Proceedings of The National Conference
On Undergraduate Research (NCUR) 2017
University of Memphis, Memphis, TN
Memphis, Tennessee
April 6-8, 2017

Investigation of Modulus of Elasticity and Surface Electrical Resistivity in High Performance Concrete Using Natural Zeolite

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Abstract

Due to severe weather-caused problems in concrete infrastructures, namely bridges and pavement, it has become very important to develop high performance concrete (HPC). HPC generally increases the durability against the chloride-induced corrosion as well as long term strength. Currently, a pozzolanic cementitious material known as natural zeolite, is being used for enhancing the performance of HPC. The purpose of this study is to investigate long-term durability and modulus of the elasticity of zeolite-based HPC to enhance the performance and serviceability of reinforced concrete bridges and pavement. In this study, several HPC mixtures are prepared by replacing cement with different percentage levels of zeolite (10%, 15%, 20%, 25%, and 30%). Different types of binary (Cement + Zeolite) and ternary (Cement + Zeolite + other cementitious material) based concrete mixtures including the control mixture (100% Cement) with water to total cementitious material ratio of 0.4 and 0.44 are prepared. Two different types of experiments namely modulus of elasticity and corrosion durability investigation (surface electrical resistivity) are conducted on concrete samples at 7, 28, 56 and 91 days. The main purpose of 4-point Wenner Probe resistivity meter is to investigate surface electrical resistivity of concrete that provides indirect indication of chloride induced corrosion. In addition, modulus of elasticity is related to stiffness and strength of concrete and it is widely used in design of reinforcement concrete structures. The compressometer is utilized for measurement of modulus of elasticity indirectly through evaluating deformation and strain of concrete samples. Overall, zeolite based concrete mixtures with water to total cementitious material ratio (W/C) at 0.40 provides promising results in terms of modulus of elasticity and corrosion durability. Further, substitution of zeolite with Ordinary Portland Cement (OPC) in concrete mixtures will reduce carbon dioxide (CO_2) emission and promotes sustainability.

Keywords: Natural Zeolite, Durability, Modulus of Elasticity, Corrosion

1. Introduction

The most widely used material in the construction around the world is concrete due to its durability and mechanical properties, ability to form into various shapes and size, and low cost. However, due to the severe environmental effects on the concrete structures, the embedded reinforcements in the concrete become corroded and structures get damaged before reaching its expected service life. Therefore, in reinforced concrete structures namely bridges and pavements, durability is the major concern since last few decades. To overcome this challenge, it has become very important to develop High Performance Concrete (HPC). HPC generally increases the durability against the chloride induced corrosion along with long term compressive and tensile strength. Therefore, a natural pozzolanic cementitious material known as natural zeolite is being used for enhancing the performance of HPC. Natural zeolite is a crystalline hydrated alumino-silicate processed (volcanic ash) mineral and it is highly effective pozzolan due to natural occurrence of aluminum silicate.

Main objective of this research is to identify proper binary and ternary based HPC mixtures design prepared with zeolite material with variation of feasible water to cementitious material ratio and different aggregate sizes. Surface electrical resistivity and modulus of elasticity testing are performed under durability investigation against the chloride-induced corrosion in concrete structures.

2. Literature Review

Najimi et al. (2012) analyzed the performance of zeolite based concrete mixtures prepared by using ¾ in aggregate, Type II Portland cement, and zeolite at 0.5 water to cementitious materials ratio. Cement was replaced by 15% and 30% by mass with zeolite. Slump was kept between 2.75 to 3.5 inches and superplasticizer was used to achieve better workability. It can be concluded that zeolite performs better with lower water to cement(w/c) ratios. Concrete mixtures with 15% zeolite performed better than 30% zeolite in concrete mixtures.

Chan et al. (1999) investigated the effectiveness of zeolite to improve the performance of concrete in comparison to silica fume and pulverized fuel ash (PFA). The performance of concrete is evaluated based on the slump test of the freshly mixed concrete and based on 7 and 28-day strength, 10-60 min initial surface absorption, and the chloride diffusion. Two series of experiment has been performed. First series focused on the effect of zeolite, silica fume and PFA using the 10, 15, 30 % and the second series evaluated the effect of varying water to cementitious material (W/C) ratios. According to this study at W/(C+P) = 0.28, the replacement of cement by zeolite, PFA, and silica fume at levels from 5% to 30% increased the compressive strength. As W/C ratio increased to 0.45 the compressive strength was lower than the control mixture.

