# Oriented and Interconnected Poly(L-lactic acid) Scaffolds for Guided Tissue Regeneration

Satyabrata Ghosh[1,3], Júlio C. Viana[2,3], Rui L. Reis[1,3], João F. Mano[1,3]
[1]3B´s Research Group - Biomaterials, Biodegradables and Biomimetics, Campus de Gualtar, 4710-057 Braga, Portugal
[2]IPC- Institute for Polymers and Composites, Campus De Azurem, 4800-058, Guimarães, Portugal
[3]Department of Polymer Engineering, University of Minho, 4800-058, Guimarães, Portugal

**Statement of Purpose:** Soft and hard tissues like blood vessels, peripheral nerves, spinal cord, urethers, intestine, etc possesses lamellar or tubular structures. Therefore, the production of constructs with an anisotropic pore structure could have benefits for some of the above tissue engineering applications. Due to the good mechanical properties and biodegradability, Poly(lactic acid), PLLA, and its copolymers remains as an obvious choice as scaffold material for fabricating tissue engineering scaffolds. Poly(ethylene oxide), PEO, is biocompatible and partially miscible with PLLA in melt. Moreover, PEO is water soluble and can be leached out from the blend by water. In addition, both polymers may be processed by melt-based techniques, such as injection moulding.

The present study focuses on the anisotropically oriented porous structure development of PLLA, as obtained from 1:1 wt % blend of PLLA/PEO by means of varying the processing parameters of injection moulding.

**Materials and Methods:** PLLA used in this study was L- lactide content of 99.6%, $M_n$ = 69,000, $M_W$ / $M_n$ =1.73, supplied by Cargill Dow, USA. The PEO used in this study was WSR N-10, $M_n$ =100,000, supplied by Dow Chemical Company, USA.

The variables of the processing conditions were melt temperature ($T_m$) and flow rate ($Q_{inj}$), as shown below:

| Condition | I | II | III | IV |
|---|---|---|---|---|
| $T_m$ (ºC) | 165 | 165 | 190 | 190 |
| $Q_{inj}$ ($cm^3/s$) | 7 | 56 | 7 | 56 |

Rheological analysis was performed at 190 ºC and 165 ºC to assess the viscosity of the polymers. SEM analysis was carried out to characterize the developed morphology after leaching of PEO by water. Mechanical tests were carried out in a Universal testing machine, INSTRON 4505, in tensile mode.

**Results and Discussion:** The structure development of PLLA/PEO blend can be explained by capillary number, $Ca = \eta_m \gamma R/\sigma$, where $\eta_m$ is the viscosity of the matrix, $\gamma$ is the shear rate, $R$ is the radius of droplet and $\sigma$ is the interfacial tension. The viscosities of PLLA and PEO at 165 ºC were 944 and 503 Pa.s and at 190 ºC were 214 and 316 Pa.s respectively at a frequency of 100 $s^{-1}$.

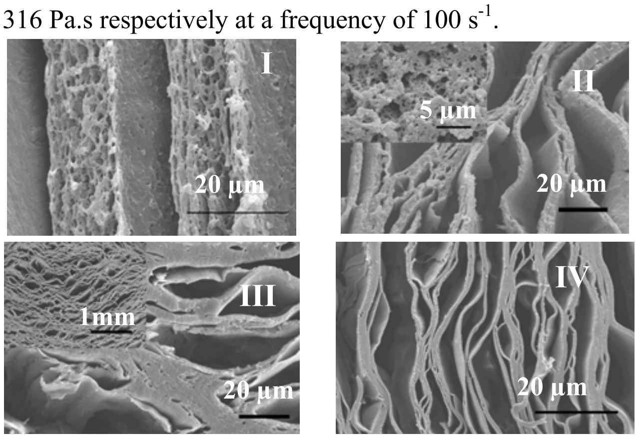


Fig.1 – SEM micrographs after leaching by water

Generally, in a flow field of multi-component system, the matrix is the low-viscous phase as it minimizes the energy dissipation in the flow direction. From the viscosity data, it can be assumed that PEO was the matrix at 165 ºC whereas at 190 ºC, the continuous phase is PLLA. At a particular temperature, as the shear rate increases the dispersed phase would be deformed more, resulting the lowering of lamellar thickness. This is evident from the SEM micrographs (Fig. 1). The micro-porosity of pore walls may enhance the transportation and diffusion of nutrients and metabolic wastes when the matrices are applied as scaffolds

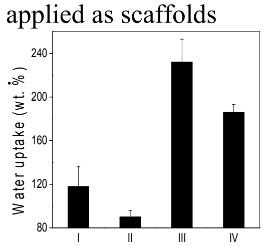


Fig.2 – Water uptake of porous scaffolds

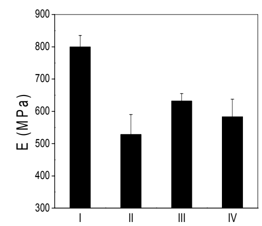


Fig.3 – Modulus (at 1 % strain) of the foams

The injection moulded specimens (2 mm thickness) were immediately put into distilled water. The average swelling of I, II, III and IV were 250, 195, 285 and 250 % respectively. The highest water uptake of condition III was due to the homogeneous distribution of the layers, resulting from low matrix viscosity, low injection speed i.e. lowest capillary number and low viscosity ratio. (Fig-2). The water uptake ~250 % (condition – III) is around three times higher than the NaCl leached PLLA of same porosity. The average porosity of I, II, III and IV were 57, 54, 74 and 71 % respectively.

The highest capillary number of condition-II (maximum matrix (PEO) viscosity and high shear rate) deforms the high viscosity dispersed (PLLA) phase, and thereby destroys PLLA structure: see SEM micrograph and note the lowest modulus. It is worth to note that the average elastic modulus of ~800 MPa of condition-I is among the highest reported modulus of PLLA with same porosity.

**Conclusions:** Novel porous scaffolds were produced by injection moulding from a blend of two biocompatible polymers, followed by leaching PEO in water. High orientation, adequate porosity, low pore wall thickness, permeability and higher surface area to volume ratio could be achieved by means of varying the viscosity of component polymers and the injection speed. Just by changing the processing parameters, different porous morphologies are obtained, and this can be tailored according to the tissues need to be engineered.

**Acknowledgements**: Financial support for this work was provided by FCT, through the POCTI and FEDER programmes, and by the European Union funded STREP Project HIPPOCRATES (NMP3-CT-2003-505758).