

Pengembangan komposit magnesium-carbonate apatite (Mg-xCA) biodegradabel sebagai kandidat material implan ortopedi =
Development of biodegradable magnesium-carbonate apatite (Mg-xCA) composites as candidate materials for orthopedic implants

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Abstrak

Beberapa dekade ini pengembangan magnesium biodegradable untuk implan ortopedi sementara (temporary orthopedic implants) menarik minat periset. Magnesium (Mg) merupakan logam ringan ($1,74-2,0 \text{ g/cm}^3$), bersifat biokompatibel dan memiliki modulus elastisitas yang mirip dengan tulang. Beberapa upaya terus dilakukan dalam hal perbaikan sifat mekanik, kemunculan gas hidrogen dan penurunan laju degradasi terutama melalui pembuatan paduan baru, modifikasi permukaan dan pembuatan struktur baru. Adanya keselarasan antara kekuatan dan laju degradasi serta sifat biokompatibilitas Mg yang terjaga selama proses penyembuhan tulang merupakan tujuan akhir yang hendak dicapai. Disertasi ini fokus pada salah satu upaya peningkatan kinerja magnesium melalui pengembangan struktur baru dalam bentuk komposit Magnesium-Carbonate Apatite (Mg-xCA) yang berbasis serbuk. Carbonate Apatite (CA) disamping dijadikan sebagai penguat (reinforcement) guna memperbaiki sifat mekanik, juga untuk memperbaiki laju degradasi dan sifat biokompatibilitas. CA dianggap lebih mudah diserap osteoblast, mempercepat pembentukan jaringan dan penyembuhan tulang (bersifat osteoinductive dan osteoconductive) tanpa membentuk fibrotic tissue dibandingkan hidroksiapatite (HA). CA yang digunakan merupakan produk lokal. Komposisi Mg-xCA dibuat dengan variasi kandungan CA ($x = 0, 5, 10$ dan 15% berat) dan waktu milling ($3, 5$ dan 7 jam). Fabrikasi Mg-xCA dilakukan melalui tahapan pemadatan awal dengan kompaksi hangat (WC) dan dilanjutkan dengan proses pemadatan lanjut, masing-masing melalui proses sinter, proses ekstrusi dan proses equal channel angular pressing (ECAP) 1 pass untuk mendapatkan hasil optimal. Karakterisasi meliputi uji densitas relatif, uji sifat mekanis, uji korosi, uji biokompatibel (indirect cytotoxicity), pengamatan strukturmikro (OM), SEM-EDS-Mapping, micro XRF dan XRD. Hasil studi menunjukkan bahwa waktu milling 5 jam dapat memberikan padatan awal yang optimal melalui proses kompaksi hangat. Karakteristik prototipe Mg-xCA paling baik diperoleh dari hasil pemadatan lanjut dengan proses ekstrusi dengan rasio ekstrusi (R) 4. Rod yang dihasilkan memiliki 10 mm , panjang maks 100 mm dan bisa diiris sampai ketebalan 1 mm dengan distribusi kekerasan relatif seragam. Penambahan dan peningkatan kandungan CA menaikkan kekerasan, kekuatan tarik dan kekuatan tekan, memperbaiki laju korosi dan sifat toksik, namun menurunkan densitas relatif dibanding Mg murni (Mg-0CA). Semua komposisi bersifat biokompatibilitas (tidak beracun). Laju korosi terendah didapatkan pada Mg-5CA sebesar $1,92 \text{ mm/th}$ ($I_{\text{corr}}: 8.560\text{E-}05 \text{ A/cm}^2$), dimana lebih kecil dari I_{corr} Mg-xHA hasil microwave sintering (berkisar $1,00\text{E-}4 - 2,51\text{E-}4 \text{ A/cm}^2$) atau laju korosi Mg-5HA ($\pm 5 \text{ mm/th}$) dengan metode uji pencelupan. Sebagian sifat mekanis (hardness, ultimate tensile stress, elongasi dan flexural stress) komposit memenuhi karakteristik tulang tengkorak manusia (human cranial bone) terutama Mg-15CA dan Mg-10CA, namun yield strength dan young modulus masih perlu ditingkatkan. Komposit Mg-xCA sangat prospek untuk terus dikembangkan sebagai kandidat material implan ortopedi.

.....In recent decades the development of biodegradable magnesium for temporary orthopedic implants has

been of interest to researchers. Magnesium is the lightest metal (1.74 - 2.0 g/cm³), biocompatible and it has a modulus of elasticity similar to bone. Efforts are being made to improve mechanical properties, the emergence of hydrogen gas and the rate of degradation, especially through the manufacture of new alloys, surface modifications and the creation of new structures. The harmony between the strength and the rate of degradation as well as the maintained properties of Mg biocompatibility during the bone healing process is the final goal to be achieved. This dissertation focuses on one of the efforts to improve the performance of magnesium through the development of a new structure in the form of a powder-based Magnesium-Carbonate Apatite (Mg-xCA) composite. Carbonate apatite (CA) besides being used as a reinforcement to improve mechanical properties, also to improve the rate of degradation and biocompatibility properties. CA is considered more easily absorbed by osteoblasts, accelerates tissue formation and bone healing (osteoinductive and osteoconductive) without forming fibrotic tissue compared to hydroxyapatite (HA). The CA used is a local product. The composition of Mg-xCA was made by varying the content of CA (x = 0, 5, 10 and 15% by weight) and milling time (3, 5 and 7 hours). Mg-xCA fabrication was performed through the initial compaction stage with warm compaction (WC) and continued with a further compaction process, each through the sintering process, the extrusion process and the 1 pass equal channel angular pressing (ECAP) process to obtain optimal results. Characterization includes relative density test, mechanical properties test, corrosion test, biocompatible test (indirect cytotoxicity), microstructure observation (OM), SEM-EDS-Mapping, micro XRF and XRD. The results show that the 5 hour milling time can provide optimal initial solids through a warm compaction process. The best characteristic of the Mg-xCA prototype is obtained from the results of further compaction by extrusion process with extrusion ratio (R) 4. The resulting rod has 10 mm, max length 100 mm and it can be sliced to a thickness of 1 mm with a relatively uniform hardness distribution. The addition and increase of CA content increases the hardness, tensile strength and compressive strength, improves corrosion rates and toxic properties, but reduces the relative density compared to pure Mg (Mg-0CA). All compositions are biocompatible (non-toxic). The lowest corrosion rate was obtained at Mg-5CA of 1.92 mm / year (I_{corr}: 8.560E-05 A/cm²), which it is smaller than I_{corr} Mg-xHA from microwave sintering (ranging from 1.00E-4 - 2.51E-4 A/cm²) or Mg-5HA corrosion rate (± 5 mm/yr) by immersion test method. Some of the mechanical properties (hardness, ultimate tensile strength, elongation and flexural stress) of the composite meet the characteristics of human cranial bone, especially Mg-15CA and Mg-10CA, but yield strength and young modulus still need to be improved. Mg-xCA composites are very prospective for further development as candidates for orthopedic implant materials.