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Unlocking the Secrets of Roman Concrete using 3D X-ray Tomography

Tenzin Gyephel[1], Dr. Marie Jackson[2], Dr. Juhyuk Moon[1]

[1] *Civil Engineering Program, Department of Mechanical Engineering, Stony Brook University*

[2] *Civil and Environmental Engineering, University of California Berkeley*

Introduction and Background Information

Roman concrete is a building material widely used by the Ancient Romans throughout the Roman Empire. It was mainly applied in the construction of foundations, roads, aqueducts, harbor structures, temples, and many other structures. Most of these structures, built over 2000 years ago, are still standing to this day.

Similar to modern concrete, Roman concrete is composed of aggregate, water, and binding agent. The aggregates of both modern and Roman concretes consist of rocks, gravel, rubble, etc. However, modern concrete uses Portland cement as the binder, while Roman concrete used either gypsum and lime or pozzolan volcanic ash found in central Italy.

Figure 1A

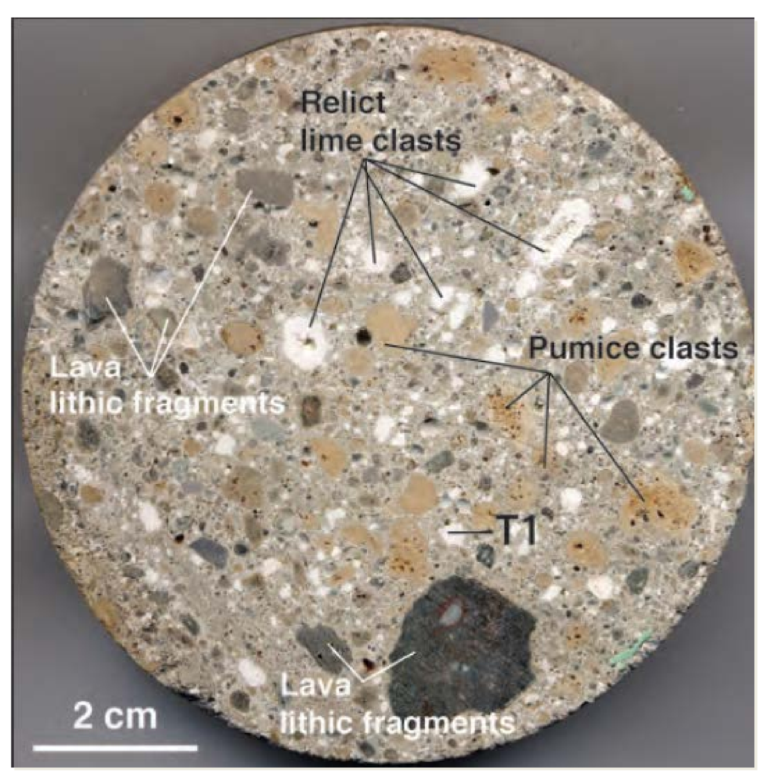

Figure 1B

Figure 1: 2000 yrs old Roman concrete under seawater

Methods and Analysis

Currently, not much is known about the mechanical properties of Roman concrete, as there are no comparable data. However, by analyzing the porosity of the concrete, we can directly "see" the porosity of the concrete.

Micro-CT and Nano-CT images provide multi-scale pore structures of the composite materials of Roman concrete. Here, two sets of Micro-CT images of Roman Concrete are analyzed through AVIZO Fire to reveal the pore structures of Roman concrete.

