Ceramics International 31 (2005) 869–872

CERAMICS
INTERNATIONAL

www.elsevier.com/locate/ceramint

Preparation of hydroxyapatite nanoparticles by reverse microemulsion

Guangsheng Guo*, Yuxiu Sun, Zhihua Wang, Hongyou Guo

Key Laboratory of Science and Technology of Controllable Chemical Reactions, Ministry of Education,
Beijing University of Chemical Technology, Beijing 100029, China

Received 27 January 2004; received in revised form 7 September 2004; accepted 2 October 2004

Abstract

Hydroxyapatite (HAP) nanoparticles have been successfully synthesized by reverse microemulsion (aqueous solution/mixed TX-100 and Tween 80/mixed *n*-butanol and *n*-hexanol/cyclohexane) at room temperature. In comparison with HAP particles, prepared by conventional direct precipitation method, the reverse microemulsion route led to a significant improvement in the particle size and the degree of particle agglomeration. The effect of different hydrophile–lipophile balance (HLB) values on the particle size was also discussed.

Keywords: Hydroxyapatite; Nanoparticles; Reverse microemulsion

1. Introduction

Synthetic hydroxyapatite (HAP) is a well-known biocompatible and bioactive material that has been widely used in medical applications as implants or as coatings on prostheses [1,2]. Many of these applications require high dense, high strength materials for lead-bearing, whose properties are largely dependent on their microstructural features, such as particle size, degree of particle size agglomeration and sintered densities. Therefore, the preparation of fine, single distribution and sinerable HAP particle is the most important step in achieving a highly sintered ceramic material with desirable microstructure. Many chemical processing routes have been employed to prepare fine and agglomerate free ceramic HAP particles, among which microemulsion route exhibited special characteristics in controlling the particle size and particle agglomeration. The microemulsion route has been used successfully to prepare HAP particles [3–8], but few of them have ever discussed the effect of some surfactant parameters such as hydrophile–lipophile balance (HLB) values on the particles.

The aim of the present work is to investigate the feasibility of preparing HAP nanoparticles by the reverse microemulsion consisting of mixed surfactants with different HLB values, discuss the effect of HLB values on the particle size and also compare the particle size of HAP prepared by two different methods.

2. Experimental

2.1. Chemicals

The starting materials include: polyoxyethylene (TX-100), polysorbate 80 (Tween 80), 13.4 M ammonia solution, cyclohexane, *n*-butanol, *n*-hexanol, $Ca(NO_3)_2{\cdot}4H_2O$ and $(NH_4)_2HPO_4$. All reagents were of AR grade and used without further purification. Deionized water was used in any synthesis or purification steps.

2.2. Preparation of HAP nanoparticles

HAP particles were prepared via two processing routes: (i) conventional precipitation route and (ii) reverse microemulsion route. For the conventional processing route, the stoichiometric amount of 0.3 M $(NH_4)_2HPO_4$ aqueous solution was titrated into 0.5 M $Ca(NO_3)_2$ aqueous solution

---

* Corresponding author. Tel.: +86 10 64423089
E-mail address: guogs@mail.buct.edu.cn (G. Guo).

doi:10.1016/j.ceramint.2004.10.003

under strong stirring; ammonia solution was used to adjust the pH of the reaction system between 10 and 11, resulting in the formation of amorphous calcium phosphate precipitates, aged at room temperature for 24 h. Then the precipitates were centrifuged, washed with water and alcohol, respectively, dried at 80 °C, sintered at 650 °C for 6 h. For the reverse microemulsion route, TX-100 and Tween 80 were selected as mixed surfactants, *n*-butanol and *n*-hexanol as the mixed cosurfactants and cyclohexane as the oil phase. Firstly, a phase diagram was established for the system of oil – mixed surfactants and mixed cosurfactant – aqueous phase containing 0.5 M $Ca(NO_3)_2$ solution, then a composition was chosen for further investigation. Next, reverse microemulsions were prepared under different HLB values through varying the weight ratio of TX-100 and Tween 80. For the formation of HAP precursors, under vigorous stirring, the amount of 0.3 M $(NH_4)_2HPO_4$ solution was directly added to the above reverse microemulsion system, then small amount of ammonia was added to the system to adjust pH in the range of 10–11. Transparent solution was obtained upon stirring the system for about 30 min, then aged without stirring at room temperature for 1 day. Finally a small amount of absolute alcohol was added into the transparent solution to afford the production of white slurry, which was centrifuged to collect the white colloidal HAP particles. The precipitates were washed with absolute alcohol for three times, dried at 80 °C and sintered at 650 °C for 6 h.

