Biodegradable Metal Matrix Composites for Orthopedic Implant Applications: a State of Art Review

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Biodegradable Metal matrix composites for orthopedic implant applications: A state of art review

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Abstract

Biodegradable implant metals and its alloys such as iron (Fe), magnesium (Mg), and Zinc (Zn) have attracted extensive interest in biomedical applications. Low mechanical strength of Zn, significant slower degradation of Fe and rapid degradation Mg impede their clinic application. Further research is going on the development of biodegradable metal matrix composite owing to best suited for biomedical applications. This article delivers a review of biodegradable metal matrix composites based on corrosion resistance, biodegradable behavior, biocompatibility, and mechanical properties as favorable implant materials for orthopedic applications.

Keywords: Orthopedic implant materials, Biodegradable, Biocompatibility

1. Introduction

Numerous orthopedic clinic applications for example knee, hip, shoulder joint substitutes, bone plates, screws, etc as implants have been used different biomaterials which are the area of interest of researchers to improve performance for orthopedic implant applications. For those purposes requirement of good corrosion resistance, admirable mechanical property with equitable biocompatibility, and biodegradable implant materials. Different metallic materials as an implant for example stainless steels [1–4], titanium (Ti) and its alloys [5–12], and cobalt-chromium-molybdenum (Co-Cr-Mo) alloys [10, 13–15] have been suited for the purposes but these are non-biodegradable, need again surgery for removal. However, the other disadvantages of these materials are allergenicity, poor wear resistance, released ions toxicity nature, and deprived bending ductility in the biological environment [16–20]. Also, the stress shielding effect is caused owing to their greater elastic modulus as associated to that of natural bone [11, 12, 21]. Metals, alloys, and composites of the metal matrix are different types of biodegradable implant materials. Biodegradable implant metals and its alloys for example Zinc (Zn), iron (Fe)), and magnesium (Mg) have favorable properties that have received increasing attention of researchers. In spite of admirable processability and higher corrosion resistance, pure Zn exhibits low mechanical strength compared to Mg. It impedes Zn as a biodegradable implant material [22]. Whereas, compared to Mg, Fe and its alloy exhibit greater mechanical properties, however,they show a considerably gentler degradation and affect their compatibility owing to the ferromagnetic characteristics in vivo [23, 24]. Mg and some of its alloys exhibit low elastic modulus (40-45 GPa) nearer to that of natural bone (10–30 GPa). However, damage to their mechanical honor earlier than enough bone restoration owing to the quick degradation of Mg alloys. It impedes their orthopedic application. To further improve the properties of biodegradable materials for orthopedic implant applications, research is going on the development of biodegradable metal matrix composites. This paper reviews biodegradable metal matrix composites as implant materials for orthopedic applications.