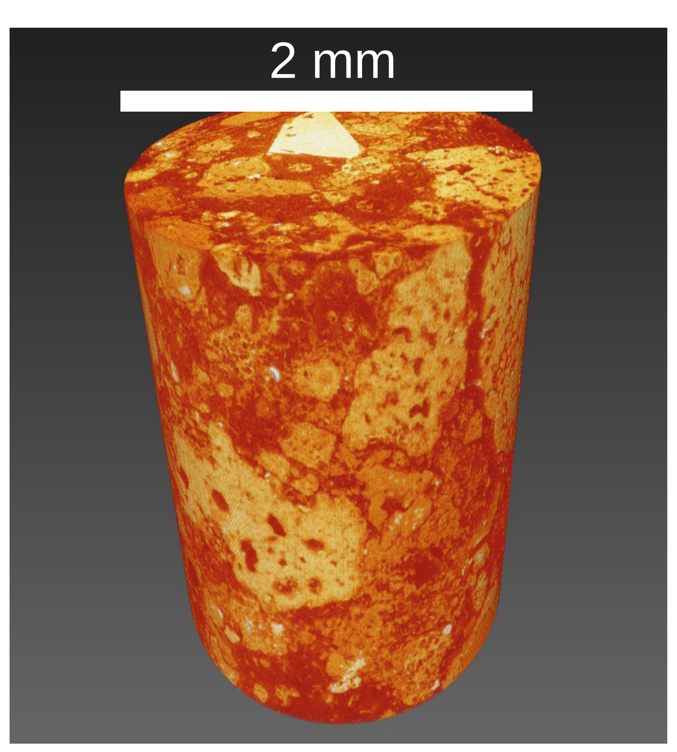

Figure 2A

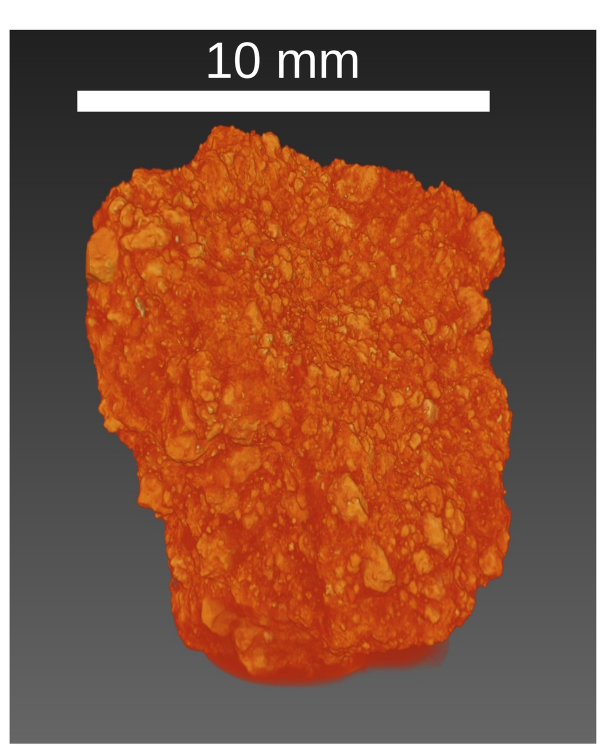

Figure 3A

High resolution X-ray computed tomography results on Roman concrete.

Fig. 2A: ultra high resolution data (2μm/voxel)

Fig. 3A: high resolution data (8.5μm /voxel)