Tanijaya et al (2008) studied Ordinary Portland Cement (OPC) mixtures with partial substitution of natural zeolite. Concrete mixtures were prepared by replacing the cement by 3%, 5% and 10% of zeolite by mass. Modulus of elasticity, compressive and tensile strength were performed on cylinders of 150 mm diameter and of 300 mm height on 3, 7, 14 and 28 days. Results for modulus of elasticity, compressive and tensile strength for zeolite based mixtures decreased compared to OPC mixtures. It showed that by increasing substantial amount of natural zeolites content, the mechanical properties of concrete namely, modulus of elasticity, compressive and tensile strength could be decreased.

3. Experimental Method

Different types of binary and ternary zeolite based mixtures along with Ordinary Portland Cement (OPC) with water to total cementitious ratio (W/C) with 0.44 and 0.40 are prepared in this study to investigate corrosion durability and mechanical properties of concrete. The main reason for keeping low w/c ratio is that high w/c ratio will create more voids in the sample to make problematic concrete matrix structure. In addition, using feasible W/C will ensure higher strength, modulus of elasticity and less voids. For this research, the targeted slump is 4-7 inches and slump test is performed to determine the workability of concrete. All mixtures contained 564 lb./yd^3 of cementitious material with Coarse Aggregate Factor (CAF) of 0.67. The coarse aggregate size is chosen as ¾ and ½ inches and sand meeting ASTM standard are used. Different tests are performed on each concrete mixture sample using the following materials.

- Type II-V Cement (TII-V)
- Other Supplementary Cementitious Materials (SCMs):
    - Ground granulated blast furnace slag of grade 120 & 100 (G120S and G100S)
    - Class C Fly Ash (C)
    - Class F Fly Ash (F)
    - Silica Fume (SF)
    - Metakaolin (M)
    - Pumice (P)
- Chemical Admixtures
    - Glenium 3030 water reducer (ASTM C494 Specification)
    - MBVR Air Entrainer (ASTM C494 Specification)

Cylinders of 4" diameter and 8" length were poured with concrete as per ASTM C192 specification. They are demolded after 24 hours and cured continuously in saturated lime water tank.

3.1. 4-Point Wenner Probe for Surface Resistivity

This device measures the surface electrical resistivity of the concrete cylinders. Figure 1 illustrates the methodologies of using Wenner Probe and calibration procedure for the test. This instrument measures the surface resistivity when the probes are placed properly on the side of the samples. Before starting surface resistivity test, the cylinder samples were dried using the paper towel. The cylinders were tested in surface saturated dry (SSD) condition except the edges, which was in dry condition. The readings were taken at four corners at 0, 90, 180 and 270 degrees.

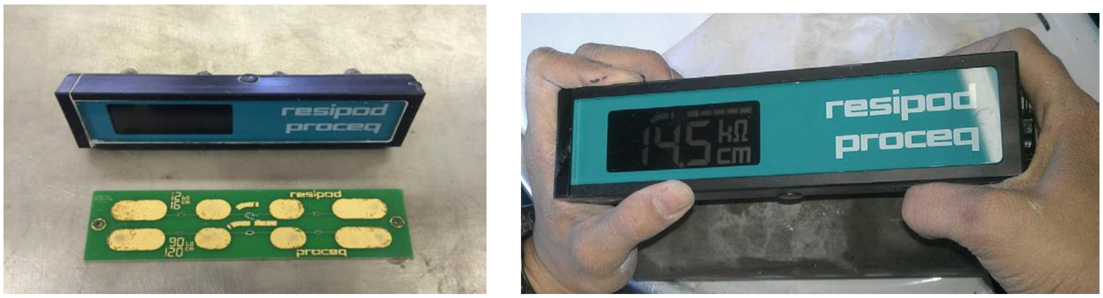


Figure 1. Measuring Surface Electrical Resistivity with 4-Point Wenner Probe

3.2. Compressometer

The compressometer is utilized for measurement of modulus of elasticity indirectly through evaluating deformation and strain of concrete samples. To use this equipment for testing, the concrete sample needs to be placed at the center of the equipment. A placer should be placed at bottom to mount the compressometer around the cylinder equally as shown in Figure 2. Then, experimentally modulus of elasticity is compared with theoretical modulus of elasticity. Theoretical modulus of elasticity is computed by this formula:

