Sol-Gel Corrosion Sensors

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Introduction

Internal corrosion on the steel inside structures can make the structures dangerous and potentially cause accidents or collapses, such as the collapse of the I-35 Bridge in Minneapolis, MN. In order to avoid such problems, engineers need to find a way to gather information about the health of the structure. Strain sensors can be attached to the outside of structures to detect excessive amounts of load bearing on a particular support. Unfortunately, strain sensors only give information about the outside material. To solve this problem, engineers are developing ways to "see" inside structures with corrosion sensors.

Sol-gel is an amorphous, mechanically stable, porous material that has been found to change its conductivity as a function of the amount of chloride ions it absorbs. When steel corrodes, it gives off an abundance of chloride ions. By absorbing these ions, corrosion sensors can detect when the corrosion has reached an unsafe level by being adhered to the steel beams embedded into the concrete of a structure. The sensors would be wirelessly powered and monitored.

Abstract

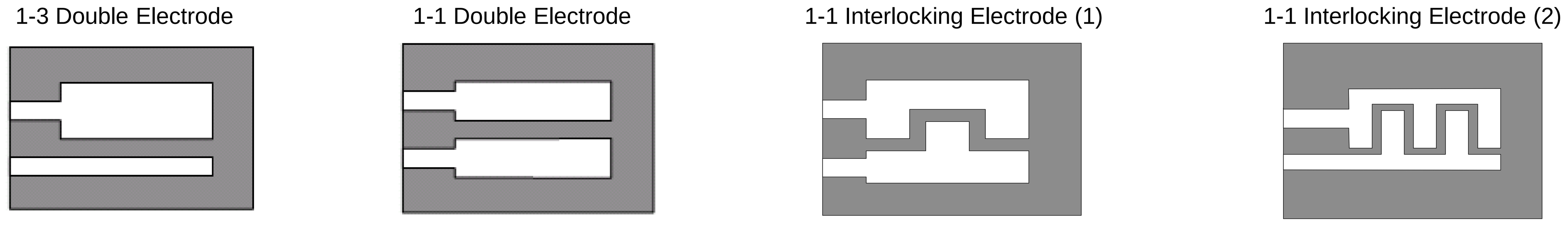
The goals of this project were to design electrodes for the sensors of different geometries to determine the optimal shape, to observe and improve the stability of the sol-gel coating, and to use different methods of coating to obtain a more uniform coating. The sensors were tested to determine the conductivity of the sol-gel as a function of the amount of chloride ions they were exposed to.

This experiment was unable to support previous research with sol-gel and there were obstacles that prevented accurate data such as material deterioration and faulty equipment. The experiment needs an optimal substrate for the sensor and sol-gel needs to be synthesized to be more stable to prevent shrinkage and cracking. Once these few issues can be resolved, a marketable corrosion sensor to monitor the safety of structures is very possible.

Experimental Procedures

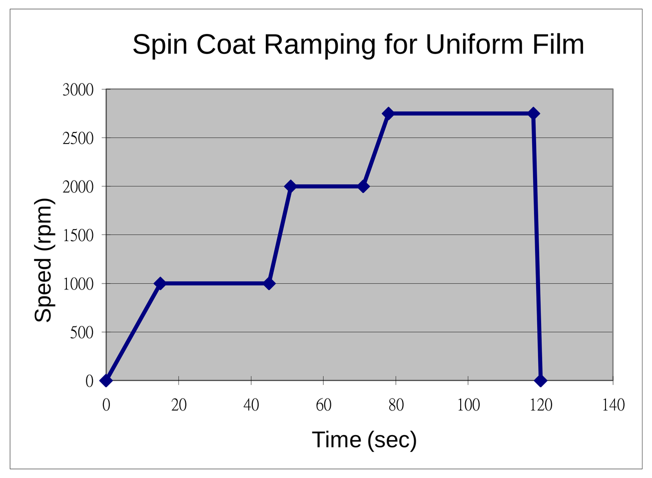
Preparation of Substrates.

