Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2019, 6(2):164-167

Review Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Mechanical Properties of Biodegradable Metals and Polymers: A Review

Happiness Ijeoma Umeobi[1]*, Onyemazuwa Andrew Azaka[1], Ozioma Udochukwu Akakuru[2]*, Hitler Louis[3]

[1]Department of Mechanical Engineering, Nnamdi Azikiwe University, Awka, Nigeria
[2]Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences
[3]CAS Key Laboratory For Nanosystem and Hierarchical Fabrication, CAS Centre For Excellence in Nanoscience, National Centre For Nanoscience and Technology, University of Chinese Academy of Science, Beijing, China
*Corresponding authors' emails: hi.ezeonuegbu@unizik.edu.ng; Tel.:+2348065777899

Abstract Biodegradable materials have found endless use in domestic and industrial applications. They have also been utilized to mitigate the challenges related with environmental pollution, littering and waste disposal. However, there are still challenges as regards to mechanical properties of these materials especially the load bearing ones. Developing biodegradable material with high mechanical strength and optimal degradation rate is very important to avoid material failure. Several technologies and treatment processes have been proposed for the improvement of mechanical properties of these materials. This study reviews research works related to improvement of mechanical properties of biodegradable metals and polymers, and technologies involved in enhancing these properties.

Keywords Mechanical Properties, Biodegradable Metals, Polymers

Introduction

A material is said to be biodegradable, if it can disintegrate or decompose into natural materials in the environment, without releasing toxic or poisonous substances into the environment. Biodegradable materials gotten from natural and renewable sources are now being used in place of conventional non-biodegradable materials. They have found use in medical, food, architecture, automobile parts, structures and many other applications. Recently, waste materials are being incorporated during fabrication of biocomposites. The essence is mainly to mitigate problems associated with pollution, litter and waste disposal. Biodegradable materials can be categorized as biodegradable metals, polymers, wood-polymer composites and Nano-biocomposites.

Metallic Biodegradable Materials

Metallic biodegradable materials are often used as bio-implants. They are created to give internal support to body tissue or replace broken or fractured biological structure [1, 2]. Examples of biodegradable materials include metals and alloys of Magnesium (Mg) Iron (Fe) and Zinc (Zn); and non- biodegradable materials like metals and alloys of stainless steel, Iron (Fe), Cobalt (Co) alloys and Titanium (Ti) alloys. Their areas of application include coronary stents, dental implants, joint replacements, orthopedic fixations, and several others. With the increased ageing population and mishaps in everyday activities, the usage of these materials is on the rise. The purpose is primarily to satisfy patients' desire to continue their daily activities without affecting their general well-being [3, 4].

According to [1], the main function of biodegradable metal implant is in three phases; the first phase is to provide support for tissue regeneration, then heal the injured area, and the last phase is gradual degradation and disappearance into the body structure. They also revealed that calcium (Ca), Sr, Si, Zinc (Zn), have great benefits with respect to bone and its formation and have been utilized favourably as alloying elements in producing Magnesium alloys of this type. The biodegradation kinetics can be regulated by the type of alloying element used, and the type of mechanical processing and coating used [2]. The conventional or non-biodegradable metal implant basically provides temporary support. They are later removed through surgery after a stipulated period, mainly because they are non-resorbable.

Biodegradable metal alloys of Magnesium can serve as a good replacement for conventional metallic biomaterials, especially in temporary implants. Repeated surgery is not necessary for this type of implant, because they are resorbing in nature.

Biodegradable Polymers

They are gotten from inartificial sources like protein, polysaccharides, and lipids and also through synthesis from renewable sources. Study by Nafisa[5] classified biodegradable plastics or polymers as starch based, chemically synthesized bioplastics, Poly (Lactic Acid) PLA, plastics and naturally occurring bioplastics. According to Schaschke and Audic [6], examples of Biodegradable polymers include Thermoplastic polyester Poly (Lactic acid) (PLA), which is obtained from agricultural origin. There is also Cholesteryl group modified Tilapia Gelatins (Cho-T-GLTNs) which is a biodegradable amphilic polymer used in medicine for liposomes and cell assembly; and biodegradable Poly (L-Lactide) (PLLA). Other examples are Polycaprolactone (PCL), Poly (Lactic-co-glycolic acid) (PLGA), Poly(3-hydroxybutyrate) (PHB) and Ecoflex [7]. Wood plastic biodegradable polymers are those in which wood powder or biomass particles are integrated.

