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Evaluate of Different Bioactive Glass on Mechanical Properties of Nanocomposites Prepared Using Electrospinning Method

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Abstract

Electrospinning is a method in which materials in solution are formed into nano- and micro-sized continuous fibers under electrostatic field. This is especially important and forms one of the essential paradigms in the area of tissue engineering. Electrospun nanocomposite of Poly (ε-caprolactone) scaffolds incorporating the Bioglass (BG), have excellent performance in cell attachment and proliferation for bone remodeling. In this study, electrospun Polycaprolactone-Bioactive glass (BGs) nanocomposite were produced using electrospinning method. Three bioactive glass were selected based on SiO_2-CaO-SrO-P_2O_5 system with exchange of SrO content was substituted for CaO and the other glass was 45S5. The morphology of electrospun nanofibers were evaluated using scanning electron microscopy (SEM). Data were statistically analyzed and compared between groups using ANOVA. The results revealed that BGs with a good dispersion and distribution in the nanofibers web increases the mechanical properteis compared with pure Polycaprolactone (PCL), but the 45S5 make more fragile the nanocomposite structure.

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Keywords: Bone tissue engineering; Electrospun nanocomposite scaffold; Poly(ε-caprolactone); Bioactive glass; Electrospinning.

1. Introduction

Tissue engineering and tissue implants are creating the biodegradable scaffolds, removing flaws and damaged bone tissue. Bone tissue engineering coordinates bone cells and biodegradable 3D scaffold to repair diseased or damaged bone tissue, Doustgani et al. (2013), Gerhardt and Boccaccini (2010). Bioactive glasses and their

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polymeric composites with various compositions is highlighted as one of the most promising materials in tissue engineering field, Allo et al. (2012). Electrospun nanofibers with high surface to volume ratio and porosity with BGs are contributed to make natural extra-cllular matrix (ECM), so promote cell adhesion, migration and proliferation, Fang et al. (2008), Huang et al. 2003, Johnson et al. (2009), Kaur et al. (2014), Kouhi et al. (2013), Liu et al. (2013), Mun et al. (2012), Rezwan et al. (2006), Woodruff and Hutmacher (2010). Nanofibers from PCL have been extensively studied, For bone tissue engineering, Ekaputra et al. (2009). Poly-ϵ-caprolactone (PCL) is a polymer with very low glass transition temperature and melting point. PCL/BG composite nanofiberus webs considerably improved the differentiation of osteoblast cells as compared to pure PCL nanofibers, Seong et al. (2010), also short BG nanofiber/PCL matrix composite scaffold has shown great mechanical stability and bioactivity, Fang et al. (2011). 45S5 bioactive glass is used particularly for porous scaffolds. In this study 45S5 BGs evaluate as nano particles into PCL nanofiberous web for investigating the mechanical properties, Fabbri et al. (2010).

2. Exprimental Procedure

2.1. Materials

Poly (ε-caprolactone) PCL (average Mw:80000) was purchased from Aldrich Company (US). Sol-gel derived glasses based on $CaO–SrO–SiO_2–P_2O_5$ system with the properties as described in Ref. Hesaraki et al. (2010), were synthesized in dental Biomaterial Laboratory, tehran University of Medical Sciences, Iran. By replacing SrO Instead of CaO with (0 to 5wt% SrO). Chloroform and methanol (merck, Germany) were used as received. 45S5 BG is kindly purchased from Yazd research campus.

2.2. Syntesis of nanocomposites

BG nanoparticles were distributed in the mixtures of chloroform/methanol solution and stirred for 6 h with a magnetic stirrer. Then polymer (PCL) was added into these nanoparticles dispersions and dissolved to obtain 10 wt% polymer composite solutions, which were then stirred nocturnal. The percentage of the added nanoparticles was 5wt% of the PCL content. The prepared composite solution was sonicated for 20 min for further dispersion. Then solution was quickly drawn into a syringe containing a needle gauge 20. Elecrospinning was carried out at a flow rate of 0.5 ml/h using a high DC voltage of 15 & 18 kV at a distance of 13 cm and the nanofibers were collected on the drum. The electrospun nanofibrous web was dried in a oven for 24 h and then kept in the desiccator.

3. Characterization of Nanofibers

3.1. Scanning electron microscopy (SEM)

Scanning electron microscope (Seron Technology AIS2100) was used to evaluate the morphology and size distribution of the nanofibers.

3.2. Differential thermal analysis (DTA)

For this purpose, STA (PT-1000 ,LINSEIS) was used in DTA mode that started from room tempreture up to 600°Cwith the heating rate of 10°C /min to record the conventional thermo analytical curves.

3.3. Mechanical characterization

Nanofibrous webs were cut into the rectangular dimensions 5*20 mm. five samples at the cross-speed head of 2 mm/min were tested and tensile strength and strain at break were calculated based on the stress–strain curves of each sample. Results were reported as an average and standard deviation of five measurements.

