INVESTIGATE THE EFFECTS OF NANO ALUMINUM OXIDE ON COMPRESSIVE, FLEXURAL STRENGTH, AND POROSITY OF CONCRETE

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ABSTRACT

INVESTIGATE THE EFFECTS OF NANO ALUMINUM OXIDE ON COMPRESSIVE, FLEXURAL STRENGTH, AND POROSITY OF CONCRETE

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Concrete is relatively porous, and it shows great results in compressive strength. Many experimental methods have been implemented to improve its performance such as compressive strength, flexural strength, and porosity. This thesis presents the compressive strength and porosity behavior of 36 concrete cylinder specimens each measuring 8" x 4"; it also presents the flexural strength behavior of six concrete beams each measuring 21" x 6" x 6". The materials that were used are as follows, a fixed 4% of silica fume (SF) and varying nano aluminum oxide (Nano-Al2O3) in these percentages 0.5, 1, 1.5, and 2. The analysis of the test data regarding compressive strength showed an increase in the mechanical properties when using a 4% SF and 0.5% Nano-Al2O3 content compared to the plain concrete (without additives) and 4% SF (without Nano-Al2O3). An addition of 1% or more of Nano-Al2O3, however, reduces the compressive strength of the concrete. In the porosity test, the continuous increase of Nano-Al2O3 reduces the porosity of concrete. Two percent Nano-Al2O3 results in 0.80% porosity; on the other hand, concrete without additives results in a porosity of 1.65%. Thus, the optimum ratio of Nano-Al2O3 should be 2%, which will be used in the flexural strength test. Lastly, in

the flexural strength test, it was observed that when using 4% SF and 2% Nano-Al2O3 that weakness occurs in about 22.6% of the plain (without additives) concrete and weakness occurs in 11.3% of the concrete after only adding 4% SF (without Nano-Al2O3).

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First and foremost, I would like to thank god for giving me the utmost strength to weave through the strengths and challenges of my daily endeavors while writing this thesis. It is through his strength and guidance that I had adequate ability to do so and without him, I would not have the wisdom and physical ability.

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I wouldn't forget my parents who have always been supportive of my education, making me feel loved and providing all the essentials I needed throughout my study. There has never been a time where I felt left out because my family's encouragement towards my goals was convenient. As the completion of this thesis gave me so much pleasure, not having these respected persons would have, probably, made the results otherwise. That is why they deserve my deepest gratitude.

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CHAPTER I

INTRODUCTION

1.1 Introduction

Concrete is one of most versatile construction materials. Cement mortar is also widely used in construction, but concrete is cheaper and has better characteristics, such as durability, abrasion and fire resistance, and impermeability. Concrete quality can vary widely depending on the ingredients used. Concrete technology is continually improving to meet more required needs using additives (1). Concrete is available in different qualities depending on the needs and the function intended. Cement concrete is seemingly a simple material but one of the most complex element used in construction. The term concrete is derived from the Latin word ‘Concretus' for compact or condensed mixture. Most of the significant structures that have survived both natural and human forces were built out of concrete, taking advantage of its strength, compactness, and durability.

The complex behavior of concrete materials and long-term drying, shrinkage, and morphology of gel structure are not well understood. Fracture mechanism and creep, which is the deformation of structure on sustained load, fatigue, and the bond, are also paramount aspects of concrete that define its unique characteristics. Of critical interest are the effects of modifiers and additives, such as polymers, fibers, silica fume, fly ash, and various nanomaterials, on the behavior of concrete. According to reference (1), concrete accounts for 60-percent of the total construction in this country. Concrete technology is thus of crucial importance, and, unlike other materials, it is made locally. The quality of concrete, the property and performance, vary significantly since it is made from natural materials. Understanding the properties and behavior of its ingredients is essential to producing good quality concrete. The interaction of all the ingredients of concrete in the plastic and hardened conditions is a continuous subject of research and investigations.

The quality of the constituent material and the process of making concrete are vital for the workability and cost effectiveness of any project. Quality control is essential in obtaining good product. Achieving a strong and durable construction is the overall objective of concrete, which needs to be balanced with economical affordability. To increase the strength and durability, one of the most recent significant innovations is the use of nanomaterials. Using nanomaterials (meaning ultrafine) could reduce the cement content on a weight basis and improve the binding effect.

1.2 The Historical Foundation of Concrete and Modern Concrete

The authors of Reference 2 below describe the use of concrete in history starting in early 600 BC A concrete floor in eastern Turkey dates back to 500BC – 1200 BC and confirms the research findings. Although the concrete form and quality used would differ from the present form, understanding of concrete and its use is historically significant. At the time, different binding materials like hydraulic lime of 700 BC were used to construct walls, floors, and water cisterns. Mud, gypsum, and lime were other ancient binder types. Natural cement and Portland cement only replaced these binders about two centuries ago.

Reference 3 depicts the use of concrete in the construction of the Roman harbor design used for long-distance trades in the ancient world. The Roman harbor design is made from ingredients close to the components of hydraulic concrete. Investigation of the structural characteristics of Roman concrete affirms the use of volcanic ash as a crucial component of the hydraulic concrete. Volcanic ash used in the making of ancient concrete had significant application in northern Africa. Concrete floors made of lime and rocks have been identified in royal palaces in Greece dating around 1200-1400 BC, specifically at the Tiryns royal palace. Romans played a significant role in the history and the use of concrete. According to Reference 4, some notable concrete structures in the Roman territory are still standing and are tourist attractions, such as the Roman concrete harbor, the Pantheon, and the Coliseum.

