Electrical Impedance Comparison between Solidification Cement and Bones

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Abstract: In this study, impedance spectroscopy (IS) was used to compare cement solid (water-to-cement ratio 0.4) and animal bone. Both before and after exposure to 1% Nitric Acid, using IS with a two-probe measuring system, the contact resistances were found to be relatively small compared to the bulk resistances. The study found that bones have much higher bulk resistance than cement paste, and both materials exhibit a decrease in resistance while increasing in density when exposed to 1% Nitric acid. Hence, the impedance-frequency model can be used to predict the behavior of both materials.

1. Introduction:

Civil infrastructures have been maintained and restored using cement pastes and cementitious composites for years (Vipulanandan, et al., 2008). In recent times, self-monitoring materials have been employed either as partial or complete components of repair materials (Vipulanandan, et al., 2004). As a result, there is growing interest in developing smart self-monitoring materials that not only possess the structural capacity to withstand loads but can also respond to environmental changes. Monitoring the performance of a structure under service conditions is one approach to enhance the structure's dependability so that it can be mended before total degradation. This kind of inspection necessitates the attachment of strain sensors at critical locations on the structure being monitored (Hou, et al., 2009). However, some of the sensors that are presently utilized have certain shortcomings that are difficult to overcome.

The electrical characteristics of bone are vital in neuro-monitoring (Balmer, et al., 2018). During surgery, this electrical measurement is utilized to alert surgeons when their surgical instruments are near crucial nerves, preventing damage to these essential structures. The method is based on utilizing an electrode located on the surgical tool to electrically stimulate the nerve (Silverstein, et al., 1991; Ansó, et al., 2014). Consequently, it's essential to comprehend the electrical properties of the bone and their relationship with the underlying bone structure and density. This fundamental experimental research is necessary to enhance and develop medical equipment that relies on bone responses to electrical stimuli.

Cement and bone share a common element as a crucial constituent, with calcium being a fundamental component in both their chemical compositions. Cement is primarily composed of calcium, silicon, aluminum, and iron (Schneider, et al., 2011). The main component of cement is calcium silicate, which is produced by heating limestone and clay together in a kiln (Schneider, et al., 2011). Other minerals, such as gypsum, may also be added to the mixture to control the setting time and strength of the cement.

Bone is a complex living tissue composed of a mineral phase and an organic phase (Palmer, et al., 2008). The mineral phase of bone is primarily composed of hydroxyapatite, which is a calcium phosphate mineral (Beniash, 2011). The organic phase of bone is made up of collagen, which provides the structure and strength of the bone (Beniash, 2011).

Impedance spectroscopy (IS) is a technique employed to evaluate the electrical characteristics of materials and their interfaces with electronically conducting electrodes (Campo, et al., 2002). Typically, literature analyses presume that the properties of the electrode-material system are nearly time-invariant, and the fundamental aim of IS was to determine these properties, their interconnections, and their reliance on applied voltage or current (Macdonald, et al., 2018). Despite this, only a few researchers have employed IS to examine the performance of composites and bones. The present study utilized impedance spectroscopy (IS) to contrast cement paste and bovine bone.

2. Objective:

The overall objective was to compare the cement paste with bone. The specific objectives of this study are the following:

1.Quantify the contact and bulk resistances of cement paste and bone samples.

2.Evaluate the self-monitoring capacity of the bulk resistance of cement paste and bone samples under different environmental conditions and measure its sensitivities with an acidic solution.

3. Methodology:

In this study, the class-H oil well cement was used, and the conductive fiber content was 0.05 % by weight of cement. The cement pastes were created by blending cement and water for five minutes, after dispersing the carbon fiber in the water. A cylindrical mold, measuring 4 inches in height and 2 inches in diameter, was utilized, with four probes made on its surface, two on each side, and an additional two on the diametrically opposite side, to enable the insertion of wire probes. The water-to-cement ratio was 0.4. In addition, a conductivity meter was employed to determine the specimen's conductivity while it was being cast. Following casting and 10 seconds of vibration, all specimens were left to cure in their respective molds for 24 hours. tests were performed on cement paste samples after 28 days of curing.

Samples of cylindrical bones were obtained from the adult bovine (as shown in Fig. 1). To prevent water loss, the samples were kept in a plastic bag before conducting resistivity measurements. The entire process of collecting, preparing, and measuring the bones was completed within a 48-hour timeframe. During the test, the frequency of the constant amplitude AC signal was varied from 20 Hz to 300 kHz, and the corresponding impedances of the cement paste and bone were measured.