3.4. Statistical analysis

Statistical data analysis were conducted using a one-way analysis of variance (ANOVA) and Tukey Test. A probability value of 95% ($p < 0.05$) was used to determine the level of significance.

4. Results and Discussion

4.1. SEM observations

The morphology of the electrospun nanocomposites was investigated with SEM. We assessed the BGs particles were distributed intra-electrospun nanofibers and the matrix of the nanofibrous webs. Also, we observed beads in nanofibers preparing with 15kv (DC voltage) and 13cm distance to drum but by enhancing the voltage up to 18kv, all of the beads disappeared (fig. 1).

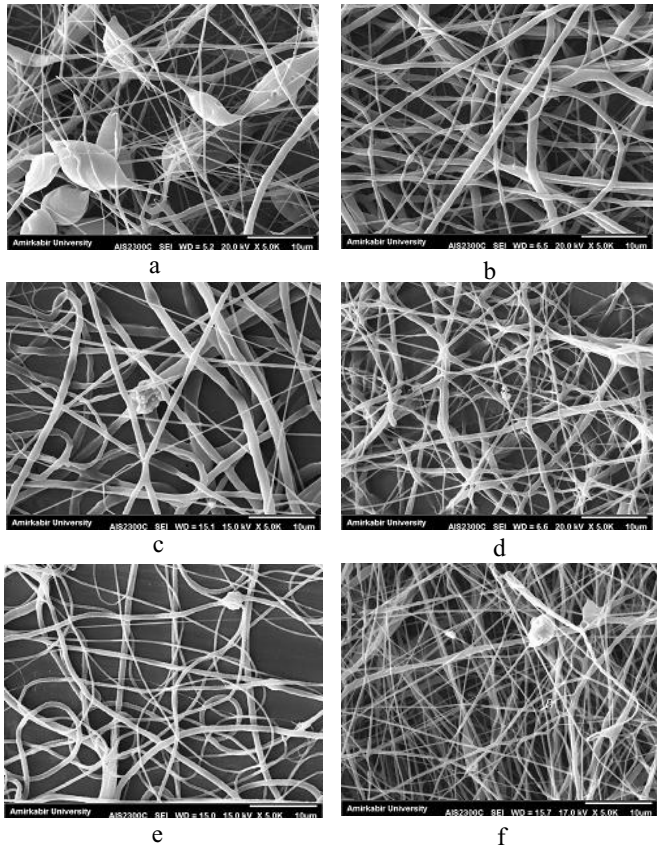

Fig. 1. (a) pure PCL, 15kv, 13cm; (b) pure PCL, 18kv, 13cm; (c) PCL/BG (0%SrO), 18kv, 13cm; (d) PCL/BG (5%SrO), 18kv, 13cm; (e) PCL/BG (10%SrO), 18kv, 13cm; (f) PCL/BG (45S5), 18kv, 13cm.

5. 2.Thermal analysis

DTA studies were performed on the Pure PCL and PCL/BG nanofibers to investigate the effect of BG nanoparticles on the structural properties of PCL matrix in the electrospun nanofibers. As seen in fig. 2, the PCL nanofibers without BG has an endothermic peak at around 60°C which is associated with the elting point of the PCL polymer, Yang et al. (2001).The same peak is also seen in the PCL/BG nanofibers heat flow curves, with the difference that its place has slightly shifted to Higher temperatures ~65°C -68°C,Kouhi et al. (2013).

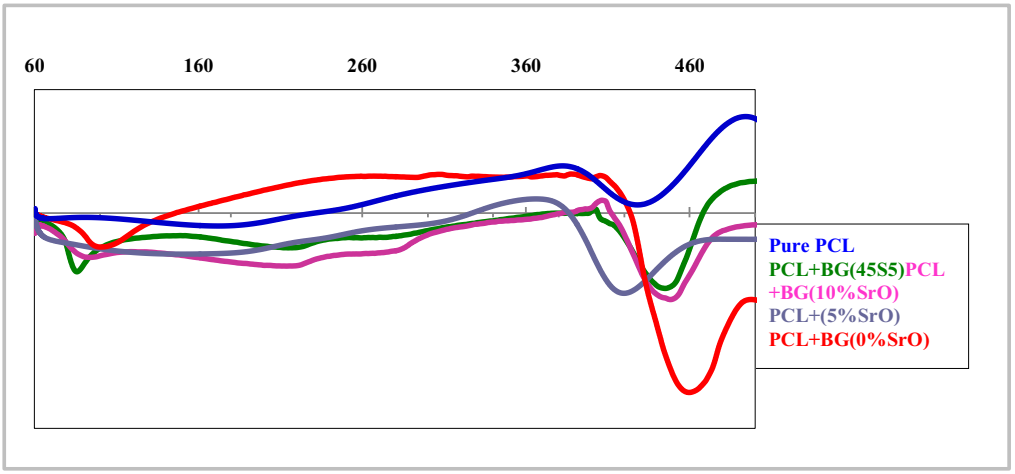

Fig. 2. DTA curves.

