Journal of Simulation and Analysis of Novel Technologies in Mechanical Engineering
13 (4) (2021) 0019~0029
HTTP://JSME.IAUKHSH.AC.IR

Research article

Evaluation of mechanical properties of bioglass materials for dentistry application

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(Manuscript Received --- 19 Mar. 2022; Revised --- 03 Apr., 2022; Accepted --- 05 Apr. 2022)

Abstract

Bioactive glass has been used successfully as a bone filler in dental surgery. Recently, attention has focused on researching the production of bioactive glass (BG) through sol-gel reactions. Among natural ceramics, BG has proper mechanical and chemical stability compared to conventional ceramics. These materials have certain biological and chemical properties such as proper biocompatibility and biodegradability. one of the strengths is its biocompatibility and biodegradability and lack of immune response besides its proper mechanical properties of about 500 MPa which has about the maximum of 180 MPa mechanical strength. The BG bio-ceramic is primarily used to repair bone and tooth damage or defects that can be reproduced by natural processes. The first successful surgery used in 45S5 bioglass was to replace the middle ear bones to solve the auditory conduction problem. Also, the microscopic analysis of pulp cells with 45S5 bio-glass produced shows the least toxic effect. Bioglass 45S5 can act as a biocompatible material that could potentially be used safely on dentin.

Keywords: Composite, Bone graft, Tooth restoration, Bioglass, Filling teeth

1- Introduction

Bioactive ceramics are ceramics that can be used for medical purposes, including implants and bioactive prostheses. The main feature of these ceramics is being biogenic with the body environment and not causing toxicity [1-4]. These coatings are used for ossification, repair, and replacement of living tissue [5-7]. those Biocompatible coatings which use these bioceramics such as bioglass, akermanite, or hydroxyapatite (HA) with sufficient bioactivity made many researchers from various fields focus on these bioceramics. These materials lead to the formation of bone tissue by absorbing calcium and phosphorus [8-12]. Recently, BG has received more attention from researchers. By combining these BGs with biopolymers and other bioceramics, the mechanical properties along with the bioactivity can be greatly improved. These materials can be

used for a variety of substrates to increase their bioactivity and biocompatibility [13-17]. Bioglass grade 45S5 is a glass with 45% SiO_2 and 24.5% other trace elements such as CaO_2 4.5%, Na_2O, and 6% P_2O_5. BGs are amorphous non-crystalline solids composed of silica and their temperature gradually decreases, after placing the material in the furnace and reaching the right temperature, it suddenly cools down and takes on an amorphous structure. Bioglass 45S5 mixed with 50% phosphoric acid to treat dentin allergy and enamel decay.

Table 1: Mechanical properties of dense and highly porous HA, 45S5 bioglass, A/W glass ceramic, and human cortical bone

Materials	Compressive strength (MPa)	Tensile strength (MPa)	Elastic modulus (GPa)	Ref.
Hydroxyapatite (HA)	>400	~40	100	[8]
45S5 Bioglass	~500	42	35	[9]
Glass-ceramic A/W	1080	215	118	[10]
Cortical bone	130-180	50-151	6-8	[14]
Cancellous bone	4-12	-	-	

Compared to bioglass 45S5, soda-lime glass has lower amounts of silica and more calcium and phosphorus [18-24]. The high ratio of calcium to phosphorus makes apatite crystals possible and calcium and silica ions act as crystallizing nuclei. As the ratio of calcium to phosphorus is low, the structure may not attach to the bone. The reason for using 45S5 bioglass in medical work is its similarity to hydroxyapatite (HA), a bone and tooth mineral. Also, the comparison of its mechanical properties is shown in Table 1. The BG material should be stored in a dry place because it easily absorbs and reacts with moisture. It is important to note that the relative cytotoxicity of Bioglass 45S5 on dental pulp cells was compared with the cytotoxicity of temporary fillers, type 1 glass ionomer and commercial superfluid desensitizer [17-28]. The number of living cells was also compared using one-way analysis of variance, and the morphological changes of the pulp cells were observed directly under a phase contrast microscope.

