World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:8, No:12, 2014

Preparation and Characterization of Calcium Phosphate Cement

W. Thepsuwan, N. Monmaturapoj

Open Science Index, Materials and Metallurgical Engineering Vol:8, No:12, 2014 publications.waset.org/9999955/pdf

***Abstract*—**Calcium phosphate cement (CPC) is one of the most attractive bioceramics due to its moldable and shape ability to fill complicated bony cavities or small dental defect positions. In this study, CPC was produced by using mixture of tetracalcium phosphate (TTCP, $Ca_4O(PO_4)_2$) and dicalcium phosphate anhydrous (DCPA, $CaHPO_4$) in equimolar ratio (1/1) with aqueous solutions of acetic acid ($C_2H_4O_2$) and disodium hydrogen phosphate dehydrate ($Na_2HPO_4.2H_2O$) in combination with sodium alginate in order to improve theirs moldable characteristic. The concentration of the aqueous solutions and sodium alginate were varied to investigate the effect of different aqueous solutions and alginate on properties of the cements. The cement paste was prepared by mixing cement powder (P) with aqueous solution (L) in a P/L ratio of 1.0g/0.35ml. X-ray diffraction (XRD) was used to analyses phase formation of the cements. Setting time and compressive strength of the set CPCs were measured using the Gilmore apparatus and Universal testing machine, respectively.

The results showed that CPCs could be produced by using both basic ($Na_2HPO_4.2H_2O$) and acidic ($C_2H_4O_2$) solutions. XRD results show the precipitation of hydroxyapatite in all cement samples. No change in phase formation among cements using difference concentrations of $Na_2HPO_4.2H_2O$ solutions. With increasing concentration of acidic solutions, samples obtained less hydroxyapatite with a high dicalcium phosphate dehydrate leaded to a shorter setting time. Samples with sodium alginate exhibited higher crystallization of hydroxyapatite than that of without alginate as a result of shorten setting time in a basic solution but a longer setting time in an acidic solution. The stronger cement was attained from samples using the acidic solution with sodium alginate; however the strength was lower than that of using the basic solution.

***Keywords*—**Calcium phosphate cements, TTCP, DCPA, hydroxyapatite, properties.

I. Introduction

CALCIUM phosphate cement (CPC) is a group of calcium phosphate ceramic which has excellent biocompatibility and bioactivity properties. It is suitable to be used only for non- or low load-bearing applications such as bone filler [1]-[3], bone augmentation [4]-[8] and drug delivery applications [9] because of its low mechanical properties.

Conventional CPC is prepared with equimolar of tetracalcium phosphate and dicalcium phosphate anhydrous. However, different ratios of TTCP/DCPA were investigated and reported [10]. Originally, CPC was composed of an aqueous solution such as water and acid solutions which demonstrated an acid-base reaction with a powder of several calcium orthophosphate combinations. CPC set by mixing with distilled water usually obtains the setting time about 30 min with the higher mechanical strength around 12 MPa after setting for 1 day [11]. In the other hand, calcium phosphate cement which is cured by only water does not have enough mechanical strength because unreacted water releases from the cement and this produces holes inside the cement [12], [13]. To improve mechanical strength, aqueous solutions such as polyvinyl alcohol (PVA) and citric acid have been studied [14]. Addition of PVA gave higher compressive strength with increase in concentration. The result of citric acid addition showed that the compressive strength was increased with the higher concentration. In contrast, compressive strength of the cement prepared with PVA was higher than that of citric acid. Not only polymer and acid solution (low pH) mixing with CPC powder were reported but also a high pH solution [15].

In this study, therefore, CPC powder with TTCP/DCPA ratio of 1:1 mixed with both high and low pH solutions were investigated by varying the concentration of $Na_2HPO_4.2H_2O$ and $C_2H_4O_2$ solutions (0.2, 0.3 and 0.5M). The effect of type and concentration of the aqueous solutions on CPC properties was investigated and discussed. The addition of sodium alginate in both aqueous solutions was also studied by varying its concentrations in order to improve the cement properties.