In order to prepare a 1% nitric acid solution, the necessary quantity of concentrated nitric acid was measured utilizing a graduated cylinder or pipette. After that, distilled or deionized water is added to the volumetric flask. Next, the measured nitric acid is added to a volumetric flask, and the flask is then capped, and the solution is thoroughly mixed by inverting it multiple times, as shown in Figure 1. Impedances of the cement paste and bone were also measured after partial immersion in 1% HNO_3 for 2 hours.

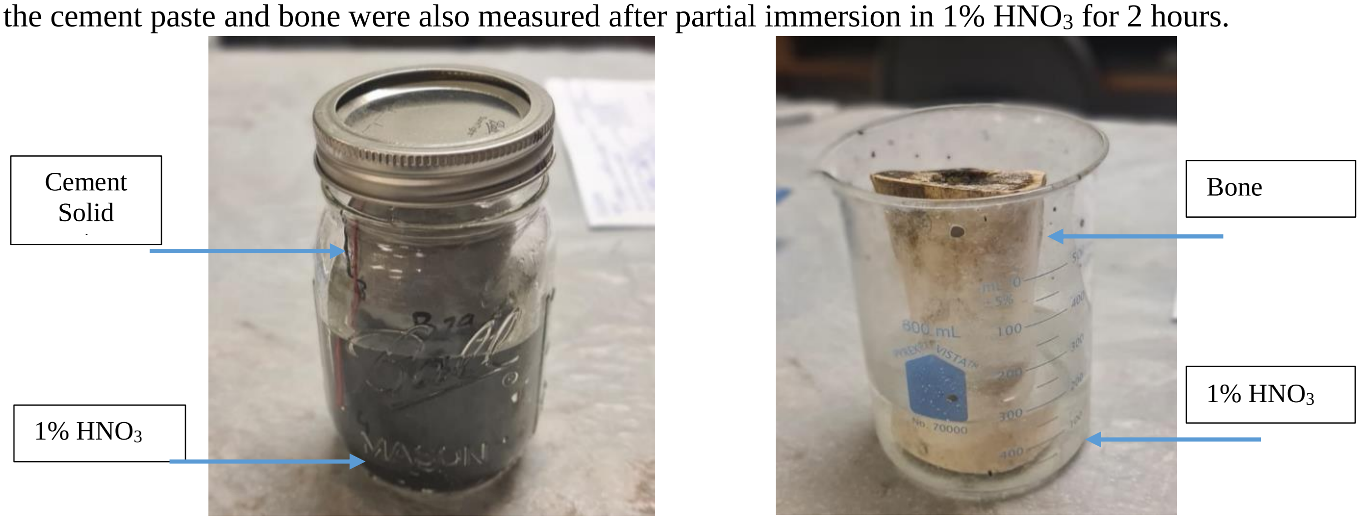

Figure 1: (a) Cement paste sample and (b) Bone sample, partially immersed in 1%Nitric Acid.

4. Results:

Before Immersion in 1% Nitric Acid

iii. Cement Paste specimen:

From Figure 2, the impedance value decreases with increasing frequency until it levels off up to a certain frequency. In this case, at 4 kHz, the impedance value begins to level off. This corresponds to case 2: Special bulk material – resistance only (Vipulanandan et al, 2013). This indicates that the impedance of the cement paste is mostly influenced by the resistance of the material. In addition the density of the dry cement paste was 2.48 g/cc as seen in Figure 5.

iv. Bone specimen:

Figure 3 shows that the impedance value of the bone decreases as the frequency increases until it reaches a specific frequency where it levels off. This leveling off occurs at 3 MHz, corresponding to case 2: Special bulk material - resistance only (Vipulanandan et al, 2013). This suggests that the primary factor influencing the impedance of the bone is its resistance. In addition, the density of the dry bone was 2.30 g/cc, as seen in Figure 5.

