The Effect of Altering The Material Composition in Ultra High-Performance Concrete (UHPC) With Regional Materials On Compressive Strength

❖ Introduction

UHPC is a modified concrete mixture with higher compressive strength and durability than standard concrete. UHPC exhibits stronger performance due to a blend of fine aggregates, cement powder, and water, which form a dense matrix. While the new product was officially developed in 1994, the first U.S. bridge was not made until 2006. Up to this point, only 250 bridges in the U.S. utilize UHPC.

UHPC has not been adapted fully into U.S. infrastructure because the cost to manufacture it is much larger than that of standard concrete. To fully incorporate UHPC as a primary construction material, the materials would need to be widely available, and not greatly increase the cost to manufacture compared to standard concrete. Because UHPC can be up to 30 times as strong as standard concrete, attempts should be made to incorporate this construction material into the infrastructure of the U.S.

Compressive strength is a common benchmark measurement for the performance of materials because it is the measurement of the resistance of stress a material can handle until it breaks or experiences failure due to the pressure. Effectively, compressive strength is equal to the maximum load that a material can withstand divided by the bearing area of the structure. This is applicable to infrastructure because all structures are under constant stress. Compressive strength helps determine the amount of stress each structure can handle and can also help to predict the lifespan of that structure.

❖ Engineering Goal

The main goal of this project is to investigate and create a new UHPC mixture that can maintain a similar compressive strength to standard UHPC while being manufactured in a cost-efficient and eco-friendly manner.

UHPC Materials/Ingredients

The increased compressive strength of UHPC is due to the dense matrix formed by the ingredients that are used. A mixture of fine aggregate and coarse aggregate eliminate the majority of air pockets and gaps that were commonplace with standard concrete. Additionally, limited water disallows the possibility of air pockets where water has evaporated.

To achieve this, common aggregates combined with cement powder are; silica fume, fly ash, and basalt sand. Both silica fume and fly ash are extremely coarse materials, which allows them to bind with the coarser basalt sand without as many gaps within the matrix. This differs from a standard concrete mix which would normally only contain cement powder and a coarse aggregate like gravel, allowing for larger gaps in the matrix of the material.



Above: Fly Ash C (Left), Norchem Silica Fume (Center), and Basalt Sand (Right)

❖ Experimental Methods

Preparation of UHPC Mixtures

Prior to mixing both the control UHPC mixture and the modified mixture, 2 inch cubes were assembled and lightly coated with mineral oil to prepare for the construction of concrete cubes.

The mixing procedure began with the massing of: silica fume, fly ash, cement powder, and basalt sand. Precise measurements were necessary to accurately create a mixture conforming to standard recipes without upsetting the balance of materials which allow for the high compressive strength. To mix the materials, silica fume and basalt sand were combined. Silica fume is the finest material that was used, and basalt sand was the coarsest. Upon combination of the materials, fly ash and cement powder were also combined with the rest of the mixture. After being fully combined, a combination of water and superplasticizer were slowly poured into the UHPC mixture. After all the materials were combined, the consistency of the mixture would change from a sand-like mixture to a pasty material that could be poured into molds.



Curing and Grinding UHPC Samples

After samples were poured and had sat overnight, they were removed from the molds. Half of the samples were left to cure in a controlled environment where they were constantly experiencing a light misting of water. The remaining samples were left to cure in a steam curer which constantly covered the samples in steam. Before each sample was tested for its compressive strength, the surfaces were grinded to eliminate imperfections which could distribute the force unevenly on the sample.

