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Preparation and electrical conductivity of different fibres prepared from vertically aligned carbon nanotubes

Mathieu Pinault[1], Karim El-Hadj[1], Nicolas Debski[1], Wilfried Neri[2], Soraya Ammi[3], Cecile Zakri[2], Philippe Poulin[2], Vincent Derycke[1], Christian Poumarede[3], Martine Mayne-L'Hermite[1*]

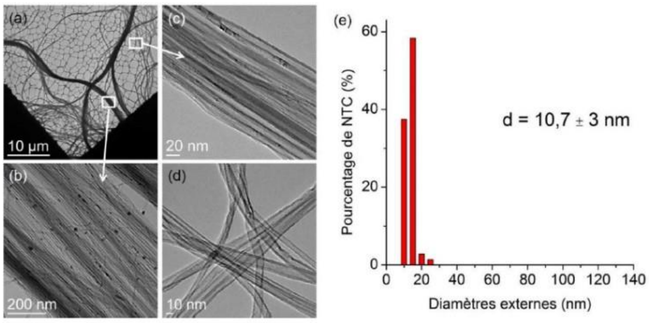
[1] NIMBE, CEA, CNRS, Université Paris-Saclay, CEA Saclay 91191 Gif-sur-Yvette France
[2] Centre de Recherche Paul Pascal-CNRS, Avenue Schweitzer, 33600 Pessac, France
[3] RTE – Paris La Défense, France

[*] martine.mayne@cea.fr

Due to their exceptional electrical, chemical, thermal and mechanical properties, carbon nanotubes (CNT) are particularly appealing as building block of fibres, in particular to form light-weight conducting cables for electricity transport [1]. One direct potential application is their use as High Voltage devices in transmission grid. Indeed, the possibility to help in the emergence of a new technology - especially for OverHead Lines (OHL) conductors with low electrical resistance as well as reduced weight and good mechanical properties - was considered as a promising topic.
Several studies are reporting the preparation of fibres from carbon nanotubes, either CNT/polymer composite fibres [2-5] or CNT fibres [6-7], together with the study of their electrical and mechanical properties. However, it is difficult to make a precise comparison between the different types of fibres since they are produced through various processes and with different types of CNTs. The characteristics and intrinsic physical properties of the nanotubes used are rarely fully documented so that their impact on the fiber performances is difficult to assess precisely. The approach followed in our study consists in elaborating CNT-based fibres from vertically aligned carbon nanotubes and, second, measuring both the intrinsic electrical properties of the individual CNTs used for fibre preparation and the electrical conductivity of the resulting fibres in order to evaluate the actual benefits of the CNT quality on the fibre performances

Both PVA/CNT composite and CNT fibres were prepared from vertically aligned carbon nanotubes synthesized by a one-step aerosol-assisted CCVD process[8]. In this process, the iron catalyst precursor (ferrocene) and carbon precursor (toluene or acetylene) are introduced simultaneously in the reactor, making it continuous and avoiding the preliminary deposition process of catalyst. In order to elaborate the composite fibres, VACNT were detached from their growth substrate to prepare stable and concentrated suspensions of CNTs with length of several µm. Such suspensions were subsequently used in PolyVinylAlcohol (PVA) to form composite fibres by coagulation techniques [2 9]. Regarding pure CNT fibres, direct dry spinning of the VACNT carpets, formed from our one-step CCVD process, was performed. It has to be noticed that, today, most of the spinnable aligned CNT carpets are prepared according to a 2 steps CVD process, whereas very few studies deal with CNT fibres obtained from carpets synthesized by CVD in a single step [10, 11]. Therefore, an adjustment of the characteristics of VACNT carpets was done, enabling to obtain quite long CNT fibres (few tenth of cm) exhibiting from few tens of µm to few µm in diameter (see figure below showing

SEM images of CNT fibres and TEM images of CNT constituting the fibres together with their diameter distribution).



(a-d) TEM micrographs of the CNT constituting the 100% CNT fibers and (e) external diameter distribution deduced from the analysis of the micrograph on nearly one hundred CNTs

Electrical measurements were performed both on fibres and individual CNT used for fibre preparation in order to check how the CNT intrinsic properties reflect on the fibre performances. Individual CNTs were connected by palladium electrodes using e-beam lithography. CNT conductivity was assessed in different conditions and on a large number of individual CNTs to obtain statistically robust results. By considering several sections of the same nanotubes (with different length) and/or by comparing measurements at both low and high electric field, the impact of metal/CNT contact resistance was determined and the intrinsic CNT conductivity was evaluated. We notably obtained CNT conductivity in the 2.10^4 – $1.5.10^6$ S/m range depending on the length/diameter ratio. Highest conductivities naturally correspond to the nanotube with small diameter and long length. For nanotubes whose crystalline structure had been improved by post annealing treatment at 2000°C under Ar [12], a limited twofold increase in conductivity was observed as compared to raw CNTs.

The electrical conductivity of the fibres was also measured. For CNT/PVA fibres, electrical conductivity depends on CNT content in the fibres and reaches around 1 S/m. However, when fibres are annealed in order to remove the polymer matrix, the conductivity is raised up to $5x10^4$ S/m which corresponds almost to the intrinsic conductivity measured on the CNT ($1x10^5$ S/m) used for these fibres. For pure CNT fibres, the first electrical measurements indicate that the conductivity depends on the spinning process, especially if twisting is applied. The electrical conductivity of such fibres without any annealing treatment is about $6x10^4$ S/m as compared to the maximum conductivity of the CNT used in these fibres which is around $1.5x10^6$ S/m. This suggests that the preparation process of such CNT fibres can still be optimized in order to fully take benefit of the intrinsic conductivity of its building blocks.

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