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# Engineering Properties of Coquina: An Interesting and Historic Building Stone

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## Engineering Properties of Coquina: An Interesting and Historic Building Stone


### Abstract

Coquina is a weak sedimentary limestone composed of shell and shell fragments that have been cemented together. It is most often found in coastal regions, such as the Anastasia Formation along the east coast of Florida. Coquina is a historically significant building material, with the best-known example being the Spanish Castillo de San Marcos in St. Augustine, Florida. It has withstood cannonball fire during battles and centuries of weathering yet is still structurally sound. Although coquina is very important historically, not much is known about its properties. Preliminary studies have shown the orientation of the shells impacts tensile strength. Additionally, larger specimens tended to have lower tensile strength. Building on previously performed tests, I will further investigate how the orientation of shells impacts coquina's tensile strength, as well as how specimen size affects tensile strength. I predict the specimens cored in the vertical direction will have a higher tensile strength because the shells will be oriented horizontally. The larger specimens will have a lower tensile strength because there is a greater number of existing fractures within the larger specimens. Indirect tension testing will be performed on the specimens. Compression on the top of the puck-shaped specimens will cause failure in tension. I will use acoustic emission monitoring to measure microcracking events during testing, specifically looking for the beginning of unstable crack growth. Unstable crack growth is a precursor to ultimate failure, where microcracks coalesce and form a macroscopic failure plane.

# ENGINEERING PROPERTIES OF COQUINA

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BOISE STATE UNIVERSITY

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RONALD E. MCNAIR POST-BACCALAUREATE ACHIEVEMENT PROGRAM

## AN INTERESTING AND HISTORIC BUILDING STONE

## MOTIVATION

Coquina is a sedimentary limestone rock composed entirely of cemented shell and shell fragments. It is typically found in coastal regions, including along the east coast of Florida. It has been used as a building material in the past due to its unique properties. Despite its historical significance, not much is not about coquina. This poster presents the first part of studies being conducted to learn more about coquina's strength properties.

## BACKGROUND

The Castillo De San Marcos in St Augustine, FL is a notable structure made of coquina. It has withstood years of cannonball fire during battle and centuries of weathering, yet is still structurally sound. This is due to the unique composition of coquina, the rock it was built out of.

Coquina is formed when waves bring seashells from the ocean to shore. As the shells settle, they naturally orient themselves horizontally. The calcium carbonate in the shells acts as a cementing agent to hold the shells together.

Coquina is lightly cemented and has a high porosity, meaning there is a lot space between shell particles. When a force is applied, the resulting force chains follow tortuous paths. As a result, when coquina does fail, the failure is highly localized and it does not fail along a plane like other rock types.

Preliminary research has shown the orientation of the shells impacts coquina's tensile strength properties. Samples cored in the vertical Z-direction have horizontally oriented shells, while those cored in the X- and Y- directions have vertically oriented shells. Figure 1 shows X-ray computed tomography (CT) images of coquina specimens. Additionally, larger samples tended to have a lower tensile strength.

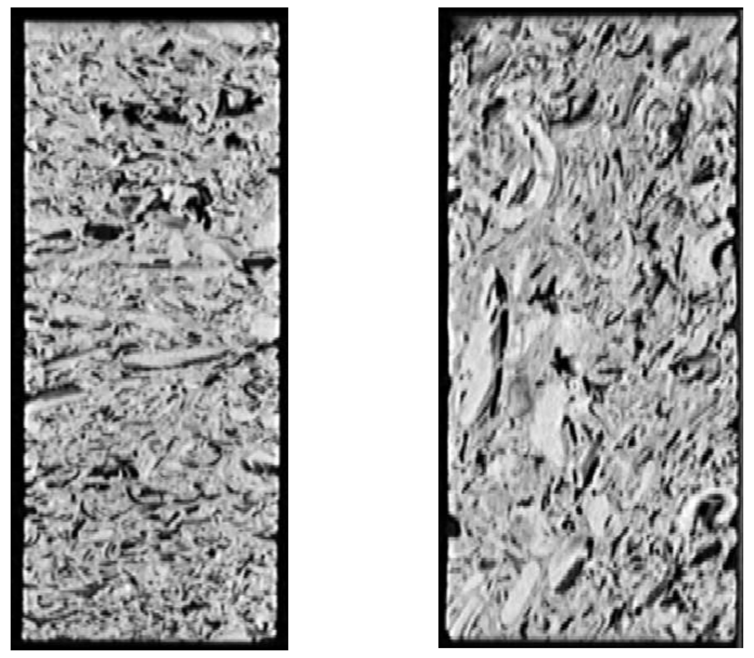


**Figure 1:** X-ray CT scans showing vertical and horizontal specimens and shell orientations.

## RESEARCH QUESTIONS

- How does the testing method impact coquina's tensile strength?
- How does specimen size affect tensile strength?
- How does the orientation of shells impact coquina's tensile strength?

## STUDY DESIGN

While preliminary studies have been conducted to determine coquina's tensile strength properties, the pool of data was relatively small. These new tests are the first part of a multipart study which will determine a variety of coquina's properties. This poster presents the data acquired from the continuation of the preliminary studies.

