Preparation and Investigation of Novel Porous Scaffolds Containing Hydroxyethyl Cellulose/Poly Vinyl Pyrrolidone/Cerium Doped Bioactive Glass Nanoparticles

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Abstract- Three different composite scaffolds from blending of (HEC/PVP) Polymer and cerium doped bioactive glass were prepared using freeze dryer technique. The prepared scaffolds were investigated by Fourier transform infrared spectrometer (FTIR) and scanning electron microscopy (SEM). Also, the effect of bioactive glass addition on the mechanical properties was measured by mechanical testing machine. The results showed the positive effect of the addition of the prepared bioactive glass nanoparticles.

Keywords– Porous scaffold, HEC, PVP, Bioactive glass, Compressive strength.

I. INTRODUCTION

Scaffold fabrication is a great field of the biomaterials and it is an important area for tissue engineering and for regenerative medicine research. Scaffold materials can be synthetic or biologic, degradable or no degradable depending on the desired application [1]. Biocompatible composite scaffolds are considered the suitable approach to obtain the desired criteria [2]. Often scaffolds synthesized from a single-phase biomaterial have problems such as low mechanical properties or low degradability. Therefore, various researchers have done on composite scaffolds containing two or more materials (such as bioactive glasses and polymers) to bring the good properties of each material.

The nanostructured bioactive glass present high specific surface area and present a great applications in tissue regeneration and drug delivery [3]. The most studied on bioactive glasses are those of the ternary SiO2–CaO–P2O5composition where amorphous silica is known to be bioactive, biocompatible, biodegradable and non-toxic in living tissue, just as in comparing recreated physiological conditions [5]. In this manner, glasses based on the SiO2-CaO-P2O5 system establish a significant type of materials that have found wide application in medicine as bone implants [8]. The properties and functionality of bioactive glasses (such as antibacterial, biological responses, mechanical properties) can be modified by addition small amount of various elements (such as zinc, copper, cerium) which make the material more compatible for different clinical applications.

Biodegradable polymers are an important group of polymer that breaks down by bacterial decomposition process to result in natural by products such as gases, water, biomass and inorganic salts [10]. According to the origin, biodegradable polymers can be classified into two classes [11]: natural polymer and synthetic polymer. Natural and synthetic polymers have been used for many biomedical applications [12]. Natural polymers have received attention as they have many advantages. They are available and non-toxic economical materials. They also provide a natural substrate for cellular attachment, proliferation and differentiation. Therefore, they represent favorite substrates for tissue engineering [13]. Cellulose is the most common and the most important natural polymer [14]. Hydroxyethyl cellulose (HEC) is a modified cellulose which the most abundant natural polymers in the world. The chemical structure of HEC exactly matches that of glycosaminoglycan (GAG) in the dermis. There are many studies to establish scaffolds using HEC for skin tissue engineering [15]. HEC is water-soluble and non-ionic carbohydrate polymer. Therefore, it is compatible with a wide range of other water-soluble polymers [16]. Due to the poor mechanical properties of natural polymers, they are utilized to repair small fractures of the bones only. By adjusting the design and manufacture of synthetic polymers, the desired mechanical properties can be obtained. Poly vinyl pyrrolidone (PVP) also called as polyvidone or povidone is a sort of a synthetic polymers. It is a widely used polymer with interesting properties. PVP is able to form complexes with a various compounds through H-bond formation between its carbonyl group and the hydroxyl groups of water, alcohol and hydroxyl containing polymers [17, 18].

In this study, we prepared composite scaffolds containing HEC, PVP and cerium doped bioactive glass to bring the good properties of each material ad study the effect of bioactive glass addition on blending polymer (HEC/PVP).

II. MATERIALS AND METHOD

2.1 Materials

Tetraethyl orthosilicate (TEOS, Merk), triethyl phosphate (TEP, Fluka), calcium nitrate tetrahydrate (Ca (NO3)2.4H2O, LOBA) and cerium (III) nitrate hexahydrate (Ce (NO3)3·6H2O, Aldrich) the purity of all mentioned chemicals ≥98%. 2 M nitric acid and 2 M ammonia solution were prepared by using 68% nitric acid (HNO3, Merk) 33% ammonia solution (NH4OH, Merk), absolute ethanol (C2H5OH, Merk), Hydroxyethyl- cellulose (HEC, Fluka), Polyvinylpyrrolidone (PVP, Sigma) and distilled water.

