

Electronic Supplementary Information

Thermal Conversion Behavior of Pyrazole-3,5-Dicarboxylate-Substituted Octacalcium Phosphate

Shimon Konosu,^a Kazuto Sugimoto,^{a,b} Iori Yamada,^a and Motohiro Tagaya^{a*}

^a *Department of Materials Science and Bioengineering,
Graduate School of Engineering, Nagaoka University of Technology,
1603-1 Kamitomioka, Nagaoka 940-2188, Japan.*

^b *Japan Society for the Promotion of Science (JSPS)
Research Fellowship for Young Scientists (DC),
5-3-1 Koji-machi, Chiyoda-ku, Tokyo 102-0083, Japan.*

* Author to whom correspondence should be addressed:

Tel: +81-258-47-9345; Fax: +81-258-47-9300, E-mail: tagaya@mst.nagaokaut.ac.jp

Experimental Procedure S1

OCP was synthesized as follows. An acetate buffer (pH = 3.6) was prepared by mixing 90 mL of a 0.1 mol/L acetic acid solution (CH_3COOH , purity: 99.7 w/w%) and 10 mL of a 0.1 mol/L sodium acetate solution (CH_3COONa , purity: 98.0 w/w%). L-carnitine (0.75 mmol, purity: 98 wt%) was dissolved in 12.5 mL of the acetate buffer. Subsequently, the pH of the solution was adjusted to 3.6. Then, 1.00 mmol of α -tricalcium phosphate (α -TCP, $\text{Ca}_3(\text{PO}_4)_2$, purity: vital material research grade, CaO:P₂O₅ molar ratio = 2.9–3.1) was added to the solution. The suspension was then stirred at 60 °C for 3 h to hydrolyze the added α -TCP and induce the precipitation of OCP. The resulting precipitates were collected by centrifugation, washed three times with ultrapure water, and freeze-dried. The freeze-dried sample is denoted as **OCP-X**.

Experimental Procedure S2

The thermal stability was evaluated using a TG-DTA apparatus (Thermo Plus TG8120, Rigaku Corporation), and was carried out under a nitrogen atmosphere with α -alumina (purity: 99.0 wt%) used as the reference. An aluminum pan was employed to be heated up to 500 °C at a heating rate of 10 °C/min.

Experimental Procedure S3

The Ca/P molar ratios of *PD/OCP-X* and *OCP-X* ($X = 0, 100, 140$) were determined by ICP-OES (ICPE-9820, Shimadzu Corporation). Approximately 100 mg of each sample was weighed without the prior drying treatment and completely dissolved in 20 mL of 0.1 mol/L HNO₃ solution with stirring for 1 h. An aliquot of 1 mL of the resulting solution was then diluted to be 50 mL with ultrapure water in a volumetric flask and used for the ICP-OES measurements. Calibration curves for Ca and P were constructed using standard solutions of Ca (Product No. 039-16161, FUJIFILM Wako Pure Chemical Corporation) and P (Product No. 164-19244, FUJIFILM Wako Pure Chemical Corporation). The Ca/P molar ratios were calculated from the calibration curves using the emission wavelengths of Ca at 317.9 nm and P at 213.6 nm.

Experimental Procedure S4

The XRD patterns were measured using a powder X-ray diffractometer (SmartLab, Rigaku Corporation). CuK α radiation ($\lambda = 0.15418$ nm) was used as the X-ray source, and the measurements were performed at 45 kV and 30 mA and carried out at a scanning rate of 5 °/min for the general analysis. The d -values were calculated from the obtained patterns using Bragg's equation **Eq. (S1)**.

$$2d\sin\vartheta = n\lambda \quad (\text{S1})$$

In addition, **PD/OCP-0**, **PD/OCP-140**, and **OCP-0** were measured at a slower scan rate of 0.2 °/min for the detailed analysis. The full width at half maximum (FWHM) values of **PD/OCP-0** and **OCP-0** were determined from the diffraction pattern peaks in the detailed analysis and are presented as the averages between three measurements.

