Mechanical Behavior of Implantable Conducting Cables

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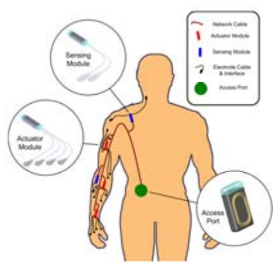
ABSTRACT

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 leadwires and interconnects that form part of the NNPS. Currently the potential use of silver cored Drawn Filled Tube (DFT) cables as leadwires 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. Silver cored MP35N wires with 25%, 28% and 41% silver 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 behavior of the cables both in the low cycle and high cycle regime. The fatigue behavior of the cables was modeled using the Coffin-Manson relationship. The effect of changes in mean stress on the fatigue behavior of the cables was also investigated.

SCHEMATIC OF NNPS CONCEPT



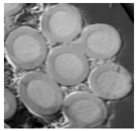
MATERIALS

316 LVM wire

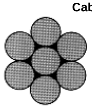
- Low carbon (0.023%) stainless steel
- Vacuum Arc Remelted

Drawn Filled Tube (DFT™) wire

- Metal-to-Metal composite
- Silver core(25%, 28%, 41% Ag)
- MP35N(Co-Ni-Cr-Mo alloy) tube



Cable configurations



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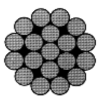

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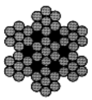


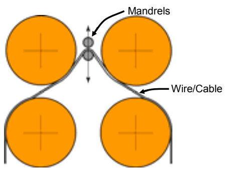
7 X 7

7 X 19

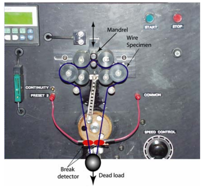
METHODS

1. **Tensile test**
   - Instron 1130 Screw driven machine with MTS controller
   - Specimen gage length : 25mm
   - Loading rate : 0.5 mm/min
   - High speed data acquisition system to determine fracture load
   - True fracture stress and strain obtined from fracture surface

2. **Fatigue Test (Cyclic strain effects)**

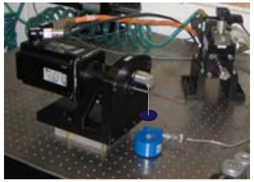


Cables are tested in cyclic fatigue via bending over a mandrel. Mandrel radius controls stress and strain experienced by electrodes/wires.



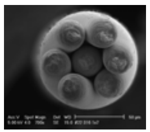
Flex tester used to conduct cyclic fatigue tests on electrodes/wires. Cyclic frequency < 5 Hz. Break detector automatically detects failure and stops cycle counter.

3. **Fatigue Test (Mean stress effects)**

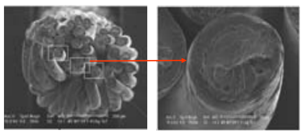


- ENDURATEC work bench machine
- 140° flex at 4Hz
- 0.25 in diameter mandrel
- Loads: 0.25 to 5N

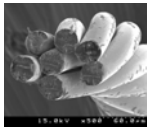
4. **Fractography**
   - Philips XL30 ESEM operated at 5Kv



