3D-printability of composite scaffolds based on PCL and bioactive glass nanoparticles for bone tissue engineering applications

TECHNISCHE HOCHSCHULE LÜBECK

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Introduction

Bone scaffolds are of interest in research because although the body's self-healing ability in terms of bone regeneration can repair minor defects (<2.5 cm), larger defects may need healing support [1]. Scaffolds can be of different origin such as autologous and allogeneic [2]. However, numerous problems arise from the use of these scaffolds, among which are donor site morbidity, scarcity of available donor tissue and rejection of the donated tissue at site of application [3]. In this work, the 3D-printability of Polycaprolactone (PCL) and mesoporous bioactive glass nanoparticles (MBGNs) for bone tissue engineering applications was researched. MBGNs are biodegradable, bioactive and the release of their ions can support bone regeneration. PCL is also a biocompatible material and was used to improve mechanical properties, resulting in a composite material. For this, Melt-Electrowriting (MEW), Fused deposition modeling (FDM) and dispense plotting were tested.

Materials and Methods

To assess the printability of PCL and PCL-composites, different 3D printers were used. Polycaprolactone (PCL, Mn = 45k) was printed either pure or as a matrix in combination with a glass reinforcement phase. For this, up to 10 wt% of MBGNs were mixed into the composite material.

- **Mesoporous bioactive glass nanoparticles:** Produced using a microemulsion assisted sol-gel approach, described in detail in [4]. Sintering was done at 700°C for 3h.
- **Fused deposition modeling:** Ultimaker S3 3D-printer, set to printing speed of 10 mm/s and nozzle temperature of 100°C was fed with PCL or PCL/MBGN filament made with a 3devo extruder.
- **Melt-Electrowriting:** A Bioscaffolder 3.1 from Gesim Gmbh was mounted with a high voltage source that was set to a voltage of 5 kV between nozzle and printing bed. The material (pure PCL) was heated to 85°C and the Taylor-cone was formed before the printing started.
- **Dispense plotting:** A Bioscaffolder 3.1 from Gesim Gmbh was heated to 85°C for pure PCL and 120°C for a PCL/MBGN composite of 10wt% MBGN content. The printing nozzle was set to a speed of 10 mm/s and an external fan helped to quickly cool down the extruded filament which prevented the formation of hill-and-valley structures.

Results and Discussion

Mesoporous bioactive glass nanoparticles

Judging from SEM-Analysis MBGNs could successfully be synthesized, their appearance is comparable to that from Nawaz et al. [4]. Energy-dispersive X-ray spectroscopy (EDX) could confirm this in the future. These MBGNs can provide a bioactive substrate for bone regeneration and are considered to be more bioactive than the surrounding matrix (PCL) [4]. As the name suggests, their surface can be characterized by pores of a few nanometers which can be loaded with drugs further on.

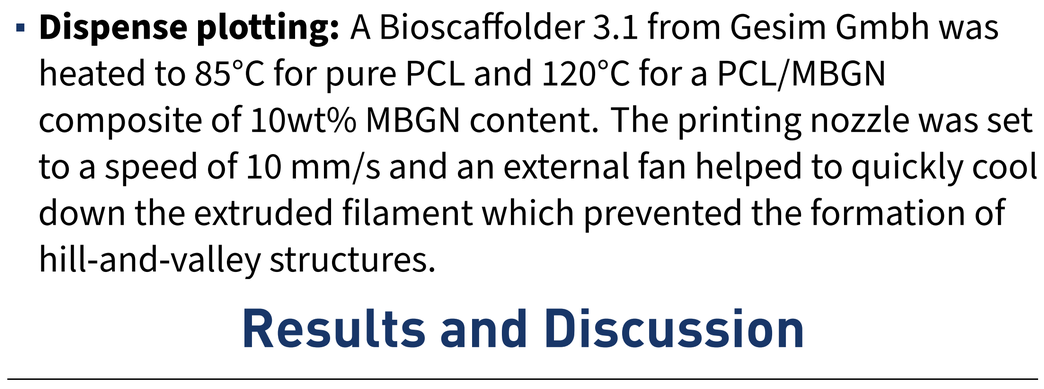

Figure 1:SEM image of mesoporous bioactive glass nanoparticles (MBGNs) which are intended for the reinforcement phase to a bioactive composite bone scaffold.

Melt-Electrowriting

MEW was successfully conducted and yielded scaffolds of well definable porosity and very fine strandwith (see Figure 2). However, it was found that for a future application as a bone scaffold MEW is not ideal as scaffolds are rather delicate and the maximum size is limited due to the use of an electric field of limited size.