Experimental Procedure S5

The FT-IR spectra were measured using an FT-IR spectrometer (FT/IR-4600, JASCO Corporation) in diffuse reflectance mode with a KBr background. The spectra were recorded over the wavenumber range between 1800–500 cm^{-1} with 128 scans and a resolution of 2.0 cm^{-1} . Here, the samples were mixed with KBr at a mass ratio of 1:100, ground thoroughly. All the spectra were corrected by subtracting the background spectrum of KBr.

Experimental Procedure S6

The solid-state ^{31}P -NMR spectra of PD/OCP were measured using a solid-state NMR spectrometer (Avance Neo 500, Bruker Corporation) equipped with a 4 mm iProbe CP-MAS probe, operating at a resonance frequency of 202.456 MHz for ^{31}P . Approximately 300 mg of sample was applied. First, cross-Polarization magic angle spinning (CP-MAS) measurements were performed at MAS spinning speeds of 5 kHz and 10 kHz, where the peak positions were confirmed, followed by direct polarization (DP-MAS) measurements at 10 kHz. For the CP-MAS measurements, the contact time was set to be 2.5 ms, the relaxation delay to be 15 s, and the number of scans to be 16. The measurements at spinning rates of 5 and 10 kHz were performed to identify the spinning sidebands. For the DP-MAS measurements, the pulse width was set to be 3.0 μs , the relaxation delay to be 20 s, and the number of scans to be 500. The chemical shifts were externally referenced to $\text{NH}_4\text{H}_2\text{PO}_4$ at 1.33 ppm.

Experimental Procedure S7

The morphologies of the samples were observed using a FE-SEM (SU8000, Hitachi High-Tech Corporation). The samples were mounted on carbon tape, coated with platinum, and observed at an accelerating voltage of 10 kV and a magnification of 40,000×.

The specific surface areas were determined from nitrogen adsorption–desorption isotherms measured at liquid nitrogen temperature (–196 °C) using a surface area and pore size distribution analyzer (BELSORP-Mini II, MicrotracBEL Corp.). The BET specific surface area was calculated based on Eq. (S2)

$$\frac{1}{V\left(\frac{P_0}{P} - 1\right)} = \frac{C - 1}{V_m C} \times \frac{P}{P_0} + \frac{1}{V_m C} \quad (\text{S2})$$

where V is the adsorbed gas volume, V_m is the monolayer adsorbed gas volume, P is the equilibrium pressure, P_0 is the saturation vapor pressure, and C is the BET constant. The BET surface area (S_{BET}) was calculated from the obtained V_m value, assuming a nitrogen molecular cross-sectional area of 0.162 nm.^(S1) Prior to the measurements, the samples were degassed at 80 °C under vacuum for 1 h using a pretreatment system (BELPREP-vac II, MicrotracBEL Corp.).

Reference for this section

(S1) Brunauer, S.; Emmett, P. H.; Teller, E. Adsorption of Gases in Multimolecular Layers., *J. Am. Chem. Soc.*, 60, 309-319 (1938).

Fig. S1

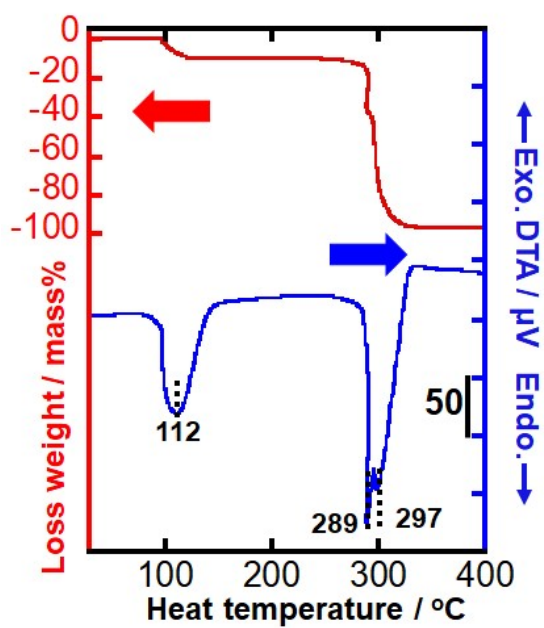


Fig S1. TG-DTA curves of pyrazole-3,5-dicarboxylic acid monohydrate reagent.

