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Novel co-axial extrusion printing head for tissue engineering

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Abstract: Additive manufacturing is a relevant technology for tissue engineering applications. However, due to some limitations in terms of the printing heads being used it is difficult to create complex multi-material hierarchical structures resembling natural tissues. The combination of 3D printing and microfluidics has the potential to overcome these limitations allowing to engineer functional artificial tissues with complex architectures. To achieve this a novel negative protrusion compression co-axial nozzle with a small expanding chamber is proposed in this paper, allowing balanced fluid flow conditions and uniform core-shell fibers.

I. Introduction

Biomanufacturing, the combined use of additive manufacturing, biodegradable and biocompatible materials, growth factors and cells is the most relevant tissue engineering approach [1,2]. This approach comprises two main methods: scaffold-based and cell laden approaches. The scaffold-based approach uses additive manufacturing techniques to create three-dimensional (3D) biocompatible and biodegradable porous structures able to support cell attachment, differentiation and proliferation [3-6]. Scaffolds can be seeded with cells after the printing process, pre-cultured in a bioreactor and implanted in the defect site; or implanted without seeded cells targeting, in this case, to be populated with recruited cells from the surrounding tissues [3-6]. The cell laden approach or bioprinting is based on the use of additive manufacturing techniques to create tissue constructs based on the use of bioinks (hydrogels encapsulating cells) [7-9].

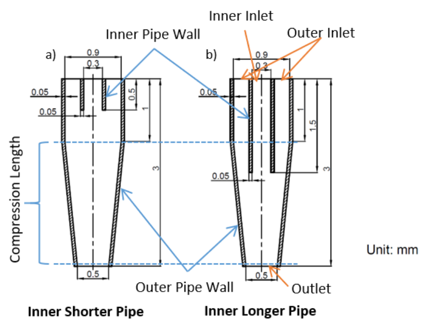

Figure 1: Schematic of compression co-axial extrusion nozzle (outlet geometry near exit).

Among the different additive manufacturing techniques currently available, extrusion-based processes are the most suitable for both scaffold-based and cell-laden approaches. A wide range of printing heads (e.g. screw, pressure, or pneumatic-assisted) are being used allowing to process a wide range of materials but limited to the fabrication of single-material scaffolds or cell-laden constructs.

At the University of Manchester (UK), we are investigating novel printing heads to allow the fabrication of more biomimetic constructs, functionally graded constructs, vasculature system and tissue interfaces. This paper presents a completely new co-axial nozzle and a 3D printing head combining two independent extruding systems (pressure and screw controlling systems) allowing to print a wide range of polymeric materials and to generate a balanced co-axial flow.

II. Novel co-axial nozzle

II.I. Negative protrusion compression co-axial nozzle

In a conventional co-axial nozzle, the fluids are extruded out of the nozzle simultaneously. Some researchers proposed protrusion geometries presenting an inner pipe slightly longer than the outer wall. In this case the inner fluid is extruded after the outer material. Based on protrusion nozzle, we proposed negative protrusion co-axial nozzle. In order to control the orientation of the polymer chains, we designed a negative protrusion compression co-axial nozzle (see Figure 1) that polymers will be compressed before extrusion, squeezing molecular chains, and increasing the anisotropy of the filament. Two different structures (inner shorter and inner longer pipe) are considered here for two mixing stages that before and after compression. However, due to the limited length of the paper, only the compression design is discussed.

II.II. Fluid flow analysis of the compression co-axial nozzle

The co-axial nozzle is the core part of a novel co-axial extrusion printing head that connects two separated extruding chambers. The initial design is presented in Figure 2a. This initial concept was slightly modified by considering an expanding chamber at the cross section of the inner and outer channel (Figure 2b). Due to the obstruction of the internal pipe, the fluid distribution behind the external pipe is uneven. Therefore, the expanded chamber aims to allow more fluid entering the right-hand side thus allowing a more balanced and uniform fluid flow and high-quality filaments.