Indirect tension testing was conducted to determine tensile strength. The vertical specimens with horizontally oriented shells were tested with the shells in a horizontal orientation. The horizontal specimens with vertically oriented shells were tested with the shells in a vertical orientation.

A small motorized load frame was used to apply a compressive force on the top of puck-shaped specimens. This compressive force caused the inside of the rock to push apart, causing the specimen to fail in tension. Specimens were slowly loaded using a displacement rate of 0.005 inches per minute following ASTM D3967-16. A load cell measured the compressive force and a linear variable differential transformer (LVDT) measured the displacement. The test setup is shown in Figure 2.

Once the force reached a maximum and began to decrease, the specimen was considered to have failed. Tensile strength for each specimen was determined using the physical dimensions of the specimen and the maximum force.

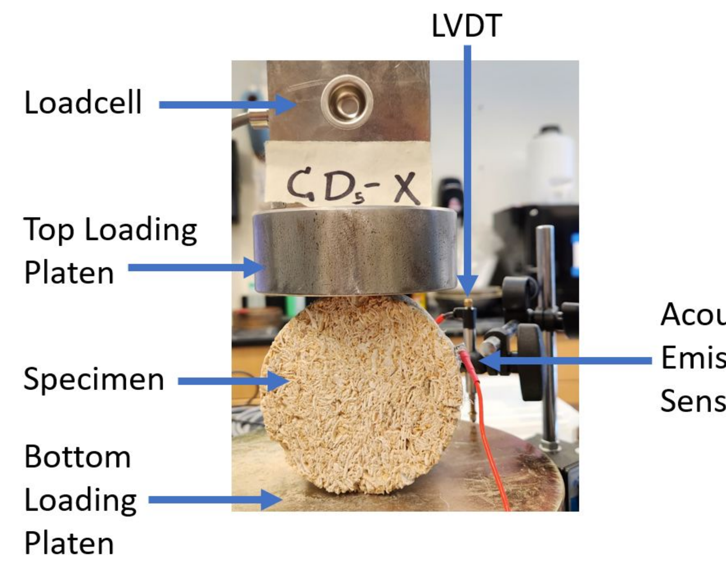


**Figure 2:** Test setup for indirect tension testing.

## RESULTS

**How does testing method impact coquina's tensile strength?**

Previous tests were performed using a hand operated load frame where the deformation rate was not constant (Hudyma et al., 2017). The force from these tests was applied more rapidly, so the specimens failed in a shorter amount of time. As a result, their tensile strengths were higher because there was no time for microcracks to form before ultimate failure. The new testing was conducted at a displacement rate of 0.005 inches per minute, which resulted in a slower, more controlled test, and slightly lower tensile strengths. Figure 3 shows the comparison between tensile strength and unit weight of the previous tests and new tests.