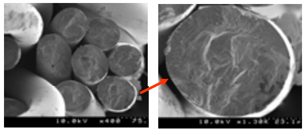
1x7 316LVM - Tension



7x7 DFT 41%Ag - Tension



1x7 316LVM - Fatigue



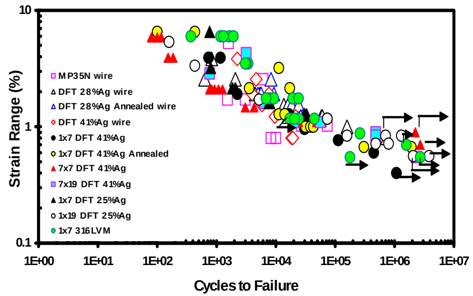
7x7 DFT 41%Ag - Fatigue

RESULTS

1. **Tensile test**

	ID	Wire dia (mm)	Cable dia (mm)	Yield stress (MPa)	UTS (MPa)	Reduction in area (%)	True fracture stress (MPa)	True fracture strain (MPa)
1	MP35N wire	0.0508	0.0508	1492	1844	85.43	12656	1.93
2	DFT 28%Ag wire	0.0762	0.0762	1336	1424	14.11	1658	0.15
3	DFT 28%Ag wire Annealed	0.0762	0.0762	732	936	46.58	1753	0.63
4	DFT 41%Ag wire	0.0762	0.0762	1239	1395	34.39	2126	0.42
5	1x7 DFT 41%Ag	0.0381	0.1143	1109	1148	30.82	1660	0.37
6	1x7 DFT 41%Ag Annealed	0.0635	0.1905	702	863	47.76	1652	0.65
7	7x7 DFT 41%Ag	0.0457	0.4115	1051	1068	33.08	1596	0.40
8	7x19 DFT 41%Ag	0.0356	0.5334	808	1111	12.38	1268	0.13
9	1x7 DFT 25%Ag	0.0635	0.1905	1593	1643	38.63	2678	0.49
10	1x19 DFT 25%Ag	0.0356	0.1778	1627	1655	43.20	2913	0.57
11	1x7 316LVM	0.0343	0.1029	1135	1239	89.90	5407	2.29

2. **Fatigue Test (Cyclic strain effects)**



Data analysis / Modeling

Coffin-Manson relationship

$$\frac{\Delta\varepsilon}{2} = \left(\frac{\sigma_f^{'}}{E}\right)\left(2N_f\right)^b + \varepsilon_f^{'}\left(2N_f\right)^c$$

$\Delta\varepsilon$ - Strain range

σ'_f - Fatigue strength coefficient ~ True fracture stress

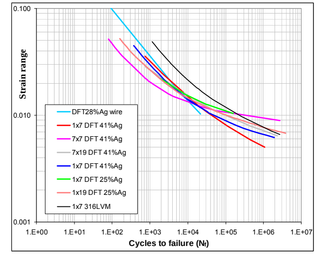
ε'_f - Fatigue ductility coefficient ~ True fracture strain

b - Fatigue strength exponent

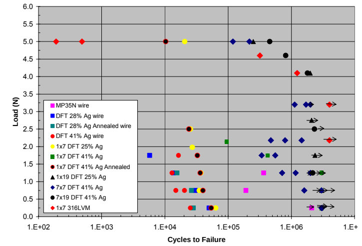
c - Fatigue ductility exponent

E - Elastic modulus

Coffin-Manson analysis



3. **Fatigue Test (Mean stress effects)**



SUMMARY

Fatigue Performance Ranking ($\Delta\varepsilon$ vs N_f)

1. 7x7 DFT 41%Ag
2. 1x7 DFT 25%Ag
3. 1x7 316LVM
4. 1x19 DFT 25%Ag
5. 7x19 DFT 41%Ag
6. 1x7 DFT 41%Ag Annealed
7. 1x7 DFT 41%Ag

Fatigue Performance Ranking (Mandrel size vs N_f)

1. 1x19 DFT 25%Ag
2. 7x19 DFT 41%Ag
3. 1x7 316LVM
4. 7x7 DFT 41%Ag
5. 1x7 DFT 41%Ag
6. 1x7 DFT 25%Ag
7. 1x7 DFT 41%Ag Annealed

Fatigue Performance Ranking (Mean stress effects)

1. 1x19 DFT 25%Ag
2. 7x7 DFT 41%Ag
3. 7x19 DFT 41%Ag
4. 1x7 316LVM
5. 1x7 DFT 41%Ag
6. 1x7 DFT 41%Ag Annealed
7. 1x7 DFT 25%Ag

ACKNOWLEDGEMENTS

This research is supported by NIH-NINDS Grant No. NS-041809 and NIH-NIBIB Grant No. EB-001740. Principal Investigator P. Hunter Peckham