2- History of bioglass ceramic

Bioactive glass is one of the first completely fabricated materials that seamlessly connects to the bone, and was made by Hench et al. He then realized that a new material required to make a living connection to the body's. Hench have a successful experiment on bioglass bioceramic and published his first article on this subject in 1992, and his lab has been studying this subject for the next 10 years. By the early 21st century, more than 500 articles from institutions and laboratories around the world were published on this topic. The first successful surgery using Bioglass 45S5 was in the placement of the middle ear bones, which were used in the treatment of ear conductive problems and now this material is used in bone re-formation processes [8-14]. Low strength of the BG in which under load is usually not desirable and many researchers work to solve this problem [15-27]. One of the suitable techniques is to combine these glasses with materials that have a higher refractive index, such as polymers. This problem can also be solved by composites whose mineral part is composed of HA.

3- Types of bioactive glass ceramic

In general, there are three types of bioactive glass including silicate, borate, and phosphate. Silicate is the most well known of these groups, including bioglass.

The borate group, which has some boron in its structure, has a higher biodegradability and in other words less chemical durability, but instead of silicate glass, they are converted to hydroxy, as well as borate. bioactive glass supports cell growth and differentiation in the outer body tissue formation. Also, this glass can react in a phosphate solution and is made as hollow materials. HA formed by borate glass is porous and can be loaded with medicine, and at the time of implantation, the drug penetrates the surrounded tissue for days or weeks. The concern about bioactive ceramics of borate is related to their toxicity due to the release of boron in the solution in the form of ion borate $(BO_3)^{-3}$. Although this cytotoxicity is seen in static *in vitro* culture conditions, its toxicity decreases in dynamic culture media. Since their constituent ions are similar to the bone mineral phase, these glasses have a good tendency to establish chemical bonds with the bone and therefore can be used in clinical practice as an absorbable substance [26-37].

4- Applications of Bioglass in maxillofacial fracture

The bone grafts are performed in different ways; however, the main technique is that the dentist makes an incision in the maxilla and transplants bone material or bone powder into the jaw, a tooth transplant is usually performed as the adult has lost one or more teeth or has some kind of gum disease. Both of these conditions can cause bone loss in the jaw. The preferred method for tooth bone transplantation is the utilization of the person's bone from the hip, tibia, or back of the jaw. the bone source of jaw transplantation can come from four sources, each of them has its advantages and risks, bone grafts from one's own body, such as the hip or jaw joint, bone grafts from another person's bones, xenograft, which includes animal bones such as cow bones, and alloplastic, which deal with synthetic substances such as calcium phosphate (CaP) [24-36].

5- Tooth restoration or filling

A tooth filling is a restorative dental treatment used to repair minimal tooth fractures, tooth decay, or damaged surfaces of teeth. Filler materials include composites, porcelain, and silver amalgam. Enamel loss is one of the most common tooth decays and may lead to tooth sensitivity. In many cases, the sensitivity to enamel loss is significantly improved or eliminated, as soon as a proper filling material replacement. However, in some cases, depending on the amount of decay or tooth damage, the damaged tooth may require replacement methods. Several methods can restore the appearance and function of teeth. The type of restoration procedure you need is determined according to the type and impairment of the tooth. One of the most common methods of tooth reformation is tooth filling. Fillers are used to filling a cavity caused by tooth decay as shown in Fig. 1.

Fig. 1 Tooth filling with composite which increase the mechanical strength of the dentin.

Options that can be put to use are composite resins (white fillings), which are preferred for several reasons than an amalgam filling. Their color resembles teeth and does not expand and contract like metal fillers and does not damage the tooth. However, they are as strong and durable as metal fillers. Another option is the glass ionomer, which acts more like a sealant than composite resins and its color is opaque, and the resin-modified glass ionomer, which resembles a glass ionomer, but has an enamel color and is made to better match the teeth and is made for more durability. This bioactive glass may be able to replace some of the minerals lost in the tooth due to decay.