$$E_c = 57{,}000\sqrt{f'_c} \qquad (1)$$

Figure 2. Measuring Modulus of Elasticity for Concrete Cylinders

4. Results/Discussions

4.1 Electrical Resistivity

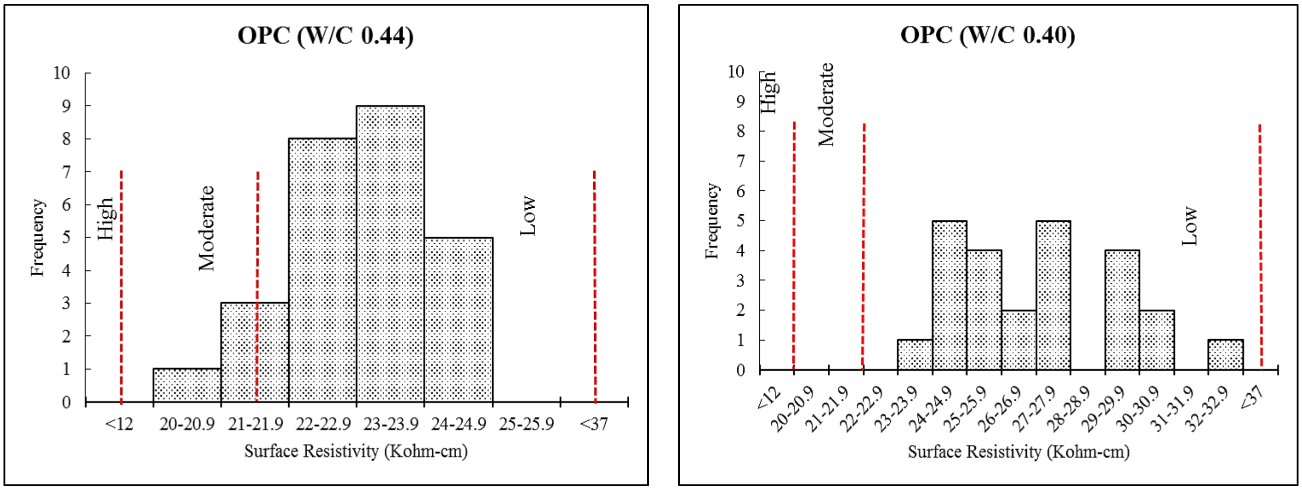


Figure 3. Comparison of surface electrical resistivity of (OPC) to 0.44 with 0.40 w/c for ½" aggregate size at 28 days

