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Characterization of poly(lactic acid) melt spun fiber aligned scaffolds prepared with hot pressing method

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ABSTRACT

Aligned fiber scaffolds are known to control cell behavior in vitro due to contact guidance and have potential applications as a cell carrier, ligament substrate, drug loading and release, nerve regeneration, implantable functional muscle, bone repair and meniscus tissue engineering. Aligned fiber scaffolds are often prepared by electrospinning, however in this study, poly(lactic acid) (PLA) melt spun fiber aligned scaffolds were prepared by a hot pressing method using a temperature of 60–180 °C. The hot pressing temperature plays an important role in surface and cross sectional morphology, dimensions, fiber parallel arrangement, thickness, pore diameter, porosity, water absorption and stress. The results indicate that PLA melt spun fiber aligned scaffolds prepared at 60 °C had optimum physical properties for applications in tissue engineering.

1. Introduction

Native extracellular matrix (ECM) is usually composed of fibrils ranging from tens of nanometers to micrometers in scale, and the organized structure of these matrix fibrils can guide tissue morphogenesis and remodeling [1]. To aid in guiding cell alignment or guiding tissue regeneration [2], aligned fiber scaffolds with nano- and microscale fiber diameter were used to achieve these functions [3]. The fiber scaffolds with different topographical features could be prepared by regulating fiber diameter, alignment, distribution and interfiber distance [3,4]. Through contact guidance aligned fiber scaffolds could induce controlled cellular responses like desired orientation and morphology [5], which having many potential applications in cell carrier [6], ligament substrate [7], drug loading and release [8], nerve regeneration [9], implantable functional muscle [10], bone repair [11] and knee injury [12].

Electrospinning is often used to prepare aligned PLA nanofiber scaffolds [13,14], however the scaffolds had lower mechanical properties and poorer bonding effect among fibers. In this paper, PLA melt spun fiber aligned scaffolds were prepared by a hot pressing method to study the relation between properties and hot pressing temperature. The aim was to prepare PLA melt spun fiber aligned scaffolds with maximum properties for its potential applications.

2. Experiment

2.1. Preparation of aligned fiber scaffolds

PLA melt spun fibers had 54.77 °C glass transition temperature and 173.89 °C melt temperature, and the fineness was 12.41 ± 0.89 μm [15,16]. PLA melt spun fibers were parallel winded by YG086 electronic yarn measuring instrument which purchased from Changzhou first textile equipment Co. Ltd. (Changzhou, China) under the condition of 100 r/min rotating speed and 100 CN tension.

The XLB 25-D plate vulcanizing apparatus, manufactured by Zhejiang Shuangli Group of Huzhou Rubber Machinery Company (Huzhou, China) was used to hot press parallel PLA fibers at different temperatures (60 °C, 100 °C, 140 °C and 180 °C). After hot pressing (60–180 °C, 5 min and 13 MPa) and cold pressing (0 °C, 5 min and 13 MPa) processes (Fig. 1), PLA melt spun fiber aligned scaffolds were ready for characterization.

2.2. Characterization

The size of aligned fiber scaffolds along the length and width direction was measured by ruler. Samples were gold sputter coated using a ETD-2000 twice, for 50 s. Then S-4800 scanning electron

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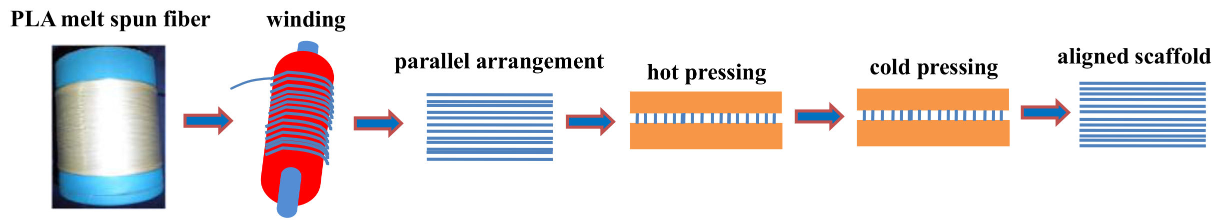

Fig. 1. Schematic diagram of aligned fiber scaffolds prepared by the hot pressing method.

microscope (SEM, Hitachi) was used to observe surface and cross sectional morphology. The pore diameter and alignment degree was measured by Image J software (National Institutes of Health, USA) [17] from surface SEM. The thickness of scaffolds was measured by Vernier caliper at five different positions while a liquid displacement method was applied to measure the porosity [18]. Five samples of each scaffold with size of 1 cm^2 were immersed into distilled water at 1 h, 2 h, 3 h and 4 h to evaluate water absorption [16]. The 5540A mechanical universal testing machine, manufactured by American Instron company was used to measure stress and strain at 100 mm/min speed and 1 cm^2 clamping length.

