Mechanical behaviour of implantable electrodes

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Abstract

A team of materials scientists is supporting the development of Networked Implantable Neuroprostheses (NNPS) Systems on an NIH-Bioengineering Research Partnership. The Materials Group is leading the material and structural evaluation, analysis, and testing of implantable electrodes and interconnects that form part of the NNPS. Currently the potential use of silver cored Drawn Filled Tube (DFT) cables as electrodes is being investigated. The response of various configurations of the DFT cables to static and cyclic mechanical loading imposed during long-term implantation is being studied. DFT cables with 25% and 41% silver core with various cable configurations (1x7, 1x19, 7x7, 7x19) have been tested. Monotonic tensile tests were performed and the fracture surfaces of the cables were observed under scanning electron microscope to reveal the fracture mechanisms involved. Fully reversed cyclic tests of the cables were conducted in a flex tester under various strain loading conditions in order to determine the fatigue behaviour of the cables both in the low cycle and high cycle regime. The fatigue behaviour of the cables was modelled using the Coffin-Manson-Basquin relationship.

1 Introduction

A team of materials scientists at CWRU is supporting the development of Networked Implantable Neuroprostheses (NNPS) Systems on an NIH-Bioengineering Research Partnership. The Materials Group is leading the material and structural evaluation, analysis, and testing of implantable electrodes and interconnects that form part of the NNPS. These implantable electrodes are constructed from small diameter wires in order to develop systems for restoration of extremity function in patients with spinal cord injuries [1,2]. The electrodes in totally implantable functional electrical stimulation (FES) systems must be reliable and withstand both static and cyclic loading for long durations. In order to understand the factors affecting the performance of such implantable electrodes, the tensile and fatigue properties must be characterized on representative cables of candidate materials. This work is part of a larger study investigating the cyclic bending fatigue behaviour of a range of different candidate materials for use in next generation FES systems.

2 Methods

In this study, the response of 316LVM and Drawn Filled Tube (DFT) cables (Fort Wayne Metals, Fort Wayne, IN) to static and cyclic mechanical loading was evaluated. 316LVM cable with 1x7 configuration and DFT cables with 25%, 28% and 41% silver core with four different cable configurations viz. 1x7, 1x19, 7x7 and 7x19 were examined. Monotonic tensile tests were performed to failure using a 25 mm span with displacement rate of 0.5 mm/min. Yield stress and UTS were measured from the load- displacement data. True fracture stress (σ_f) and true fracture strain (ε_f) were obtained from the fracture surface.

Fully reversed strain controlled flexural fatigue tests were carried out using a Flex tester. In a flex tester the cable sample is placed between identically-sized mandrels of chosen dimensions. Reciprocal movements (1Hz) of the mandrels produce a well-defined radius of curvature to the cable, and hence definite strain amplitude. A break detector connected to the sample shuts off the machine when a current/voltage break is detected. A small dead load (84 gms) is used to keep the sample from wandering off the mandrels. Multiple tests were conducted using mandrel diameters ranging from 1mm to 19mm. Fracture surfaces of the cables were observed under a scanning electron microscope (SEM) to reveal the fracture mechanisms involved. The fatigue behaviour of the cables was modelled using the Coffin-Manson-Basquin relationship [3].

3 Results

Tensile test results are shown in Table 1. In spite of differences in the configuration of the five 41% Ag DFT cables, their ultimate tensile stresses were found to be similar. As expected, lower the silver content higher the UTS. The true fracture strain of the DFT cables were quite less than that of 316LVM 1x7 cable.

ID	Wire dia (mm)	UTS (MPa)	σ_f (MPa)	ε_f
1x7 DFT 41%Ag	0.038	1148	1660	0.37
7x7 DFT 41%Ag	0.046	1068	1596	0.40
7x19 DFT 41%Ag	0.036	1111	1268	0.13
1x7 DFT 25%Ag	0.063	1643	2678	0.49
1x19 DFT 25%Ag	0.036	1655	2913	0.57
1x7 316LVM	0.034	1239	5407	2.29

Table 1 Tensile properties of cables

Under flexural fatigue, the cycles to failure increased with an increase in the mandrel diameter (decrease in cyclic strain range) for all the cables tested (Figure 1). The data points with an arrow indicate that the specimen did not fail after the number of cycles listed.