Results

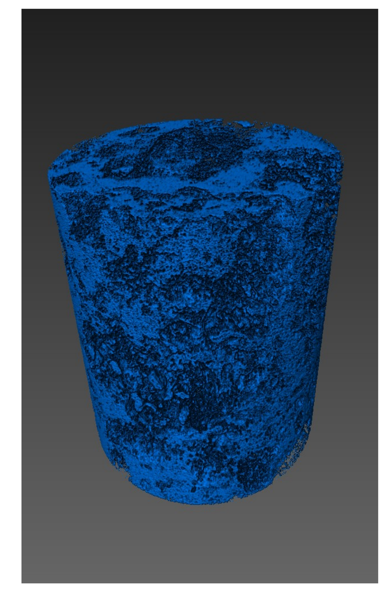

Figure 2B

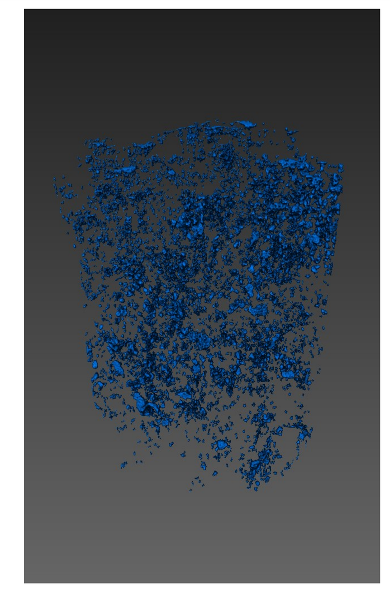

Figure 2C

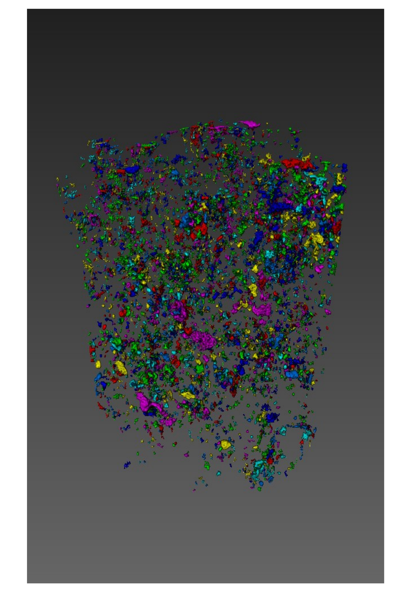

Figure 2D

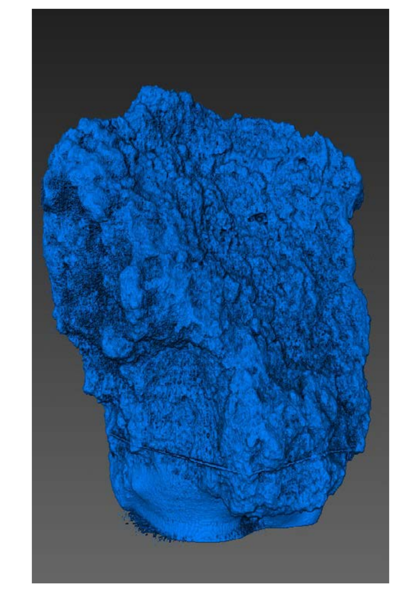

Figure 3B

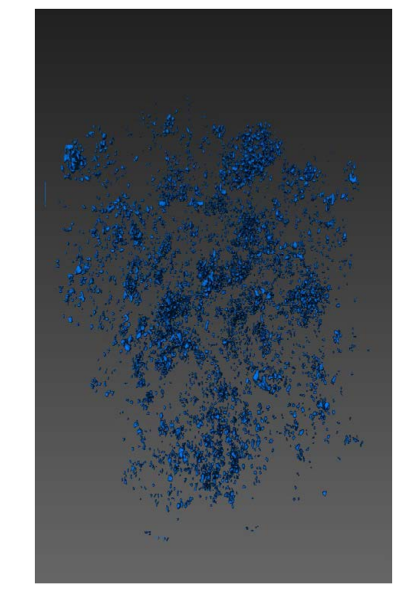

Figure 3C

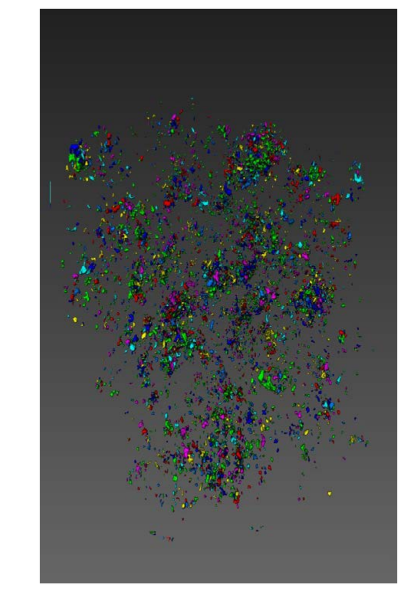

Figure 3D

Figure 2B: 3-D Volume Rendering of complete internal pore structure.
Figure 2C and Figure 2D: 3-D Volume Rendering and color differentiation of individual pores in the aggregates.

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Figure 3C and Figure 3D: 3-D Volume Rendering and color differentiation of individual pores in the aggregates.

