High Level Strain Sensors: The first step, a functional electrode.

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Background

One of the main applications of strain gauges are those for small scale monitoring of structure during their lifetime. Large structures that are predominantly made of metal are key to daily functioning of millions of people around the world. In terms of scale monitoring, a small change in their structures can have catastrophic effects. This is where the gauges are used, they are used to measure for small changes in the length in the material that the structure are comprised of. These metals are strong and dependable when functional. Overtime when exposed to harsh environments, they begin the process of fatigue which leads to failure. It is the step of failure which the gauges are being used to watch for and prevent. When using small scales of movement 1-5% values, dependant on resistance levels required, [1] are the standard strain values most are expected to monitor and as such most gauges do not reach above this level as to do would constitute a catastrophic failure. As new materials are being implemented for the construction of these structures the traditional 1-5% ranges are not ideal for continuous monitoring anymore. Therefore there is a need to replace these gauges with more updated strain sensors that have a greater range over movement.

A key to consider when creating these alternative sensors was the environment in which they are being placed. Harsh environments are classed as areas that are subjected to extremes that humans or components would not survive. The dangerous aspects of which are of temperature, chemical, and mechanical stresses. [2,3] For the application that these alternate sensors were designed for is an area that was remote that had limited human access and underwater with a changing force pattern from tidal currents. The primary design these sensors were designed for was to monitor the movement on underwater cable while they are in service. Whether that be in in shallow or deep waters, as such they will be subjected to a constant force from the tide in shallow waters and tidal drift in deep water. This contributes to the low-level strain that is turned into permanent strain over the sensor's lifetime and as such the sensors were designed to strain greater than traditional gauges.

Figure 1 – Saltwater Tank aging experiment set up with four different type of samples.

Methods

The key part of the strain sensor development is the electrode layer. Balancing the level of resistance with the level of strain possible required a fine level of control when mixing components. To achieve that each component needed to be understood, and then carefully controlled when mixing the two parts together. The created an electrode with a low level of Carbon Black powder electrode and a low level of resistance close to that of traditional strain gauges that it is set to replace.

This involved testing the polymer matrix, Ecoflex 00-50, to the 100% strain boundary required, as per ASTM D412, to achieve a confirmed baseline for the material. The conductive filler, Ketjenblack 300-J, a carbon black powder was mixed into the pure Ecoflex, in predetermined weights to achieve the optimal balance between conductivity and strain. Based upon the percolation threshold of the carbon black powder.

The method in which the powder was incorporated is based on treating the powders as inks,[4,5] using Milling, carried out using an EXAKT80E three roll mill, then cast into moulds and allowed to air dry for 24 hours to fully cure.

Results

To date, the most optimal electrode produced is a 6% Powder by weight producing an initial resistance of an average of 1.6K ohms, with 100% strain. That increased to 1200K Ohms after $10^{\wedge 7}$ cycles.

Figure 2 – Close-up of wired electrode sample, corrosion from saltwater exposure on uncoated wire surface.

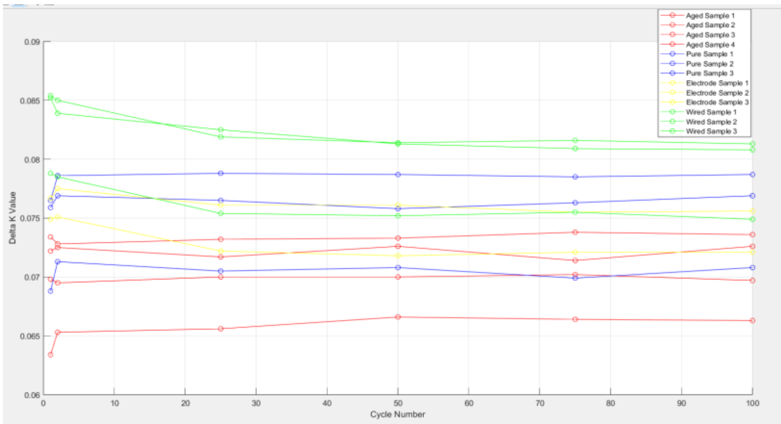

Figure 3 – Post-water Tank aging samples stiffness over 100 cycles.

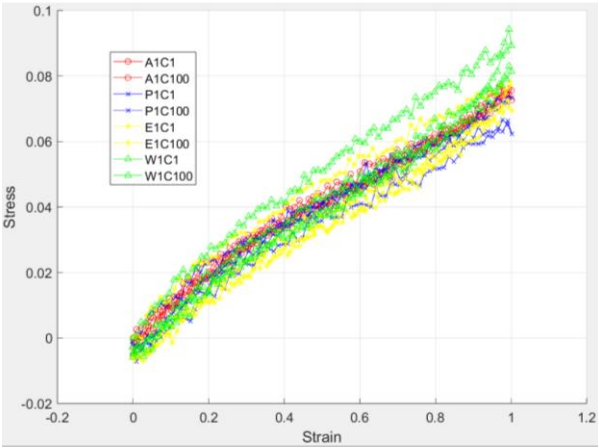

Figure 4 – Stress-Strain Graph of Post-water Tank aging samples stiffness showing first and last cycle, demonstrating the reduction in material over cycling life post tank submersion.

Electrodes function after tank submersion. They are functional in terms of resistance over the 100 cycles and a further test of 100,000 cycles showed a continued resistance that is steady and showed an increased prior to electrode failure due to sample failure.

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