- Cleaned with concentrated nitric acid overnight,
- Washed with deionized water
- Dried in an oven at 52^{O}C
- Stencil - printed negative of electrode configurations on paper, cover with double stick tape, cut out and place on substrate
- Sputter Coat with gold palladium and remove stencil



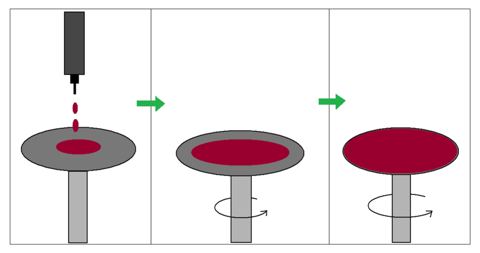
Sol-Gel Synthesis.

- Mix 750 micro liters of deionized water, 0.7011 grams of Tin (IV) Chloride Pentahydrate, and Tetra Methoxy Silane (TMOS) in a polyethylene beaker.
- Sonicate for 20 minutes
- Add 5 micro liters of Polyvinyl Alcohol (PVA) to increase plasticity and avoid cracking



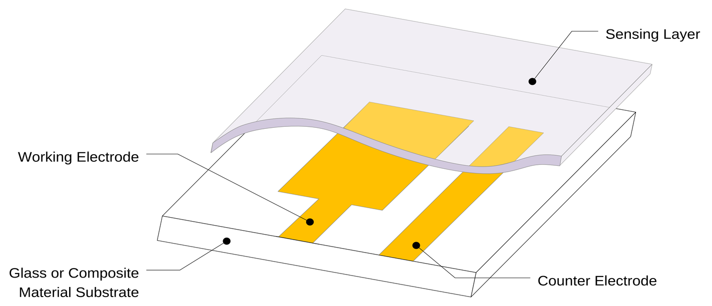
Coating Substrates with Sol-gel

- Dip Coating
  - Used for larger substrates
- Spin Coating
  - Lowest speed spreads sol-gel
  - Increased speed creates uniform coating

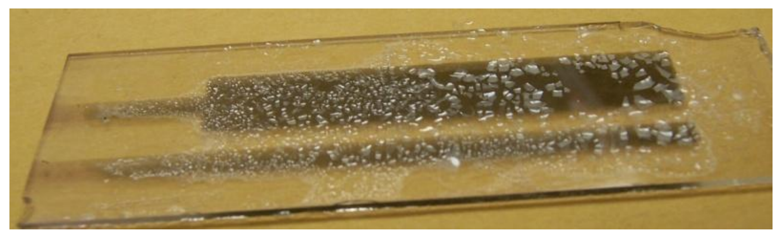


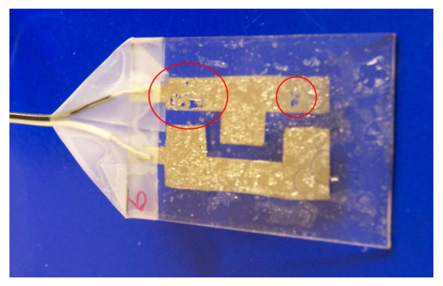
Results and Discussion

Method of Coating	Pros	Cons
Spin	• Thin, Uniform Coating	• Difficult to find optimal ramping speeds • Sol-gel shrunk & cracked
Dip	• Effectively Coated Substrate	• Coating not uniform • Sol-gel shrunk & cracked



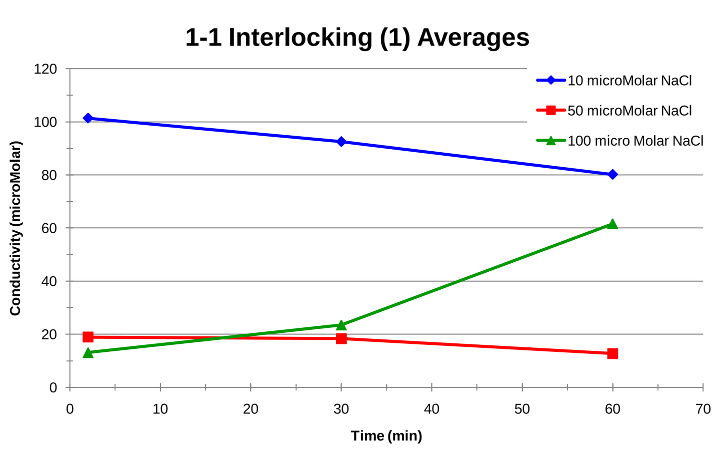
Both types of coating eventually shrunk and cracked, even when more PVA was originally added during the sol-gel synthesis. This cracking is due to sol-gel's general tendency to shrink as it cures and being exposed to the hydrolyzed NaCl could've expanded gaps in the sensor. Water may have gotten between the glass and the sol-gel, breaking the weak bonds between them, thus breaking the sol-gel itself.