The compression co-axial nozzle comprises three main regions: the upper region, the co-axial matching region, and the compression region. The upper region connects to the extruders with a seal part. The co-axial matching regions slowly combines two independent fluid flows into a core-shell structure. Small dimensions and short pipe were considered (inner diameter of $300\mu m$ and outer diameter of $900\mu m$; $13\ mm$ of height).

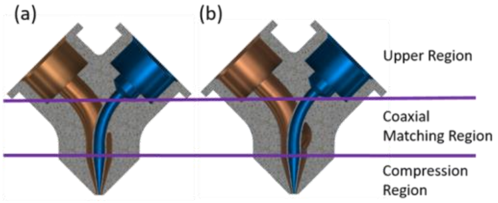

Figure 2: Schematic of co-axial nozzle (a) conventional co-axial nozzle; (b) novel expanding chamber nozzle.

Fluid flow simulations were performed using ANSYS Workbench Fluent (ANSYS, US) considering two different polymers (PLA and ABS). Simulations assumed a Newtonian behavior (the viscosity of both PLA and ABS was considered to be 5 $Pa.s$).

Figure 3 presents the fluid flow velocity results. As observed on the section view at plane L, an imbalanced velocity distribution occurs in the case of a compression co-axial nozzle without an expanding chamber. This uneven velocity distribution will produce a non-uniform filament. In order to solve this problem, a small expanding chamber (5mm of diameter) was designed at the cross section of the inner and outer channel (Figure 3b). This structure allows more fluid flow into the right-side channel but still presents a larger velocity at the right side. Therefore, the size of the expanding chamber was slightly decreased (4.5 mm of diameter) (Figure 3c) allowing to obtain a symmetrical velocity distribution profile.

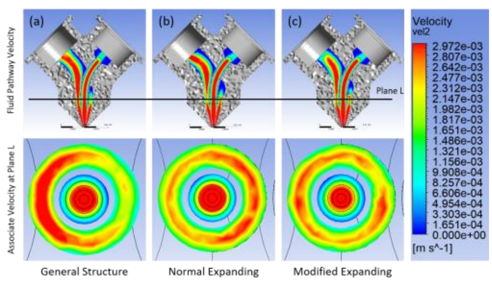

Figure 3: Fluid pathway and associated fluid velocity profiles for (a) compression co-axial nozzle without expanding chamber; (b) with a large expanding chamber nozzle; (c) with a small expanding chamber.

III. Novel 3D printing head

The novel co-axial nozzle is assembled to two different extrusion systems (Figure 4). A pressure-based extruder, which extrudes materials by applying air pressure generated, and a screw-assisted extruder designed to process high-viscosity materials. The screw is driven by a stepper motor with a velocity transfer screw. Material inlet chamber and extruding chamber were divided since high viscosity materials usually require a pre-heating stage. Two systems are equipped with temperature controlling systems that different materials can be extruded over melting point.

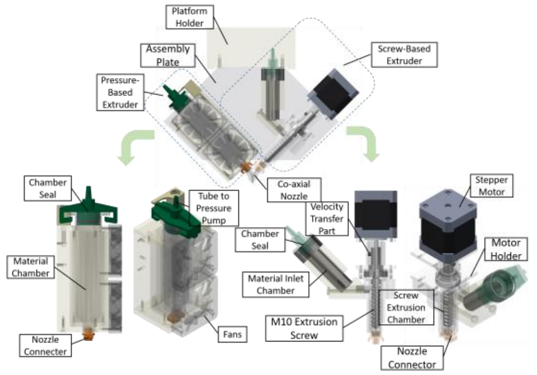

Figure 4: Co-axial extrusion printing head with one pressure-based and one screw-based extruders with temperature controlling system.

IV. Conclusions

This paper presents a novel co-axial nozzle with a compressive region and an expanding chamber. This nozzle allows the fabrication of core-shell fibers with a more uniform and balanced fluid flow, guaranteeing high alignment of polymer chains. This novel nozzle can be assembled to different extrusion systems to process a wide range of materials.

AUTHOR'S STATEMENT

Authors state no conflict of interest.

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