[5] S. Coyle, K.-T. Lau, N. Moyna, D. O'Gorman*, IEEE Transactions on Information Technology in Biomedicine* 14 (2010) 364

[6] M. Billinghurst, T. Starner, *Computer* 32 (1999) 57

[7] D. Negru, C.-T. Buda, D. Avram, *Fibres & Textiles in Eastern Europe* 20 (2012) 53

[8] M. in het Panhuis, J. Wu, S.A. Ashraf, G. G. Wallace, *Synthetic Metals* 157 (2007) 358

[9] B. S. Shim, W. Chen, C. Doty, C. Xu and N.A. Kotov, *Nano letters* 8 (2008) 4151

[10] R. Zhang, H. Deng, R. Valenca, J. Jin, Q. Fu, E. Bilotti, T. Peijs., *Sensors and actuators A-Physical* 179 (2012), 83