Modern concrete is somewhat different and possesses different characteristics. Concrete is now reinforced with steel bars and tendons to harness even higher structural strength. Also of importance are the varied additives used in today’s concrete that can improve shrinkage, set time, and curing. Portland cement has been in use now for a long time and is the main binder used; although others, such as silica fume and fly ash, are becoming more common. Water is the necessary ingredient needed to bind the aggregate and give the mixture the required hydrations during construction. Concrete is differentiated from cement mortar by aggregate, it containing gravel of considerable size.

1.3 The History of Nanoparticles and Research Objectives

Nanomaterials have a particle size of less than 100 nanometers (nm). For concrete technology, most nanomaterials used in concrete are less than 200nm. The ultrafine nanomaterial helps reduce cement requirement and improve the binding effect. Nanomaterials lessen the micropores and become filler agents thus yielding a denser concrete. As fillers, the nanomaterials reduce the growth of micropores in the ultra-high performance concrete (UHPC) structures. Nanoparticles can be the bridge between bulky and large ingredients (aggregate and sand) and the new molecules developed during the hydration process. Nanoparticles have quantum effects based on the close association with their electrons caused by the small size. The quantum effect harnesses the binding impact with other materials in bulk. The physical properties of the material at the nanoscale are unique compared to the materials in the bulk scale. For metals and their oxides, the nanoparticles exhibit significant change; although the change is not always favorable (5).

Nanomaterials have been found throughout history and numerous civilizations have used such materials. In 600 BC nanowires and carbon nanotubes were manufactured in India (6). Craftsmen used the nanomaterials in the 4th century in their manipulation of heat (7). Lycurgus cups of the 4th century were coated with colloidal gold and silver (7). Between the 9th and 17th century, ceramic glazes used in the Islamic world contained metallic nanoparticles (7). The stained-glass windows used in cathedrals between the 6th and 15th centuries used nanoparticles of gold chloride (7). The Damascus saber blades of the 13th to 18th centuries contained carbon nanotubes and cementite nanowires (7). From the 19th century on, fundamental discoveries would be attributed to the modern understanding and basis of nanotechnology. Some of the findings include the following: In 1857 Michael Faraday discovered the colloidal rugby gold that depicted different colors of nanostructured gold; Victor La Mer and Robert Dinegar discovered monodisperse colloidal materials in 1950 (7); and Erwin Muller discovered the field ion microscope in 1951. Another discovery was the monocrystalline semiconducting quantum dots in a glass matrix by Alexei Ekimov in 1981 (7).

1.4 Nanotechnology for Construction Materials as a Research Need

Nanotechnology for construction materials is credited to the Richard Feynman report of 1959 (7). Significant advancements took place between 1992 and 2001, noting an increase in nanotech products. Although nanotechnology has a less substantial impact on the world economy, countries are in an advantageous position to execute nanotechnology plans. The use of nanotechnology in infrastructural materials like concrete has had a significant impact in recent years. Concrete is the most used material on Earth, used at an average amount of 10km^3/year, compared to clay, timber, and steel, used at an average amount of 2, 1.3 and 0.1 km^3 respectively (8). The primary binder of concrete is Portland cement. The use of nanoparticles has been focused on the ‘greening' process due to the high rate of pollution caused by Portland cement. The secondary focus is the increase in the durability and strength of concrete. The calcium leaching control has been used as a substitute process. CSH gel has an increased porosity resulting in the increased permeability of water and other aggressive materials leading to corrosion (8).

Nanoparticles have had a significant impact in increasing concrete durability. The basis of this impact is the increase in compressive strength of the mortar and reducing corrosion by water and other aggressive materials. As reported by Reference 9 below, the nanoparticles would improve the crystallization between the Ca (OH)2 particles. Using nano-Al_2O_3 above 1% has been found to decrease the compressive strength of mortar. Other than interference to the structure, the bulk materials of Al_2O_3 would decrease the ratio of water, thus decreasing hydration development (10). Conforming to Reference 11 below, making the belite cement would show comparably better mechanical strength than the Portland hydrated cement; however, the initial mechanical strength is low. The use of nanomaterials can enhance activation of the initial strength of the belite cement. The use of nano-alumina shows better results compared to nano-silica, although both show improvement in the mechanical properties of the concrete (12). The research project is focused on the study of the use of nano aluminum oxide.

Adding 1% Al_2O_3 to a concrete mixture increases the compressive strength of the concrete by decreasing the micropores within the concrete structure (10). Adding the proper amount of nano-Al_2O_3 in the mixture reduces the porosity of the concrete. The nano-alumina replaces the tiny pores within the concrete structure, preventing the passage of water and other aggressive materials into the structure to lead to corrosion. The use of nano- Al_2O_3 increases the surface area and changes the microstructure of the mortar which in turn increases the durability of the concrete. As stated in Reference 13, a slump -flow test for fresh mortar using a V-funnel confirms that for self-compacted mortar with nano-Al_2O_3 (SCM+ Na) the rate of materials flow was decreased significantly compared to the ordinary mortar.

1.5 State of Purpose and Objective

Many researchers have studied the effect of adding nano aluminum in mortar cement and concrete. Most of the studies focused on compressive strength. Few, if any, investigated the effect of nano aluminum on porosity and flexural strength. In addition, few have investigated the combined effect of additives such silica fume and nano aluminum on concrete.

