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Data Article

Dataset on microstructural characteristics and mechanical performance of homogeneous and functionally graded fibrous scaffolds

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ABSTRACT

Data in this article are supplementary to the corresponding research article [1]. Morphological features of homogeneous and graded nanofibrous electrospun gelatin scaffolds were observed using scanning electron microscopy. Microstructural properties including fiber diameter and pore size were determined via image analysis, using ImageJ. Uniaxial tensile and fracture tests were performed on both homogeneous and graded scaffolds using a universal testing machine. Stress-strain curves of all scaffolds are presented. Computing software, MATLAB, was used to design fibrous networks with thickness-dependent density and alignment gradients (DAG). Finite element analysis software, Abaqus, was used to determine the effect of the number of layers on the fracture properties of DAG multilayer scaffolds.

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1. Data

The microstructural properties of homogeneous and graded electrospun scaffolds are tabulated in Table 1 (fiber diameter) and Table 2 (pore size). Thickness measurements of homogeneous and graded electrospun scaffolds are listed in Table 3. The stress-strain curves of all electrospun scaffolds are plotted in Fig. 1 (uniaxial tensile test) and Fig. 2 (fracture test). In order to study the effect of layering on fracture properties of graded fibrous networks, computational analyses were performed. Fibrous networks featuring density and alignment gradients were modeled with up to five layers (Table 4). The effect of number of layers on stress intensity factor is presented in Fig. 3.

For further interpretation and discussion on the experimental dataset, readers are encouraged to refer the research article [1].

2. Experimental design, materials, and methods

2.1. Preparation of homogeneous and graded electrospun scaffolds

Fish skin gelatin (Sigma Aldrich, USA) and glacial acetic acid (Merck, Germany) were used in preparing a 25 wt % gelatin solution in a mixture of 90 wt % glacial acetic acid and 10 wt % water. Homogeneous and graded scaffolds were produced with a bespoke electrospinning set-up. Detailed preparation of electrospun scaffolds has been reported in the corresponding research article [1].
2.2. Morphology observation and quantification

Morphology of electrospun scaffolds were visualized using scanning electron microscope (SEM, Hitachi) at an accelerating voltage of 10 kV. Prior to SEM observation, each scaffold was cut into 10 mm × 10 mm squares and gold coated. SEM images were captured at magnification ×6000. ImageJ (NIH, Bethesda, MD, USA) was used to measure fiber diameter and pore size of scaffolds. The average fiber diameters and pore sizes were determined by measuring and averaging the diameters of ten randomly chosen fibers and pore sizes respectively from one SEM image for each type of scaffolds. Individual fiber diameter and pore size measurements of homogeneous and graded electrospun scaffolds are shown in Tables 1 and 2, respectively.

2.3. Mechanical testing

Uniaxial tensile and fracture tests were performed on homogeneous and graded scaffolds. All mechanical test samples were cut to rectangles 24 mm in width and 3 mm in height. For fracture test samples, an 8 mm notch was introduced perpendicular to loading direction. Thickness of each test sample was measured at three separate points (center and both ends) using digital calipers (Facom, France). All measurements were averaged to determine mean thickness. The thickness data are tabulated in Table 3.
Table 3
 Thickness of homogeneous and graded electrospun scaffolds.

