University of Victoria | Graduate Studies

PROGRAMME

REVISED
The Final Oral Examination
for the Degree of

DOCTOR OF PHILOSOPHY
(Department of Mechanical Engineering)

Junghyuk Ko

2011	University of Victoria	MASc
2007	University of Konkuk	BEng

"Melt electrospinning using Polycaprolactone (PCL) polymer for various applications: Experimental and Theoretical analysis"

Friday, December 12th, 2014
4:00PM
Engineering Office Wing, Room 502

Supervisory Committee:
Dr. Martin B.G. Jun
Department of Mechanical Engineering, UVic (Supervisor)
Dr. Stephanie M. Willerth
Department of Mechanical Engineering, Division of Medical Science
UVic (Member)
Dr. Chris Papadopoulos
Department of Electrical and Computer Engineering,
UVic (Outside Member)

External Examiner:
Dr. Woo Soo Kim,
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Chair of Oral Examination:
Dr. Chris Lalonde, Department of Psychology, UVic

Abstract

This thesis presents melt electrospinning technique to fabricate highly porous and controllable poly (ε-caprolactone), PCL, microfibers for tissue engineering applications and rehabilitation applications. Electrospinning without solvents via the melt may be attracting for tissue engineering of cell constructs where solvent accumulation or toxicity is a worry. It is also able to produce controllable microfibers. However, fiber diameters are relatively big from melt electrospinning process, compared to the fibers from solution electrospinning. The typical microfiber diameter from melt electrospinning was reported approximately 0.1mm. To develop melt electrospinning technique, we focus on the design of melt electrospinning setup based on numerical analysis using Solidworks 2013 simulation package and practically establish melt electrospinning setup and thermal control system for accurate experiments. One of main purposes of this thesis is the build-up of mathematical modeling to control and predict the electrospun microfiber via a better understanding of the parameters such as nozzle diameter, applied voltage, distance between nozzle and counter electrode, temperature, flow rate, linear transitional speed and etc. The model composes of three parts: 1) melt electrospinning process modeling, 2) fibrous helix movement modeling, and 3) build-up of microfibers modeling. The melt electrospinning process modeling describes an electric field, the shape of jet continuously changes and the polymer melt is stretched into a Taylor cone and a straight jet. The fibrous helix movement modeling describes movement of electrospun microfibers influenced by Lorentz force, which moves along helix pattern. Lastly, the build-up microfiber modeling describes the accumulation of the extruded microfibers on flat and round counter electrodes based on physical forces. These models are verified by experimental data from our own customized melt electrospinning setup. Moreover, the fabricated scaffold is tested by seeding neural progenitors derived from murine R1 embryonic stem cell lines and it demonstrates the potential of scaffolds for tissue engineering applications. To increase cell attachment and proliferation, highly porous microfibers are fabricated by combination of melt electrospinning and particular leaching technique. Finally, auxetic stretchable PCL force sensors are fabricated by melt electrospinning for hand rehabilitation. These stretchable sensors can be manageable by applied external loads or strain and also be attachable on the desired substrate. We have attempted the sensors working on real human hand and proved them working properly.

Awards, Scholarships, Fellowships

2014 June 7th	Podium Presentation Awards at Canadian Biomaterials Society (CBS) conference in Halifax, Nova Scotia
2013 Dec. 6th	Best Teaching Assistant Nominee from Department of Mechanical Engineering in University of Victoria
2013 Aug. 5th	Korean Canadian Scientists' Scholarship Foundation (KCSSF)
2013 April 4th	3rd and 4th Prizes in UTÝB TURKISH TEXTILE AND CLOTHING SECTOR INTERNATIONAL R&D BROKERAGE EVENT PROGRAMME
2012 – 2013	Fellowship, University of Victoria
2011 – 2012	Fellowship, University of Victoria
2009 – 2010	Fellowship, Graduate award, University of Victoria

