Orthopedic Cast Material Modified for Real Time Monitoring of Mechanical Stress Changes

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Abstract: In this study, the effects of stresses on the modified cast material were investigated. The standard cast material (plaster of Paris) was modified with 0.05% conductive filler to make it piezoresistive. The hollow cylindrical specimens were made with modified cast material and were tested under compressive and tensile stresses after 7 days of curing. The density of the modified cast material after 7 days of curing was 1.27 g/cc, 36% less compared to class H cement (2 g/cc). The initial resistivity of the cast material reduced from 3.29 Ω-m to 0.89 Ω-m with addition of 0.05% conductive filler. The change in resistivity with the application of stress was monitored for the modified cast material. With the addition of 0.05% conductive filler, the resistivity change for a maximum peak compressive stress of 608 psi was 190%, while it was about 90% at a peak tensile stress of 85 psi after 7 days of curing compared to the failure strain of 3.7% in compression. The modulus of elasticity of the modified cast material was 112.7 MPa.

1. Introduction:

A cast is a supportive material that surrounds an injured body part to protect, immobilize and promote healing. Casts can also be used to treat and help to correct certain congenital deformities such as clubfoot, hip displacement and spinal deformities. Plaster of Paris or Gypsum is one of the most frequently used casting material two possible reasons – Ready availability and Cheap Material. Plaster of Paris was first widely used chemically, surgically and in construction works in Paris, France. 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. [1]

Plaster of Paris is chemically represented as calcium sulphate with water ($2CaSO_4.H_2O$). 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 solidifies within 5 to 15 minutes. The stage 1 is called the setting stage with a slight expansion in volume. The stage 2 is the solidification.

Stage 1: Plaster of Paris formation

Stage 2: Solidification- $2\,(CaSO_4\cdot\frac{1}{2}\,H_2O) + 3\,H_2O \rightarrow 2\,(CaSO_4.2H_2O)$ + 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].

Plaster is the traditional material used for casting. It is considered the most versatile of the splinting materials, is completely moldable and can withstand considerable forces. One of the important downside of this cast could be its hardening via an exothermic process. In some cases, these exothermic processes can cause temperatures to rise to dangerous levels that can risk thermal injury. Other disadvantages include high water permeability and setting times. A rather large concern regarding the use of cast material is to assess the injury beneath cast. There are common complications that could occur due to poor plastering techniques. Currently there is no technique to access the actual condition of casting in real time [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 compressive and tensile stress for 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 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 by adding POP in stages into the water. After mixing, POP specimens were prepared using cylindrical hollow molds. The Cylindrical hollow molds have internal diameter of 0.79 inch, outer diameter of 2 inches and a height of 4 inches.

The compression and tensile tests were performed using universal compression testing machine. The compression tests were performed according to ASTM C39 while for tensile test, the procedure of Brazilian tensile testing (splitting tensioning test) was used according to ASTM C496.

4. Results and Discussion:

Density

The density of the POP samples with and without conductive fillers was about 1.27 g/cc after 7 days of curing indicating existence of high porosity.

Resistivity

Initial resistivity of cast material without conductive filler was 3.29 Ω-m immediately after mixing while it was 0.89 Ω-m with 0.05% of conductive filler.

Compressive Stress

With the addition of 0.05% conductive filler, the resistivity change for a maximum peak compressive stress of 608 psi was 190% after 7 days of curing compared to the failure strain of 3.7% in compression. (Figure 1(a) & (b))

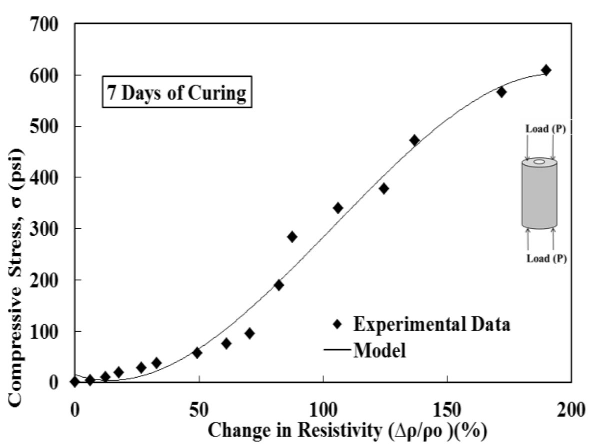

Figure 1(a): Change in resistivity with compressive Stress for modified cast material after 7 days.

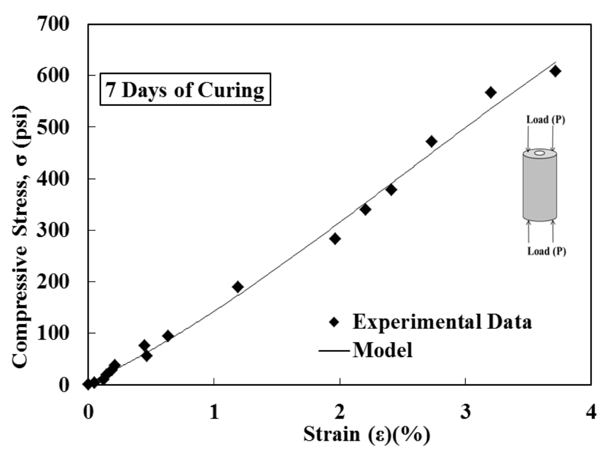

Figure 1(b): Compressive stress vs strain for modified cast material after 7 days curing.

Modulus of Elasticity

The modulus of elasticity of modified cast material was 112.7 MPa, 220 times less compared to modulus of concrete of 25 GPa. (Figure 1(b))

Tensile Stress

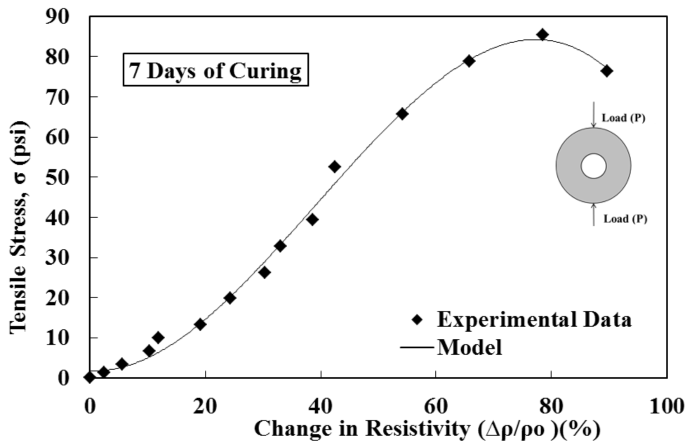

Figure 2: Change in resistivity with tensile stress in modified cast material.

The change in resistivity for the hollow cylindrical samples under tensile loading was 90% at a peak tensile stress of 85 psi after 7 days of curing. (Figure 2)

5. Conclusion:

The 0.05% modification produced a change in resistivity of 190% for a maximum peak compressive stress of 608 psi while the change in resistivity under peak tensile stress of 85 psi was 90% after 7 days of curing. The failure strain in compression was 3.7% due to high porosity presence in the structure. The modulus of elasticity of modified cast material was 112.7 MPa, 220 times less compared to modulus of concrete of 25 GPa.

6. Acknowledgements:

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7. References:

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