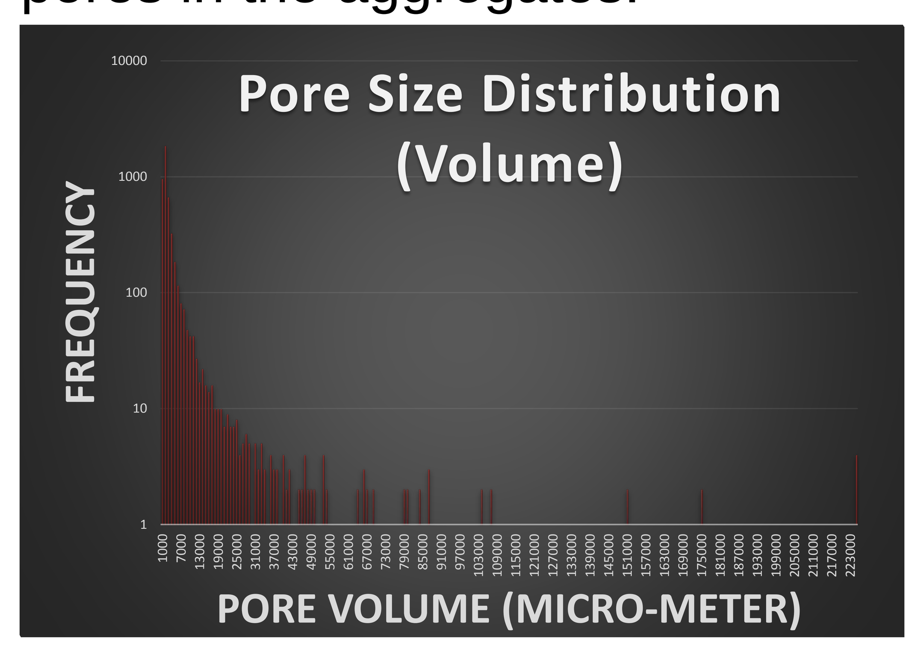

Figure 3A

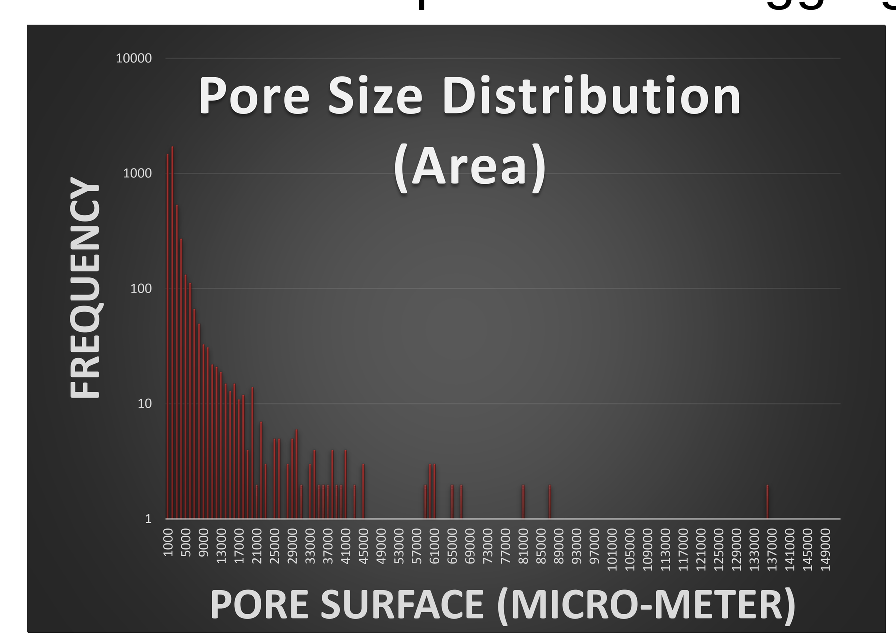

Figure 3B

Figure 4A and Figure 4B: Pore size distribution in the aggregates in relation with Volume and Surface Area of pores of Fig. 2 sample.