Thus, the purpose of this thesis is:

a) Investigate the effect of nano aluminum on the compressive strength, porosity, and flexural strength of concrete.

b) Investigate the combination of additives of silica fume and nano aluminum on the compressive strength, porosity, and flexural strength of concrete.

1.6 Literature Review

Several research studies have been conducted to confirm the impact of nanomaterials on concrete. Reference 12 studied the frost resistance and the mechanical properties of concrete with nano-alumina and nano-silica using the nanoparticle as a particle substitute in cement. By subjecting the specimens to cycles of freezing and thawing in water in several cycles, the outcome of the research showed that frost resistance improved in the nanoparticle concrete due to the more compacted microstructure. The nano-Al2O3 gave better results in the improvement of frost resistance than the nano-SiO_2. On the contrary, the compressive strength of ordinary concrete with nano-SiO_2 was higher than with nano-Al_2O_3 in the same amount. References 9 and 12 confirmed that nanoparticles of SiO_2 improved the properties of concrete. The survey assessed for split tensile strength, pore structure, thermal behavior and the microstructure of concrete with nano-SiO_2, the normal Portland cement concrete.

According to Reference 11, studies indicate significant progress in the field of nanomaterials and the development of the cementitious composites at the nanoscale. The research shows that the engineered materials (0D nanoparticles, 1D nanofiber and 2D nanosheet) have significant application in the development of concrete. The outcome is that although 0D and 1D material have been useful, there is a need for review of the nanocomposites to improve cement. The study results show that incorporation of nanomaterials in low dosages has a significant effect on the workability, mechanical properties, hydration, and the microstructure of the cement-based composites.

Studies on the nanoparticles of metal oxides had earlier confirmed improvement in the mechanical properties. A study shown in Reference 14 confirm metal oxides’ nanoparticles to have stability in electrical, structural and optical properties. The research shows that aluminum oxide nanoparticles have relatively better properties over most of the metal oxides. Nano-alumina has a myriad of applications across many industries as an abrasive material and as gas diffusion barriers. The alumina nanoparticles have a wide band-gap material. This means that its existence can vary, and it can take various crystal forms, such as alpha which is the compact pace. In keeping with Reference 15, the alpha phase is most stable mainly due to its hard-insulating and transparent properties.

Other studies show that nano-alumina application is practical and economically viable. As reported by Reference 16, there are many ways to generate Al_2O_3 nanoparticles. The methods include using pyrolysis, hydrothermal methods, sol-gel, sputtering and laser ablation. Pursuant to Reference 17, the use of pulsed laser ablation has more benefits compared to others. The purity process is faster than in other methods, and the nanoparticle collection methods are easier than in the gaseous environment. Also, the process is immune to any complex agents common in other processes. Conforming to References 18 and 19, the method is cost effective and saves time.

A study shown in Reference 20 confirms that the choice of the material would influence the phase of alumina obtained. For example, starting with boehmite, (AlO(OH)), the alpha alumina will be formed at a temperature of around 1200^0C. The stages passed will begin by gamma (γ) followed by delta (δ) then theta (θ) before finally forming alpha (α). If gibbsite, Al (OH)3, is used instead of boehmite, different transition elements will be produced. It will begin with Chi (X) followed by Tau (τ) then Kappa (κ) which precedes theta (θ) before forming alpha (α) (13).

According to Reference 13 nano-crystalline ceramics exhibit unusual mechanical and physical properties owing to their small size. Based on the findings in Reference 22, at elevated temperatures, nano-crystalline ceramics exhibit both extensive and plastic deformation due to grain-boundary sliding. In addition to this, nano-crystalline ceramics also exhibit superplasticity at high strain rates. Also, the high strains occur in Al2O3 and other nanoparticles, such as siliconnitride. In keeping with Reference 23, ceramic nanostructures have low thermal conductivity. Heat conduction would be achieved at a low level of conductivity depending on the path of protons.

A recent study, as described in Reference 24, shows that there is high research need within the field of use of nanoparticles in concrete. The research focuses on the supplementary cementitious materials (SCM) which are the materials used to replace a portion of cement in concrete to improve strength and enhance durability. The research findings show that the supplementary cementitious materials (SCMs) used in Portland cement for decades, and most of the research focuses on the exploration of new materials or modification by use of limestone or nano-silica to improve performance. The study creates a research need since, despite use of nano-silica, efficiency is yet to be attained.

According to Reference 25, improvement of concrete quality would be incomplete without the phase change materials (PCM). The phase change materials are added to modify the energy storage capacity of concrete. Concrete has found significant application in residential and commercial construction. The energy storage capacity of concrete is most significant in the residential buildings, as the relatively large thermal mass of concrete helps store energy during the day and releases that energy at night. This makes the quality of cement a vital element of any scientific innovation in the construction field. As reported in Reference 26, aluminum nanoparticles had found earlier application as a phase change material in other fields (explosive and propellant mixtures). Reference 27 showed mortar and paste samples with Ground Granulated Blast-Furnace Slag (GGBS) have a high content of Al_2O_3 which slowed hydration; this helped improve the abrasion characteristics.