II. Experimental

TTCP powder was prepared by mixing DCPA and calcium carbonate ($CaCO_3$) with equimolar ratio using ball milling for 3 hrs. The mixture was calcined in a platinum crucible at 1400°C for 4 hrs and quenched into a room temperature. The calcined TTCP powder was ground in a planetary mill with speed of 400 rpm to obtain fine powder, particle size ($D_{0.5}$) around 10 μm. Crystal structure and particle size of TTCP powder was characterized by XRD (PANalytical, X-Pert PRO) and a laser particle size analyzer (Mastersizer 2000), respectively. CPC powder was obtained by mixing the ground TTCP powder and DCPA at TTCP/DCPA molar ratio of 1:1 in agate mortar before mixing with the aqueous solutions.

Disodium phosphate dihydrate ($Na_2HPO_4.2H_2O$) and acetic acid ($C_2H_4O_2$) were used as cement liquids. The powder to liquid mass (P/L) ratio was 1.0 g/0.35 ml, used to produce CPC paste samples. CPC paste was filled into an acrylic mold (10 mm width x 10 mm length x 5 mm height) for setting time measurement by the Gilmore apparatus. The mean setting time value (n = 3) and standard deviation were reported. The phase formation of the set cement was carried out using X-ray diffraction (XRD: PANalytical, X-Pert PRO) technique. The cement samples loaded in the form of cylindrical pellets (3 mm diameter and 6 mm height) were used to measure

W. Thepsuwan and N. Monmaturapoj are with the National Metal and Materials Technology Center, Pathumthani, 12120 Thailand (phone: 662-564-6500; fax: 662-564-6501; e-mail: witoont@mtec.or.th, narupork@mtec.or.th).

Open Science Index, Materials and Metallurgical Engineering Vol:8, No:12, 2014 publications.waset.org/9999955/pdf

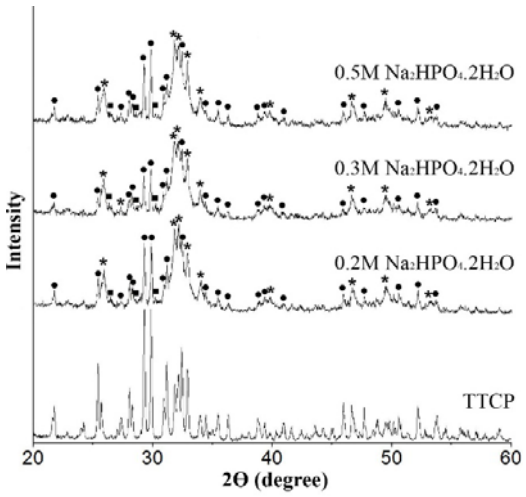
compressive strength under an Instron universal testing machine. The pellets were compressed along their heights in between the platens of the machine at a cross-head speed of 1 mm/min. The compressive strength was calculated from the break load and dimensions of the pellets. Before phase analysis and strength testing, the set cement samples were kept in 100% humidity at physiological conditions for 24 hrs and then dried.

III. Results and Discussion

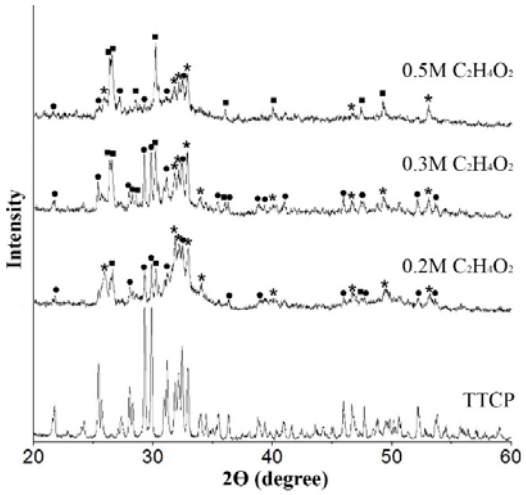
From XRD result, all peaks of as-synthesis TTCP powder can be indexed as the crystal structure of tetracalcium phosphate (JCPDS No. 25-1137). This XRD result implies that TTCP powder can be obtained by the following reaction:

$$2CaHPO_4 + 2CaCO_3 \rightarrow Ca_4O(PO_4)_2 + H_2O + 2CO_2 \qquad (1)$$

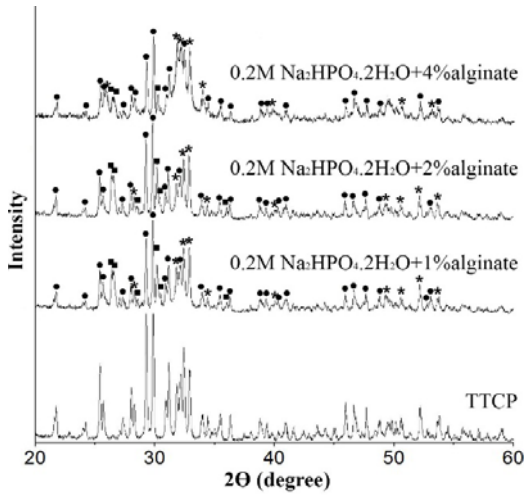
XRD pattern of the cement after setting by mixing 1.0 g of CPC powder with 0.35 ml of 0.2M, 0.3M and 0.5M $Na_2HPO_4.2H_2O$ solution shows in Fig. 1 (a). There were no difference in phase formation among cements using 0.2M, 0.3M and 0.5M of the $Na_2HPO_4.2H_2O$ solution. The patterns can be indexed hydroxyapatite (HA: JCPDS No. 09-0432) as a major crystal structure and TTCP peaks as a minor phase, which resulting in the transformation of TTCP to HA. However, some TTCP still remained. This could be implied the uncompleted reaction with the aqueous solution occurred. In addition, the HA peaks were rather broadened, indicating that the precipitated material is not well-crystallized.



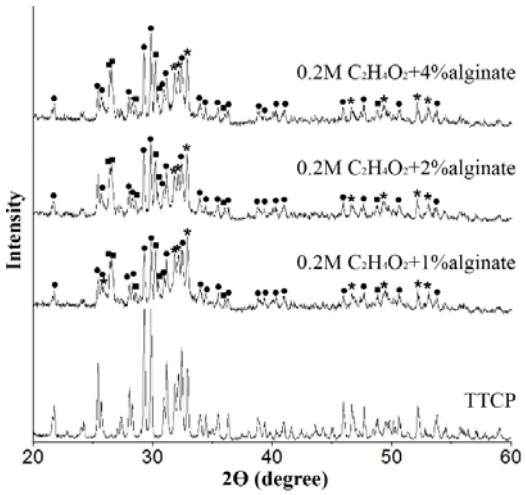
(a)



(b)



(c)



(d)

Fig. 1 XRD patterns of TTCP and CPC with (a) $Na_2HPO_4.2H_2O$, (b) $C_2H_4O_2$, (c) 0.2M $Na_2HPO_4.2H_2O$+alginate and (d) 0.2M $C_2H_4O_2$+alginate ; * HA, ● TTCP, ■ DCPA

Open Science Index, Materials and Metallurgical Engineering Vol:8, No:12, 2014 publications.waset.org/9999955/pdf

Fig. 1 (b) shows the XRD pattern of cements mixing by using $C_2H_4O_2$ at different concentrations. For 0.2M acetic acid solution, the patterns associated to hydroxyapatite (JCPDS No. 09-0432) had developed as a major peak by having TTCP phase (JCPDS No. 25-1137) and calcium phosphate or monetite (CaHPO4; JCPDS No. 09-3755) as minor phases. With increasing concentration of $C_2H_4O_2$, it seems that HA structure exhibited a low development due to a few peaks of HA with low intensity could be observed, particular in 0.5M. No phases related to brushite or dicalcium phosphate dehydrate (DCPD) could be detected. This was not consistent with previous studies which reported that at low pH < 4.2 the brushite or DCPD is the most stable one [16].