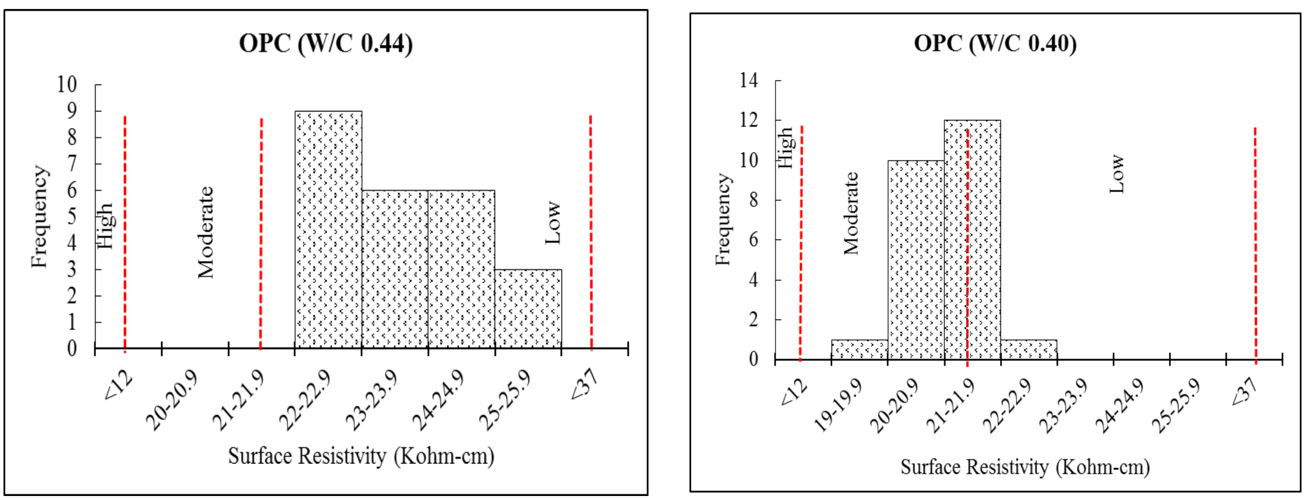
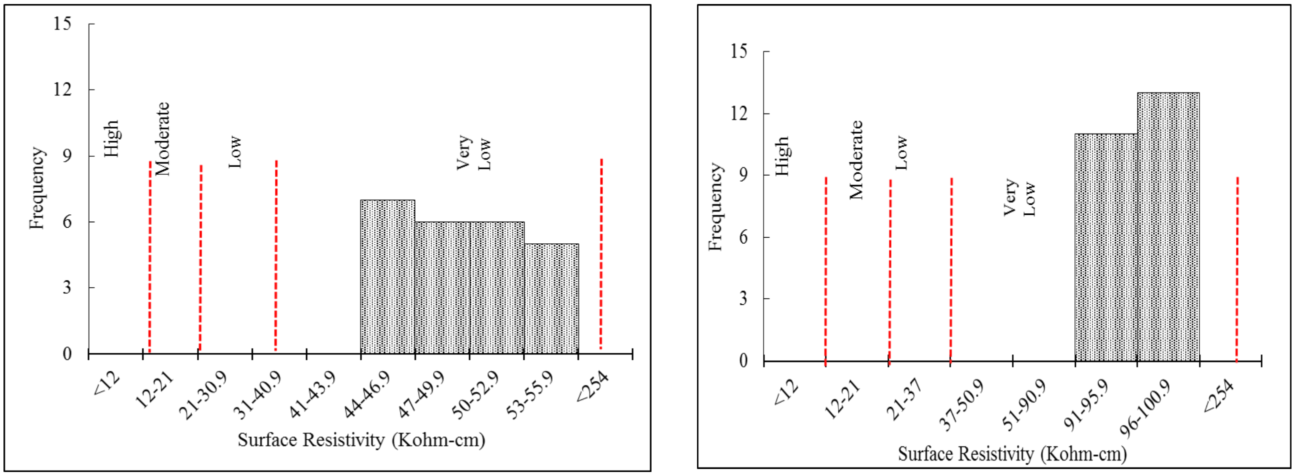


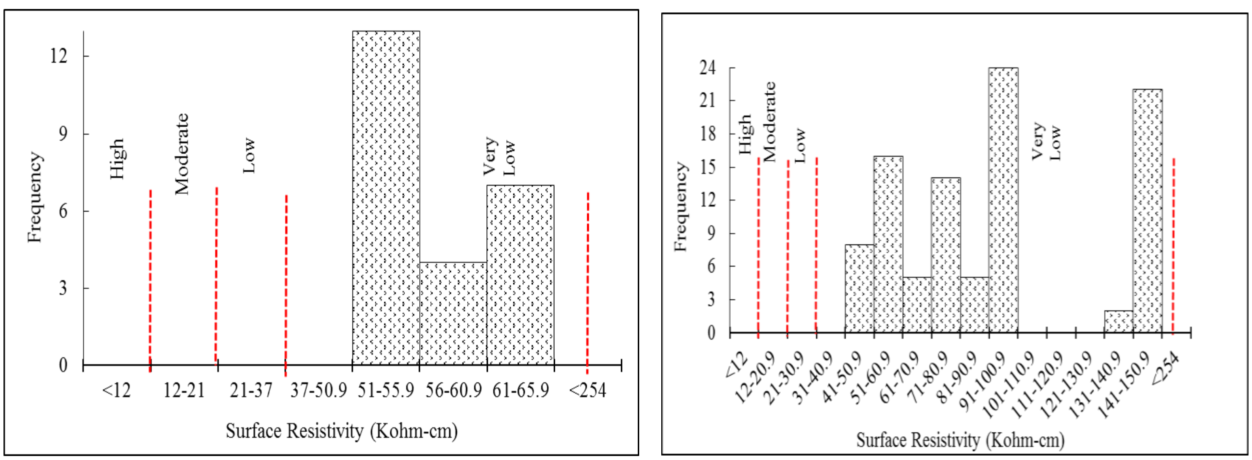
Figure 4. Comparison of surface electrical resistivity of (OPC) to 0.44 with 0.40 w/c for ¾" aggregate size at 28 days