2.3. Characterization

The identification of the sample was carried out by X-ray diffraction (XRD). A transmission electron microscope (TEM) was employed to measure the particle size and the degree of agglomeration of the HAP nanoparticles.

3. Results and discussion

Fig. 1 shows the partial phase diagram for the system of 0.5 M $Ca(NO_3)_2$ aqueous solution – mixed TX-100 and Tween 80 and mixed *n*-butanol and *n*-hexanol – cyclohexane at room temperature, here W, O, S + C denote water phase, oil phase, mixed surfactant phase composed of TX-100, Tween 80, *n*-butanol and *n*-hexanol, respectively. The volume ratio between *n*-butanol and *n*-hexanol is maintained at 5:3, mixed surfactants and mixed cosurfactants is 5:4. The boundary between the microemulsion and the non-microemulsion region was established by a systematic titration based on the clear-turbid observation. The microemulsion region is the shaded area and any mixtures of cyclohexane, mixed TX-100 and Tween 80, and mixed *n*-butanol and *n*-hexanol, and 0.5 M $Ca(NO_3)_2$ solution within this area are transparent because of the small dispersion size (usually less than 100 nm) of water droplets in the stable microemulsion system. Out of this area, the mixtures are turbid. In order to achieve the microemulsion system containing much more water and at the same time maintaining transparent state after 0.3 M $(NH_4)_2HPO_4$ solution was added to the above microemulsion, composition at point A consisting of 47.6 wt.% cyclohexane, 37.4 wt.% mixed surfactants and mixed cosurfactants, and 15 wt.% 0.5 M $Ca(NO_3)_2$ solution, was selected for the microemulsion processing.

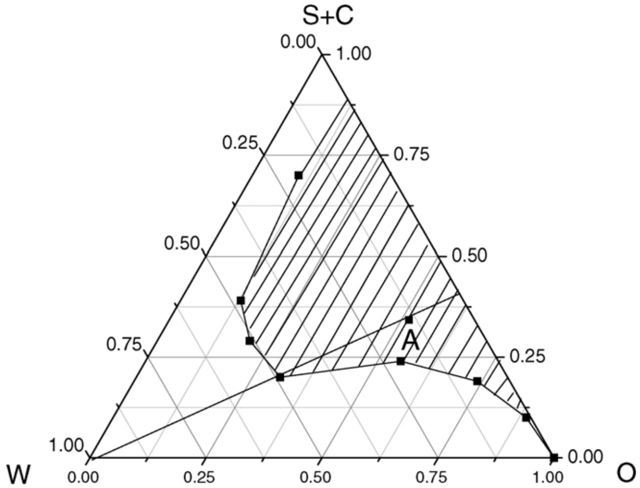

Fig. 1. The partial phase diagram established for the system of cyclohexane – mixed surfactants and mixed cosurfactants – 0.5 M $Ca(NO_3)_2$ aqueous solution at room temperature, the microemulsion region is marked as shaded area.

The HLB values of TX-100 and Tween 80 are 11.9 and 15, respectively, so the effect of HLB values between 11.9 and 15 on the particle size was discussed. As shown in Table 1, the particle diameter and length become larger gradually with the increase of HLB value, the particle size distribution becomes wide too and the emulcificated oil phases are cyclohexanes in this study. The HLB value becomes bigger, the property of hydrophile becomes stronger too, that means the diameter in size of water droplet will be bigger, so the particle size of the final HAP particles would be larger and the particle size distribution would be wider.