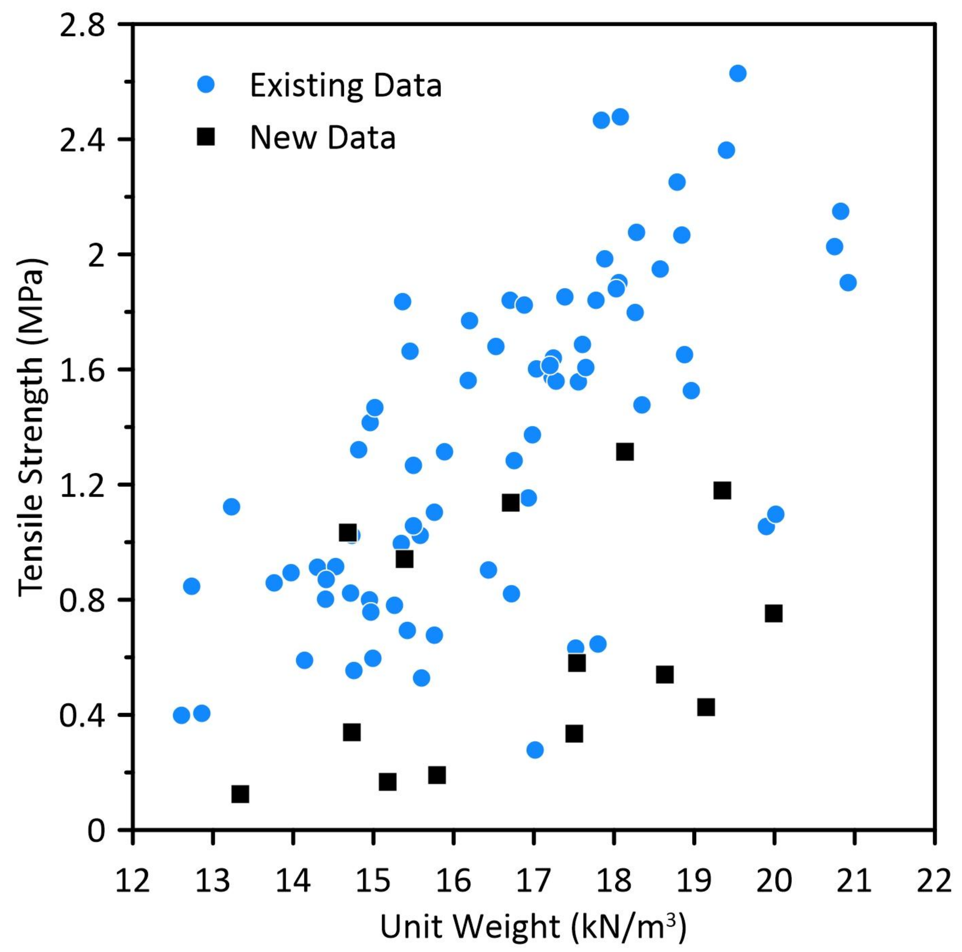


**Figure 3:** Comparison of results from previous and new testing showing the effect of testing method.

**How does specimen size affect tensile strength?**

Figure 4 shows the effects of both specimen size and specimen orientation on the tensile strength of coquina. Specimens with a larger diameter had a lower tensile strength. This is due to the size effect which states that larger specimens have more pre-existing flaws which results in lower tensile strengths (Tsur-Lavie and Denekamp, 1982). Smaller specimens have a larger range of tensile strengths, but a higher average tensile strength than the larger specimens. The range in tensile strengths for the two largest diameter specimens is approximately the same.

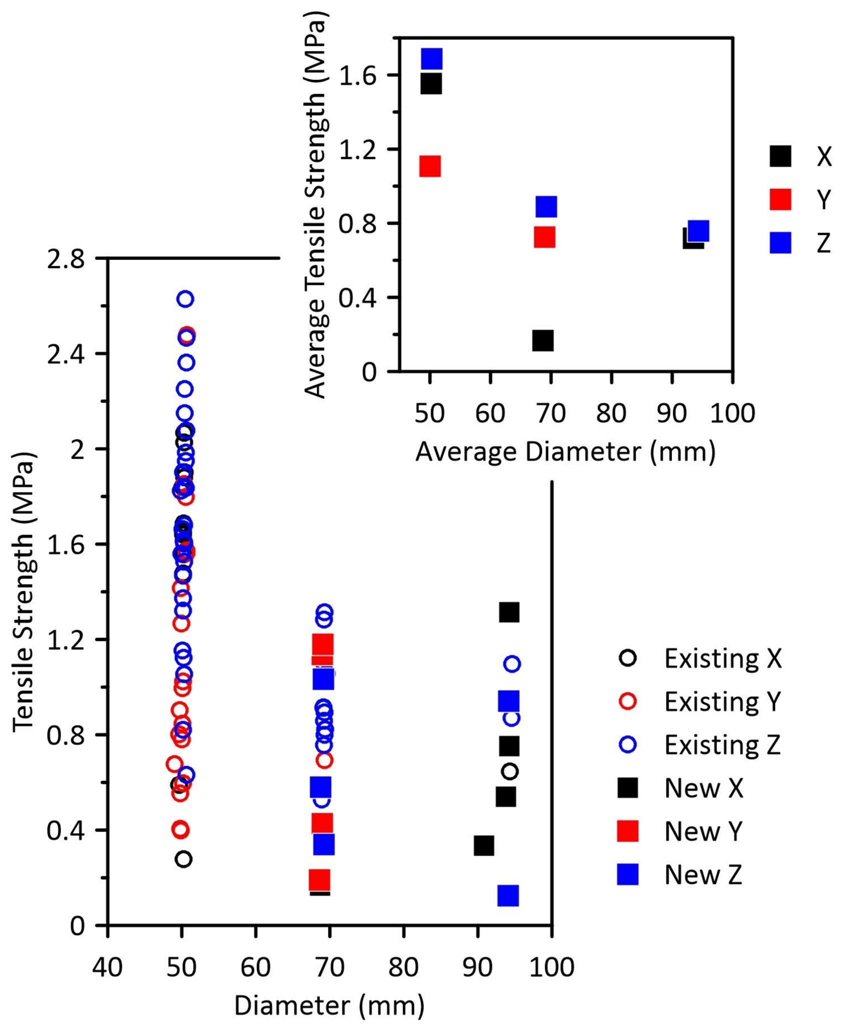


**Figure 4:** Effect of specimen size and specimen orientation on tensile strength.

**How does the orientation of shells impact coquina's tensile strength?**

The inset of Figure 4 shows the average tensile strengths as a function of orientation and diameter. Specimens tested with horizontal shell orientations (Z) had the highest average tensile strength. Although specimens with vertical shell orientations (X and Y) on average had lower tensile strengths, more testing must be performed to assess if there is a difference in the two tensile strengths.

## SUMMARY

Both new and previous tests show a correlation between unit weight, shell orientation, specimen diameter, and tensile strength. Specimens with higher unit weights had higher tensile strengths. Specimens with horizontal shell orientations (Z) also had higher tensile strengths. However, those with larger diameters had lower tensile strengths, demonstrating that the size effect is present in coquina. Further research is needed to accurately determine the differences in the X and Y orientations.

## REFERENCES

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