2.2. Synthesis of cerium doped bioactive glass

The prepared bioactive glass composition [52 SiO2, 33 CaO, 7 P2O5, 8Ce2O] in (wt. %) was prepared by sol–gel strategy [19, 20]. At first, TEOS, distilled water and 2 M nitric acid were successively mixed in absolute ethanol at room temperature. The mixture was permitted to react for 60 min for the acidic hydrolysis of TEOS. At that point a progression of reagents was added under magnetic stirring at room temperature in the following arrangement: triethyl phosphate, calcium nitrate tetrahydrate, cerium (III) nitrate hexahydrate letting 45 min for each substance to react absolutely. After the latter addition, the mixture was hold under stirring for 60 min to complete the hydrolysis reaction. Then, 2 M ammonia solution was dropped as a gelation catalyst into the resulted transparent solution under stirring. The obtained gel was hold in a conventional ultrasonic bath. Lastly, the gel was heated at 75 ℃ for 3 days. The dried gel was heated at 650 ℃ for 2 hours (3 ℃ /min). The glass powder was ground and sieved.

2.3. Synthesis of cerium doped bioactive glass

Initially, the polymeric solutions were prepared from (5%W/V) of HEC and (5% W/V) of PVP with ratio 80:20 respectively. Gradually addition of determined bioactive glass to the dissolved in calculated amount of (HEC/PVP) polymer. The blend of bioactive glass and polymer is left on the stirrer to break the agglomerates and ensure the homogenous distribution of bioactive nanoparticles in the blend. Then, the blend was poured into molds and was kept at -20 oC for overnight. Finally, the frozen blend were lyophilized for 24 hours at −56 ℃.

III. CHARACTERIZATION TECHNIQUES

Infrared transmittance spectra of the calcined glass powder and the prepared scaffolds were recorded using FT-IR spectrometer, Tensor 27 Model, in 400–4000 cm-1 range. Morphological of porous structure of prepared scaffolds before were investigated by using SEM, Quanta FEG 250 model. The mechanical properties of different composite scaffolds were measured by mechanical testing machine.

IV. RESULTS AND DISCUSSION

FT-IR spectroscopy was carried out to elucidate the presence of HEC, PVP and abioactive glass powder in the prepared scaffolds. Fourier transform infrared (FT-IR) spectra of the prepared biocomposite (1SC, 2SC, 3SC) and of 8% cerium oxide doped bioactive glass (X= 8%) is shown in figure 1. FT-IR transmittance spectra of the calcined glass powders shows characterized peaks of silicate glass. Where, the band situated at nearly 460 cm-1 is ascribed to a bending mode of Si–O –Si, that around 770 cm-1 is expressed about Si–O–Si symmetric stretching vibration and the wide band located between 900 and 1150 cm-1 is assigned to Si–O–Si asymmetric stretching mode [21, 22]. The peak at about 580 cm-1 is matched to O–P–O phosphate bending vibration [23]. It is known, silicate glasses have a habit of moisture absorption. Therefore, the beaks at about 1600 cm-1 are resembled to hydroxyl bending and the wide bands at about 3500 cm-1 are assumed to hydroxyl symmetric stretching mode [24].

The presence of various chemical functional groups in of the polymer blend from HEC and PVP without bioactive glass (1SC) is indicated by FTIR spectra as shown in Figure1. Wide band around 35000 cm-1 which is characteristic to OH-stretching bond of adsorbed water in both HEC and PVP [25, 26]. Peak at 2950 cm−1 is assigned to stretching CH for both PVP and HEC. Also, the peak at nearly 1670 cm−1 is assumed to bending O-H bond. The peak absorption at 1590 cm−1 is assigned to the stretching vibration of the C=O and that at 1370 cm−1 is due to the C–H bond [25, 26]. The peaks at 1300 cm−1 and the doublet at 1440 cm−1 are due to the C–N stretching vibrations and the attachment of CH2 groups in the pyrrole ring of PVP [26, 27]. While, a wide band which at about 1070 cm-1 is assigned to stretching vibration of C-O and small peak which around 930 cm-1 is assumed to OH-primary alcohol of HEC [25].

