Orthopedic Cast Material Modified for Real Time Monitoring of Stress, Temperature and Water Seepage using Electrical Resistivity

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Abstract: In this study, the effects of stress, temperature and water seepage on the modified orthopedic cast material were investigated. The standard plaster of paris was modified with conductive filler to make it piezoresistive and also sensitive to the temperature and moisture changes. The conductive filler contents in the cast material were varied up to 0.05% by the weight of cast material to enhance the sensing properties of the cast material. Initial Resistivity of cast material without conductive filler was 3.3 Ω-m, while it was 1.46 Ω-m and 0.9 Ω-m with addition of 0.02% and 0.05% percentages of conductive filler. With addition of 0.02% conductive filler, the resistivity change for a maximum peak compressive stress of 890 psi was 256%, while it was about 450% at a peak stress of 950 psi for 0.05% conductive filler addition after 28 days of curing compared t the failure strain of 0.2%. The piezoresistivity to maximum peak compressive stress ratio for 0.02% conductive filler addition was 0.287%/psi while for 0.05% it was 0.47%/psi. The temperature was varied from 65°F to 200°F. The maximum change in resistivity was about 10.4% for a change in temperature from 65°F to 200°F for a 28 day cured specimen. The maximum change in resistivity during water seepage for 60 minutes was about 53% decrease with increase in weight of 1.6%.

1. Introduction:

Plaster of Paris takes its name from Paris, France, where it was first widely used chemically, surgically and in construction works. Plaster of Paris is produced by removing the impurities from the mined gypsum and then heating it under controlled conditions to reduce the amount of water of crystallization. Plaster of Paris was well known as a building material for many centuries before it was introduced as casting material. Egyptians as well as Romans used it for plastering walls however not more is known on plaster use after the end of Roman occupation.[1]

Plaster of Paris ($2CaSO_4.H_2O$) is calcium sulphate with water. It is prepared by heating gypsum ($CaSO_4.2H_2O$) at 120°C to allow partial dehydration. When mixed with water, it gives out heat and quickly sets to a hard porous mass within 5 to 15 minutes. The first step is called the setting stage with a slight expansion in volume. The second stage is the hardening stage.

Stage 1: Plaster of Paris formation

Stage 2: Casting:$2\,(CaSO_4 \cdot \frac{1}{2} H_2O) + 3\,H_2O \rightarrow 2\,(CaSO_4.2H_2O)$ + Heat

Its first documented medical use dates back to 1852 when A. Mathyson, a Dutch Army Surgeon, rubbed powdered plaster into cotton bandages to form splints. The first use of plaster of Paris as a cast for injured limbs took place through a technique known as plâtre coulé that became popular in Europe at the beginning of 19th century [2]. Application of plaster of Paris requires good knowledge of anatomy and pathology that we are aiming to treat. It has to be applied with a great care that is also need in its supervision afterwards. There are a number of complications that relate to long periods of immobilization and include joint stiffness, muscle atrophy, cartilage degradation, ligament weakening, and osteoporosis [3]. Some risks can be minimized with correct Casting Monitoring Technique

2. Objective: The main objective was to quantify the changes in the electrical resistivity for the effect of stress, temperature and water seepage for orthopaedic cast material.

3.Materials and Method:

Commercially available Plaster of Paris (POP) was used for characterizing the cast material. The Plaster of

Paris was modified with conductive fillers to make it a piezoresistive material. The POP was modified by adding upto 0.05% of conductive filler (CF), by weight of the plaster of Paris. The water to plaster ratio used was 0.5. The Plaster of Paris slurries were prepared using hand mixing. First, measured amount of mixing water was poured into the container. Then little amount of conductive fillers were added to the water and then a little amount of POP was mixed to the mixture. Then little by little POP and conductive fillers were gradually added to the container and mixed for about 1 minute so that it could be properly dispersed in the mixing water. After mixing, POP specimens were prepared using cylindrical, molds. The Cylindrical molds are with a diameter of 2 inches and a height of 4 inches.

4.Results and Discussion:

Density

The density of the plaster of Paris samples with and without conductive fillers was about 1.1 g/cc.

Resistivity

Initial Resistivity of cast material without conductive filler was 3.3 Ω-m right after the mixing while it was 1.46 Ω-m and 0.9 Ω-m with 0.02% and 0.05% percentages of conductive filler.

Piezoresistivity

The 0.02% modification produced a piezoresistivity of 256% for a maximum peak compressive stress of 890 psi for 28 days of curing. The 0.05% modification produced a piezoresistivity of 450% for a maximum peak compressive stress of 950 psi for 28 days of curing.