Fig. 2 shows TEM micrographs of uncalcined and calcined HAP samples via different preparation routes. (A) and (B) micrographs corresponds to the uncalcined samples and via conventional and microemulsion route, respectively. (C) and (D) corresponds to calcined ones at 650 °C, while (E) corresponds to sample in microemulsion during the induction period at room temperature. The diameter of the individual acicular particles is estimated to be about 50–

Table 1
The effect of HLB value on the particle size

HLB value	The particle diameter (nm)	The particle length (nm)
11.9	10–15	21–57
12.2	15–20	28–78
13.5	20–25	28–64
14.5	15–25	36–86
15.0	20–30	32–93

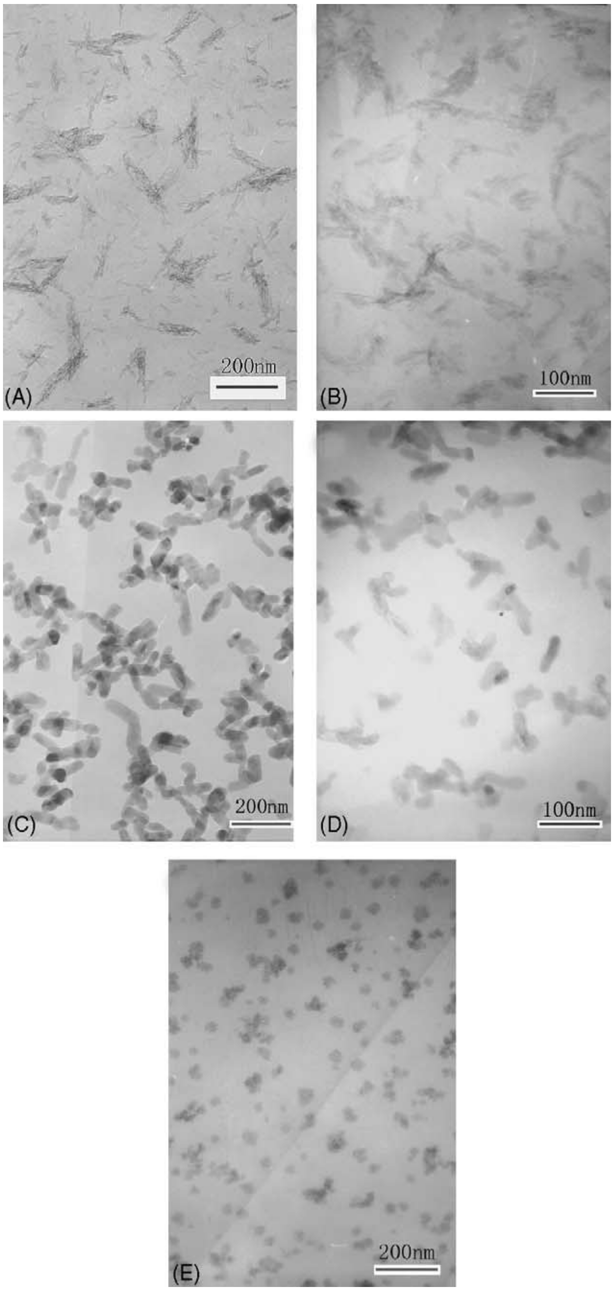

Fig. 2. TEM photographs of hydroxyapatite precursor particles with different heat treatment and via different preparation route.

80 nm for (A) and (C) samples, and significantly smaller 15–25 nm for (B) and (D) ones. The average diameter of water droplets is about 30 nm. The smaller particle size of the (B) and (D) samples compared to that of (A) and (C) ones are attributed to the smaller size of the aqueous phase in the microemulsion (E) system. The samples derived from microemulsion route have smaller particles size and better particle size distribution than that via conventional precipitation route, in basically realized single distribution.