By increasing the amount of bioactive glass in the prepared scaffolds (2SC, 3SC), peaks of polymer gradually decrease and the effect of nanoparticles bioactive glass progressively appears. By comparison of composite scaffolds

(3SC) and bioactive glass powder reveals the same peaks with lower intensity at regions 1500, 1700, 1500 and 1100 cm-1. Also, the peaks around 2950 cm−1 and 920 cm−1 are assumed to the bonds of the used polymer.

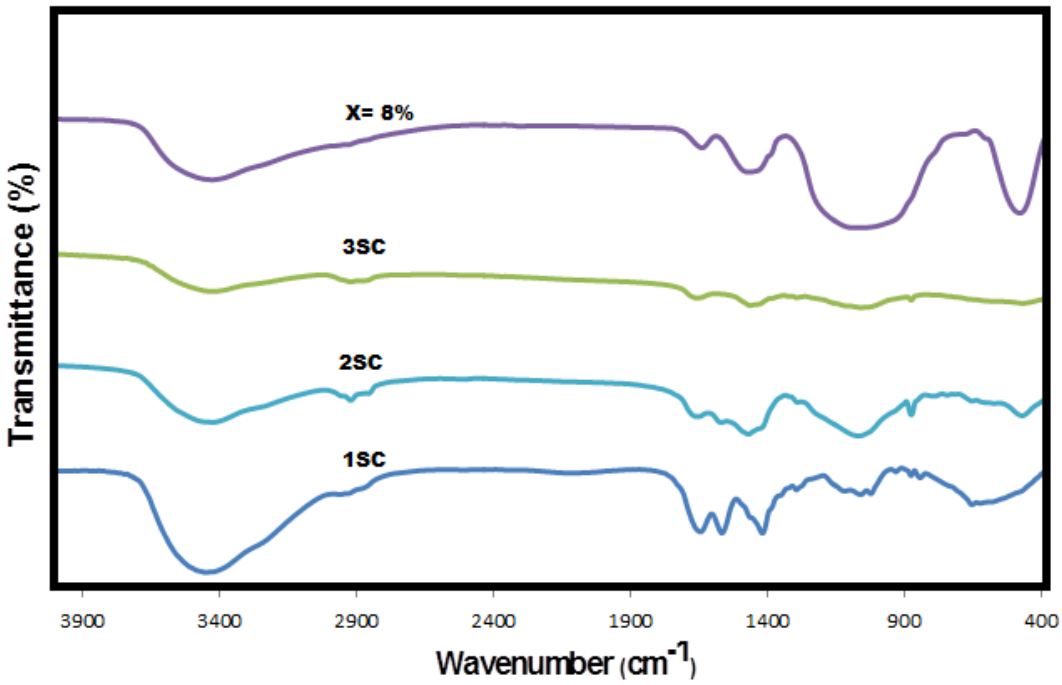
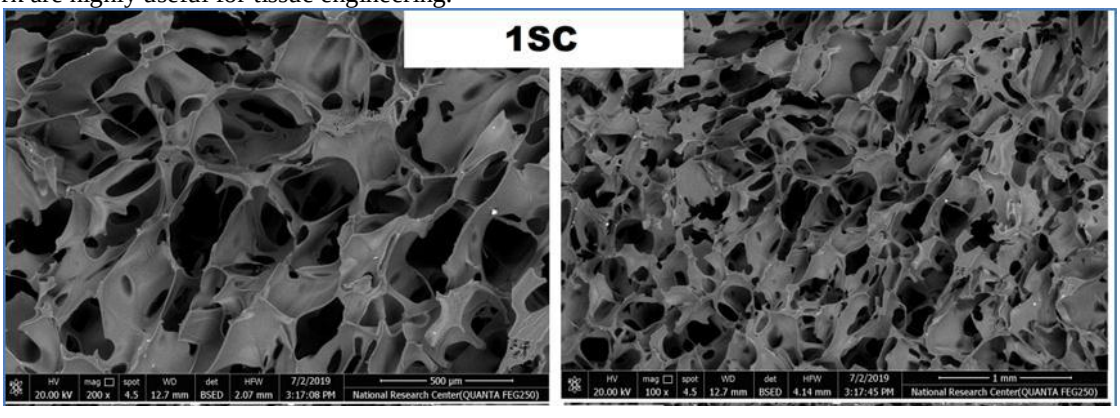


Figure 1. Fourier transform infrared (FT-IR) spectra of the prepared biocomposite (1SC and 3SC) and of cerium doped bioactive glass.

