COMPOSITE 3D VASCULARIZATION BY USING SACRIFICIAL ELECTROSPUN SUB-MICROMETRIC FIBRES

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ABSTRACT

The creation of an extensive vasculature in composite structures is a challenge. The Bond and White groups are pioneers of different methods to achieve composite vascularisation, all of them based on the removal of sacrificial micro-fibres previously embedded in a polymer matrix.
We propose the use of electrospinning to produce sacrificial sub-micrometric fibres. Advantages derived by the use of this technique are: (i) the collection of fibres in form of a non-woven mat that can be easily embedded in a polymer matrix; (ii) the intrinsic morphology of the non-woven mat that resembles the blood vascular network of living system; (ii) the control of fibre diameters from hundreds of nanometers to few micrometers; (iii) the control of fibre spatial arrangement.
Here we present, as a proof of concept, the use of water soluble poly(ethylene oxide) electrospun fibres that can be easily embedded in a low-temperature thermoset polymer matrix and subsequently removed by simply immersing the composite in water. Fibres with different diameters can be used for generating vessels with different diameters. Moreover, non-woven mats either with a random fibre arrangement or with aligned fibres can be used to generate a biomimetic vasculature and unidirectional vessels, respectively. High-temperature thermoset polymer matrix can be similarly vascularized by a smart choice of electrospun fibre material.

1. INTRODUCTION

The complexity in fabricating composites possessing a 3D network of interconnected channel containing healing substances is a real and practical limitation to the exploitation of this type of smart materials. Different methods have been proposed to achieve micro-vascularization of composite materials [1-3]. Here we use electrospun non-woven membranes made of sub-micrometric fibres that, once impregnated in the polymer matrix, can be removed by water dissolution. We present vascularized polymer matrices fabricated by using Polyethylene oxide (PEO) fibres either randomly oriented or aligned in a preferential direction.

2. MATERIALS AND METHODS

2.1 Materials.

PEO (M_v ~ $4x10^5$ g/mol) and Rhodamine B were purchased by Sigma-Aldrich. A bicomponent epoxy resin Elan-tech® EC 157/W 61 was supplied by Elantas (Italy).

Electrospun mesh preparation

Electrospun non-wovens were produced by using a previously described electrospinning apparatus [4,5]. PEO was dissolved in MilliQ water at a concentration of 7% w/V and the solution was electrospun by using the following conditions: needle-to-collector distance = 20 cm, applied voltage = 18 kV and flow rate = 0.9 ml/h.

2.2 Composite fabrication

Epoxy matrix was prepared by mixing at RT the pre-polymer and the curing agent at a ratio 100/17 by weight, according to manufacturer instructions. The mixture was degassed under vacuum. To produce composite films the electrospun membrane was placed on a PTFE film and the uncured mixture was gently poured on it to get a complete impregnation. The excess of uncured resin was eliminated by using filter paper. The impregnated electrospun membrane was maintained at 40°C for 24, and 120°C for 2h.

2.3 Characterization techniques

SEM observations were carried out by using a Philips 515 SEM at an accelerating voltage of 15 kV, on samples sputter-coated with gold. The distribution of fiber diameters in electrospun non-woven samples was determined through the measurement of about 250 fibres. SEM was also performed on composites before and after water immersion (composite sections obtained by fracturing in liquid nitrogen). After water treatment, the possibility to fill the empty channels of vascularized composites was investigated by immersing the latter in a pink aqueous solution of Rhodamine (0.007% w/V) overnight under stirring.

3. RESULTS AND DISCUSSION

Electrospun non-woven membranes of PEO composed of fibre with diameter distribution 300 ÷ 50 nm are shown in Figure 1.

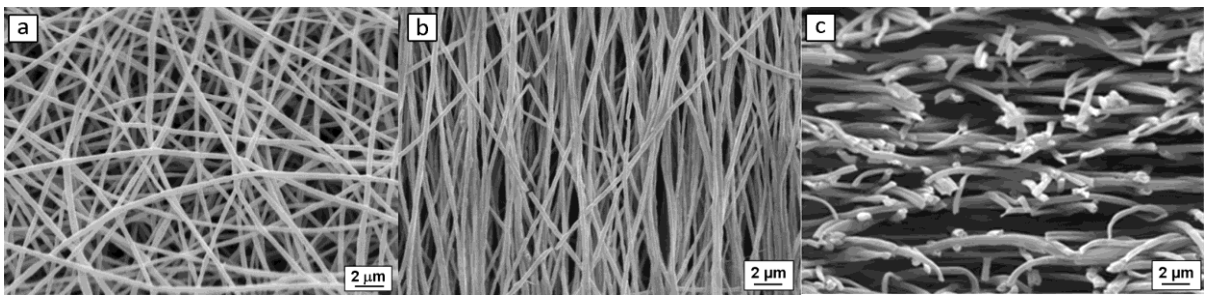


Figure 1: a) PEO random fibres; b) PEO aligned fibres; c) section of electrospun membrane.

