Effect of fiber on the fracture strength of implant-cement interfaces

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Abstract:
The interfacial mechanics at the implant-cement interfaces is a critical issue for implant fixation and the filling of tissue defects created by disease. Early loosening and failure of implants have been issues in medical field today. Electrospinning is a process by which fibers with sub-micron diameters can be obtained from an electrostatically driven jet of polymer solution. These fibers have a high surface area to volume ratio, which have numerous interface tissue engineering applications. The present study is based on the hypothesis that the differences of the surface properties at titanium/cement interface due to incorporation of micro and sub-micron diameters fiber may have significant influence on the quality of titanium/cement union. The objectives of this research is to design and construct electrospinning unit for the fabrication unidirectional and bidirectional Polyacrylate fibre (PCL) fiber and to measure the interface fracture strengths of sandwiched titanium and cement samples with uni- and bi-directional fibers at the interface under tension, shear and mixed load. The new objectives is to then apply the fibers on a titanium rod and test the strength under cyclic loading. Both uni- and bi- direction fibers were collected on carbon tape and Ti for Scanning electron microscope (SEM) imaging of the fibers and interface fracture experiments, respectively. Titanium (Ti) and poly methyl methacrylate (PMMA) cement sandwiched specimen were prepared. The tension, shear and mixed tests were conducted on Ti/PMMA using Evex tensile test system. The experiment found that the interface fracture toughness of all different kinds of sandwiched Ti/PMMA samples with fibers was significantly higher than the respective sandwiched Ti/PMMA samples without fibers.

Background:
Electrospinning is the process of producing fibers in the range of micro to nano scale using polymer solution [1]. These micro to nano fibers from the electrospinning has many applications in a diverse range of fields, such as biomedical engineering, filtration, electrical engineering, and optics [2]. In the biomedical field, the studies of joint replacement show that loosening of the implant from the bone-cement is the first mechanical event of loosening [3]. Loosening can occur due to unsustainable interface stresses, usually initiated from defects along the interface [4]. The use of the electrospun fiber in the field of biomedical industry has been increasing rapidly recently. The fibers are being used in the medical field for improving surface properties of implants [5]. In this study, experiment was performed to analyze the differences of the surface properties at titanium/cement interface due to incorporation of micro and sub-micron diameters. This study hypothesized that fiber pattern and loading directions may have significant influence on the quality of titanium/cement union.

Materials and Methods:
Design and manufacture of the setup:
PCL fiber was used because of ease of fiber fabrication, biocompatibility and cost. PCL beads were dissolved in acetone with concentrations varying from 6-15 wt.% using sonicator. The sonication process was carried out at approximately 80°C for 5 hours. Viscosity of the solution was measured using Malvern CVO rheometer to record wt% of PCL and viscosity ratio.

To produce unidirectional aligned fiber, vertical drum extraction method was used. Fig 1 shows the vertical setup for the electrospinning process. The distance between the syringe needle and the collector was fixed at 20 cm. However, the speed and the applied voltage was changed to obtain the fine fiber. A DC motor was mounted on a Newport linear stage and the motion of stage was controlled by Newport actuator and motion controller. Fig 2 shows the unidirectional fiber on the titanium plate collected during the experiment.

Experiment Design Process:
Fig. 4 shows the flowchart of the experiment design process to evaluate the objectives:

Future Testing:
The next step for testing, currently underway, is the cyclic loading test using the pull-out method. This is the same idea as the sandwiched samples only applied to a cylindrical rod tested under fatigue loading on a test machine in tensile/compression tester. The fatigue test is performed on both fibreless and fibre specimens. With the fatigue pull-out method a system had to be developed in order to conduct the test in a simple and efficient way. This was accomplished by making the mechanism in Fig 5. The mechanism allowed for two obstacles to be overcome at once. The first being a way to vertically fix the rod while curing took place while the second obstacle was to keep the fixed rod vertical while applying the required load for curing.

Results:
The relation between wt% of PCL in fiber solution and viscosity of the sonicated solution is shown in Fig 6. There is an increase of viscosity was found with the increase of wt% of PCL in the polymer solution. Uni-and bi-direction PCL fibers were successfully produced using the electrospun unit as shown in Fig 7. Diameter of produced fibers was found to be in the range of 919 nm - 1.56 μm as shown in Fig 6.

Conclusion:
Both unidirectional and bidirectional fibers were successfully produced using the fabricated electrospin unit. Several Ti/cement were prepared to measure the effect of loading and fiber pattern on interface fracture toughness with and without fibers. The data shows that shear loading has higher influence on interface bonding of Ti/PMMA samples to compare sample under mixed and tensile loading. Similarly, Ti/PMMA samples with unidirectional fiber has higher interface bonding strength compare to samples without fibers. Test are continuing for effects of fatigue stress on titanium/PMMA both with and without fibers.

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