2. Biodegradable metal matrix composite development

Improvements in the properties of biodegradable materials for biomedical applications, metal matrix composites have been developed from the last two decay. The performance of metal and its alloys such as Fe, Zn, and Mg for applications in orthopedic implants can be improved by a feasible approach such as metal matrix composites (MMCs) with choosing the appropriate reinforcements. Further proper selecting of the constituents, the type, and concentration of the reinforcements can be used to optimize the properties of MMCs with interaction surrounding tissues. Yang et al.[25] were prepared pure Zn matrix composites with reinforcement of hydroxyapatite (HAp) by spark plasma sintering (SPS) for orthopedic implant applications. Bioceramic hydroxyapatite (HAp) is bioactive that supports bone ingrowth, osseointegration cell, and proliferation [26, 27]. It was observed that crystallographic and chemical structures of HAp like to the natural bone [28]. It was found that Zn-HAp composites showed enhanced biocompatibility and adaptable degradation rates together in vivo and in vitro. Iron-based metal matrix composites (MMCs) are used as biomaterials for enhanced degradation speeds as compared to iron and stainless steel. Ulum et al. [29] established a sequence of biomaterials as composites using reinforcements such as b-tricalcium phosphate (TCP), hydroxyapatite (HAp) or TCP-HAp mixes into a matrix such as pure iron. The presences of these bioceramics were enhanced degradation rate. In another article, Ulum et al. [30] also established that bioactivity of MMCs was improved as compared with pure iron and iron alloys in vivo. Wang et al.[31] were fabricated composites of iron-matrix with bioceramic reinforcement such as calcium silicate (CS). It suggested that iron-matrix composites biodegradable bone implants could an effective approach to improved biomedical performance. The reinforcement such as calcium silicate (CS) bioceramic has already established its greater bioactivity and biodegradability as associated with bioceramics such as calcium phosphate, counting TCP and HAp in the number of studies [32–34]. Immersion tests in simulated body fluid (SBF) were used to evaluate in vitro surface bioactivity of the composite materials. Cytotoxicity was assessed in vitro over uninterrupted interaction with human bone marrow stromal cells (hBMSCs). Although fewer researches in the field of iron-matrix composites biodegradable bone implants have reported. There is the possibility of enhancing the bioactivity and degradation rate of iron base composites through bioceramic reinforcements. Needed more research efforts to optimize further operational enhancements in bioactivity and degradation rate of iron base composites. In vivo Mg degrades and liquefies entirely upon satisfying the tissue recuperation with no insert remainders. However, Mg degrades hastily in a bodily atmosphere within the body earlier than sufficient recovery of tissues. These materials also influence the load-bearing performance of orthopedic implants owing to rapid degradation. Mg matrix composites strengthened with diverse nanoscale particles might also improve the corrosion resistance. It leads to their precise degradation. The mechanical properties of biodegradable composites of Mg matrix can improve when the addition of numerous types of nano-particles in Mg matrices via synergistic strengthening mechanisms as shown table1.

Table1 (Shahin et al.,[35])

Reinforcements	Mechanical properties
Al2O3	Excellent hardness and wear resistance
ZrO_2	High mechanical strength and toughness
Y_2O_3	Better compressive strength
GNPs	Higher strengthening ability
CPC	Outstanding elastic modulus
Si_3N_4	Improves capability of load bearing
SiC	Increases ductility and compressive strength
HAp	Improve hardness, toughness, and yield strength
FAp	Increase the compressive strength
TCP	Increase hardness

The capacity of MMCs as new substances for biomedical programs intensive efforts have been made. In spite of the promising features of MMCs, protection and toxicity concerns obstruct their implant applications. Therefore, the biological residences of these composites including cytotoxicity, biocompatibility, and biocorrosion are essential to further explore. The corrosion rate was reduced when using FAp reinforcement particles used in MMCs [36]. Uniform degradation of Mg matrices was caused in the case of the homogeneous dispersion of nanoparticles [37, 38]. Razavi et al. [39, 40] explored composite of AZ91 Mg matrix with several weight fractions (10, 20, and 30 wt%) of FAp. FAp nano-particles with 20 wt% concentration revealed an excellent promising with the properties of natural bone basis on their load-bearing capabilities such as hardness, yield strength, and degradability of implant. The adding of reinforcements such as FAp and HAp in Mg matrix, the corrosion resistance enhanced in physiological environments [36, 37, 41]. Enhancement of corrosion resistance of Mg matrices reported owing to the low solubility of HAp in a physiological environment [42]. However, the formation of large clusters or agglomeration was found in case of the higher concentrations of HAp in the metal matrices ensuring in the choppy degradation system, therefore less than 10 wt% of HAp is proposed to use [43–45]. 20 wt% HAp nano-particles used in AZ91 Mg matrix led to the porous surface structure of the composite, which unfavorably distressed the ductility and strength of Mg alloys [46]. 5, 10, and 15 wt% concentration of HAp in Mg matrices have used to manufactured composites and found that 15 wt% HAp in the composite revealed uneven distribution of HAp, foremost to irregular erosion in the composite [47]. b-TCP nano-particles used in MMCs revealed higher corrosion resistance [48–51]. As compare to HAp, TCP has a high dissolution rate that could assist to accomplish the whole degradation of insert composite after remedial of cracked bone [45]. CPC helps the creation of fresh bone tissues as it reacts with body fluid, foremost to the quick development of bone and the degradation can be molded to a certain speed both in vivo and in vitro [45]. Feng et al. [52] found that ZK60A matrix composites having lower concentrations of CPC reinforcements (2.5–5 wt%) showed minimum defects, caused in enhanced corrosion resistance; whereas the composites having CPC with 7.5, and 10 wt% exhibited cracks and holes on stacking. Normally, artificial body fluids are not simply degraded to GNPs; nevertheless, their whole degradation can be achieved through humanoid enzymes [53]. Biomedical applications of MMCs greatly depend on their biocompatibility in bodily surroundings. Commonly, the biocompatibility of MMCs is influenced by their contacts through several biological structures consisting of proteins, cells, and other intricate biomolecules. Biocompatibility and application of reinforcements used in MMCs as shown in table2.

