INNOVATIVE ELECTROSPUN BIOMIMETIC MYOTENDINOUS-INSPIRED JUNCTIONS FOR SOFT ROBOTIC APPLICATIONS

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Introduction

The skeletal muscle can be considered the best actuator in nature. Aiming to reproduce its performances with artificial muscles, in the last years soft-robotics has received significant attention from the scientific community [1]. Among the several techniques to produce biomimetic fibrous muscle-inspired soft-actuators and scaffolds, electrospinning, working at the nanoscale, is one of the most promising [1, 2]. However, a problematic challenge is how to attach these fibrous actuators to the joints they will have to actuate, minimizing stress concentrations. Nature has developed sophisticated conical junctions to connect muscles to their tendons, called myotendinous junctions (MTJ) [3]. The aim of the study is to develop electrospun MTJ of Nylon 6.6 (tendon side) (NY) and polyurethane (muscle side) (PU) with different geometries, investigating their structure via SEM and micro-CT and evaluating their mechanical performances during tensile and fatigue tests.

Methods

Mats of aligned nanofibers were produced on a high-speed rotating drum collector [4] by firstly electrospinning NY, covering with paper masks (triangular for conical MTJ-like junctions and rectangular for flat ones [3]) the areas not to be further covered with electrospun nanofibers, then electrospinning PU. The mats were then rolled into bundles and removed from the collector, obtaining bi-material bundles with junctions of different geometries. In addition, to study the performances of the pure materials, bundles of pure NY or PU were produced and tested. Bundles morphology was investigated via SEM and micro-CT. Mechanical properties of the bi-material and pure bundles were investigated via a tensile test. For the bi-material bundles, the NY part was placed on dedicated capstan grips while the PU part was kept in the middle of the gauge length. Then a monotonic ramp in displacement control at 0.33 %/s of strain rate was applied till breakage for all the fabricated materials (n=5 for each category). Subsequently, for each bundle type (n=5 for each cathegory), a fatigue test with a frequency of 1 Hz in displacement control was performed, cycling inside the linear region identified with the results of the tensile tests. Specifically, 10 packages of 10000 cycles were performed for a total of 100000 cycles. After each package, the specimens were fully unloaded at 0 N and reloaded.

Results & Discussion

The SEM investigation of NY and PU nanofibers showed a morphology similar to tendon collagen fibrils (NY) and muscle fibers (PU). The micro-CT investigation revealed an MTJ-like morphology for conical junctions, while the SEM showed progressive layers of overlap of NY and PU nanofibers along the junctions. As shown in Fig. 1, the mechanical properties of pure NY bundles showed an elastic-brittle behavior, while the pure PU a ductile one with an extensive non-linear toe region. Both the bi-material bundles showed a ductile PU-like behavior: the one with conical junction showed an extended toe-region and a stiffer linear region, combining the most distinctive features of both materials. The fatigue tests showed a progressive stiffening of pure NY and a progressive decay of force of the pure PU as the cycles increase. The bi-material bundles showed intermediate values of between the two pure materials. Moreover, the bundles with the conical junctions showed a slower force decay compared to the flat ones. These results suggest the ability of the conical junctions to reduce the stress concentrations as the MTJ does.

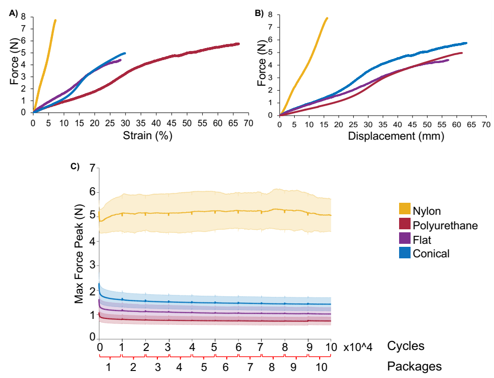

Figure 1: Typical force-strain A), force-displacement B) and mean maximum peaks of force (and SD) for the cyclic tests C) of the different sample categories.

References

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