The high cost of polymer production and quest for mechanical property improvement have led to blending it with biodegradable fillers from low cost natural fibres and nanofibrillated cellulose [8]. During experimental investigations involving biodegradable polymers, the mechanical properties that are usually of interest are stiffness, strength and elongation-at-break. As the polymer degrades, these properties are measured alongside its weight. The relationship is such that, a reduction of molecular weight during degradation, results in a reduction in stiffness, strength, and elongation-at-break [9]. Low cost and light weight biodegradable polymers with acceptable mechanical strength and stiffness have been developed by blending natural fibres from bamboo, plantain leaf, oil palm, jute, kenaf, coir, borassus fruit, sansevieria, arundo, althaea, ferula, and curaua with thermoplastics [7]. Byungjoo et al [10] established that light weight biodegradable polymers with improved mechanical strength can be developed by incorporating waste products of wood powder and rice bran.The target mechanical properties of a particular biodegradable polymercomposite could be achieved by adjusting input parameters such as particle size, porosity, molecular weight, and fillers concentration and by using appropriate treatment like annealing, hydrophobic, hydrophilic processes [11]. Coating biodegradable polymers with bioactive glass has been demonstrated and improvement in tensile strength and degradation rate of the resulting material has been confirmed [12].Mechanical properties of polymers have been upgraded by using nanofibrillated cellulose as reinforcement [8]. Maria et al [13] reported than addition of more than 5% biodegradable polymer to non-biodegradable polypropylene plastics caused a loss in mechanical properties.

Setbacks Associated with Biodegradable Metal and Polymer Materials

There are many challenges encountered with some existing metallic biomaterials. Most of these setbacks are often related to their material properties, and they include: mechanical instability, low wear resistance, low resistance to failure by fatigue, and low resistance to corrosion. Other complications are poor implant integration, hypersensitivity reaction in patients, infections and inflammation risks, necrosis, pain and loss of function. This makes improvement of the existing metallic biomaterials or development of new ones the primary concern of researchers in this field of study. Providing a working metallic biomaterial with desirable properties is their main focus. The desired properties of a metallic biomaterial are low elastic modus combined with high strength (for longer service period), high wear resistance, high resistance to failure by fatigue, high corrosion resistance, biocompatibility, non-toxic, and Osseo-integration [3, 4].

Regardless of the favorable mechanical and biological properties of biodegradable Magnesium alloy implants; there is no perfect control of over its biodegradation kinetics. These alloys are capable of breaking down and releasing its minerals into the bones. This break down or degradation does not usually occur at a suitable rate; it is rapid especially in the human body and in bodily fluids. This brings about the release of Mg^{2+} ions and consequently undue degradation may result in premature loss of mechanical strength of the implanted material before the tissue has been fully regenerated. Another problem is seen in orthopedic implants made of Mg-Alloys; pockets of gas may be formed around the implant as a result of the release of hydrogen gas at low corrosion or degradation rate. These challenges have created the need for controlled or optimized degradation or corrosion rate.

There is need to provide a solution to the untimely and excess release of metal ions from biodegradable metals into the bones, by exploring corrosion rates of magnesium alloyed with non-toxic alloying elements of Zn, Re, and Zn/RE. It will also provide optimized biodegradation kinetics for the biodegradable implant materials under study. The optimum degradation rate needs to be ascertained, in order to serve as a guide for medical doctors, especially in determining average healing time for their patients, as well as the next check-up date.Also, some alloying elements like Al, Li, Pr, Zr, Y, Nd, and Gd have been reported by [1] and [14] to be unsuitable as alloys for biomaterials, because they have been proved to be toxic to human health. Despite the biocompatibility of Ca, Sr and Si, the major challenge with using them as alloying elements is that they have low solubility in Magnesium; hence the resulting mechanical properties are not encouraging.

