PORCELAIN ENAMELLED STEEL SHEETS AS SMART COLLECTORS IN THE ELECTROSPINNING PROCESS FOR THE PRODUCTION OF POLYMER NANOFIBROUS MATS FOR BIOMEDICAL APPLICATIONS

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Porcelain Enamelled Steel Sheets as Smart Collectors in the Electrospinning Process for the Production of Polymer Nanofibrous Mats for Biomedical Applications

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Objectives:
Electrospinning is the most suitable technique for direct production of continuous nanofibers. The technique consists in the application of high electric fields (10 kV ÷ 30 kV) to polymer solutions or melts, to produce fibers with diameter ranging from nanometers to micrometers; the fibers a re randomly deposited in the form of non-woven mats. The polymer solution, placed into a syringe whose metallic needle is connected to a high voltage power supply, forms a drop that is progressively charged. When the charge density within the drop reaches a limit value, the electrostatic attraction produced by the electric field towards a grounded electrode - which also constitutes the collecting substrate – causes deformation and stretching of the drop.

This leads to the formation of a charged solution jet that is elongated and accelerated and it is subjected to instability phenomena through a spiraling path that causes thinning of the fluid jet and, as a consequence, the achievement of a nanometric fiber (Figure 1). During this path from the needle to the collector, the solvent evaporates and dried polymer nanofibers are collected in the form of a web.

The nanofiber assemblies obtained through electrospinning possess large exposed surface area coupled with satisfactory mechanical properties for most potential applications, and in particular in the biomedical field for regeneration or replacement of damaged tissues (infarction, burns,….).

In fact the nanofibers, being dimensionally similar to the fibers that constitute the natural extracellular matrix, can be considered an ideal biomimetic structure to induce and facilitate cell adhesion and cell growth processes. In particular, when adult stem cells are used, the nanofibrous structure of the mat might also address differentiation towards a specific cell phenotype.

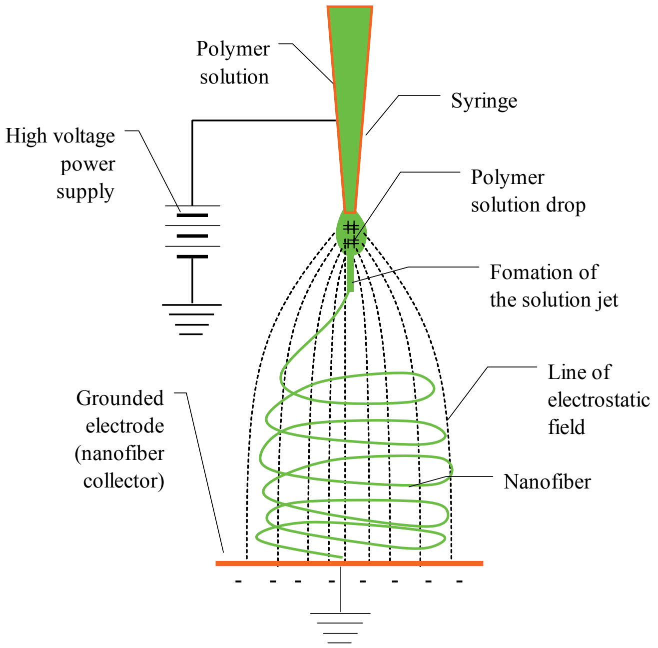

Fig. 1 Scheme of the electrospinning process

However, owing to the modest porosity of the electrospun mats (fractions of micron) cell colonization inside of the substrate is very poor (cell dimensions: tens of microns), thus preventing the formation of a real three-dimensional tissue. Hence, among scientists working in the tissue engineering field there is a strong need to obtain nanofibrous substrates with enhanced and controlled porosity.

In order to increase porosity in electrospun mats, one of the processing element on which it is possible to play is the appropriate choice of the nanofiber collecting plate. In particular, replacing the conventional conductive collectors with composite collectors made up of a conductive substrate and a non-conducting surface, it is possible to obtain electrospun mats with enhanced porosity. In fact, when the electrically charged polymer nanofibers reach a non-conducting surface, charges are not dissipated (polymer fibers are generally non-conductive) thus causing formation of repulsive electrostatic forces of the accumulated charges on the collector as more charged fibers are deposited. As a consequence the obtained electrospun mat will be characterized by an internal structure with a lower fiber packing density, and hence with a higher porosity, compared to those collected on a conductive surface.