2.3. Statistical analysis

The experimental data were expressed as mean ± standard deviation, and the significant difference between groups was analyzed by using one-way analysis of variance (ANOVA) in the Origin 8.0 software. The statistical significance was set as $p < .05$ and $p < .01$, respectively [19].

3. Results and discussion

3.1. Surface and cross sectional morphology

As hot pressing temperature increasing from 60 °C to 140 °C, fibers arranged more closely and pores decreased (Fig. 2). When the hot pressing temperature was larger than melt temperature (173.89 °C) of PLA fibers, fibers would melt forming a transparent plastic film [20] with no fibers could be seen on the surface of scaffolds (180 °C). Transferred heat from the plates to fibers would produce increased temperature to melt PLA fibers.

3.2. Dimensional stability

Dimension of scaffolds (Fig. 3(a)–(b)) along the length and width direction before and after hot pressing was smaller at 60–140 °C ($p > .05$), while there was some shrinkage along the length showing significant increases along the width at 180 °C ($p < .01$). A good bonding effect among fibers were easily obtained with a lower hot pressing temperature.

3.3. Physical properties

Alignment degree of fibers in scaffolds ($p > .05$) shows in a neat parallel arrangement (Fig. 3(c)). PLA melt spun fibers melted into a transparent plastic film at 180 °C. Thickness (Fig. 3(d)) decreased as hot pressing temperature increasing from 60 °C to 180 °C. The unmelted fibers could form a fluffy porous structure with larger thickness, while the melt flow of these melted fibers formed a thin film with smaller thickness.

Pore diameter (Fig. 3(e)) and porosity (Fig. 3(f)) also decreased as the increasing of hot pressing temperature, this was due to the melted fibers formed a dense structure in aligned fiber scaffolds. At lower temperature of 60 °C and 100 °C the obvious pores could be achieved, and the pore diameter of 5–15 μm fitted approximately what is theoretically needed for fibroblast ingrowth [21]. As temperature increased to 180 °C, there was almost no pores.

Water absorption of aligned scaffold prepared at 60 °C was larger than the other two scaffolds, and the value of 180 °C was not shown in Fig. 3(g) due to its compact structure. The water absorption increased rapidly at first 1 h, then it retained no apparent change almost in a straight line parallel to the horizontal axis as time increasing from 1 h to 4 h. The water could infiltrate into

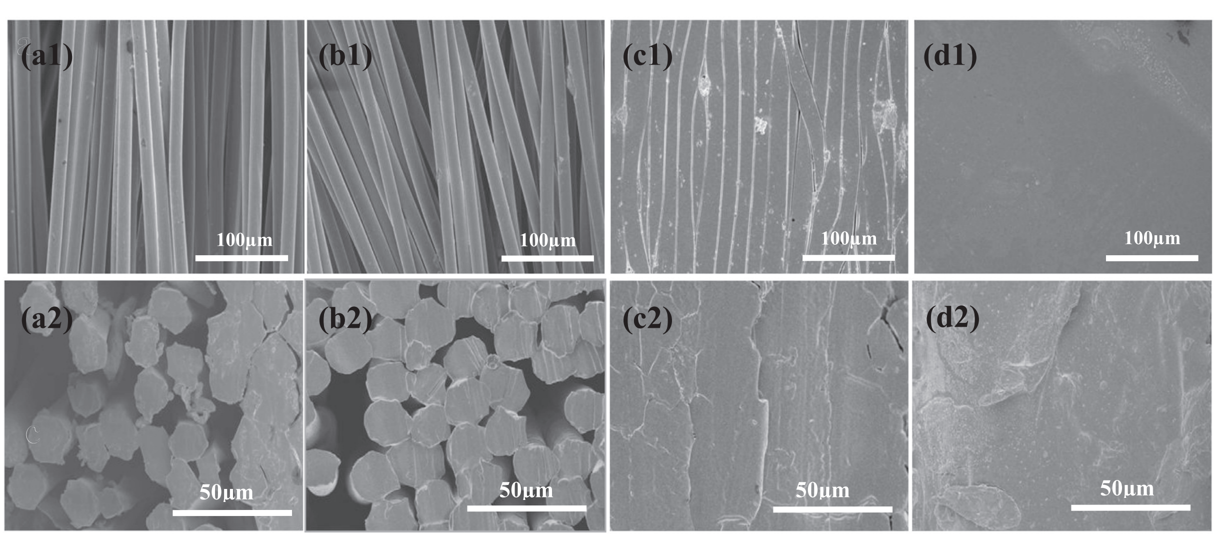

Fig. 2. Surface and cross sectional SEM figures of scaffolds prepared at 60 °C (a1) and (a2), 100 °C (b1) and (b2), 140 °C (c1) and (c2), 180 °C (d1) and (d2).