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FEATURES OF BIOGLASS TECHNOLOGY FOR BONE TISSUE REGENERATION

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Abstract: *One of the main directions of research in the field of regenerative medicine is focused on the replacement of bone defects with materials that interact with the cells of a living organism and provide the body with a structure on which new tissues can easily grow. Most often, bioglasses are used for this, which are obtained in various ways - from classical cooking to sol-gel technologies, while each of them has its own advantages and disadvantages. In the work, a comparative analysis of various bioglass production technologies from the point of view of practical implementation in production is carried out, and the requirements for the main indicators of the product are outlined.*

Keywords: *Bioglass, Hydroxyapatite, Sol-gel, Glass melting, Bone regeneration*

INTRODUCTION

Tissue engineering is a constantly evolving field. One of the main areas of research in this field focuses on the replacement of bone defects with materials designed to interact with the cells of a living organism to provide the body with a structure on which new tissue can easily grow.

Among the most commonly used materials is bioglass, which is often used due to its versatility and good properties (Mendoza-Cerezo, L., Rodríguez-Rego, J. M., Soriano-Carrera, A., Marcos-Romero, A. C. & Macías-García, A., 2023). Certain types of glasses have great potential for creating engineered bone scaffolds, as they can bind to host bone, stimulate bone cells to osteogenesis, and resorb at the same time as bone is being repaired (Baino, F. & Vitale-Brovarone, C., 2011).

Also, glasses can be the basis for the production of calcium phosphate ceramics based on hydroxyapatite, which is considered a bioactive material that has a favourable effect on the adhesion, growth and osteogenic differentiation of osteoblasts (Filová, E., 2014). Thus, the most well-known bio-glass 45S5 is proposed (Aguilar-Reyes, E.A., León-Patiño, C.A., Jacinto-Diaz, B. & Lefebvre, L.P., 2012) for the production of foam bioactive glass using the powder technology. This process combines powder technology with polymer foam technique and allows the fabrication of materials with different structures and properties. The foams showed an open porosity (64–79%) and pore size (335-530 μm) that are optimal for bone ingrowth. In all cases, the glass crystallised during sintering, and the material consisted mainly of $Na_6Ca_3Si_6O_{18}$ and $Na_2Ca_4(PO_4)_2SiO_4$ phases.

It has been proposed (Poh, P.S.P., Hutmacher, D.W., Steven, M.M. & Woodruff, M.A., 2013) to fabricate bioactive composite scaffolds for bone tissue engineering based on 45S5 Bioglass®

(45S5) or strontium-substituted bioactive glass (SrBG). The glasses have been incorporated into polycaprolactone (PCL) and fabricated into 3D bioactive composite scaffolds using additive manufacturing technology. The scaffolds are non-cytotoxic and support cell attachment and proliferation, while the incorporation of bioactive glass (BG) promotes the deposition of calcium phosphate on the scaffold surfaces, leading to earlier cell differentiation and matrix mineralisation compared to the PCL scaffold. Thus, PCL/45S5 and PCL/SrBG composite scaffolds show potential as next-generation bone scaffolds.

To produce bioglasses, the most popular methods are sol-gel synthesis and classical glass melting, with the issue of not only the technological advantages and disadvantages of these methods, but also the structure of the final product – glass – remaining relevant. Therefore, research aimed at studying the influence of the glass synthesis method on their structure and properties is of great interest

EXPOSITION

The aim of the study was to determine the effect of synthesis methods on the structure of bioactive glasses of the same chemical composition.

The research tasks were to synthesise and study the structure of 45S5 bio-glass obtained by the sol-gel method, to synthesise and study the structure of the same bio-glass obtained by cooking and rapid cooling, and to compare the results.

The chemical composition of the glass is given in Table 1.