Morphology of 1SC, 2SC and 3SC scaffolds was investigated using scanning electron microscope (SEM). As shown in figure 2, scaffolds exhibit porous structure with interconnected continuous pores ranging in the size from 8 μm to 220 μm. Open porous and interconnected networks are required for cell nutrition, proliferation, migration for tissue vascularization and formation of new tissues [28, 29]. As shown images the pore size decrease and the pore walls becomes thicker by increasing the concentration of bioactive glass nanoparticles. The variety of pore size is important for the ingrowth of cells and new tissue and beneficial to the exchange of nutrients and metabolic waste [30]. It is clear in 2SC; there is homogenous distribution of nanoparticles bioactive glass in the polymer blend. However, there is agglomeration of nanoparticles bioactive glass in 3SC. The existence of these nanoparticles led to decreasing in pore size. Therefore, the porosity decreases with glass addition. Also, there are interconnectivity between pores as shown in SEM images. Scaffolds with higher porosities and a homogeneous interconnected pore network are highly useful for tissue engineering.



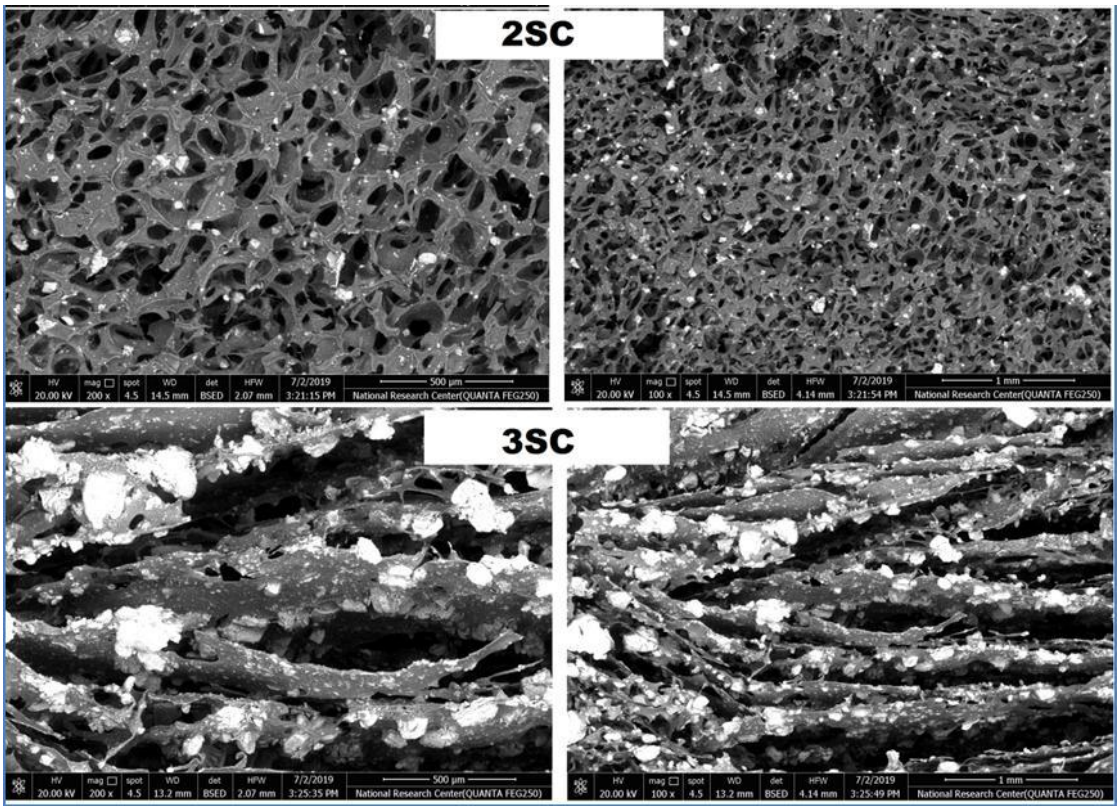


Figure 2. SEM images of the prepared scaffolds with two different magnifications for each scaffold.

