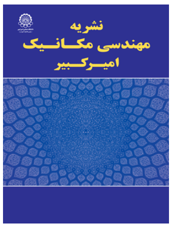

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 52(12) (2021) 881-884
DOI: 10.22060/mej.2019.16159.6288

Study of Young's Modulus and Failure Strength of Polyurethane-Based Binary Polymer Composite Structures Based on Stress-Strain Curve for Tissue Engineering Vascular Graft Application

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ABSTRACT: The coronary arteries are of the important cardiovascular diseases. The autograft is the main treatment for this problem, but in many patients, the autografts are not applicable. So, due to a large number of requirements, it needs to find suitable replacements for diseases of blood vessels. Nanomaterial structures are highly contributive in tissue engineering vascular scaffolds due to their ability in mimicking the nanoscale dimension of the natural extracellular matrix and the existing mechanical match between the native vessel and the structure. The aim of this research was developing and mechanically improving nanofibrous hybrid structures using blend electrospinning methods with different ratios of the polyethylene terephthalate, polyurethane and polycaprolactone. The morphological and mechanical properties of all fabricated structures were evaluated. The average fiber diameter, porosity, stress and Young's modulus changes' range in composite structures (polycaprolactone/polyurethane and polyethylene terephthalate/polyurethane) were obtained 343 ± 94 to 382 ± 83 nm, 58.6 ± 3.12 to 81 ± 1.7 %, 2.66 ± 0.39 to 19.05 ± 3.2 MPa and 3.18 ± 0.09 to 41.4± 3.31 MPa, respectively. According to results, the fabricated scaffolds as well as polyethylene terephthalate/polyurethane structure exhibited suitable mechanical and biological properties and clinical requirements as a small-diameter vascular graft.

Review History:

Received: 17 Apr. 2019
Revised: 10 Jul. 2019
Accepted: 2 Sep. 2019
Available Online: 16 Oct. 2019

Keywords:

Composite structure
Mechanical properties
Artificial blood vessels
Electrospinning
Tissue engineering

1. Introduction

Atherosclerosis as an important cardiovascular diseases is a great cause of death worldwide [1]. The autograft is a common treatment for this problem but in some patients has limited clinical success due to small size, previous harvesting and the age of patients [2]. Therefore, synthetic vascular prostheses have been clinically approved to treat this disease [3]. The previously obtained results have shown the synthetic vascular prostheses were being successfully used in large-diameter (> 6 mm) blood vessel replacement while in small diameter replacements have rejected due to series of problems such as thrombosis, lack of functional endothelial coverage and the intimal hyperplasia [4,5]. The desirable properties of the Nano-structure such as the high specific surface area, high porosity, good cell attachment makes it very attractive in vascular tissue applications [6]. Electrospinning as a simple and reliable technique has been applied for the fabrication of nanoscale structures such as vascular graft that can resemble the natural ExtraCellular Matrix (ECM) in native graft [7]. At the moment, the woven synthetic vascular prostheses such as PolyTetraFluoroEthylene (PTFE) and Poly Ethylene Terephthalate (PET) have been successfully used in vascular graft replacements with a large diameter but in a small diameter due to mismatch the properties of natural vascular have failed. In this regard, according to the composite structure of natural vessels, this study focused on the fabrication of synthetic vascular prostheses using nonwoven hybrid nanofiber structure by the electrospinning method for replacing a small diameter vascular graft. In other hands, the aim of this research was developing and mechanically improved hybrid nanofiber structures using blend electrospinning methods with different ratios of the polyethylene terephthalate, PolyUrethane (PU) and PolyCaproLactone (PCL).

2. Methodology

Materials and methods

The PCL (Mw 80,000), PET and PU, TetraHydroFuran (THF), N, N-DiMethylFormamide (DMF), DiChloroMethane (DCM), ethanol and chloroform were purchased from Sigma Aldrich, USA. TriFluoroacetic Acid (TFA), 1,1,1,3,3-HexaFuoro-2-Propanol (HFIP) were purchased from Merck, Germany. The solvents were used without further purification. The neat and hybrid nanofiber structures

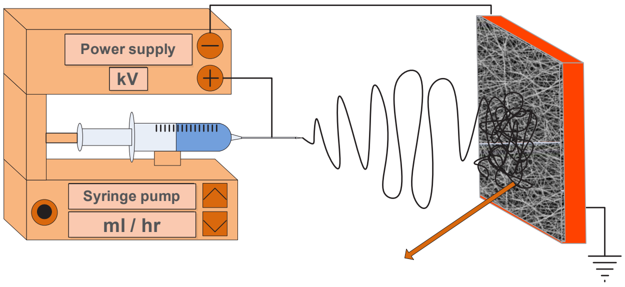

Fig. 1. A schematic of electrospinning setup

*Corresponding author's email: davoodmk@eng.usb.ac.ir fabricated using custom-designed electrospinning setup (Fig. 1). The information of the fabrication the neat and hybrid nanofiber structure and their electrospinning conditions have presented in Table 1. In following the morphological and mechanical properties all structures were evaluated using Scanning Electron Microscopy (SEM), Fourier Transform InfraRed spectroscopy (FTIR) and tensile properties.