After Immersion in 1% Nitric Acid

ii. Cement Paste specimen:

When the cement paste is exposed to 1% HNO_3, there is a decline in the impedance values. In addition, the impedance value decreases as the frequency increases until it reaches a certain point where it stabilizes. Specifically, at 0.6 kHz, the impedance value starts to level off, which corresponds to case 2: Special bulk material - resistance only (Vipulanandan et al, 2013). In addition, the density of the cement paste after immersion in 1%HNO_3 was decreased to 2.07 g/cc, as seen in Figure 5. The pH of the solution was also increased from 1.6 to 11.6, as shown in Figure 6.

iii. Bone specimen:

When the bone specimen is exposed to 1% HNO_3, there is a decline in the impedance values. In addition, the impedance value decreases as the frequency increases until it reaches a certain point where it stabilizes. Specifically, at 4 MHz, the impedance value starts to level off, which corresponds to case 2: Special bulk material - resistance only (Vipulanandan et al, 2013). In addition, the density of the bone after immersion in 1%HNO_3 was decreased to 1.82 g/cc, as seen in Figure 5. The pH of the solution was also increased from 1.6 to 5, as shown in Figure 6.

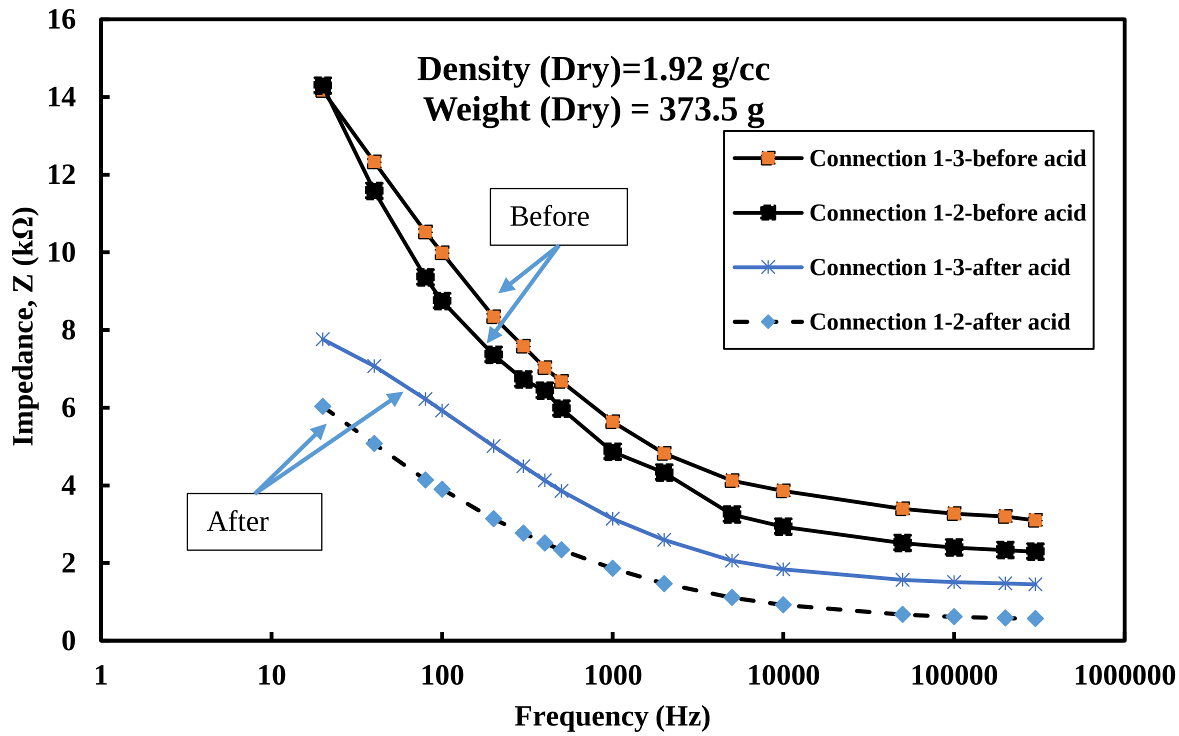

Figure 2: Impedance versus frequency for cement paste sample before and after exposure to 1%HNO_3