Compressive Strength Testing

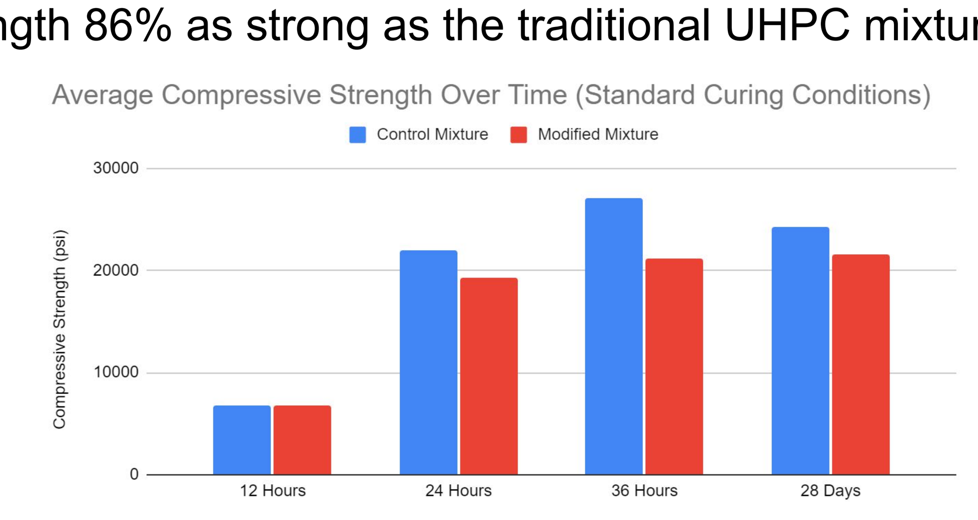
Samples were tested in a Humboldt Compression Machine, 100,00lbs, (445kN) which applied constant compressive stress on the samples until each experienced failure. After the samples experienced failure, data was collected from the screen which displayed the peak load which was used to calculate the compressive strength.

Left: Assembled cubic molds, UHPC mixture, and machine used for grinding the samples.
Above: Humboldt Compression Machine used for testing.

❖ Data Analysis

❖ Normal Curing

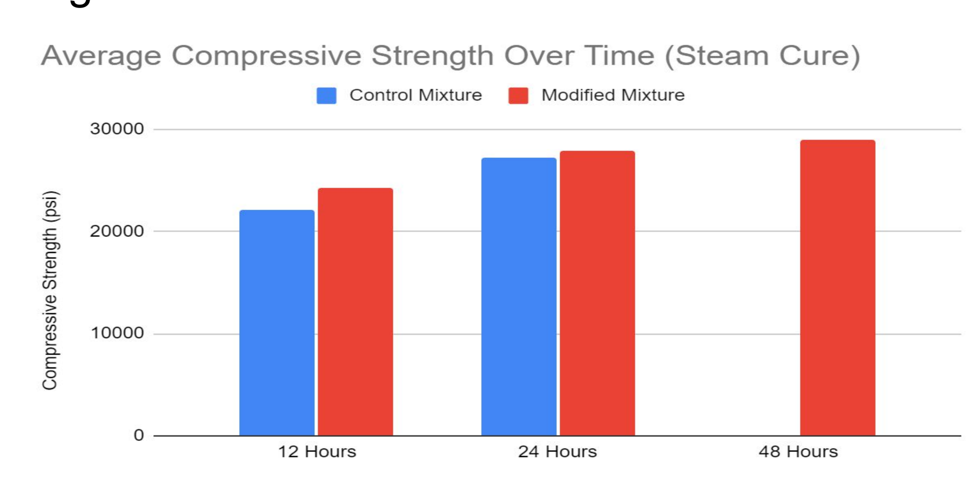
When the samples were left to cure in standard curing conditions, on average the new mixture had a compressive strength 86% as strong as the traditional UHPC mixture.



When the samples were tested 12 hours after pouring, the compressive strengths between both mixtures were closest, but gradually grew further apart as time passed and as they were curing longer.