CHAPTER II

METHODOLOGY AND EXPERIMENTS

2.1 Methodology

The methodology of this thesis is to accomplish the stated purpose of this research; I intend to use a plain mix (without silica fume and nano aluminum oxide) to compare as my benchmark. Then I intend to study the effect of compressive strength and porosity by adding 4% silica fume to the cementations (without nano aluminum oxide). Then I intend to add four different amounts of nano aluminum oxide (0.5%, 1%, 1.5%, 2%) and observe its effect on compressive strength and porosity. After that, the optimal result of the porosity in the combination of silica fume and nano aluminum oxide will be taken to study its effect in flexural strength. Since I am dealing with composite materials, all samples are going to be tested after 28 days. Lastly, I intend to study the cost of using nano aluminum oxide in concrete that has a unit weight of 142 lb/ft^3.

2.2 Materials

A. Portland Cement Type III:

Portland cement type III produces high qualities in pressure driven concrete compared with ordinary Type I-II Portland cement. Type III Portland cement reaches high and early strength (28). It also is normally utilized in grouts, mortars and cement.

B. Superplasticizer:

Superplasticizers are high range water reducers and synthetic admixtures utilized where all around scattered molecule suspension is required (28). These polymers are utilized as dispersants to stay away from molecule isolation (coarse and fine aggregate), and to enhance the stream qualities of suspensions.

C. Coarse Aggregate:

The shape of coarse aggregates and its shape will improve concrete's strength and has more effectiveness in high strength concretes (28). One of the main problems of coarse aggregate is that it is not easy to determine the crushing strength of the aggregate, so the concrete compressive strength cannot exceed too much.

D. Fine Aggregate

All-purpose sand was used in the mix because it is cheaper and shows great results in concrete. Since salts are making the concrete weaker, all-purpose sand is already washed and derided.

E. Silica Fume

Approximately 4% of concrete cementitious was used in the mix to make the concrete more graduated to bond the nanomaterials. Silica fume indicates an increasing compressive strength (29) and decreasing porosity because it reacts with the water and cement creating more bonds.

F. Nano Al_2O_3

Using Al_2O_3 implies that aluminum oxide, which has a size of less than 30nm. aluminum oxide Al2O3 nanopowder nanoparticles water dispersion (Alpha, 20wt%) (30), be used in the research. The characteristics of Al_2O_3 are to enhance density, smoothness, thermal fatigue resistance, fracture toughness, creep resistance, and polymer products' wear resistance. Also, Al_2O_3 reduces the growth of the micropores in the concrete structures and increases the durability of the concrete.

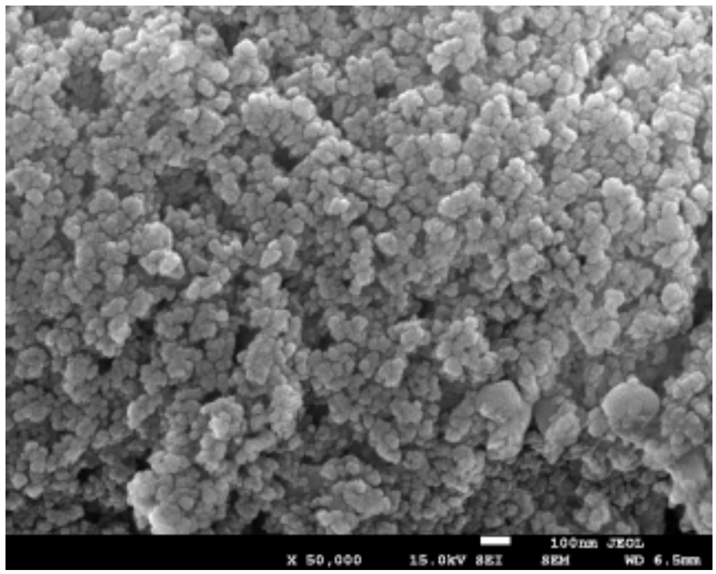


Figure 2.1: Nano Al2O3 (30)

2.3 Gradations of Materials

The focus of this study is to reduce the porosity of the concrete. That could be done be focusing on the gradations of the materials. If we could compact the concrete by closing the pore-places in the concrete, the experiment would be a success. Coarse aggregate maximum particle size is 3/8. Fine aggregate particle size has a maximum of 0.1 in; cement size particle is between 50 µm to 90 µm (31); silica fume particle size is less than 1 µm (32); and nano Al_2O_3 size is 30nm (30). Figure 2.2 is a drawing that shows the gradations of all materials in the concrete.

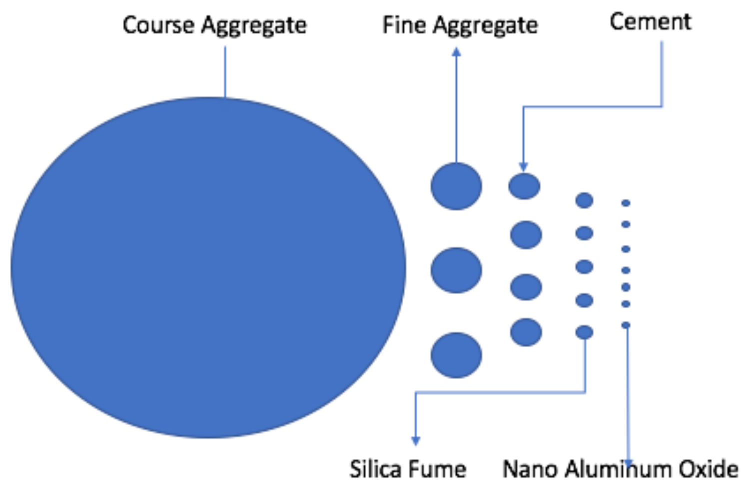


Figure 2.2: Gradation Material

2.4 Mix Design

The main goal is to achieve a concrete of 6000 psi and to examine the effect of adding nano aluminum oxide on the compressive strength of a concrete specimen. Moreover, during the experiment, 4% silica fume is used to examine its effect on the concrete, then 4 deferent percentage of nano aluminum oxide (0.5%, 1%, 1.5%, 2%) were added to determine the impact of nanomaterials in the tests.