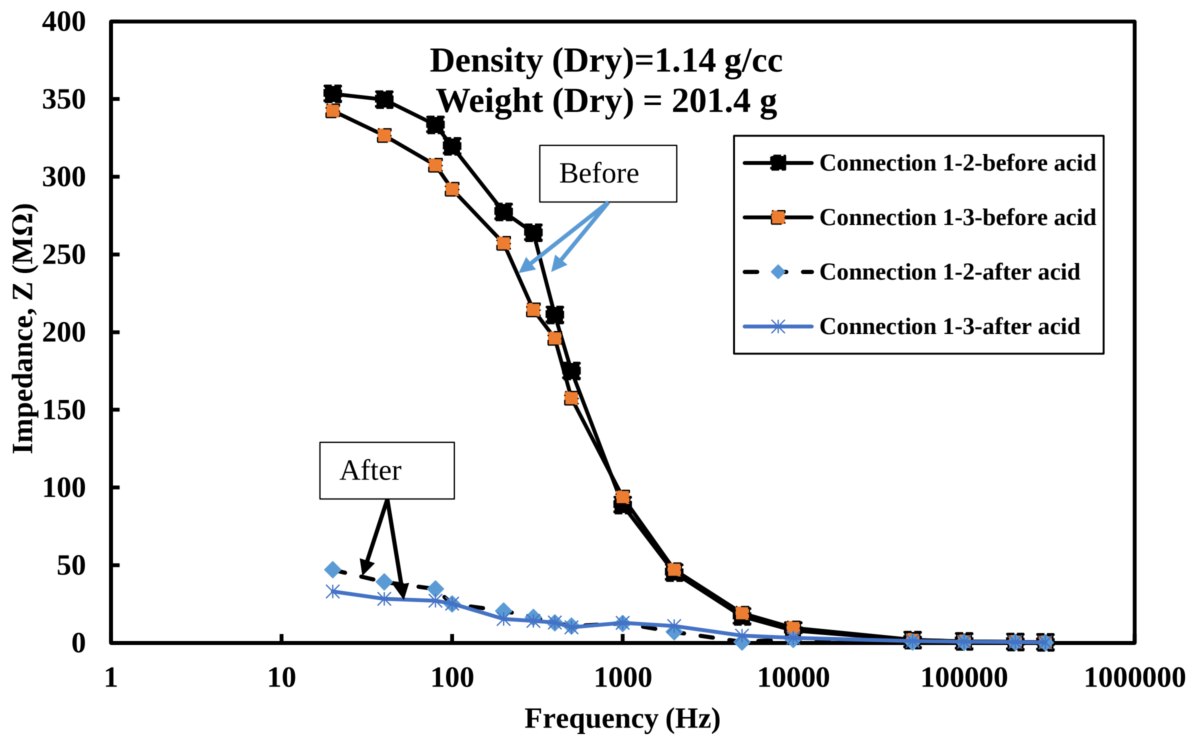

Figure 3: Impedance versus frequency for the bone sample before and after exposure to 1%HNO3.

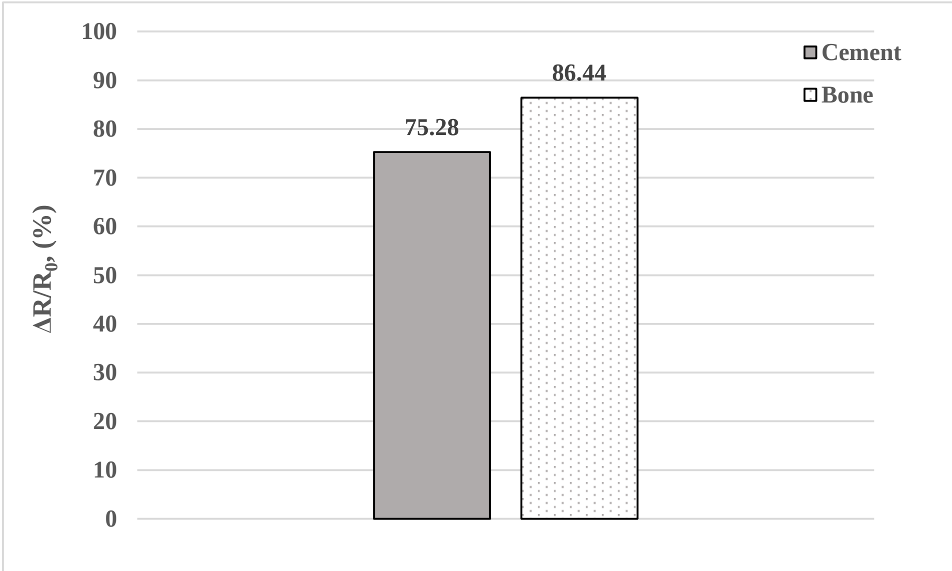

Figure 4: Fractional change in resistance of cement and bone samples before and after partial exposure to 1%HNO_3.