Mix Design
85TII-V/15Z

Mix Design
75TII-V/15Z/10SF

Figure 5. Comparison of surface electrical resistivity of binary to ternary mixture for 0.40 w/c and ½ in aggregate size at 28 Days



Mix Design:
80TII-V/20Z

Mix Design:
60TII-V/20Z/20F
70TII-V/20Z/10M
55TII-V/20Z/25C
55TII-V/20Z/25P

Figure 6. Comparison of surface electrical resistivity of binary to ternary mixture for 0.40 w/c and ½ in aggregate size at 28 Days

From Figures 3 to 6, it can be observed that majority of concrete mixtures fall in between moderate to low class of permeability based on FDOT. Binary and ternary-based HPC mixtures appeared to have higher electrical resistivity compared to OPC mixture. In addition, it is visible that ternary mixtures have higher surface electrical resistivity compared to binary mixtures. Also, the mixtures with 0.4 W/C and 1/2" aggregate size shows promising results in terms of electrical resistivity data. Table 1 represent the relationship between surface resistivity data and chloride ion permeability class in accordance with Florida Department of Transportation (FDOT) specification.

Table 1. Surface Resistivity – Permeability Class From FDOT

Chloride Ion Permeability	Surface Resistivity Test kΩ−cm
High	< 12
Moderate	12 – 21
Low	21 – 37
Very Low	37 – 254
Negligible	> 254