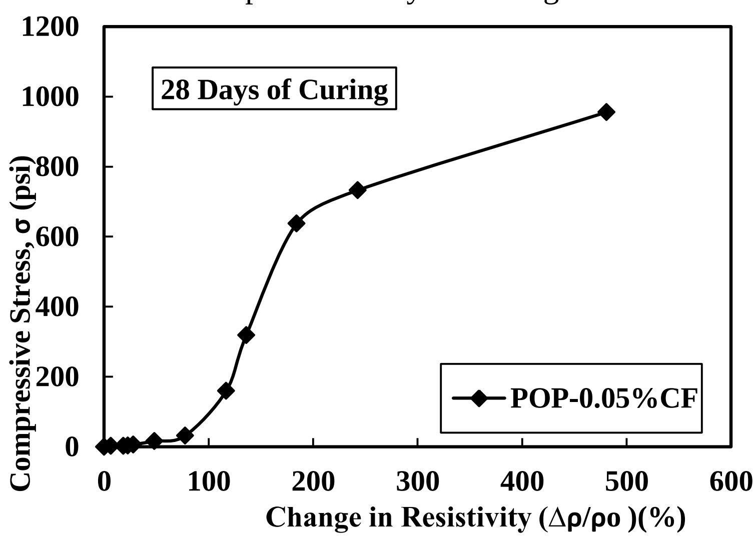
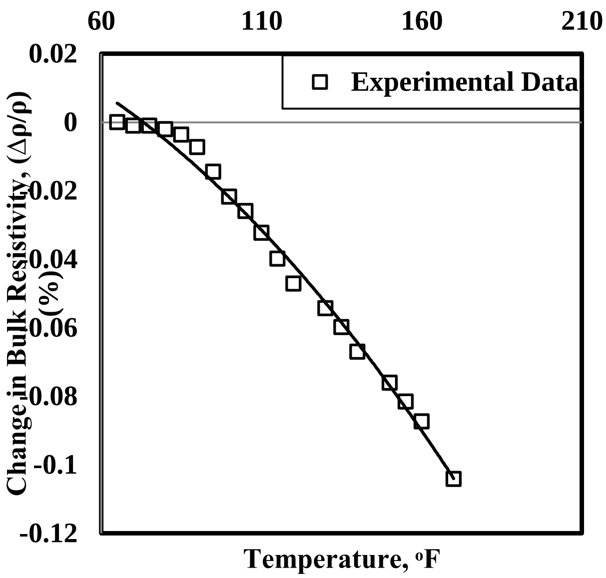


Figure 1.Effect of conductive filler content on Piezoresistivity of POP samples.

The piezoresistivity to maximum peak stress ratio for 0.02% was 0.287%/psi while for 0.05% it was 0.47%/psi. The maximum piezoresistivity to stress was observed in 0.05% conductive filler with 28 days, 64% increase.

Temperature

The POP sample is placed in the oven for a temperature cycle of 65°F to 200°F and then taken back to room temperature (65°F). The rate of change of resistivity was near to linear for POP sample. The maximum change in resistivity was about 10.4% for a change in temperature from 65°F to 200°F. (Fig. 2)



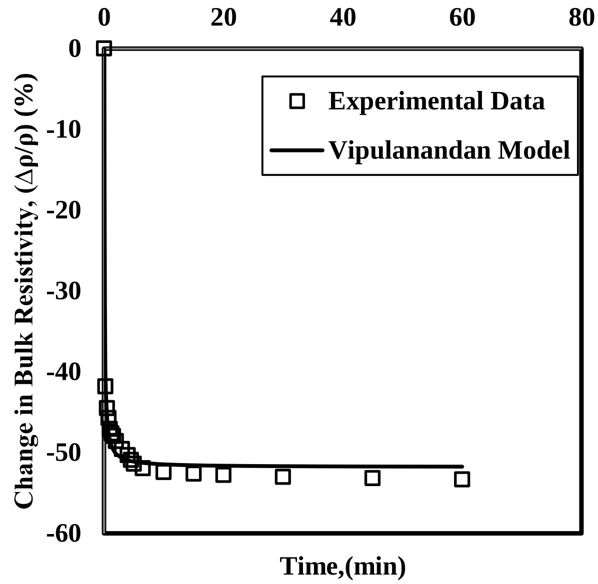


Figure 2.Change in Resistivity with temperature change for POP sample with 0.05% CF.

Figure 3. Resistivity change with water seepage for POP specimen with 0.05% CF.

Water Seepage

POP Cylindrical samples were placed in water to observe the change in resistivity within the first one hour. The resistivity was found to decrease as water seeps into the sample. The maximum change in the resistivity for water seepage was about 53% decrease. (Fig. 3)

5. Conclusion:

The 0.05% modification produced a piezoresistivity of 450% for a maximum peak compressive stress of 950 psi after 28 days of curing. The electrical resistivity decreased with temperature increasing. The maximum change in resistivity was about 10.4% for a change in temperature from 65°F to 200°F. The maximum change in the resistivity for water seepage was about 53% decrease.

6. Acknowledgements:

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7. References:

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