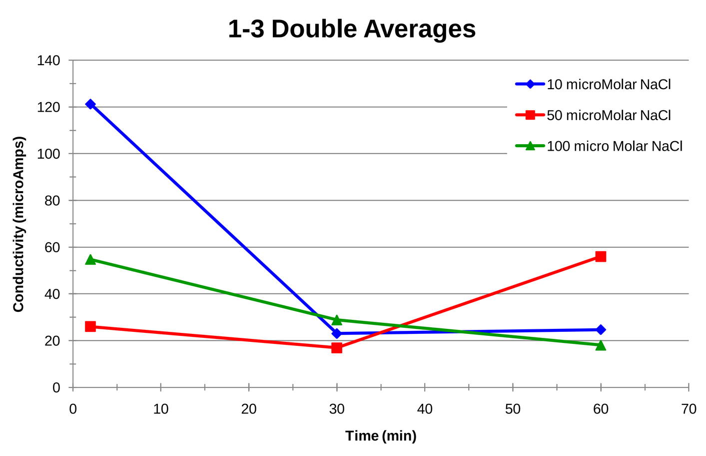


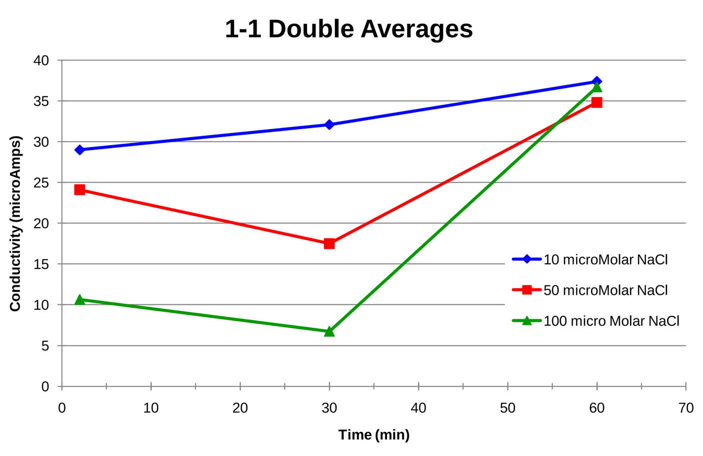


During the coating process, sometimes the sol-gel would wipe parts of the electrode off the glass substrate. Many times the electrode was still intact enough to work and able to give a reading, but other times it was completely nonconductive. Before being used for trials, the conductivity of every electrode was tested. The sol-gel may have excited the gold palladium electrode, breaking the bonds between it and the glass substrate.

A composite material, Glass Fiber-Reinforced Polyurethane, was also tested as a substrate. The gold palladium bonded with it much stronger than the glass substrate. After being coated with sol-gel, the electrode was completely intact and always still conductive. When it cured, if there was still a layer of sol-gel left, it was nearly invisible. The gel was also very easily removed from the composite, making it difficult to test with. Experiments with this substrate are beyond the duration of this stage of the experiment.



