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Short communication

# Preparation and mechanical properties of carbon fibers with isotropic pyrolytic carbon core by chemical vapor deposition

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## HIGHLIGHTS

- A novel carbon fiber with obvious core/sheath structure was developed by CVD.
- The core of the fiber was isotropic pyrolytic carbon.
- This carbon fiber has shown excellent performance in mechanical properties.
- The fiber shows same mechanical properties in both axial and radial directions.

## ARTICLE INFO

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## ABSTRACT

This paper reports the development of a novel carbon fiber with isotropic pyrolytic carbon core via isothermal–isobaric catalyst-free CVD of propylene. The morphological and microstructural characterizations of the carbon fibers developed were carried out by polarized light microscopy, scanning electron microscopy and transmission electron microscopy. Both the elastic modulus and hardness of the two components of these carbon fibers were measured using nanoindentation technique. The results show that the isotropic pyrolytic carbon core has a homogeneous and complex microstructure, which accounts for approximately 64% of the whole carbon fiber volume. It is this unique core structure that enables these carbon fibers to possess excellent overall mechanical properties with nearly isotropic performance in both the axial and radial directions.



## 1. Introduction

Carbon fibers (CFs) synthesized by chemical vapor deposition (CVD), have been a research subject in carbon materials for the past decades due to their good mechanical and electrical properties and are expected to be an ideal reinforcement for ceramic, polymer and carbon matrix composites [1]. However, the applications of CFs have been limited due to the anisotropy of the obtained composites, in which the matrix will be strengthened by the CFs only in the fiber direction. If high strength is required in more than one direction, a preform is needed in which the fibers must be uniformly distributed and aligned along the loading directions [2].

Much effort has been made in designing and developing appropriate preforms to meet particular needs, as evidenced by the development of one-dimensional, two-dimensional, three-dimensional and even more complicated preforms [3,4]. Although effective, the method using complicated preforms has the drawbacks such as time-consuming manufacturing procedures and high costs [5]. So far, however, there have been few literature reports concerning this issue with an attempt to produce high performance isotropic CFs. It should be also pointed out that the pitch-based isotropic carbon fibers have isotropic structures too but their modest properties make them belong to the category of general-purpose carbon fibers, so they are not suitable for the purpose of high performance [6]. In this work, we consider that the development of a type of isotropic CF with excellent mechanical properties could be a good solution.

It is well known that of all pyrolytic carbon materials, the isotropic pyrolytic carbon has outstanding and isotropic mechanical properties [7]. It is hence conceivable that isotropic pyrolytic carbon could be an ideal candidate for the main constituent of the CFs with isotropic properties. And for CVD, it has proved itself as a flexible and convenient method to produce CFs with various core–sheath microstructures, such as the high textured pyrolytic carbon core [8], the carbon nanotube core [9] and the carbon

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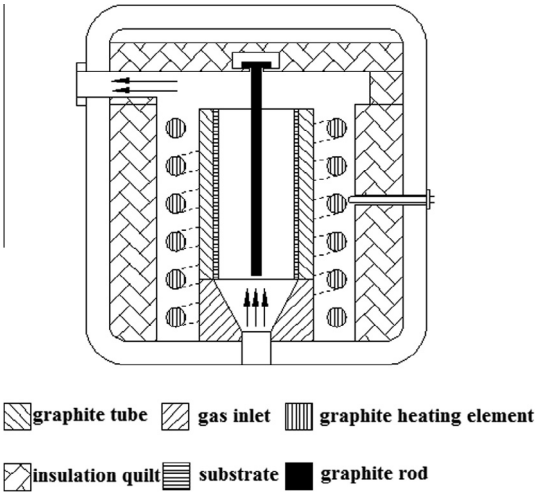


**Fig. 1.** Schematic diagram of the apparatus for the production of CFs.

onions core [10], combined with anisotropic pyrolytic carbon layers sheath. Successful preparation of CFs with various structures suggests that more complex carbon architectures could be obtained through suitable design of experimental parameters, including temperature and concentration of carbon source etc.