The successful incorporation of PEO random fibres in the thermosetting matrix is shown in Figure 2, together with the image of the same composite after water immersion overnight. The section of composite before water treatment was characterized by the presence of fibres and holes, the latter as a consequence of fibre debonding and pulling out during the fracture. After water treatment the section of the matrix displayed many holes and channels as a consequence of the dissolution of fibres oriented perpendicular and parallel to the section, respectively.

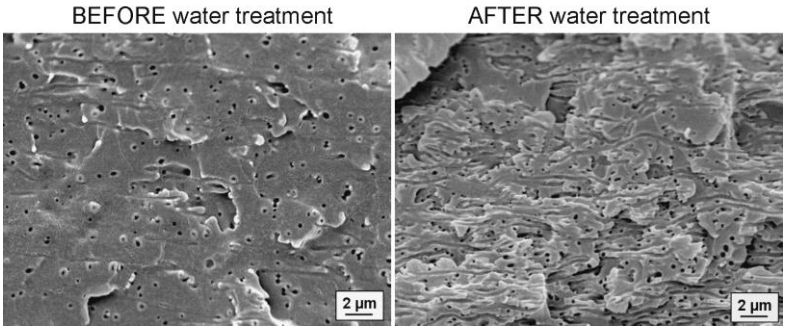


Figure 2: SEM images of composite sections filled with PEO random fibres before and after water immersion.

The incorporation of non-woven membranes made of aligned fibres generated, after fibre dissolution, unidirectional empty channels within the matrix (Figure 3).

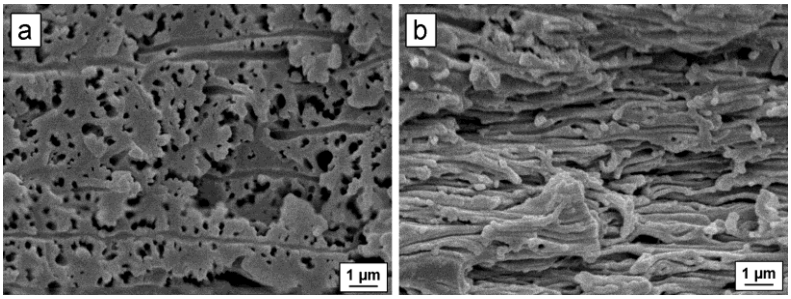


Figure 3: SEM images of composite sections filled with PEO aligned fibres after water immersion: a) section transversal to fibre direction and b) section parallel to fibre direction.

The capability of filling the empty channels with a liquid solution was verified by immersing the composite in a coloured water solution. Pictures in Figure 4 were acquired before and after immersion in Rhodamine B water solution.

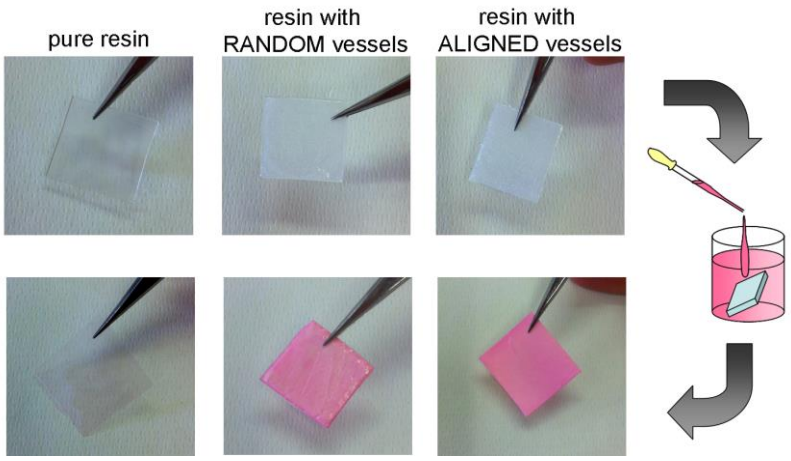


Figure 4: Coloured vascularized matrix after immersion in Rhodamine B water solution

4. CONCLUSION

In this work we demonstrated the possibility to easily generate a vascularized sub-micrometric structure inside a polymer matrix by using non-woven electrospun membranes impregnated in the polymer matrix and subsequently removed by water immersion. We also demonstrated that the empty and branched vessels, whose orientation can be governed during electrospun process, can be filled with a liquid substance.

ACKNOWLEGDEMENTS

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