❖ Steam Curing

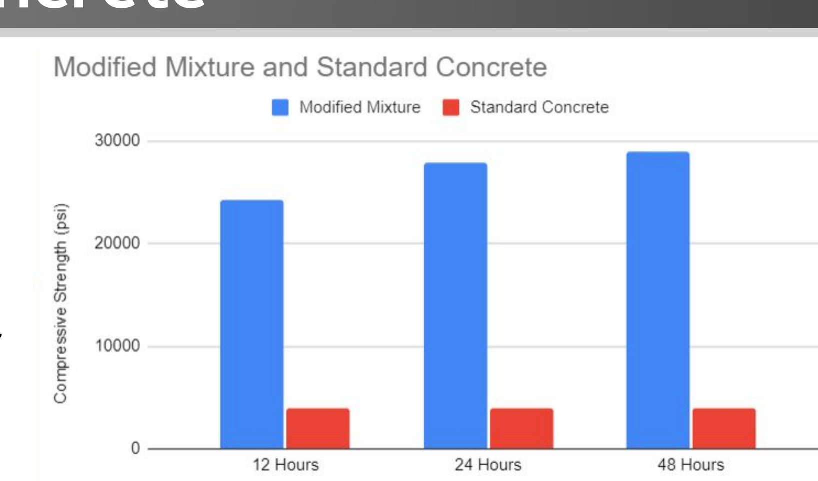
When the samples were left to cure in steam curer, on average the new mixture had a compressive strength 106% as strong as the traditional UHPC mixture.



Data was only collected at 12 hours and 24 hours due to malfunctions of the steam curer. At both of these time intervals, the compressive strength o the modified mixture was greater than that of the standard mixture.

❖ Comparison To Standard Concrete

The steam curing process left UHPC samples in a metal box filled with steam. The steam stimulated the chemical reactions of the samples. After testing the compressive strength of these samples, the modified mixture's compressive strength was already 6 times stronger than standard concrete after curing for only 12 hours in the steam curer. After the 24 hour time period, the modified mixture's compressive strength was nearly 7 times stronger than standard concrete. After 48 hours of curing the modified mixture's compressive strength was over 7 times stronger than standard concrete.



❖ Discussion

Upon compiling data, we found that the new mixture was not successful in creating a mixture that possessed the same compressive strength as normal UHPC, but it did successfully create a new UHPC mixture that was nearly as strong as normal UHPC mixtures and many times stronger than normal concrete, all in a cost-efficient and eco-friendly manner. Our hypothesis was that the modified concrete mixture would maintain a similar compressive strength to standard UHPC, however we found out that this was not the case. The decrease in compressive strength for the modified mixture is likely due to the change in cement powder. The new cement mixture contained elevated $CaCo_3$, a material composed of crushed limestone and calcined, which affects the compressive strength.

One possible explanation for the decrease in compressive strength due to the introduction of limestone is that limestone is naturally a brittle material than most other aggregates. An increased in brittle material means that the strength is compromised throughout the structure. Another possible explanation for this is that it upsets the chemical reactions within the mixture. Because the mixtures were composed with the same ratios of aggregate as standard UHPC, it is possible that the reduced levels of silica, alumina, and iron changed the chemical reactions that occur within the concrete samples. The chemical reactions are necessary to boost the strength of the concrete as it sets and cures.

Additionally, we found it interesting that the steam cured samples had increased compressive strength. We believe that this is largely due to the fact that steam curing allows for the chemical reaction to occur constantly throughout the curing process. We believe that the modified mixture had better compressive strength compared to the standard UHPC when steam cured because the $CaCo_3$ had a stronger chemical reaction which allowed for the materials to bind together stronger in the matrix.

❖ Conclusion & Future Work

We can conclude that altering the material composition of UHPC with regional materials does affect the compressive strength of concrete. In this investigation, the increase in limestone decreased the compressive strength of the concrete. In the future, we would like to attempt to create a new mixture that has a higher compressive strength while retaining the same goals of cost-efficiency and environment friendliness. We would also like to examine why the modified mixture was stronger than the standard mixture when bother were cured in a steam curer.

❖ References

https://www.cement.org/learn/concrete-technology/concrete-design-production/ultra-high-performance-concrete
https://www.sciencedirect.com/science/article/pii/S223878542031396X
https://theconstructor.org/concrete/high-performance-concrete-composition-features/6093/
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