It is important to note that majority of the biodegradable polymers do not degrade under normal condition. In other words, they degrade only under enhanced condition such as availability of temperature, humidity, light, oxygen, and microorganisms; hence they will still cause plastic environmental pollution through careless disposal. This phenomenon is evident in the publication of Bagheri et al [7], in which the biodegradability of some biodegradable polymers were compared with non-degradable Poly (Ethylene Terephthalate) (PET) in sea water and fresh water.

Conclusion

This study has revealed that mechanical property enhancement is very crucial in development of biodegradable materials. It has also confirmed researchers are tirelessly making effort to develop new materials with structural integrity as regards to mechanical properties and corrosion. The technologies put in place so far to achieve these goals have been summarized in this study.

References

[1]. Chen J., Tang L., Yu X., Etim I.P., Ibrahim M. and Yang K. (2018) Mechanical Properties of Magnesium Alloys for Medical Application: A Review. Journal of Mechanical Behaviour of Biomedical Materials 87, 68-79

[2]. Karthika P., Olha B., Ming C., Madison R., Liam F., Jordan S., Richard S., Marcus T., Cameron C., and Alex Cao C., David M., Kostya K.O., and Kateryna B(2017) Metallic Biomaterials: Current Challenges and Opportunities *Materials,* 10(884), 1-33, Doi:10.3390/ma10080884

[3]. Hussain Z., Mohd I.N., and Dhindaw B.K(2017) Effects of alloying Elements on properties on Biodegradable magnesium composite for Implant Application *Journal of Powder Metallurgy and mining* 6(3):179, 1-8, Doi: 10.4172/2168-9806.1000179

[4]. Mohamed A.H., Abdul Sammad M., and Naser A. (2015) Wear Characteristics of Metallic Biomaterials: A Review, *Materials,* 8, 2749-2768, Doi: 10.3390/ma8052749

[5]. Nafisa J., Ishrat M. and Gulzar A.N (2015) Bioplastics and food Packaging: A Review, Congent Food & Agriculture 1(1), DOI: 10.1080/23311932.2015.1117749

[6]. Schaschke C. and Audic J.L (2014) Editorial: Biodegradable Materials, *International Journal of Molecular Sciences.* 15, 21468-21475

[7]. Bagheri A.R., Laforsch C., Greiner A., and Agarwal S (2017) Fate of so-called Biodegradable Polymers in Seawater and Freshwater, Global Challenges 1(4), 1-5

[8]. Yottha S., Ronald S., Craig C., Lih-Sheng T., Srikanth P and Jun P (2012) Effect of Material Parameters on Mechanical Properties of Biodegradable Polymers/Nanofibrillated Cellulose (NFC)

Nanocomposites, *Proceedings of polymer Processing Society*, *28th Annual Meeting*, *December 11-15, 2012*, *Pattaya*, *Thailand*, 1-5
[9]. Gleadall A.C (2015) Modelling degradation of biodegradable polymers and their Mechanical Properties (Doctorate Degree thesis), Department of Mechanical Engineering, university of Leicester, United Kingdom
[10]. Byungjoo J., Jin W.H., Kyung S.L and Sung W.C (2012) Improvement of the Mechanical Properties of Biodegradable Polymers using a Microcellular Foaming Process and Natural By-Products, *Polymer-Plastics Technology and Engineering*, 51(4), 401-406, DOI: 10.1080/03602559.2011.639835
[11]. Saiful I.A., Noor F.A.S and Wan A. (2012) Biodegradable polymers and their Bone Applications: a Review, *IJBAS-IJENS* 12(1), 31-49
[12]. Stamboulis A., Hench L.L., and Boccaccini A.R (2002) Mechanical Properties of biodegradable Polymer Sutures Coated with Bioactive Glass, Journal of Material science: Materials in Medicine 13(9). 843-848
[13]. Maria D.S., David B., Marina P.A., Jose M.F and Juan M. (2018) interference of Biodegradable Plastics in the Polypropelene recycling Process, Materials 11(10), 1-18
[14]. Feyerabend F., Fischer J., Holtz, J., Witte F., Willumeit, R., Drucker, H., Vogt, C., and Hort,N. (2010) Evaluation of short-term effects of rare earth and other elements used in magnesium alloys on primary cells and cell lines. Acta Biomater. 6, 1834–1842.