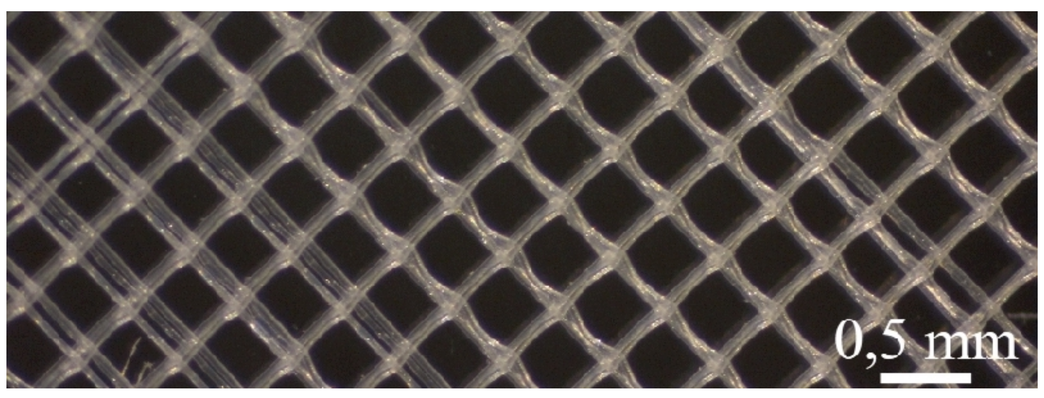

Figure 2:Light-Microscopy camera (Zeiss Axiocam 105 Color, Carl Zeiss AG) image of a scaffold produced using Melt-Electrowriting (MEW).

Fused deposition Modeling

Although many different print settings were tried, it was not possible to reproducibly print PCL or PCL/MBGN scaffolds. The material flow was not consistent and material tended to accumulate at the nozzle.

Dispense plotting

Dispense plotting yielded satisfying results both in term of print quality as well as reproducability. Depending on the weight percentage of MBGNs used, the viscosity of the composite material changed which is why the temperature was varied as mentioned before. Furthermore, the use of a fan was essential to maintain a good printing quality and porosity in all dimensions, as the filament cooled down quicker.

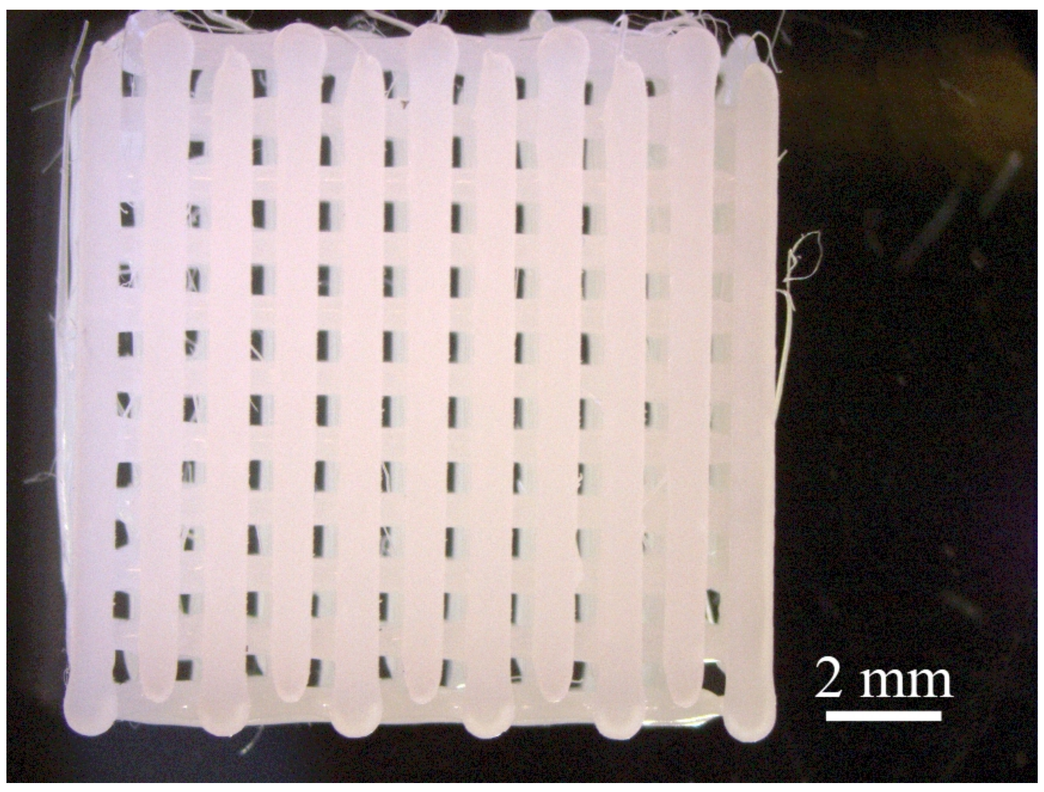

Figure 3:Light microscope camera image (Zeiss Axiocam 105 Color) of a PCL/MBGN (5 wt%) scaffold. Top view.

Conclusion and Outlook

To produce bone regenerating bioactive scaffolds, 3D printing was found to be the most fitting technique as it yields reproducible results of homogeneous, finely-tunable porosity. When choosing composite-materials instead of pure polymers, the printing parameters are well adaptable.
FDM on the other hand runs into flow issues when printing with PCL. However, literature shows that in principle FDM printing of PCL (-composites) is possible and should not be completely neglected in the future. Lastly, MEW produces scaffolds with the finest strands which tend to be to delicate and small for the application of bone tissue engineering.

Outlook

Important factors contributing to a successful bone scaffold remain to be researched. Among which are:

- Bioactivity (immersion in simulated body fluid)
- Cell viability e.g. ingrowth of osteoblasts
- Mechanical characteristics
- *In vivo*-tests

References

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