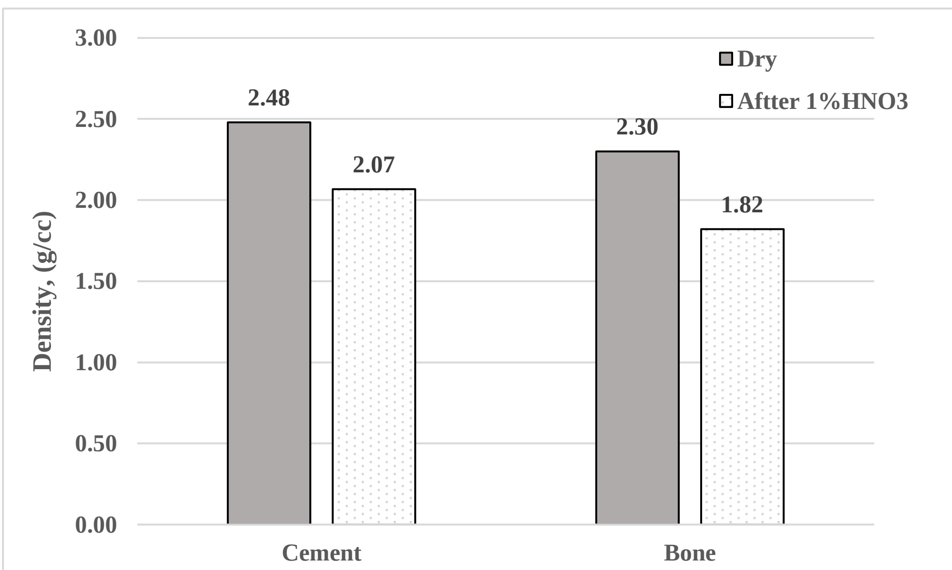

Figure 5: Density of cement and bone samples before and after partial exposure to 1%HNO_3.

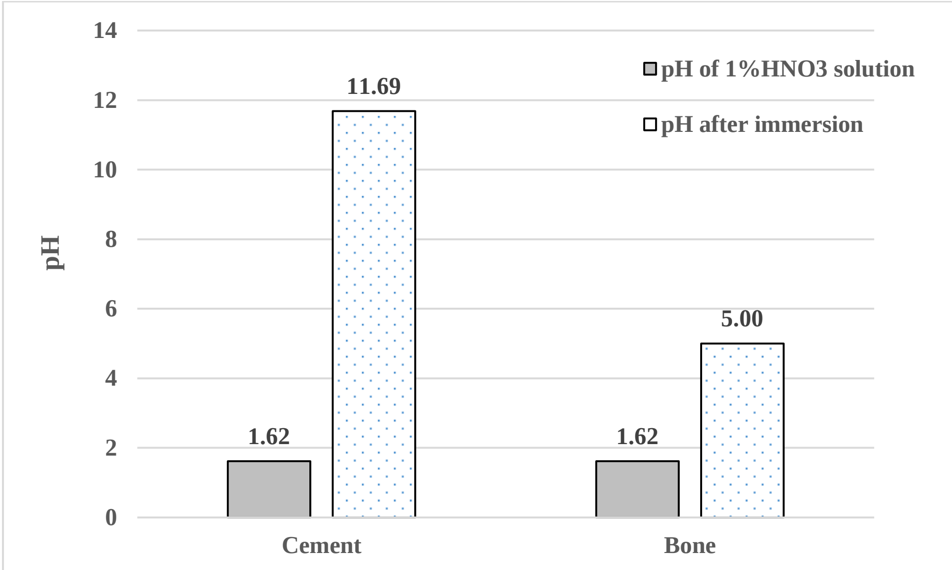

Figure 6: pH values of 1%HNO_3 solution before and after partial immersion of the cement and bone samples.

5. Conclusion:

From this study, the following conclusions are advanced:

1) The impedance value of cement paste over the frequency range of 20 Hz to 300 kHz (for a given w/c =0.4) decreases from 20 Hz to 50 kHz beyond which it becomes nearly constant. This behavior shown by cement paste signifies the impedance of the cement paste, and it follows case 2.
2) The electrical assessments can be employed to anticipate the bone's local characteristics which decrease from 20 Hz to 10 kHz beyond which it becomes nearly constant. In addition, the bulk resistance of the bone is much higher than that of cement paste.
3) If the cement pasted or bone specimens are subjected to 1% HNO3, there is a significant reduction in the impedance value in both specimens.

6. Acknowledgments

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7. References

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