1) By using the American Concrete Institute (ACI) method, Table 19.2 (28) was used to get the ratio between water over cementitious material and average compressive strength of concrete.

Table 2.1: Relation between water/cementitious material ratio and average compressive strength of concrete (28)

Table 19.1: **Relation between water/cementitious material ratio and average compressive strength of concrete, accordording to ACI 211.1–91 (Reapproved 2002)**

Average compressive strength at 28 days, MPa (psi)	Effective water/cementitious material ratio, by mass	
	Non-air entrained concrete	Air entrained concrete
41.4 (6000)	0.41	–
34.5 (5000)	0.48	0.40
27.6 (4000)	0.57	0.48
20.7 (3000)	0.68	0.59
13.8 (2000)	0.82	0.74

The goal is to reach 6000 psi of average compressive strength at 28 days using non-air entrained concrete (28).

Water/Cementitious material ratio = 0.41

2) Table 19.4 (28) achieves the approximate requirements for mixing content for different and normal maximum size of aggregates, assuming the maximum aggregate size is 3/8 in and slump test is 3-4 in:

Table 2.2: Approximate requirement for mixing Water and Air (28)

Table 19.4: **Approximate requirements for mixing water and air content for different workabilities and nominal maximum sizes of aggregates according to ACI 211.1–91 (Reapproved 2002)**

Workability or air content	**Water content, kg/m³ (lb/yd³) of concrete for indicated maximum aggregate size**							
	10 mm ($\frac{3}{8}$ in.)	**12.5 mm ($\frac{1}{2}$ in.)**	**20 mm ($\frac{3}{4}$ in.)**	**25 mm (1 in.)**	**40 mm ($1\frac{1}{2}$ in.)**	**50 mm (2 in.)**	**70 mm (3 in.)**	**150 mm (6 in.)**
	Non-air-entrained concrete							
Slump:								
30–50 mm (1–2 in.)	205 (350)	200 (335)	185 (315)	180 (300)	160 (275)	155 (260)	145 (220)	125 (190)
80–100 mm (3–4 in.)	225 (385)	215 (365)	200 (340)	195 (325)	175 (300)	170 (285)	160 (245)	140 (210)
150–180 mm (6–7 in.)	240 (410)	230 (385)	210 (360)	205 (340)	185 (315)	180 (300)	170 (270)	–
Approximate entrapped air content, per cent	3	2.5	2	1.5	1	0.5	0.3	0.2

After assuming the slump test is 3-4 in and assuming the maximum aggregate size is 3/8 in, the water content (lb/yd^3) of concrete will be 385 lb/yd^3.

The following steps will establish the amount of cement:

W/C=0.41

W=385 lb/yd^3

(385 (lb/yd^3)/C) = 0.41

Cement content = (385 (lb/yd^3)/0.41) = 962.5 lb/yd^3

3) Using Table 19.4 (7) to estimate the unit weight of fresh concrete as given:

Table 2.3: First Estimate of Density (28)

Table 19.10: **First estimate of density (unit weight) of fresh concrete as given by ACI 211.1–91 (Reapproved 2002)**

Maximum size of aggregate		**First estimate of density (unit weight) of fresh concrete**			
		Non-air-entrained		**Air-entrained**	
mm	**in.**	**kg/m³**	**lb/yd³**	**kg/m³**	**lb/yd³**
10	$\frac{3}{8}$	2285	3840	2190	3690
12.5	$\frac{1}{2}$	2315	3890	2235	3760
20	$\frac{3}{4}$	2355	3960	2280	3840
25	1	2380	4010	2285	3850
40	$1\frac{1}{2}$	2415	4070	2320	3910
50	2	2445	4120	2345	3950
70	3	2495	4200	2400	4040
150	6	2530	4260	2440	4110

Maximum size of aggregate = 3/8 in, so the unit weight of fresh concrete = 3840 lb/yd^3.

4) Using Table19.9 (28) to get the dry bulk volume of coarse aggregate per unit volume of concrete as given:

Table 2.4: Dry Bulk volume of coarse aggregate (28)

Table 19.9: **Dry bulk volume of coarse aggregate per unit volume of concrete as given by ACI 211.1–91 (Reapproved 2002)**

Maximum size of aggregate		Dry bulk volume of rodded coarse aggregate per unit volume of concrete for fineness modulus of sand of:			
mm	**in.**	**2.40**	**2.60**	**2.80**	**3.00**
10	$\frac{3}{8}$	0.50	0.48	0.46	0.44
12.5	$\frac{1}{2}$	0.59	0.57	0.55	0.53
20	$\frac{3}{4}$	0.66	0.64	0.62	0.60
25	1	0.71	0.69	0.67	0.65
40	$1\frac{1}{2}$	0.75	0.73	0.71	0.69
50	2	0.78	0.76	0.74	0.72
70	3	0.82	0.80	0.78	0.76
150	6	0.87	0.85	0.83	0.81

Fine-modulus from lab test = 2.56 and maximum size of aggregate = 3/8 in, by doing interpolation between 2.4 and 2.6 the volume of coarse aggregate = 0.484 m^3/m^3

So,

0.484 m^3/m^3 x 27 = 13.068 ft^3/yd^3

Coarse aggregate OD = 13.068 x 100 = 1306.8 lb/yd^3

Coarse aggregate SSD = 1320 lb/yd^3

5) Fine aggregate will be found by using the following equation:

Total Weight of concrete = Water Content + Cement Content + Coarse Aggregate + Fine aggregate.