The total porosity of this sample results in 0.44%

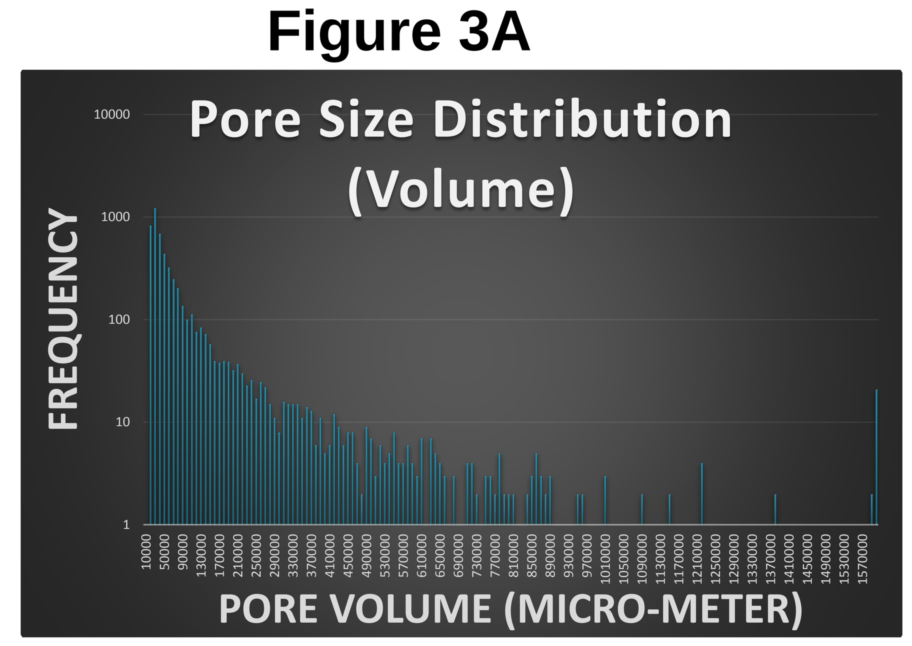

Figure 4A

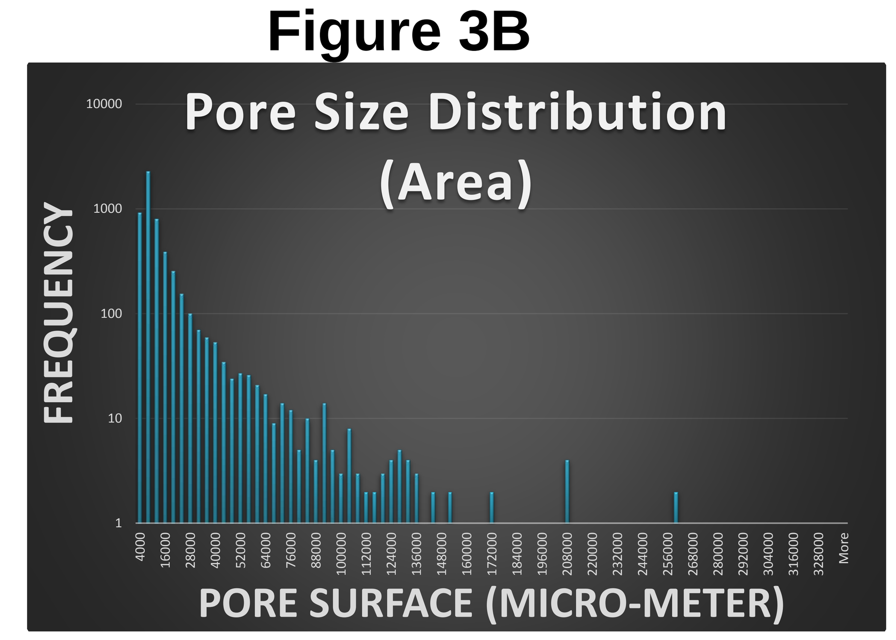

Figure 4B

Figure 5A and Figure 5B: Pore size distribution in the aggregates in relation with Volume and Surface Area of pores of Fig. 3 sample.

The total porosity of this sample results in 0.49%.

Discussion and Conclusion

The measured porosity is extremely low compared to that of modern Portland concrete. This explains the fact that Roman concrete is more resistant under chemical attacks. This further proves the durability of Roman concrete, as its structures have survived for more than 2000 years while modern concrete structures, less resistant to seawater, are only designed to last about 100 years. In addition to that, compared to the direct carbon dioxide emission from the production of cement, the Romans used significantly less lime and baked it at a much lower temperature compared to the current production process of modern concrete. This results in using far less fuel and releasing significantly less carbon into the atmosphere.

Acknowledgment

The Sovrintendenza Capitolina Beni Culturali di Roma Capitale provided drill cores of Markets of Trajan concretes.