4.2 Modulus of Elasticity

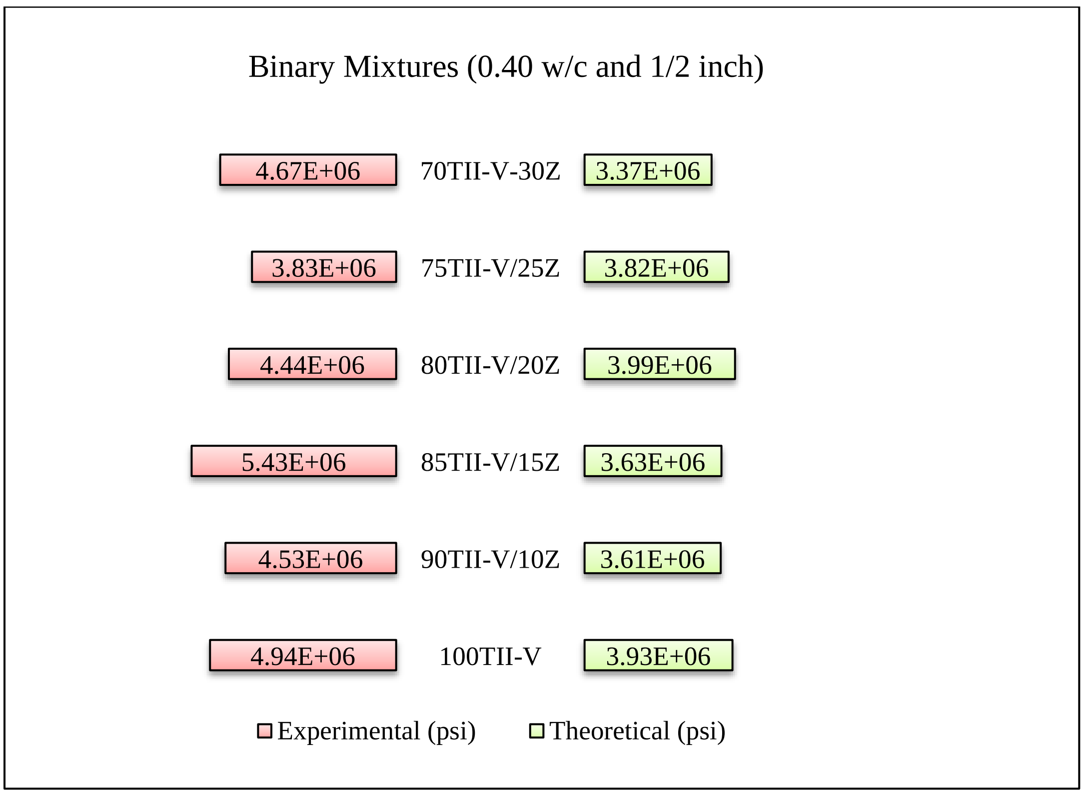
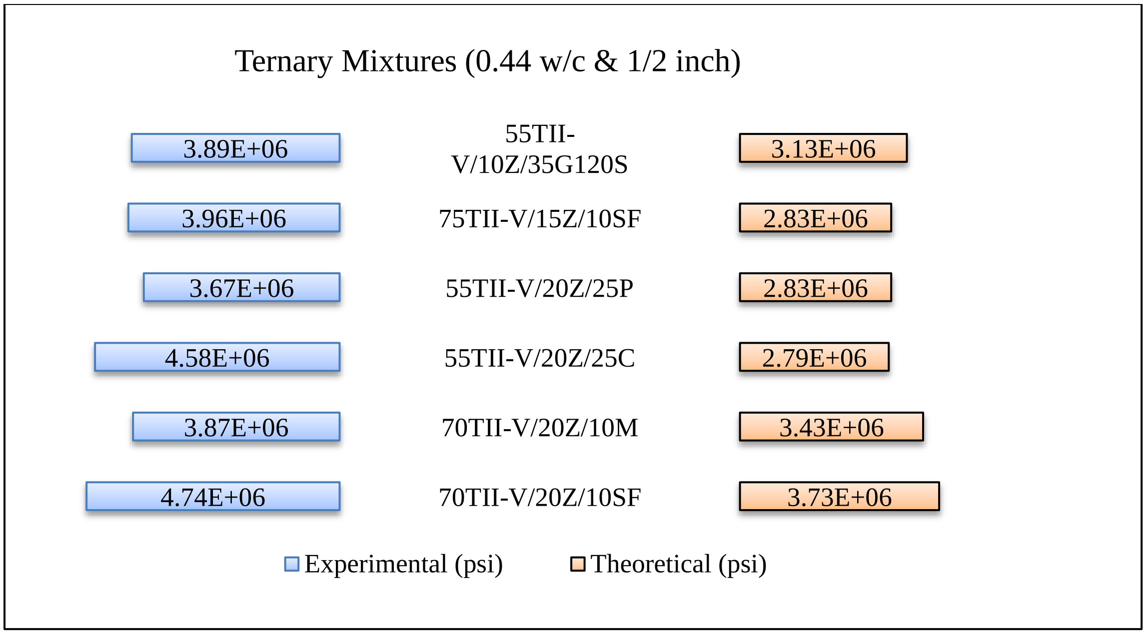


Figure 7. Comparison of experimental to theoretical modulus of elasticity for binary mixtures