Table 1 Electrospinning conditions of structures

	Electrospinning Conditions			
Structures	Concentration	Voltage (kV)	Flow rate (ml/hr)	Distance (cm)
PET	15 %w/w	25	0.5	25
PU	15 %w/w	20	2	20
PCL	10 %w/w	18	3	25
PET75/PU25	8 % v/v	20	2	25
PET50/PU50	8 % v/v	20	2	25
PET25/PU75	8 % v/v	20	2	25
PCL75/PU25	8 % v/v	20	2	25
PCL50/PU50	8 % v/v	20	2	25
PCL25/PU75	8 % v/v	20	2	25

3. Results and Discussion

The morphology of the neat and hybrid nanofiber structures evaluated using scanning electron microscopy images, FTIR analysis, and obtaining the porosity of the electrospun scaffolds. According to the results (Table 2), the average fiber diameter in hybrid nanofiber structures is significantly smaller than the neat structures.

Table 2. Average fiber diameter and porosity of the neat and hybrid nanofiber structures

Samples	Average fiber diameter (nm)	Porosity (%)
PCL	433 ± 80	89.1 ± 0.69
PU	470 ± 95	63.0 ± 0.46
PET	404 ± 44	74.0 ± 1.37
PCL75/PU25	372 ± 122	81.0 ± 1.70
PCL50/PU50	363 ± 85	78.8 ± 3.20
PCL25/PU75	382 ± 83	74.3 ± 0.15
PET75/PU25	375 ± 89	69.5 ± 2.30
PET50/PU50	369 ± 91	65.0 ± 1.50
PET25/PU75	343 ± 94	58.6 ± 3.12

The results showed that with increasing the PCL and decreasing the PU ratios in the hybrid structures the porosity of the structures has increased.

The neat PET and PET50/PU50 as a hybrid nanofiber structures revealed the highest load, tensile and Young's modulus. According to the results (Table 3) the range of the maximum load, tensile stress, tensile strain and Young's modulus for the hybrid structures were obtained within 2.03 ± 0.33 to 40.88 ± 9.21 N, 2.66 ± 0.39 to 19.05 ± 3.20 MPa, 101 ± 14 to 421 ± 51.35 %, and 3.18 ± 0.09 to 41.4 ± 3.31 MPa, respectively.

The PET/PU as hybrid nanofiber structure due to high elasticity of PU and high tensile strength of PET has an optimum load, stress, strain and Young's modulus.

For the PCL/PU hybrid nanofiber structures with 75 % of PCL, the maximum load, maximum stress, and maximum Young's modulus were obtained. Interestingly, in a hybrid nanofiber structure containing an equal value of the PCL and PU, the minimum load and stress were observed. In addition, due to optimum strength between PET and PU, in PET/PU structure the highest strain were obtained.

4. Conclusions

According to the results it has been obtained that the neat PCL, PU and PET polymers, due to the difference in their degradation, elasticity and stiffness can improve the mechanical properties of the PCL/PU and PET/PU as the hybrid nanofiber structures. Also it has been demonstrated that PCL/PU and PET/PU nanofiber structures due to mimic the properties of the extracellular matrix of the native vessels can be applied for vascular tissue engineering applications.

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Table 3. Mechanical properties of the neat and hybrid nanofiber structures

Structures	Maximum load (N)	Tensile stress at maximum load (MPa)	Tensile strain at maximum load (%)	Young's modulus (MPa)
PET	10.03 ± 0.75	4.04± 0.45	100 ± 8	18.0 ± 1.8
PU	7.26 ± 0.90	3.19 ± 0.54	321 ± 71	1.2 ± 0.39
PCL	7.00 ± 1.68	2.7 ± 0.44	142 ± 17	4.8 ± 0.11
PCL75/PU25	19.39 ± 4.81	14.74 ± 4.47	101 ± 14	23.0 ± 3.42
PCL50/PU50	2.03 ± 0.33	3.00 ± 0.66	288 ± 12	6.0 ± 0.548
PCL25/PU75	9.81 ± 1.62	5.98 ± 1.21	271 ± 85	5.46 ± 1.68
PET75/PU25	7.11 ± 1.52	2.66 ± 0.39	388 ± 5.2	19.3 ± 2.04
PET50/PU50	40.88 ± 9.21	19.05 ± 3.20	339 ± 85	41.4 ± 3.31
PET25/PU75	18.60 ± 3.08	9.24 ± 0.61	421 ± 51.35	3.18 ± 0.09

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