Fig. 3 shows the XRD patterns of samples derived from microemulsion route calcined at different temperature. The XRD patterns indicate that the samples were amorphous at 25 °C, while sharp peaks appear when calcined at 650 °C for 6 h and a high-purity crystalline HAP powder was obtained when the microemulsion-derived precursor was calcined at 750 °C for 2 h. When calcined at 1200 °C for 1 h, the HAP particle still remains purity phase without any impurities such as CaO and β-TCP, whose peaks correspond to crystalline HAP with no additional peaks on a large scale (JCPDS #73-0293).

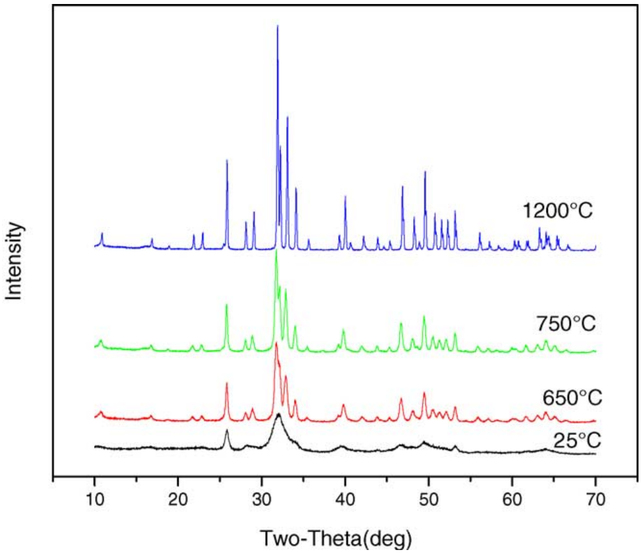

Fig. 3. The X-ray diffraction patterns of the samples derived from microemulsion route calcined at different temperature.

4. Conclusion

Nanosized HAP particles have been successfully synthesized by reverse microemulsion with different HLB values. In comparison with HAP particles, prepared by conventional precipitation method, the microemulsion route led to a smaller particle size and the better degree of particle agglomeration. The HAP particle diameter and length increased with the increase of HLB values.

Acknowledgements

The authors are grateful to the National Natural Science Foundation of China (no. 20271006) for the financial support.

References

[1] L.L. Hench, Bioceramics: from concept to clinic, J. Am. Ceram. Soc. 74 (1991) 1487–1510.

[2] W. Suchanek, M. Yoshimura, Processing and properties of hydroxyapatite-based biomaterials for use as hard tissue replacement implants, J. Mater. Res. 13 (1998) 765.

[3] G.K. Lim, J. Wang, S.C. Ng, L.M. Gan, Processing of fine hydroxyapatite powders via an inverse microemulsion route, Mater. Lett. 28 (1996) 431.

[4] G.K. Lim, J. Wang, S.C. Ng, C.H. Chew, L.M. Gan, Processing of hydroxyapatite via microemulsion and emulsion routes, Biomaterials 18 (1997) 1433.

[5] G.K. Lim, J. Wang, S.C. Ng, C.H. Chew, L.M. Gan, Formation of nanocrystalline hydroxyapatite in nonionic surfactant emulsions, Langmuir 15 (1999) 7472.

[6] G.K. Lim, J. Wang, S.C. Ng, L.M. Gan, Nanosized hydroxyapatite powders from microemulsions and emulsions stabilized by a biodegradable surfactant, J. Mater. Chem. 9 (1999) 1635.

[7] M.G.S. Murray, J. Wang, C.B. Ponton, P.M. Marquis, An improvement in processing of hydroxyapatite ceramics, J. Mater. Sci. 30 (1995) 3061.

[8] G.C. Koumoulidis, A.P. Katsoulidis, et al. Preparation of hydroxyapatite via microemulsion route, J. Colloid Interface Sci. 259 (2003) 254–260.