Fine aggregate = Total Weight of concrete – (Water Content + Cement Content + Coarse Aggregate).

Fine aggregate = 3840 – (385 + 962.5 + 1320) = 1172.5 lb/yd^3

Superplasticizer is recommended to be between 3 to 4.5 gram per 1 kg. Also, the silica fume and the nano aluminum oxide percentage will be taken from the percentage of cement and will be used as additive materials.

Table 2.5: Summary of the Mixing Mix Design

#	lb/y^3	%
Water	385	10.03
Cement	962.5	25.07
Coarse Aggregate	1320	34.38
Sand	1172.5	30.53
Superplasticizer	3.61	0.09
4% Silica Fume	38.50	1.00

Table 2.6: Summary of Nano Aluminum Oxide in the mix design

Nano Al2O3	lb/y^3	%
0.50%	4.813	0.125
1%	9.625	0.251
1.50%	14.438	0.376
2%	19.25	0.502

2.5 Mixing Process

Instead of using a regular concrete mixer, a hand machine mixer was used to make sure that the nano aluminum oxide particles are homogeneous with the concrete and are mixing well.

Figure 2.3: Dual Paddle Programmable Power Mixer with Stand

Steps of mixing plain concrete involved collecting all the materials needed (water, cement, coarse aggregate, fine aggregate, superplasticizer); letting the water stand in the mixer bucket; adding the superplasticizer over the water and mixing it; and adding the cement over the mix and mixing it until fully homogenized. In addition, fine aggregate is added over the mix and mixed until it is fully homogenized; and the coarse aggregate was added over the mix and mixed until it was fully homogenized.

Step of mixing concrete + 4% silica fume included collecting all the materials needed (water, cement, coarse aggregate, fine aggregate, superplasticizer, silica fume) and letting the water stand in the mixer bucket. Furthermore, the silica fume was added over the water and mixed, since the silica fume is a material that has a chemical reaction with the water and will be more effective when adding the cement; the superplasticizer was added over the water and mixed; the cement was added over the mix and mixed until fully homogenized, the fine aggregate was added over the mix and mixed until fully homogenized, and the coarse aggregate was added over the mix and mixed until fully homogenized.

Steps of mixing concrete + 4% silica fume + nano aluminum oxide involved going to the mixing process, since the nano aluminum oxide water dispersion and the 1000g of nano aluminum oxide battle has 20% of nano content and 80% of water. Therefore, the following table shows the exact amount of nano aluminum oxide water dispersion is required to reach 0.5%, 1%, 1.5%, and 2% of nano content and how much water will be used after adding the nano.

Table 2.7: Summary of the Nano Aluminum Oxide Water Dispersion and Water in the Mix Design

Nano Al2O3	lb/y^3	% of Nano	% Water
0.50%	24.06	0.63	9.52
1%	48.12	1.25	9.02
1.50%	72.19	1.88	8.52
2%	96.25	2.51	8.02

Collecting all the materials needed (water, cement, coarse aggregate, fine aggregate, superplasticizer, silica fume); letting the water stand in the mixer bucket; adding the nano Al_2O_3 fume over the water and mixing it. (It will be homogeneous very quickly because of the choice of nano that was used was water dispersion.) After that, the silica fume was added over the mix and mixed, since the silica fume is a material that has a chemical reaction with the water and will be more affective when adding the cement; the superplasticizer was added over the mix and mixed; the cement was added over the mix and mixed until fully homogenized, the fine aggregate was added over the mix and mixed until fully homogenized and the coarse aggregate was added over the mix and mixed until fully homogenized.

Table 2.8: Test Matrix

#	PLAIN	4% SF	0.5% NA+ 4% SF	1% NA + 4% SF	1.5% NA + 4% SF	2% NA + 4% SF	TOTAL
Compressive strength (Cylinders)	3	3	3	3	3	3	36
Porosity Test (Cylinders)	3	3	3	3	3	3	
Flexural Test (Beams)	3	3	0			3	9

2.6 Test and Experiment

Measuring mechanical properties of concrete is especially critical considering how they will affect its structural stability, as well as that of the building material constructed using such concrete (33). In this regard, the addition of individual components such as surfactants, pozzolans, fibers, or steel bars will have a direct impact on the concrete’s strength, among other mechanical properties (33).

Similarly, the water content during the curing process as well as the environmental humidity and the temperature may affect the porosity of the resulting concrete material (33). Lastly, the proportion of the different constituents and the environmental temperature has a direct impact on the concrete's tensile strength. An unbalanced composition or an excessively low or high temperature during the curing of the concrete material may result in the preparation of a highly fragile concrete, that will easily crack during the curing process or if installed on regions with cold water (33). The present report illustrates the different methods used for the measurement of the flexural strength, compressive strength, and porosity of the concrete.