Table2 (Shahin et al.,[35]

Reinforcements	Biocompatibility	Application
Al_2O_3	Cell adhesion,proliferation,and Improves protein adsorption	Knee prosthesis,Bone plate,Bone screws
ZrO_2	Greater bone stability,improves cell viability, and nontoxic and bio-inert to blood cells and fibroblast	Bone screw,Femoral head,Artificial knee
Y_2O_3	Cell viability Improves	Implant in dental
GNPs	Nontoxic to cells, no tissue reaction,and biocompatible even in blood contact	Endovascular materials,Bone plates,Bone screw
CPC	Nontoxic to tissues and higher protein adsorption , bioinert and do not cause inflammation,Induce osteoblastic differentiation in progenitor cells	Dental implant, Joint replacements and bone tissue
Si_3N_4	Bone-cell adhesion and Promotes bone fusion in spinal surgery	Spinal fusion devices,Prosthetic hip,Knee joints
SiC	Durable coating for bone prosthetics,slightly toxic	Bone plate,Bone screw,Hip replacement
HAp	The release of Mg ion reduces,Nontoxic and bioactive,osteoblastic differentiation, and excellent cell proliferation	Bone screw and pins,Bone joint
FAp	Osteoconductivity and Enhance cell viability	Bone plate,Bone pins,Bone screw
TCP	Bone growth and enhance bone adhesion	Bone screw,Bone pin

3. The different method used for manufacturing MMCs

Numerous processing methods are used for manufacturing MMCs such as powder metallurgy [54], semi-solid casting [54] , stir casting [54], disintegrated melt deposition [54], friction stir processing

[54], ultrasound-assisted particle dispersion method [55], vacuum cold spraying [56], sol-gel method [57], accumulative roll bonding [54]. A common, cheap, and fairly simple method of producing MMCs is stir-casting where the reinforcement particles are added into the molten matrix metal. A mechanical stirrer like impeller is placed in the molten metal and rotated to get a uniform distribution of the reinforcement with the molten metal. Friction stir processing (FSP), as a derivative from friction stir welding, is broadly used in the field of research to integrate nano-particles within a metallic matrix. It produces bulk or surface nanocomposites. Disintegrated melt deposition is used to produce Mg base nano-composite and this process is derived from the stir casting process.

4. Conclusion

Compared to existing titanium (Ti), Zn, Fe, Mg and its alloys, and cobalt-chromium-molybdenum (Co-Cr-Mo) alloys, MMCs possess the fabulous perspective for orthopedic implant applications. The adding of particular nano-particles as reinforcements to metal matrices improves the possessions of composites. The corrosion resistance, mechanical properties, biodegradability, and biocompatibility of MMCs are improved and optimize for implant biomaterials. Although current development in the area of metal matrix composites for orthopedic implant materials is promising, further broad and efficient researches are stagnant essential with the purpose of recognizing their long-standing clinic application.

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