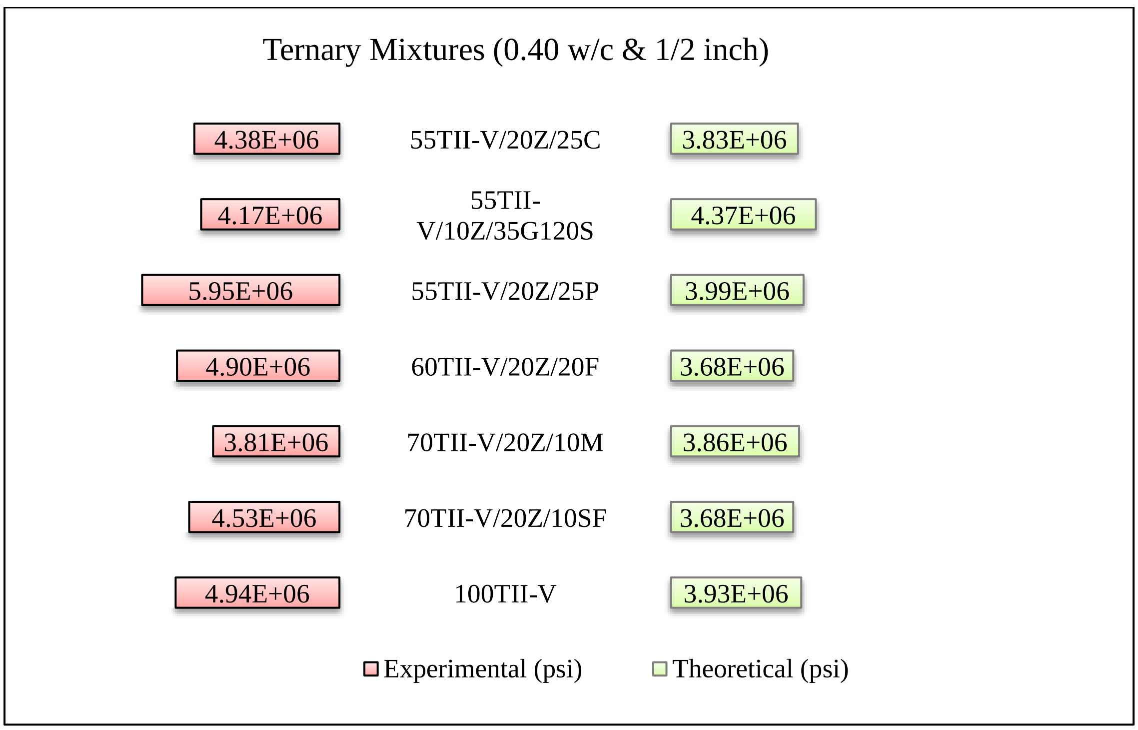
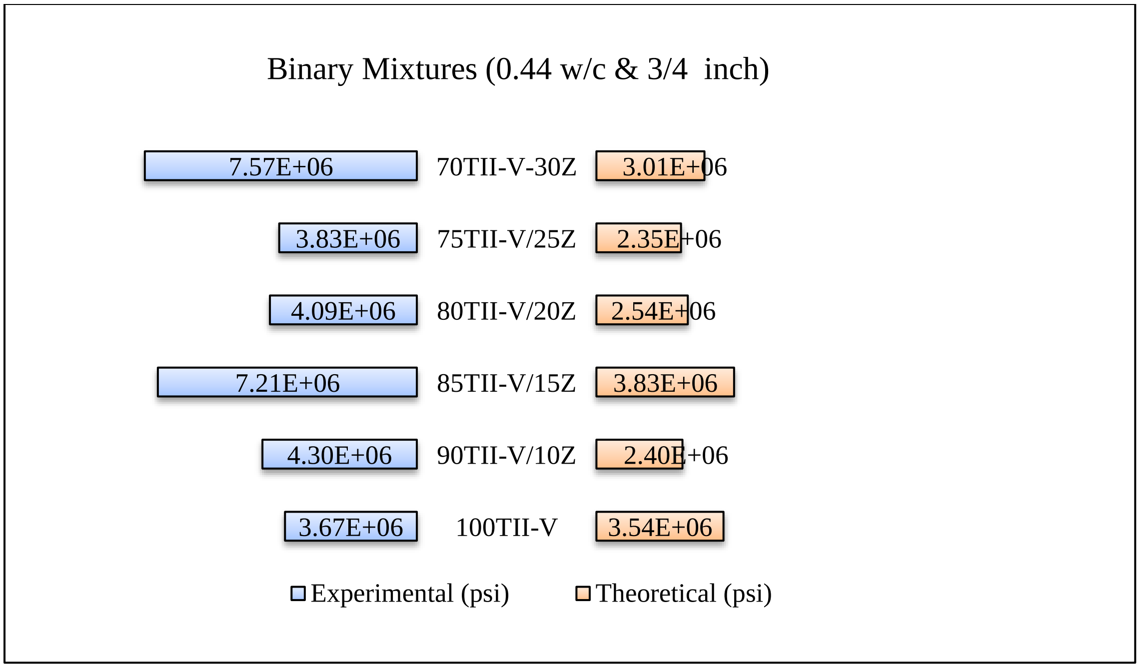