Presentations

1. **Junghyuk Ko,** Jason K. Lee**,** Patrick C. Lee, and Martin B.G. Jun, Production and Characterization of Coaxial Microfibers with Different Molecular Weight Using Melt Electrospinning Technique, 2015, submitted to 10th International Conference on Micro Manufacturing (ICOMM), Milan, Italy.
2. **Junghyuk Ko**, Seungwon Jun, Martin B.G. Jun, 3D mathematical modeling and fabrication of tubular scaffolds for vascular tissue engineering using melt electrospinning, 2014, International Conference on Biofabrication, Pohang, Korea.
3. **Junghyuk Ko** and Martin B.G. Jun, 3D modeling of melt electrospinning process, 2014, 3rd International Conference on Electrospinning, San Francisco, California, USA.
4. **Junghyuk Ko**, Yonghyun Cho, Sukhwinder Bhullar, and Martin B.G. Jun, "Fabrication and Characterization of Novel Stretchable Force Sensor Using Melt Electrospinning", 2014, 9th International Conference on Micro Manufacturing (ICOMM), Nanyang Technological University, Singapore.
5. **Junghyuk Ko**, Hanbin Choi, and Martin B.G. Jun, Electrospinning: the Hybrid Methods in Achieving the Optimal Scaffolds for Cell Growth, 2013, Canada-Korea Young Generation Conference (CKYGC), Toronto, Ontario, Canada.
6. **Junghyuk Ko**, Nima K. Mohtaram, Patrick C.D. Lee, Stephanie M. Willerth, Martin B.G. Jun, Parametric Studies of Melt Electrospinning Poly ε (caprolactone) Fibers for Tissue Engineering Applications, 8th International Conference on Micro Manufacturing (ICOMM) 2013, University of Victoria, BC, Canada.

7. **Junghyuk Ko**, Nima K. Mohtaram, Stephanie M. Willerth, and Martin B.G. Jun, Electrospinning of Nonaligned and Aligned Polycaprolactone Fibers For Tissue Engineering, 7th International Conference on Micro Manufacturing (ICOMM) 2012, Northwestern University, IL, USA.
8. **Junghyuk Ko**, Gabriele Gilardi, Edmund Haslam, Martin B. Jun, Edward J. Park, 2010, Fuzzy PID controller for artificial finger using shape memory alloy (SMA) actuator, CSME, V2.56.8 – Rev. 1182.

Publications

1. **Junghyuk Ko**, Nima Khadem Mohtaram, Patrick C.D. Lee, Stephanie M. Willerth, and Martin B.G. Jun, Mathematical model for predicting topographical properties of poly (ε-caprolactone) melt electrospun scaffolds in various temperature and linear transitional speed, 2014, submitted to Journal of Micromechanics and Microengineering.
2. **Junghyuk Ko**, Sukhwinder Bhullar, Yonghyun Cho, Martin Byung-Guk Jun, Design and Fabrication of Auxetic Stretchable Force Sensor for Hand Rehabilitation, 2014, submitted to Journal of Sensors and Actuator A.
3. **Junghyuk Ko**, Dayun Kan, and Martin B.G. Jun, "Enhanced cell attachments on scaffolds using melt electrospinning and particular leaching for tissue engineering applications", 2014, Journal of Manufacturing letters, MFGLET-D-14-00034R1.
4. **Junghyuk Ko**, Sukhwinder Bhullar, Nima Khadem Mohtaram, Stephanie M. Willerth, and Martin B.G. Jun, Controlling Topographical Properties of Poly (ε-caprolactone) Melt Electrospun Scaffolds through Mathematical Modeling, 2014, Journal of Micromechanics and Microengineering, 24(6), doi:10.1088/0960-1317/24/6/065009.
5. S K Bhullar, **J Ko**, F Ahmed and MBG Jun, Design and fabrication of stent with negative Poisson's ratio, 2014, International Journal of Mechanical, Industrial Science and Engineering, **8**(2), p. 2538-2544.
6. **Junghyuk Ko**, Nima Khadem Mohtaram, Farid Ahmed, Amy Montgomery, Michael Carlson, Patrick C.D. Lee, Stephanie M. Willerth, Martin B.G. Jun, Fabrication of poly (ε-caprolactone) microfibers scaffolds with varying topography and mechanical properties for stem cell-based tissue engineering application, 2014, Journal of Biomaterials Science Polymer Edition, **25**(1), p. 1-17.
7. **Junghyuk Ko**, Kathleen Kolehmainen, Farid Ahmed, Martin B.G. Jun, Stephanie M. Willerth, 2012, Towards high throughput tissue engineering: development of chitosan-calcium phosphate scaffolds for engineering bone tissue from embryonic stem cell, Am J Stem Cell, Vol.1(1), pp 81-89.
8. **Junghyuk Ko**, Martin B. Jun, Gabriele Gilardi, Edmund Haslam, Edward J. Park, 2011, Fuzzy PWM-PID control of cocontracing antagonistic shape memory alloy muscle pairs in an artificial finger, Mechatronics, Vol. 21(7), pp. 1190-1202.