2.6.1 Flexural Strength Test

Though the concrete material is hard, it needs to have a certain flexibility, most especially during the curing process of the material. Such flexibility will enable the resulting concrete material to adapt to the changes in volume and size upon variations in the environmental temperature. Thus, an appropriate flexibility level will contribute to minimizing the risk of the formation of cracks in the concrete matrix (34).

The flexural strength test is widely used in the evaluation of the flexibility of both concrete and other construction materials. This test measures the strength required to flex or fold a beam. During the flexural strength test, the axes of the beam bar must be coplanar, while the load applied on the beam test bar is perpendicular to such plane. While other designs are possible, the most commonly used flexural strength method for the measurement of the flexibility of concrete materials is the third point load method. Where the loads are applied at $^1/_3$ of the span length considered from each side of the beam, as illustrated in the diagram shown in figure 2.4. When using this design, the flexibility of the concrete material can be correlated to the maximum bending height of the concrete material while applying the maximum load (34).

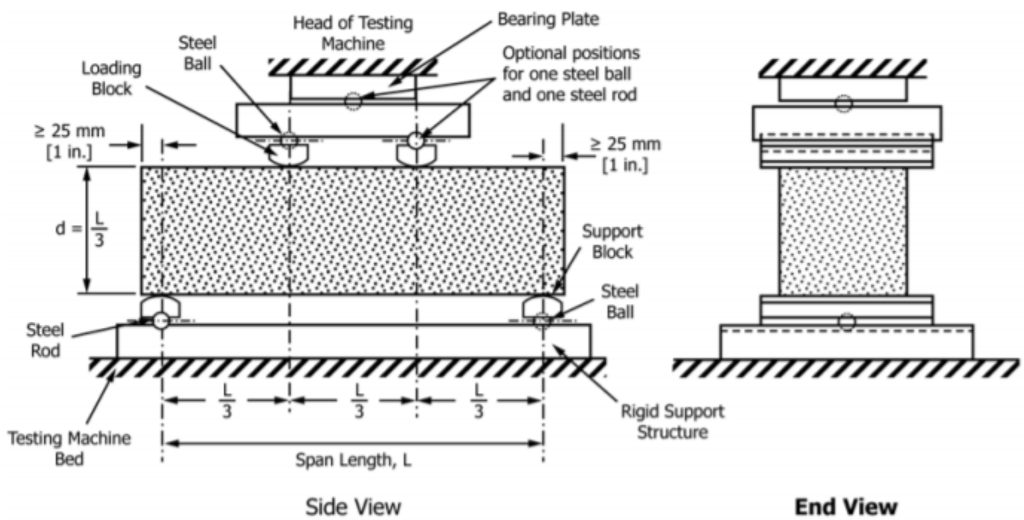


Figure 2.4: Schematic diagram showing the different variables involved in the design of the third point flexural strength test method (34)

The dimensions of the beam test bar are crucial for the outcome of the test. In this sense, the beam must be approximately five centimeters longer than the span length of the testing machine. On the other hand, it should be one-third of the span length of the testing machine. The beam's standard size is of 21"x 6"x 6". Other essential requirements to consider when preparing the beam is that the top and bottom surfaces of the beam should be precisely perpendicular to the beam's axis. Any deviation from the right angle would result in an unbalanced distribution of the applied load; that would deform the concrete sample at a different strength, hence resulting in a falsified recording of the concrete's flexibility. Additionally, the external surface of the test sample must be smooth, and free of any scar, indentation, or hole that would represent an especially fragile point in the test sample, resulting in its breakage at a substantially lower load (34).

2.6.2 Compressive Strength Test

Strength is probably one of the most important mechanical characteristics of the concrete considering how it must endure the high weight of the rest of the building materials without becoming deformed.

As a result, civil engineers have focused their attention on the development of different tests to measure the strength of the concrete and cementitious materials under different settings. Briefly, these methods consist of the evaluation of the degree of the deformation resulting from applying a compressive load on the material, as illustrated by the schematic diagram shown in figure 2.5. (35)

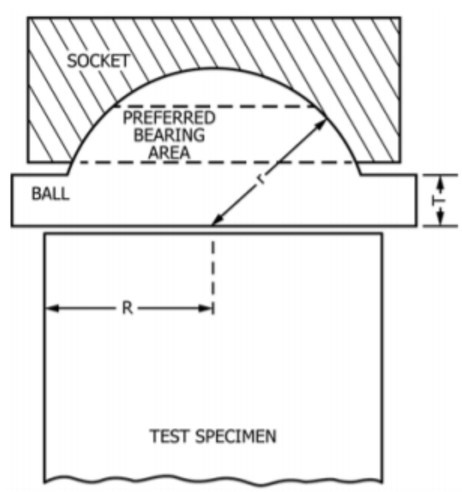


Figure 2.5: Schematic diagram of an upper bearing block used in the measurement of the compressive strength of concrete and contentious materials (35)

The main requirements to use this compressive test method include the need to prepare a cylinder test sample with similar characteristics as the one used in the evaluation of the flexural strength. In this regard, the top and bottom surfaces of the cylinder need to be perpendicular to the central axis of the cylinder. Additionally, the surfaces must be smooth, without any traces of scars, indentations, or holes. It is also important that the density of the concrete material is, at most, 50 lb/ft^3, as higher densities could harm the steel balls used in the application of the load. (35)