6.3. Mechanical properties

Analysis of the mechanical properties of the nanocomposite fibrous webs and the results of the present studies showed meaningful enhancement in tensile strength as the BG nanoparticles was added (fig. 3). tensile strength for PCL without BG was 1.33 MPa, which significantly ($p < 0.05$) increased to 2.17 MPa by increasing the BGs nanoparticles due to the reinforcement effect of BGs (ceramic materials have stiffer mechanical properties than polymers) within the polymer matrix while the tensile strain at break decreased (table 1). The glass nanoparticles are distributed in composite web, amplificate the composite strength with enhancement of strontium component. Strontium by two processes; stimulating in bone formation and decrease bone resorption lead to improve solubility in biological environment and increase bone strength.This study indicated that increasing the Sr improve the tensile strength. Replacement of Ca^{2+} with Sr^{2+} According to the lower charge-to-size ratio of Sr^{2+} (owing to a slightly larger ionic radius), cause an expansion of the silicate network, making it less strongly ionically cross-linked, Brauer et al. (2012). Research indicates replacing Ca^{2+} with Sr^{2+} increase the Compressive strength and elastic modulus of BG, so improve the tensile strength of nanocomposite. Also 45S5 was distributed in nanofiberous web, but the composite is more fragile because of 45S5 BG nanoparticles (table 2).

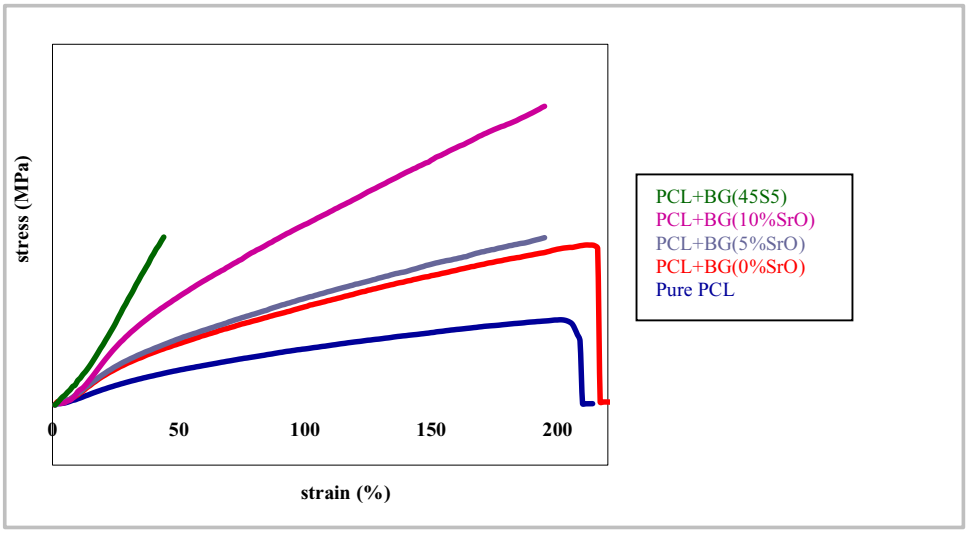

Fig. 3. Tensile Strength curves.

Table 1. Tensile Strength.

Pcl+BG	*(a)*	*(b)*	*(c)*	*(d)*	*(e)*
Tensile Strength±Standard Deviation	1.05±0.03	1.33±0.04	1.40±0.12	2.17±0.42	1.35±0.07
Significant Differences between a & b, c, d, e	-	-	**	**	-

(a). Pure polycaprolactone nanofiber without bioactive glass; (b). PCL/BG (0%SrO) nanocomposite;
(c). PCL/BG (5%SrO) nanocomposite; (d). PCL/BG (10%SrO) nanocomposite;
(e). PCL/BG (45S5) nanocomposite; **. Significant Differences between a & b, c, d, e

Table 2. Tension.

Pcl+BG	*(a)*	*(b)*	*(c)*	*(d)*	*(e)*
Tension±Standard Deviation	71.33±11.44	81.22±1.62	94.30±2.	88.44±12.38	26.58±4.92
Significant Differences between a & b, c, d, e	-	-	**	**	**

(a): Pure polycaprolactone nanofiber without bioactive glass; (b): PCL/BG (0%SrO) nanocomposite;
(c): PCL/BG (5%SrO) nanocomposite; (d): PCL/BG (10%SrO) nanocomposite;
(e): PCL/BG (45S5) nanocomposite; **. Significant Differences between a & b, c, d, e.

6. Conclusions

The method presented in this study as a viable capability to produce a homogeneous suspension from PCL and BGs nanoparticles. Investigating the tensile strength of the composites shows that bioactive glass particles caused a significant increase in the tensile strength of composites and enhancement of SrO percent instead of CaO improve the mechanical properties of electrospun nanocomposite.

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