For CPC powder mixing with the combination of $Na_2HPO_4.2H_2O$ and alginate solution, the XRD pattern shows the peaks related to HA, TTCP and DCPA in Fig. 1 (c). The more the alginate concentration added, the higher the HA peaks and lower the TTCP and DCPA peaks could observed. However, the peaks of HA seems weaker than that of the cements without alginate. A similar trend also noticed in cements mixing with $C_2H_4O_2$ and alginate. The small discrepancy was stronger peaks of HA, TTCP and DCPA could be seen as shown in Fig. 1 (d).

Table I reports the final setting times of cement samples. In general, cement mixed with self-hardening such as distilled water took time to set about 30 min [11]. In $Na_2HPO_4.2H_2O$ basic solutions (pH = 9.1), the setting time decreased with increasing solution concentration, which were about 76, 54 and 31 min for 0.2M, 0.3M and 0.5M, respectively. Similarly, a shorter setting time found with increasing concentration of $C_2H_4O_2$ (21, 7 and 1 min), even shorter than those of $Na_2HPO_4.2H_2O$ basic solutions. This implies that the cement can be set faster in acidic solution than in basic solution. Moreover, the present of high crystallization of DCPA could be shortening the setting time of the cement especially the cement using 0,5M $C_2H_4O_2$ solution compared to others. However, the setting times of cements seemed too short when using $C_2H_4O_2$. The addition of alginate might expand the setting time in cement samples using $C_2H_4O_2$ solution as shown in Table I. In contrary, the more the alginate adding in $Na_2HPO_4.2H_2O$ basic solution, the longer the cements could be set.

The strength of cement depends upon various factors for example particle size of the cement powder, nature of additives and wetting ratio. The effect of concentration of accelerator in the medium was investigated in order to optimize the cement. The relation between concentration of solutions and cement strength illustrates in Fig. 2. The range of compressive strength obtained (10–12 MPa) was found comparable in previously reported values for calcium phosphate cements [17], [18]. The effect of the accelerator ($Na_2HPO_4.2H_2O$ and $C_2H_4O_2$ acid) concentration on the compressive strength was studied by keeping the wetting ratio constant. The compressive strength of the cement prepared with $Na_2HPO_4.2H_2O$ was better than that of $C_2H_4O_2$ solution. Moreover, the increase in concentration was the result of the lower compressive strength of cements as shown in Fig. 2 (a).

TABLE I
SETTING TIMES OF CPCS WITH DIFFERENCE AQUEOUS SOLUTIONS

Solution	Alginate amount (%)	pH	Setting time (min.)
0.2M $Na_2HPO_4.2H_2O$	-	9.1	76 ± 12
0.2M $Na_2HPO_4.2H_2O$	1	9.1	88 ± 6
0.2M $Na_2HPO_4.2H_2O$	2	9.1	58 ± 2
0.2M $Na_2HPO_4.2H_2O$	4	9.1	38 ± 3
0.3M $Na_2HPO_4.2H_2O$	-	9.0	54 ± 6
0.5M $Na_2HPO_4.2H_2O$	-	9.1	31 ± 1
0.2M $C_2H_4O_2$	-	2.0	21 ± 2
0.2M $C_2H_4O_2$	1	1.9	30 ± 5
0.2M $C_2H_4O_2$	2	2.0	27 ± 3
0.2M $C_2H_4O_2$	4	2.0	28 ± 1
0.3M $C_2H_4O_2$	-	1.9	7 ± 1
0.5M $C_2H_4O_2$	-	1.5	1 ± 1

By adding alginate at difference concentrations, the strength of cements using $Na_2HPO_4.2H_2O$ solution was decreased whereas the strength of cements mixing with $C_2H_4O_2$ solution was increased. This could be concluded that sodium alginate might reduce the strength of CPC cements using basic solution by delaying the setting time of CPCs. But in the case of acidic solution, alginate could induce the strength by retarding the setting time of the cements.