| Type of scaffolds | Thickness (mm) |
|-------------------|----------------|
|                   | Reading 1      | Reading 2      | Reading 3      | Average |
| SH scaffolds      | 0.17           | 0.29           | 0.34           | 0.27    |
|                   | 0.34           | 0.33           | 0.30           | 0.32    |
|                   | 0.17           | 0.28           | 0.30           | 0.25    |
|                   | 0.29           | 0.30           | 0.29           | 0.29    |
|                   | 0.17           | 0.25           | 0.31           | 0.24    |
|                   | 0.36           | 0.32           | 0.32           | 0.33    |
|                   | 0.10           | 0.09           | 0.10           | 0.10    |
|                   | 0.08           | 0.07           | 0.08           | 0.08    |
|                   | 0.08           | 0.08           | 0.09           | 0.08    |
|                   | 0.07           | 0.07           | 0.06           | 0.07    |
| MH scaffolds      | 0.08           | 0.11           | 0.10           | 0.10    |
|                   | 0.19           | 0.20           | 0.19           | 0.19    |
|                   | 0.22           | 0.24           | 0.22           | 0.23    |
|                   | 0.2           | 0.22           | 0.25           | 0.22    |
|                   | 0.12           | 0.16           | 0.17           | 0.15    |
|                   | 0.13           | 0.16           | 0.18           | 0.16    |
|                   | 0.07           | 0.07           | 0.07           | 0.07    |
|                   | 0.14           | 0.16           | 0.15           | 0.15    |
|                   | 0.14           | 0.16           | 0.19           | 0.16    |
|                   | 0.10           | 0.09           | 0.04           | 0.08    |
|                   | 0.07           | 0.09           | 0.12           | 0.09    |
| DH scaffolds      | 0.16           | 0.19           | 0.20           | 0.18    |
|                   | 0.21           | 0.21           | 0.19           | 0.20    |
|                   | 0.17           | 0.18           | 0.18           | 0.18    |
|                   | 0.18           | 0.19           | 0.20           | 0.19    |
|                   | 0.18           | 0.21           | 0.23           | 0.21    |
|                   | 0.13           | 0.14           | 0.15           | 0.14    |
|                   | 0.10           | 0.11           | 0.12           | 0.11    |
|                   | 0.10           | 0.09           | 0.09           | 0.09    |
|                   | 0.15           | 0.13           | 0.09           | 0.12    |
| Graded scaffolds  | 0.61           | 0.61           | 0.62           | 0.61    |
|                   | 0.70           | 0.67           | 0.70           | 0.69    |
|                   | 0.54           | 0.55           | 0.61           | 0.57    |
|                   | 0.34           | 0.30           | 0.30           | 0.31    |
|                   | 0.41           | 0.42           | 0.44           | 0.42    |
|                   | 0.41           | 0.43           | 0.44           | 0.43    |
|                   | 0.70           | 0.69           | 0.68           | 0.69    |
|                   | 0.69           | 0.72           | 0.70           | 0.70    |
|                   | 0.62           | 0.66           | 0.62           | 0.63    |
|                   | 0.48           | 0.50           | 0.55           | 0.51    |
|                   | 0.40           | 0.44           | 0.44           | 0.43    |

Fig. 1. Stress-strain curves of homogeneous and graded electrospun scaffolds obtained via uniaxial tensile test.
Fig. 2. Stress-strain curves of homogeneous and graded electrospun scaffolds obtained via fracture test.

Table 4
Network parameters of DAG networks constructed with various number of layers.

| Number of Layer, \( n \) | Fiber Density, \( r_f \) (1st layer) (\( \mu \text{m}^{-1} \)) | Density Gradient, \( \Delta G \) (%) | Fiber Alignment, \( \varphi \) (°) | Model Size, \( r \) (\( \mu \text{m} \)) |
|--------------------------|------------------------------------------------|---------------------------------|---------------------------------|-----------------|
| 1                        | 36.3 ± 0.5                                        | 0                              | 90                              | 5               |
| 2                        | 67.5 ± 1.3                                        | 52 ± 2                         | 15, 90                          | 5               |
| 3                        | 68.3 ± 1.6                                        | 29 ± 2                         | 15, 52.5, 90                    | 5               |
| 4                        | 68.1 ± 1.5                                        | 19 ± 3                         | 15, 52.5, 65, 90                | 5               |
| 5                        | 68.7 ± 0.7                                        | 16 ± 2                         | 15, 33.75, 52.5, 71.25, 90      | 5               |
All the samples were gripped along their width and extended at a rate of 3mm/min until failure. Stress-strain responses of homogeneous and graded scaffolds are presented in Fig. 1 (uniaxial tensile) and Fig. 2 (fracture test). For each mechanical test, four to six test samples were used.

2.4. Computational analysis

2.4.1. Finite element modeling

Fibrous networks composed of density and alignment gradients (DAG) were generated using MATLAB (Version 2017, MathWorks, Natick, MA, USA). Table 4 listed the parameters used to generate DAG networks consisting of up to five layers. The networks were then imported into finite element software, Abaqus (Version 2017, SIMULIA, Providence, RI, USA) for modeling. Fibers were modeled with Timoshenko beam (B31) and were analyzed using nonlinear finite element analysis, which considers large strain and rotation. All fibers were defined with diameter Φ of 300 nm, Young’s modulus, E, of 100 MPa and fracture strength, σf, of 30 ± 4 MPa.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Weily Khoo, She Man Chung, Shing Chee Lim, Cheng Yee Low, Jenna M. Koh, Shapiro, Ching Theng. Fracture Behavior of Multilayer Fibrous Scaffolds Featuring Microstructural Gradients, Mater. Des. 184 (2019) 108184.