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Structures of Green Culms and Charcoal of *Bambusa multiplex*

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Bambusa multiplex (Lour.) Raeusch that is bamboo native to southern Asia and naturalized in other areas of Asia and America has a straight culm of a height of 5~8 m and a diameter of 0.03~0.05 m with small lumens between internodes of a length of 0.2~0.3 m. The culm is thick and heavy. It has been used as wood pulp and is expected to be the useful material for cellulose nanofibers. Its charcoal would be the promising carbon material for new fabricated devices. Therefore, we studied the structures of the green culm and the charcoal of *Bambusa multiplex*, mainly by X-ray diffraction (XRD) and fluorescent element analysis (XRF), analytical scanning electron microscopy (SEM) and scanning transmission electron microscopy (STEM). Culms of *Bambusa multiplex* were sampled and seasoned in Thailand. Some of culms, cut off their branches and leaves, were carbonized around 700^{o}C for 3 h in a conventional charcoal kiln. SEM energy dispersive X-ray spectroscopy (EDS) mapping was performed using large depth of focus (LDF) mode with a JSM-7200F operated at 15 kV. For TEM/STEM, two aberration corrected microscopes, JEM-ARM 200F and JEM-3100F R05 were used and operated at 200 kV and 80 kV, respectively with a cold field emission gun. Both were configured with a Gatan US-1000 camera and a GIF Quantum ER energy filter for image recording and electron energy loss spectroscopy (EELS).

Fig. 1 shows a light microscopy image of a transverse section of a green culm of *Bambusa multiplex*. *Bambusa multiplex* has a typical anatomical structure of bamboo [1] and resembles *Phragmites australis* (common reed) [2] and *Arundo donax* (giant reed) [3], which also belong to Poaceae Family, although it is different from those reeds in scale of outer shape and size of cells. Fig. 2(a) and Fig. 3 show the XRD and XRF results for different points **a** and **b** of a green culm and points **A**-**E** of a charcoal tube, as shown in Fig. 2(c). The culm and the charcoal tube are indicated in Fig. 2(b). XRD revealed that the green culm comprises amorphous cellulose and natural crystalline cellulose. XRF revealed that it contains Si atoms in and near its skin. With these results, we concluded that neither carbonization nor graphitization was completed for the charcoal at the present low carbonized temperature. The outside of the charcoal tube **B** still contained a large amount of Si like the green bamboo skin, which was confirmed by SEM EDS mapping in Fig. 4. Fig. 5(a) shows TEM image of a flake of the charcoal powder. The EELS fine structure of C-K edge obtained from the area enclosed by the circle is shown in Fig. 5(b). The excitation peaks π^* and σ^* related with the π and σ bonds appear in the amorphous charcoal. The charcoal powder is composed of carbon nanotubes or nanofibers disorderly distributed and graphite crystallites in very small areas, as seen in Fig. 6.

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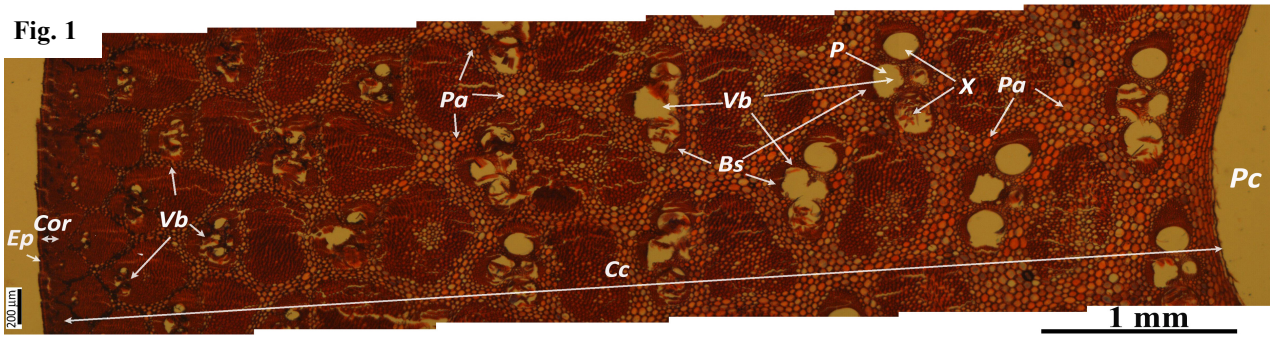