Among potential insulating materials that can be used in the fabrication of the composite collecting devices, porcelain enamel is a very promising material owing to its intrinsic characteristics (low electrical conductivity, low roughness, good cleanability, resistance to corrosive agents and chemical solvents,...). In addition, the use of porcelain enamel offers the possibility to design collecting surfaces that allow to obtain peculiar distributions of the electrostatic field during the electrospinning process.

The aim of the research was to study and set up solutions for production of suitable porcelain enamelled steel sheets as electrospinning collectors, on which in some cases conductive serigraphic pastes were applied. Methods for the design of smart porcelain enamelled collectors have been identified, in order to obtain electrospun mats with controlled nanofiber deposition in particular through the use of:

- enamels with different electrical conductivity to influence the mat density and porosity;
- enamels and serigraphic pastes to obtain controlled distributions of the nanofibers within the mats.

Results and conclusions:

The enamelled collectors were produced using low carbon steel. Enamels have been applied on the steel sheets both by electrostatic dry powder deposition and by wet application. Different frits formulations were tested in the production of the porcelain enamelled collectors and in particular the production processes 1A/1C and 2A/1C were considered. In the latter case (process 2A/1C), the dry and wet deposition technologies have been appropriately combined. In addition, in order to study the effect of the enamelled collectors on the nanofiber collecting process, enamels possessing different values of electrical conductivity, density and roughness were used. Serigraphic pastes having good electrical conductivity were deposited on some of the enamelled collectors, and were then grounded thus enabling preferential nanofiber deposition pathways.

The development of the new generation of electrospinning collectors based on the use of porcelain enamels and conductive serigraphic pastes gave rise to the following results:

- an interesting increment of the polymer mat porosity (Figure 2);
- a real concentration of the polymer nanofiber distribution in spatial positions corresponding to concentration of electrostatic charges as a consequence of the application of conductive serigraphic pastes (Figure 3).

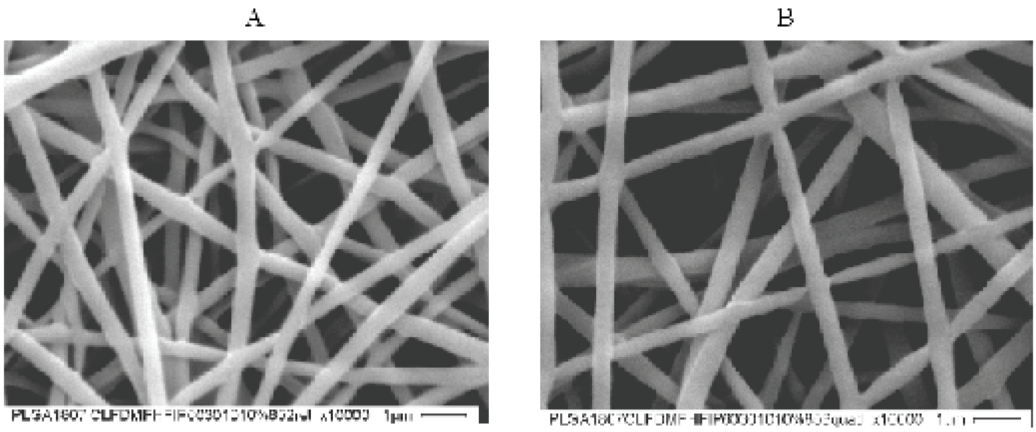

Fig. 2 SEM images of electrospun polymer mats deposited respectively on a conventional metallic collector (A) and a porcelain enamelled collector (B)

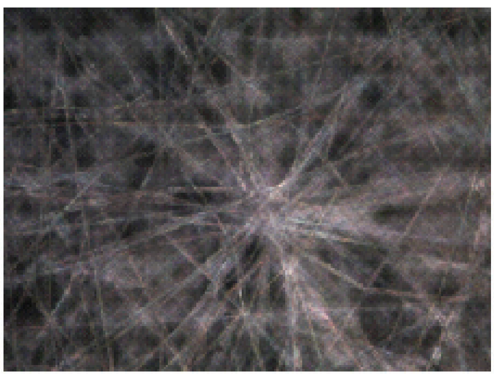

Fig. 3 Optical microscope micrograph (magnification 400X) of a nanofiber local accumulation (pin-hill) induced by an electrostatic charge concentration in a porcelain enamelled collector