Fig. S2

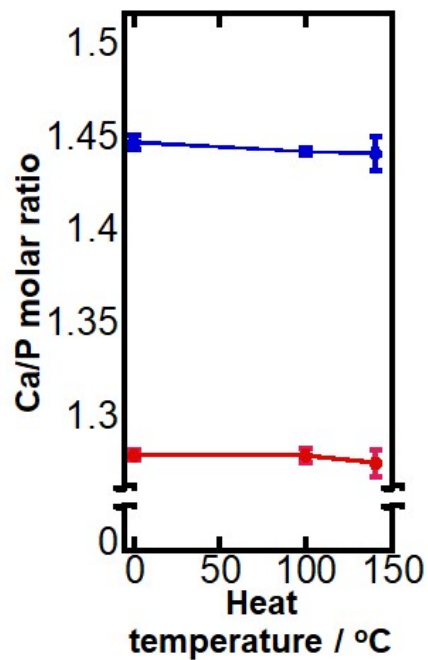


Fig S2. Change in the Ca/P molar ratios determined by ICP. Blue-color and red-color indicate *PD/OCP-X* and *OCP-X*.

Fig. S3

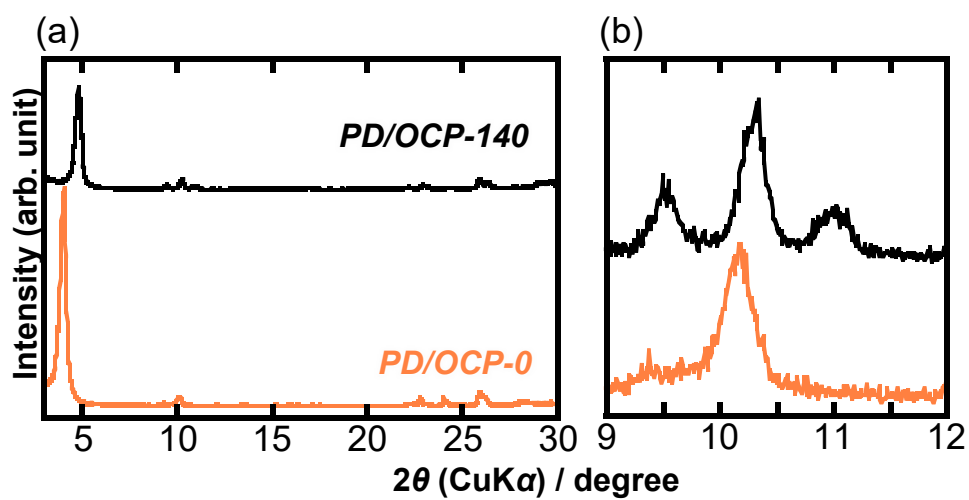


Fig S3. XRD patterns of *PD/OCP-X* with the heat treatment at (a) wide- and (b) narrow- 2θ -angle regions. Here, (b) was magnified from (a).

Fig. S4

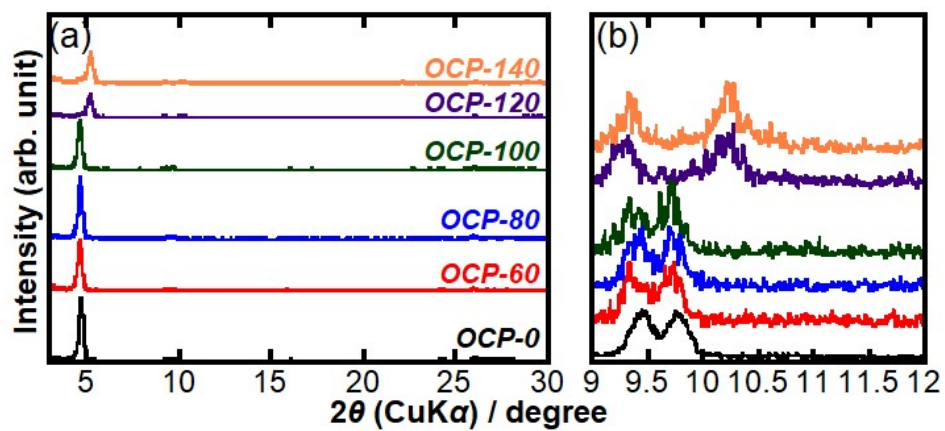


Fig S4. XRD patterns of **OCP-X** with the heat treatment with expanded views of (a) wide- and (b) narrow- 2θ -angle region.