Table 1 – Chemical composition of biologically active glass, mol.%

Glass	SiO_2	CaO	Na_2O	P_2O_5
45S5	46.2	26.9	24.3	2.6

The gel-like glass (45S5-1) was prepared using ethyl silicate ETS-40 ($(C_2H_5O)_4Si$), triethyl phosphate ($OP(OC_2H_5)_3$), calcium nitrate tetrahydrate ($Ca(NO_3)_2{\cdot}4H_2O$) and sodium nitrate ($NaNO_3$). The components were added gradually to a (0.1 M) aqueous solution of HNO_3. After the addition of each reagent, the solution was stirred for 1–2 hours at room temperature. The final solutions were kept for 10 days at ambient temperature to allow for the hydrolysis and polycondensation reaction to form a gel. The gels were dried under ambient conditions for 14 days. After grinding, the dried gels were subjected to heat treatment to 650 °C for 12 h.

According to classical glassmaking technology (45S5-2), silicon dioxide in the form of marshmallow (SiO_2), ammonium hydrogen phosphate ($(NH_4)_2HPO_4$), calcium carbonate ($CaCO_3$) and sodium carbonate (Na_2CO_3) were mixed in a stoichiometric ratio to produce glass. Glass frits were obtained by pouring the melt directly into cold water and then drying to a constant weight.

The glasses obtained from the zol-gel and from the melt were crushed and sieved to obtain bio-glass powders with a particle size of <63 μm.

X-ray analysis of the glasses was performed using a DRON-3 X-ray diffractometer with a CuKα radiation source.

X-ray diffraction patterns of 45S5-1 and 45S5-2 glasses are shown in Fig. 1.

From the presented results, it can be seen that the glassy material 45S5-1, obtained by the sol-gel method, demonstrates a diffraction pattern characteristic of the glass-ceramic structure. The diffractogram of glass 45S5-1 indicates the presence of a hexagonal phase of $Na_2Ca_2Si_3O_9$ (combeite), and also reveals some traces of a crystalline apatite-like phase rich in phosphorus $Na_2Ca_4(PO_4)_2SiO_4$ (silicocorhenanite).

For glass 45S5-2 obtained from the melt, an X-ray amorphous halo at 2θ of about 20-30° is observed, which is characteristic of the structure of amorphous glass.

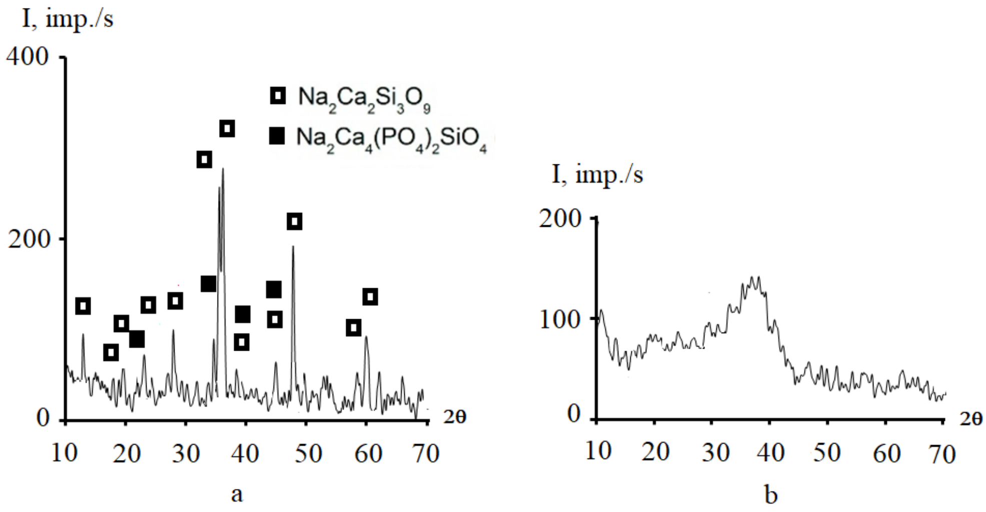

Fig. 1 - X-ray diffraction patterns of the experimental glass materials: a – produced by the sol-gel method, b – produced from the melt

CONCLUSION

The results show that the synthesis route has a significant impact on the glass structure. The melt-derived 45S5 glass exhibits a completely amorphous structure, while the gel-derived glass stabilised at 650 °C reveals the presence of crystalline silicate and phosphate phases. These results can be useful in choosing a method for synthesising bio-glass, taking into account its further application.

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