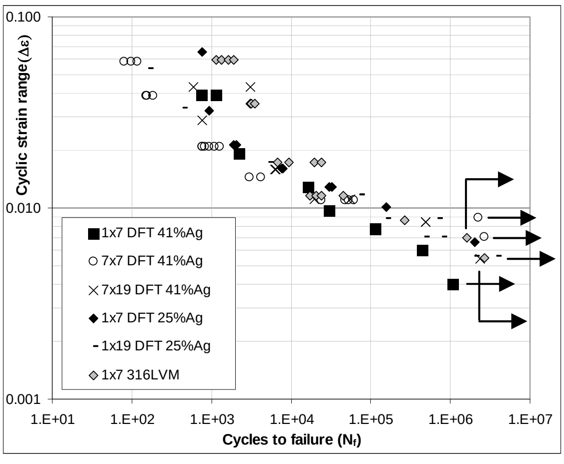
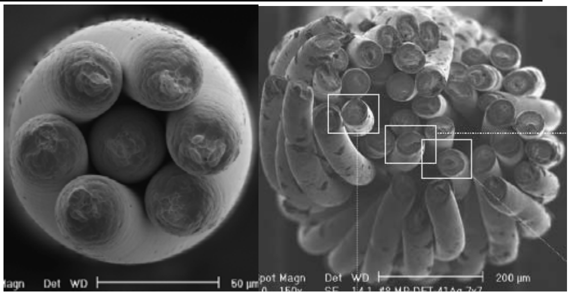
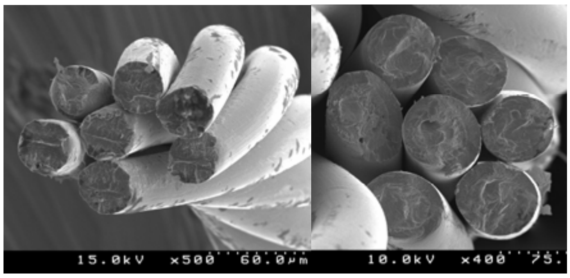


Figure 1 Strain life behaviour of cables



1x7 316LVM 7x7 DFT 41%Ag

Figure 2 Fracture surface of cables tested under tension



1x7 316LVM 7x7 DFT 41%Ag

Figure 3 Fracture surface of cables tested under flexural fatigue

The fracture surface of each individual wire in the 316LVM cable tested under tension exhibited similar features, with extremely high reduction in area (e.g. ~ 90%) and a dimpled fracture surface (Figure 2). However the DFT wires exhibited flatter fracture surface (Figure 2). In 316LVM cable fatigue fracture initiated at the top and bottom of each wire and then propagated towards the center of each wire producing catastrophic fracture (Figure 3). However no such phenomenon was evident in the DFT cables (Figure 3).

4 Discussion and Conclusions

For clinical applications high cycle fatigue regime is of interest. Based on the performance in the high cycle fatigue regime the cables tested are ranked using Coffin-Manson-Basquin relationship. The ranking of cables according to Mandrel radius (mr) vs. Cycles to failure (N_f) and Cyclic strain range ($\Delta\varepsilon$) vs. N_f is shown in Table 2.

ID	Rank	
	mr vs N_f	**$\Delta\varepsilon$ vs N_f**
1x7 DFT 41%Ag	5	6
7x7 DFT 41%Ag	4	1
7x19 DFT 41%Ag	2	5
1x7 DFT 25%Ag	6	2
1x19 DFT 25%Ag	1	4
1x7 316LVM	3	3

Table 2 Ranking of cables according to Mandrel radius (mr) vs Cycles to failure (N_f) and Cyclic strain range ($\Delta\varepsilon$) vs N_f

References

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