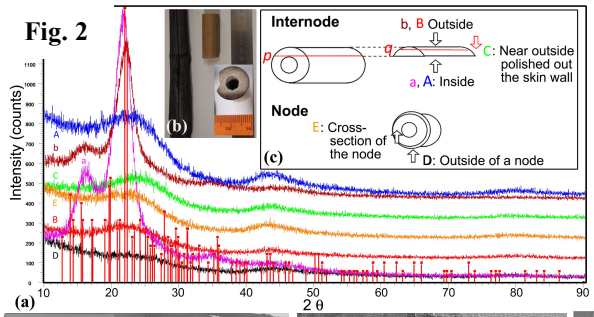

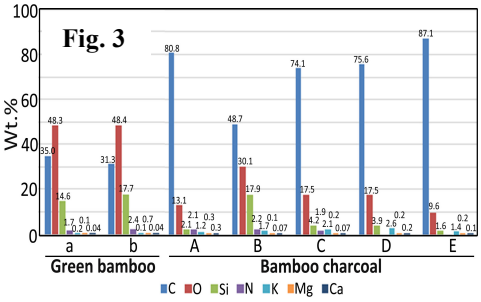

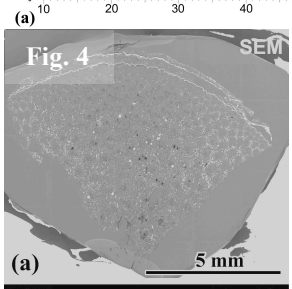

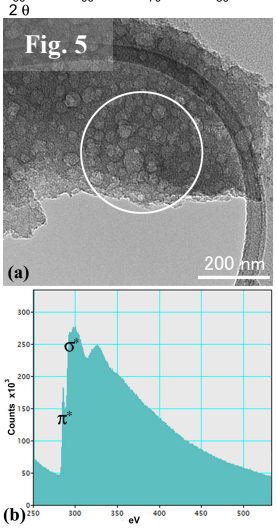

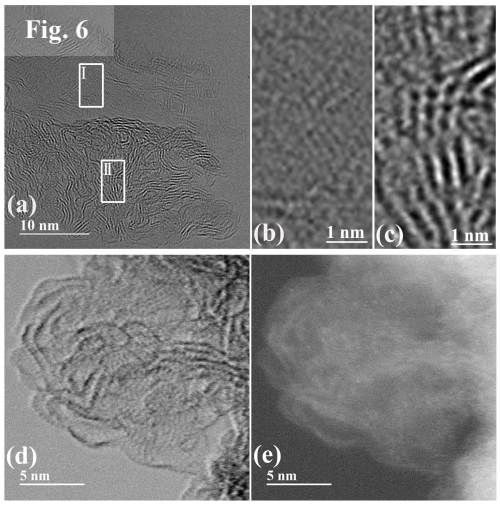

Fig. 1 A montage image of a transverse section of a green culm of *Bambusa multiplex*. *Ep*: epidermis. *Cor*: cortex. *Cc*: central cylinder. *Vb*: vascular bundle. *Bs*: vascular bundle sheath. *Pa*: parenchyma cell. *P*: phloem. X: xylem. *Pc*: pith cavity.

Fig. 2 (a) XRD from points **a** and **b** in green culm and points **A-E** in charcoal indicated in (b). The points are assigned in (c).

Fig. 3 XRF from points **a**, **b** and **A-E.**

Fig. 4 SEM (a) and EDS mapping of Si-K (b). Cross-section through a node of charcoal tube.

Fig. 5 TEM image of a flake of the charcoal powder on a hole in the holey carbon film. (b) EELS fine structure of C-K edge. JEM-ARM 200F was used at 200kV.

Fig. 6 (a) HR-TEM image of another flake of the charcoal powder. The area is an edge of a flake jutted out into a hole in the holey carbon film. (b, c) Enlarged images of the areas enclosed by rectangles I and II, respectively, in (a). (d, e) A pair of HR-STEM BF and HAADF images of another edge of the charcoal flake. JEM-3100F R05 was used at 80 kV.

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