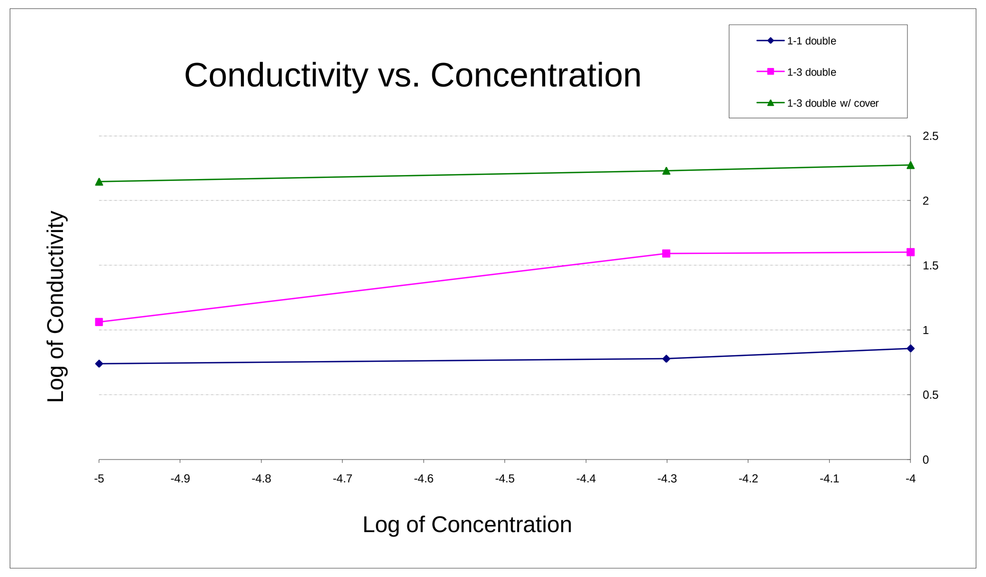


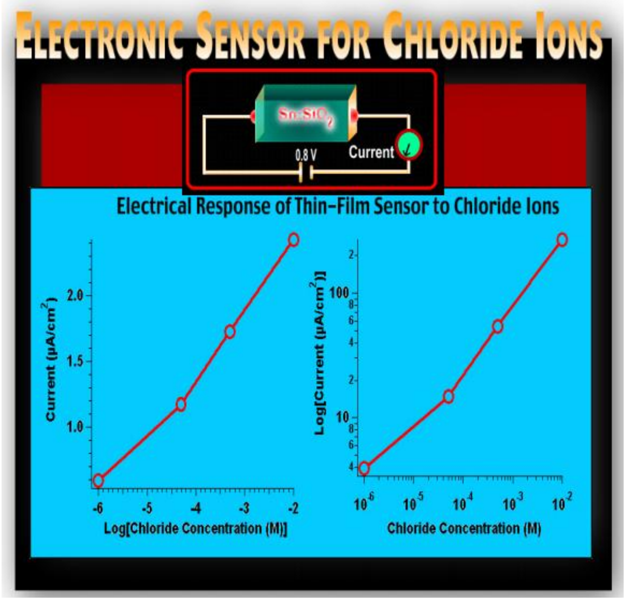


To test the electrodes, they were soaked in three different concentrations of salt water. Conductivity versus time was graphed, but had very scattered results.

The reasons for such scattered data could be due to several reasons. The instrument that was used to take readings was made by the Electrical Engineering Department. It was very erratic and took a while to get a steady reading. The sol-gel was also very prone to shrinkage and cracking and thus, may have affected the conductance of the sensor. Also, when the sol-gel etched away parts of the electrode, though it was still conductive it may have affected the reading.

With so many uncertainties and varying results, it is difficult to determine which electrode configuration worked the best. However, it was concluded that sensors with covers worked much better than those without. Substrate covers prevented the coating from cracking and therefore conductivity through the sol-gel itself was much stronger. Covers also prevented the coating from being over-exposed to the salt water which was found to increase degradation of the coating on uncovered substrates.





Taken from Previous Research Results

In previous experiments, conductivity and concentration were found to be directly proportional. The results from this experiment agreed with precious results, but not nearly as drastically.

Conclusions

Future Experimentation:

- Make Sol-Gel more stable possibly with Carbon Nanotubes
- Find optimal substrate that bonds with electrodes and Sol-Gel
- Determine best electrode configuration
- Substrates with covers that sandwich the sol-gel prevents cracking

This research is in its early stages and once these problems are resolved, the development of a globally marketable corrosion sensor to monitor the health of structures is very promising.

Acknowledgements and References

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