The mechanical properties of 1SC, 2SC and 3SC scaffolds was measured by mechanical testing machine. The curves of 1SC, 2SC and 3SC scaffolds between compressive stress and the corresponded strain (%) are shown in figure 3. Totally, there is increasing in strain by increment the stress in all prepared scaffolds. Also, the scaffold bears higher stress by increasing the bioactive glass addition. It is clear, the 3SC possess the higher compressive stress and higher young modulus which calculated from the slope of the straight line region of the curve. As shown in table 1 the mechanical properties improve by increasing the the bioactive glass addition in the prepared scaffolds. Where, the polymer scaffold without bioactive glass presents low mechanical properties. While, the scaffold contains 50%bioactive glass and 50% polymer blend demonstrates the higher mechanical properties (see table-1). The mechanical properties increase in the scaffolds contained glass as the addition of bioactive glass led to the decrease in pore size as seen in SEM images. There is a reverse relationship between the mechanical strength and the porosity. This result is normal as the macropores in the scaffolds make the structure not compact. The prepared scaffolds possess compression strengths lower than 2 MPa. This means the prepared scaffolds have compressive strength in the order of that cancellous bone. Where, the compressive strength of cancellouse bone in range from 0.1MPa to 16 M Pa and Young's modulus ranges from 0.05GPa to 0.5GPa [31, 32- 34]. According to cortical bone, they are not suitable and not strong as compressive strength of cortical bone in range from130 MPa to 200 MPa [31, 34].

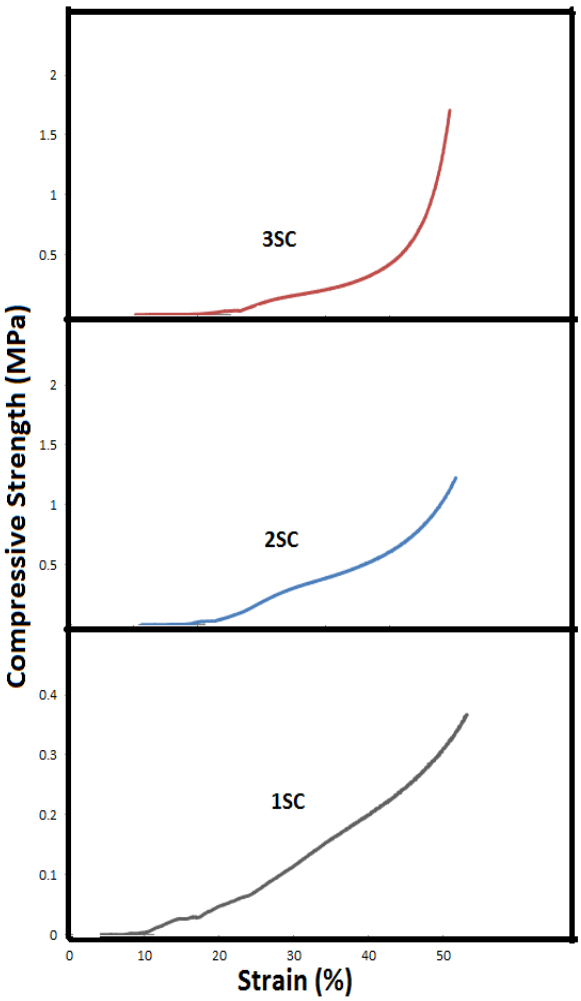


Figure 3. compressive stress versus strain (%) for the prepared scaffolds (1SC, 2SC, 3SC).

Table -1: Illustrate the influence of addition of cerium doped bioactive glass on the common important mechanical properties.

Sample	Maximum Load (N)	Stiffness (N/m)	Compressive strength (MPa)	Young's modulus (MPa)
1SC	80.0	25329.6	0.4	1.2
2SC	257.0	144064.7	1.2	6.6
3SC	357.8	509502.7	1.7	23.3

V. CONCLUSION

Three different composite scaffolds from blending of (HEC/PVP) Polymer and cerium doped bioactive glass nanoparticles were prepared using freeze dryer technique. Morphological and mechanical properties of the prepared scaffolds were investigated. Also, mechanical properties of different composite scaffolds were measured by mechanical testing machine. Results showed that the prepared scaffold possess porous structure and the pore size bioactive glass addition. Also, there is homogenous distribution of nanoparticles bioactive glass in the polymer blend. According to mechanical results, the prepared scaffolds have compressive strength in the order of that cancellous bone. Moreover, the compressive strength and Young modulus increase with increasing the amount of bioactive glass in the scaffolds.

VI. REFERENCE

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