In this study, we, for the first time, proposed to produce a new kind of CF with an isotropic pyrolytic carbon core by classical isothermal–isobaric catalyst-free CVD technique. The morphology and microstructure of the as-made CFs were characterized by polarized light microscopy (PLM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM) and their mechanical properties were characterized by using nanoindentation technique.

## 2. Experimental materials and procedures

The CVD apparatus used in our experiment is a homemade vertical cylinder graphite resistance furnace as shown by the schematic diagram (Fig. 1). The gases were introduced into the isothermal deposition zone through a cone gas inlet at the bottom. In the isothermal zone was placed a 64-mm-diameter and 280-mm-height graphite tube which was also just located over the gas inlet. On the surface of the inner wall of this graphite tube was uniformly glued a 3-μm-thickness graphite paper substrate. A tungsten-rhenium thermocouple was placed at the tube center to control the temperature. A 14-mm-diameter graphite rod was suspended at the center zone to adsorb the soot which could be produced during the process to prevent the gas inlet from being blocked. The deposition was conducted at 900 °C under ambient pressure for 15 h. Propylene (99.9%) and hydrogen (99.9%) were used as the carbon source and the carrier gas, respectively, with a volume ratio of 1:6 (the flow rate of propylene and hydrogen are 0.4 L/min and 2.4 L/min, respectively). The furnace was under a hydrogen atmosphere during both the heating and cooling processes.

The morphological and microstructural characterizations of the CFs developed were carried out by using a Leica DM4500P polarized light microscope, a FEI Nova Nano SEM230 scanning electron microscope and a JEOL JEM-2100F high resolution transmission electron microscope (HRTEM). The TEM specimens were prepared by reference to the standard procedure of fiber TEM cross-section. Both the elastic modulus and hardness of the components of CFs

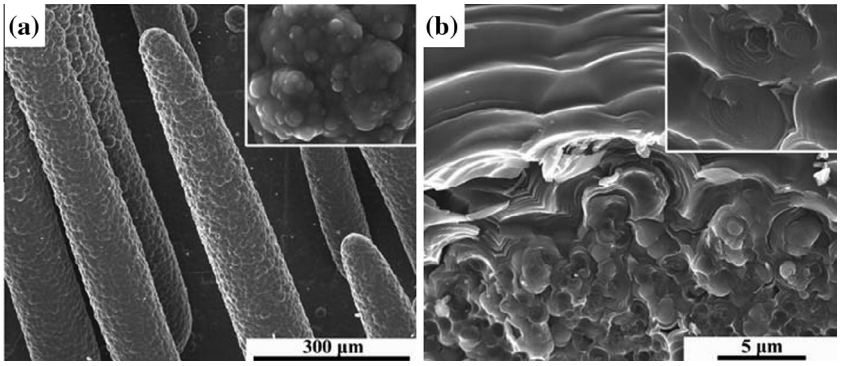


**Fig. 2.** SEM images of (a) overview of CFs on the substrate with the inserted image showing the magnified surface of a CF, (b) fracture cross-section of a CF with the inserted image showing the magnified core.

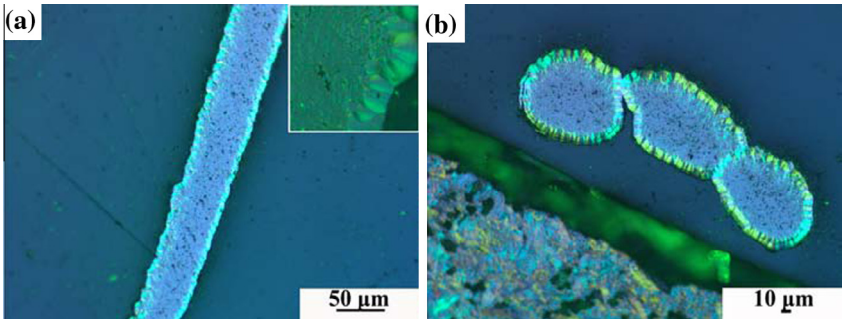


**Fig. 3.** PLM images of (a) the axial-section with the inserted image showing the magnified core and outer layers, (b) the cross-section of the CFs.