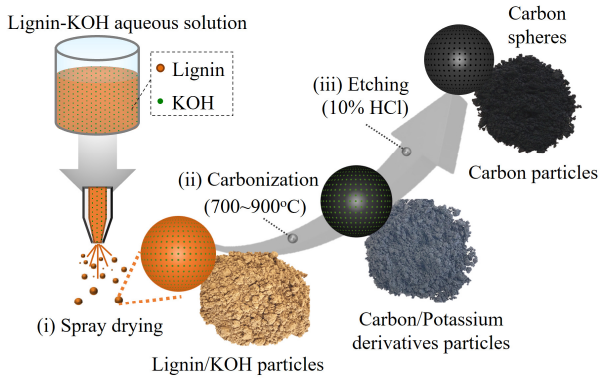
Precisely tailored synthesis of sustainable porous carbon spheres derived from Kraft lignin

(Hiroshima U.) ○ (Reg) Cao K. L. A · (Reg) Ogi T.*

1. Introduction

Carbon spheres have attracted tremendous interests in recent years due to their fascinating structure-induced physicochemical properties and great potential for widespread applications. The production of carbon-based materials from green, renewable, and cost-effective resources in accordance with sustainable development goals is of high interest and encouraged. In this regard, lignin has been considered as a potential sustainable source for the preparation of advanced porous carbon materials due to its high carbon content (~ 60 wt.%), abundance, low cost, and extensively crosslinked polyphenolic structure. In this work, the carbon particles with the precise design and controllable structure from dense to hollow sphere were successfully fabricated via a spray drying method followed by the carbonization process, using Kraft lignin as the carbon source and potassium hydroxide (KOH) as the activation agent.[1,2]



The samples were marked as **KLC-X-Y**
where **X** represents the mass ratio of KOH to lignin (X = 0.33, 0.67, 1.00, 1.33)
Y indicates the carbonization temperatures (Y = 700, 800, 900°C)

Fig. 1. Preparation of spherical carbon particles derived from Kraft lignin.

2. Results and discussion

In a typical procedure, the preparation of carbon particles involves three steps as illustrated in Fig. 1. The effect of KOH concentration on the morphologies and internal structures of carbon particles were assessed using SEM and TEM, and typical images are presented in Fig. 2. In the absence of KOH, the majority of the particles exhibited a non-spherical morphology with wrinkled surfaces (Fig. 2(a-1)) and hollow structures were produced (Fig. 2(a-2)). In contrast, when KOH was present in this reaction system, the carbon particles show uniform morphologies with spherical shapes in the SEM images (Fig. 2(b-1–c-1)). Interestingly, as the KOH/lignin mass ratio increased from 0.33 to 1.33, the structure of carbon particles changed from dense to hollow. These results indicate that the shape of carbon particles could be easily adjusted by controlling the KOH concentration.

The structural parameters including specific surface areas and pore characteristics are summarized in Table 1. With an increasing amount of KOH and carbonization temperature, the resulting carbon particles exhibited both an increase in specific surface area as well as total pore volume. The **KLC-1.33-900** was found to have the highest specific surface area and total pore volume in comparison with the other samples. In addition, these

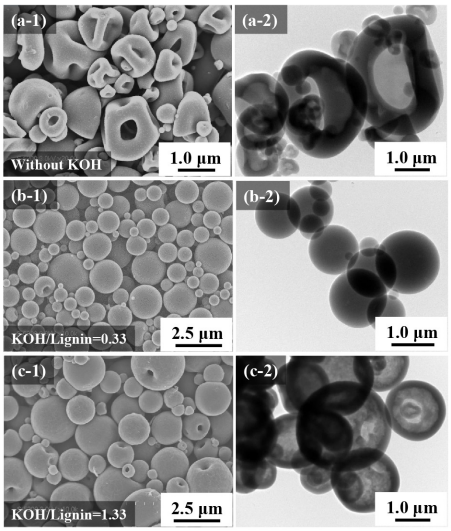


Fig. 2. SEM (left) and TEM (right) images of carbon particles derived from Kraft lignin in the case of (a) without KOH, using different KOH/lignin mass ratios of (b) 0.33, and (c) 1.33.

Table 1. Textural properties of carbon particles derived from Kraft lignin.

Sample	S_{BET} ($m^2 g^{-1}$)	Total pore volume ($cm^3 g^{-1}$)	$V_{micropore}$ ($cm^3 g^{-1}$)	$V_{mesopore}$ ($cm^3 g^{-1}$)
LC-700	471.9	0.233	0.179	0.058
KLC-0.33-700	936.0	0.418	0.361	0.063
KLC-1.33-700	1996.2	1.206	0.774	0.253
KLC-1.33-800	2207.3	1.341	0.904	0.276
KLC-1.33-900	2424.8	1.566	0.934	0.467

carbon particles can be used as electrode materials in supercapacitors for energy storage applications. The two-electrode supercapacitor showed a specific capacitance value of 31.8 F g^{-1} at a current density of 0.2 A g^{-1}, which is higher than that obtained from the commercial activated carbon Kuraray YP-50F (29.2 F g^{-1}).

3. Conclusions

The spherical carbon particles derived from Kraft lignin have been synthesized via a spray drying method followed by the carbonization process. The carbon particles generated in this study could be obtained with spherical morphologies and it could be precisely controlled from dense to hollow sphere by altering the KOH concentration. These carbon particles have applications as electrode materials in supercapacitors for energy storage devices. These promising properties in conjunction with the green synthesis approach suggest intriguing strategies for the design of carbon spheres as advanced materials from Kraft lignin as a low-cost raw material.

References

1) Cao, K. L. A. *et al.*, J. Colloid Interface Sci., **589**, 252 (2021).
2) Cao, K. L. A. *et al.*, Adv. Powder Technol., **32**, 2064 (2021).

*ogit@hiroshima-u.ac.jp