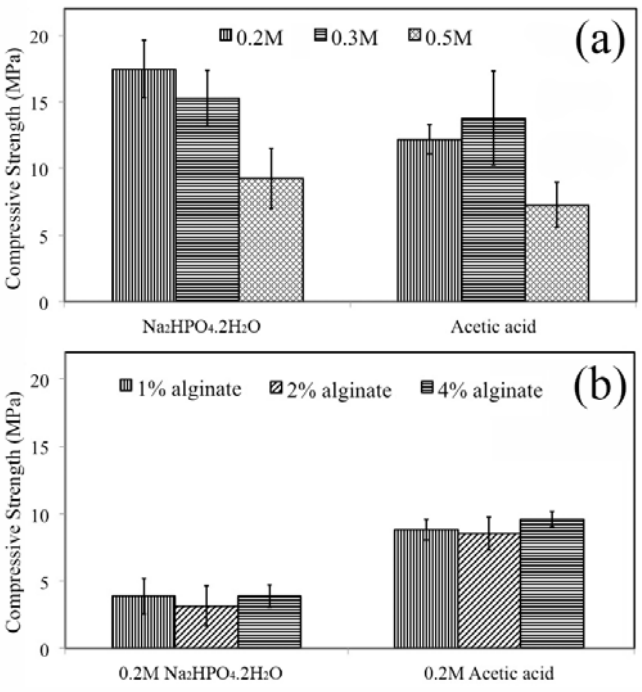


Fig. 2 Compressive strength of set CPCs: (a) 0.2M, 0.3M, 0.5M of $Na_2HPO_4.2H_2O$ and $C_2H_4O_2$ without alginate and (b) 0.2M of $Na_2HPO_4.2H_2O$ and $C_2H_4O_2$ with (1%,2%,4%) alginate

IV. CONCLUSIONS

Calcium phosphate cements were successfully prepared by mixing tetracalcium phosphate (TTCP) and dicalcium phosphate anhydrous (DCPA) in equimolar ratio to obtain the cement powder. Hydroxyapatite could precipitate in all CPCs mixed with both basic ($Na_2HPO_4.2H_2O$) and acidic ($C_2H_4O_2$)

solutions after soaking in 100% relative humidity for 1 day. With increasing the concentration of aqueous solutions, the setting times were decreased. The cement using acidic solution seems exhibited a shorter setting time than that of basic solution due to the present of high crystallization of dicalcium phosphate dehydrate. By the way a higher strength was found in the cements mixed with basic solution. Adding alginate into the cements, the higher the HA peaks and lower the TTCP and DCPA peaks appeared with increasing concentration resulting in a long setting time in cement samples using $C_2H_4O_2$ solution but a short setting time in the cement using basic solution. This leaded to stronger cement using acidic solution after adding sodium alginate.

ACKNOWLEDGMENT

This work was supported by National Metal and Materials Technology Center Thailand, Project No. P-1200966. The authors gratefully thank Mr. Naruemon Chuesawathee for his lab assistance.

REFERENCES

[1] C.D. Friedman, P.D. Costantino, S. Takagi, L.C. Chow, "Bone Source hydroxyapatite cement: a novel biomaterial for craniofacial skeletal tissue engineering and reconstruction," J. Biomed. Mater. Res., Vol. 43,1998, pp. 428–432.

[2] D.B. Kamerer, B.E. Hirsch, C.H. Snyderman, P. Costantino, C.D. Friedman, "Hydroxyapatite cement: a new method for achieving watertight closure in transtemporal surgery," Am. J. Otol., vol. 15, 1994, pp. 47–49.

[3] B.R. Constantz, I.C. Ison, M.T. Fulmer, R.D. Poser, S.T. Smith, M. VanWagoner,et al., "Skeletal repair by in situ formation of the mineral phase of bone," Science, vol 267, 1995, pp. 1796–1799.