Figure 8. Comparison of experimental to theoretical modulus of elasticity for ternary mixtures



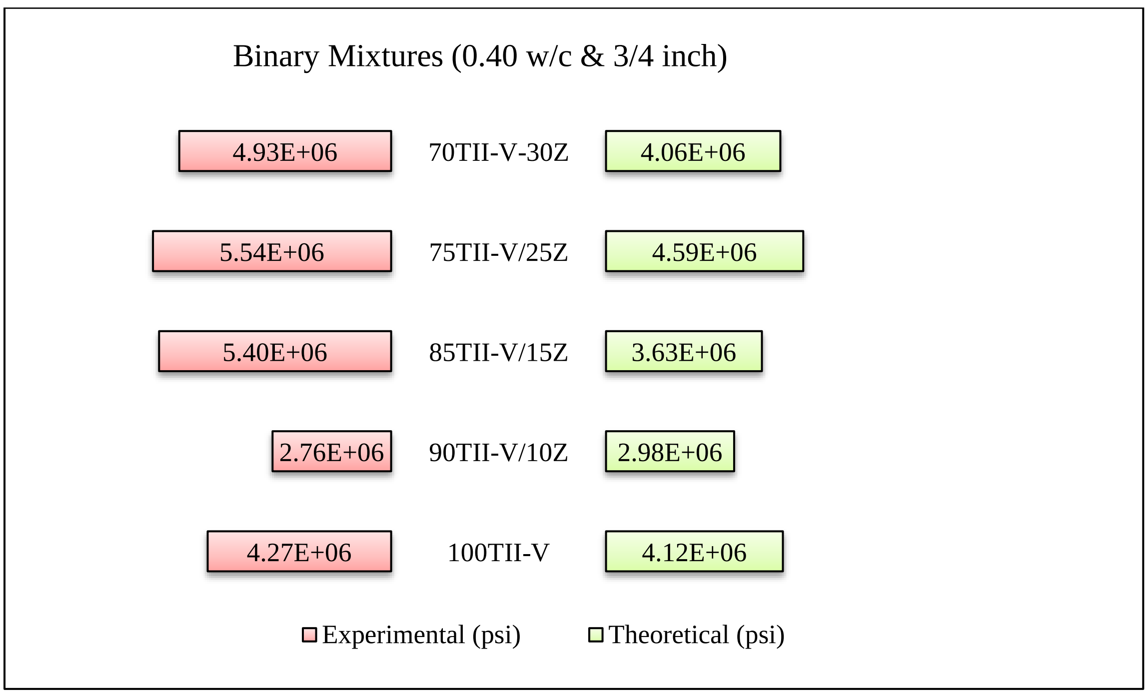


Figure 9. Comparison of experimental to theoretical modulus of elasticity for ternary mixtures

Figures 7 to 9 compare the theoretical values vs. experimental values of modulus of elasticity data for 0.44 and 0.40 W/C and ½" and ¾" aggregate size. Based on the graphs, it can be concluded that ternary and binary mixtures are performing better than OPC mixture in terms of modulus of elasticity. Especially, 75TII-V/25Z and 85TII-V/ 15Z mixtures are the optimum mixtures which can be implemented in the concrete mix design since their values are higher compared to other zeolite based mixtures.

5. Acknowledgment

Author would like to acknowledge Headwaters Resources (Fly Ash), BASF (Silica fume and Chemical admixtures like MBVR and Glenium 3030) and CalPortland Cement (Type II-V) for providing the necessary materials to perform this research.

6. Conclusion

This research shows that High Performance Concrete (HPC) mixtures with zeolite increase the surface electrical resistivity and modulus of elasticity of concrete. In addition, zeolite based concrete mixtures with water to total cementitious material ratio (W/C) at 0.4 and ½" and ¾'' aggregates provide promising results in terms of surface electrical resistivity and modulus of elasticity. Based on the analysis, it can be concluded that zeolite material is sensitive to high W/C ratios and size of the aggregates. In addition, the strength and electrical resistivity for ternary mixtures at W/C 0.4 and ¾" is still being under investigation.

7. Resources

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