Fig. S5

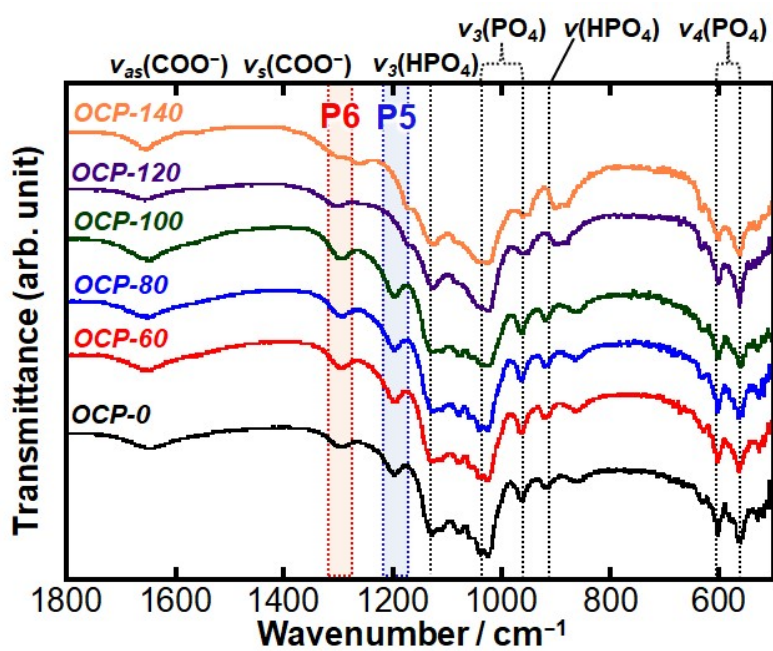


Fig S5. FT-IR spectra of **OCP-X** with heat treatment.

Fig. S6

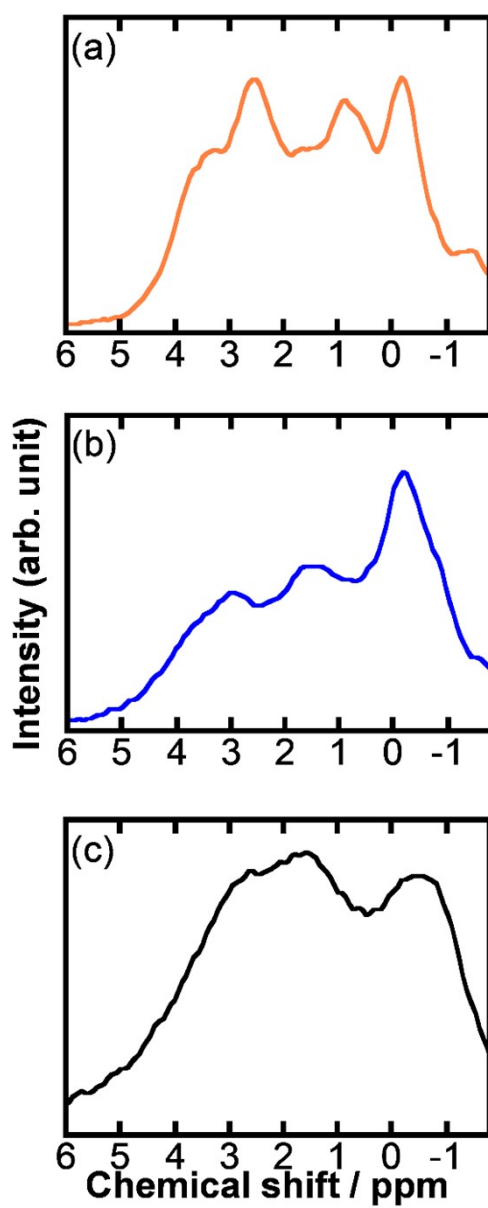


Fig S6. Solid-state ^{31}P NMR CP-MAS spectra of (a) *PD/OCP-0*, (b) *PD/OCP-100*, and (c) *PD/OCP-140*.