[4] W.G. Horstmann, C.C.P.M. Verheyen, R. Leemans, "An injectable calcium phosphate cement as a bone-graft substitute in the treatment of displaced lateral tibial plateau fractures," Injury, vol. 34, 2003, pp. 141–144.

[5] E.J. Strauss, K.A. Egol, "The management of ankle fractures in the elderly," Injury, vol 38 (Suppl. 3), 2007, pp. S2–S9.

[6] P.A. Liverneaux, "Osteoporotic distal radius curettage—filling with an injectable calcium phosphate cement. A cadaveric study," Eur. J. Orthop. Surg. Traumatol., vol. 15, 2004, pp. 1–6.

[7] R.D. Welch, H. Zhang, D.G. Bronson, "Experimental tibial plateau fractures augmented with calcium phosphate cement or autologous bone graft," J. Bone Joint Surg., vol. 85, 2003, pp. 222.

[8] A. Aral, S. Yalçin, Z.C. Karabuda, A. Anil, J.A. Jansen, Z. Mutlu, "Injectable calcium phosphate cement as a graft material for maxillary sinus augmentation: an experimental pilot study," Clin. Oral Implants Res., vol. 19, 2008, pp. 612–617.

[9] [9] M.P. Ginebra, T. Traykova, J.A. Planell, "Calcium phosphate cements: competitive drug carriers for the musculoskeletal system," Biomaterials, vol. 27, 2006, pp. 2171–2177.

[10] S. Hirayama, S. Hirayama, S. Takagi, M. Markovic, L.C. Chow, Properties of calcium phosphate cements with different tetracalcium phosphate and dicalcium phosphate anhydrous molar ratios, J. Res. Natl. Inst. Stand. Technol., vol. 113, 2008, pp. 311–320.

[11] S. Hirayama, S. Takagi, M. Markovic, L.C. Chow, "Properties of calcium phosphate cements with different tetracalcium phosphate and dicalcium phosphate anhydrous molar ratios," J. Res. Natl. Inst. Stand. Technol., vol. 113, 2008, pp. 311–320.

[12] H. Suzuki, H. Suzuki, M. Sakurai, M. Watanabe, "The effect of stimulator on hardening of calcium phosphates," Phos. Res. Bull., vol. 12, 2001, pp. 31–38.

[13] K. Muroyama,T. Matumoto, K. Yamashita, T. Umegaki, "Effect of addition of water-soluble polymers of hydraulically hardened calcium phosphates," Mukimateriaru, vol. 3, 1996, pp. 380–385.

[14] M. Watanabe, M. Tanaka, M. Sukurai, M. Maeda, "Development of calcium phosphate cement," J. Eur. Ceram. Soc., vol. 26, 2006, pp. 549–552.

[15] S.Takagi, L.C.ChowandK.Ishikawa, "Formation of hydroxyapatite in new calcium phosphate cements," Biomaterial, vol. 19, 1998, pp. 1593-1599.

[16] M.P. Ginebra, C. Canal, M. Espanol, D. Pastorino, E.B. Montufar, "Calcium phosphate cements as drug delivery materials," Adv. Drug Deliv. Rev., vol. 64, 2012, pp. 1090–1110.

[17] F. C. M. Driessens, M. G. Boltong, O. Bermudez and J. A. Planell, "Formulation and setting times of some calcium orthophosphate cements: a pilot study," J. Mater. Sci.: Mater. Med., vol. 4, 1993, pp. 503-508.

[18] F. C. M. Driessens, J.A. Planell,M.G. Boltong, I. Khairoun and M.P. Ginebra, J. Eng. Med., "Proceedings of the Institution of Mechanical Engineers, Part H," 1998, pp. 212-427.

Open Science Index, Materials and Metallurgical Engineering Vol:8, No:12, 2014 publications.waset.org/9999955/pdf