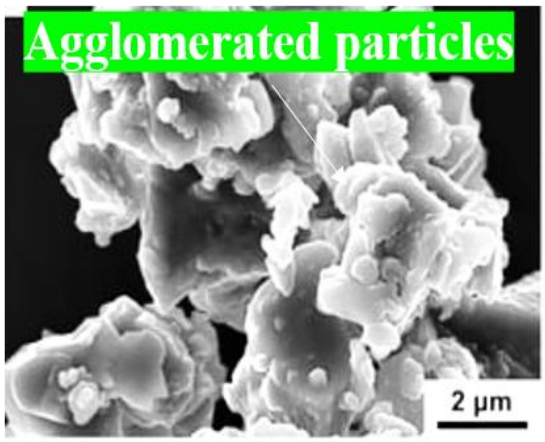

Fig. 2 Scanning electron microscope (SEM) image of bioactive glass [37].

The special engineers in biomaterials and advanced structures use this type of glass in dentistry, and our research shows that its use in dental restorative materials is very promising [36-42]. Unlike other medical products that do not interact with the body, the body becomes aware of the presence of this substance in the tooth and reacts to it, which is why it is called "bioactive" glass. The tooth erodes and loses its solute at the site of decay. Bioactive glass can help increase the survival of fillings because in this new study it was found that the depth of bacterial penetration into the contact surface containing BG is considerably lower than composites without this glass [41-47]. For the first time in the world, OSU College has launched a laboratory to test tooth fillings and simulate fillings in similar oral conditions. The antimicrobial effect of bioactive glass is part of the release of calcium and phosphate ions that have a toxic effect on oral bacteria and helps neutralize the acidic environment at the filling site [48-55]. Determination of optimum concentration of light starter in dental composites based on the properties of essential materials and development of a resin-based self-repairing dental composite can be improved by increasing their shelf life [56-59]. One way to improve longevity is to fill the micro-cracks that develop during or after composite hardening in the dental cavity. The flexural strength of most BG is in the range of 40-60 MPa, which is not sufficient for load-bearing approaches. Its elastic modulus is 30-35 GPa, which is very close to the membrane bone. BG bioceramic may also be used as a bioactive material in composite materials or as a powder. The first successful surgery to use Bioglass 45S5 was to replace in the middle ear bones to solve a hearing conduction problem.

6- Nanocomposites and their application as dental restorative materials

The use of composite resins is moving towards being able to completely replace fillers such as amalgam, but the main problem of these composites is volumetric contractions, which occur during the polymerization process [42-48]. These volumetric contractions create empty spaces between the tooth and filler, which causes the accumulation of food particles

and fluids in it and exacerbates tooth decay.

Fig. 3 Onlay with proper mechanical features

With the support of nanofilters, the percentage of volumetric contractions can be reduced and the strength of the composite can be dramatically increased so that they have natural tooth properties. The use of polymetallic dental and bone composites like methacrylate due to its proper biological compatibility with the body and relatively good strength, low weight, and low price in biomechanical and medical applications as prosthetics or for replacement and repair of bones is necessary [55-63]. One of the weaknesses of these materials is the relatively low fracture toughness and low resistance to crack growth compared to dental and bone material, which can eventually lead to the occurrence and growth of cracks from the joint season of composite-tooth or from inside the dental composite material and replacement prostheses or dental-bone control and needs dental cosmetic restoration as shown in Fig. 3.

7- Conclusion

The use of nanomaterials such as HA and alumina is a suitable option for retrofitting these dental-bone composites. In this study, the effect of adding different materials to BG was investigated as a case study. It is shown that the toughness of bioglass material increases, by adding the above nanoparticles, somewhat improves crack growth resistance. However, the effect of various trace elements nanoparticles on increasing the toughness of BG failure is higher than HA. A highly loaded hybrid composite to the dental crown confirms other studies' achievement that shows the benefits of high filler loading in accordance with the properties of hard dental tissues. High biocompatibility of BG is its main advantage while its disadvantages including low mechanical features, low fracture resistance due to amorphous 2D glass lattice. The flexural strength of most BG is in the range of 40-60 MPa, which is not sufficient for load-bearing approaches. Its elastic modulus is 30-35 GPa, which is very close to the membrane bone. BG bioceramic may also be used as a bioactive material in composite materials or as a powder. The first successful surgery to use Bioglass 45S5 was to replace in the middle ear bones to solve a hearing conduction problem.

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