2.6.3 Porosity Test

The last mechanical property of concrete addressed in the present report is its porosity. The evaluation of the porosity of the concrete material is especially critical if such concrete will be used as building material in regions with a high variation of temperature throughout the year. In this regard, the exposure of concrete to temperatures below 5ºC or above 30ºC are substantially more sensitive to deterioration through cracking processes if the concrete shows a relatively high porosity (36). Taking this into account, civil engineers have developed different methods to control and minimize the porosity of the material through the addition of different materials that, like surfactants, modify the superficial tension during the curing and aging process of the concrete, affecting the evaporation of water during such means, and hence the porosity of the final product. This practice, however, can only be done in the preparation of the paste of concrete. As such, the civil engineers will typically prepare a test sample to measure the porosity expected on site and then adjust the exact formulation of the concrete before applying it as a building material.

The method commonly used in the measurement of the porosity of concrete materials evaluates the porosity as a function of the amount of absorbed water when the concrete material is immersed in water. The samples' height is 8" and 4" diameter. In this regard, the test involves the following necessary steps:

(1) Preparing the concrete test sample, which may be either a cube or a cylinder.

(2) Drying and weighing the concrete test sample.

(3) Immersing the concrete sample in water and letting stand still for 30 minutes.

(4) Weighing the concrete test sample while it is submerged in the water.

(5) Calculating the amount of water absorbed by the concrete test sample as the difference between the weights recorded in steps 2 and 4.

(6) Estimating the porosity of the concrete by applying the equation: (37)

$$P = \left(1 - \frac{W_d - W_s}{\rho_w}\right) * \frac{1}{V_t} * 100 - 100 \qquad \text{(Equation 1)}$$

- W_d is the weight of the dry sample.
- W_s is the weight from the submerged sample.
- ρ_w is the density of the water.
- V_t is the total volume of cylinder.

CHAPTER III

RESULTS AND DISCUSSION

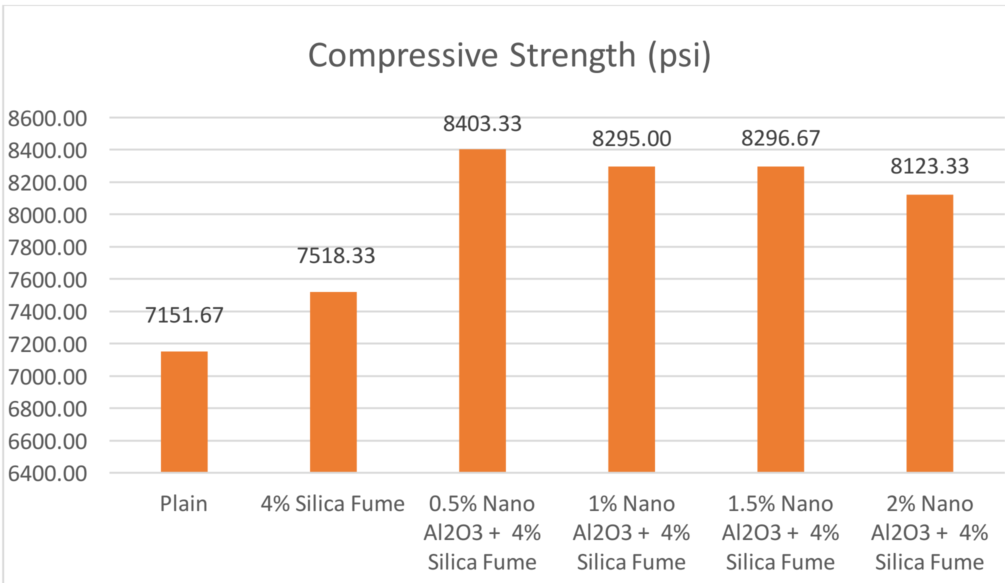
3.1 Compressive strength

In compressive strength, 18 cylinders were tested. Additionally, using constant amounts of SF (4%) and varied amounts of nano aluminum oxide (0.5%, 1%, 1.5%, 2%), the results are as indicated below:

Table 3.1: Compressive strength (psi)

#	Plain (psi)	4% SF (psi)	0.5% NA + 4% SF (psi)	1% NA + 4% SF (psi)	1.5% NA + 4% SF (psi)	2% NA + 4% SF (psi)
1	6765	6740	8240	8660	8560	7750
2	7230	7360	8415	8130	7935	8035
3	7460	8455	8555	8095	8395	8585
AVG	7151.67	7518.33	8403.33	8295.00	8296.67	8123.33

From the given table 3.1 above, the strength of 4% silica fume is higher than that of plain. Also, when a given portion of nano Al_2O_3 is added to a constant amount of silica fume, the compressive strength is affected. For example, when adding more than 1% of Al_2O_3, the strength reduces.



Graph 3.1: Compressive strength (psi)

By examining the results from Table 3.1 and Graph 3.1:

A) Plain concrete has a low strength, but after adding 0.5 % nano Al_2O_3 and 4% silicate fumes, the strength increases and reaches the optimum level. An addition of 1% or more of nano Al_2O_3, however, reduces the compressive strength of the concrete. Thus, for better results an engineer ought to use 0.5 % of the nano Al_2O_3.

B) When nano Al_2O_3 (1%-2%) molecules are used, the compressive power decreases to a figure 3.1, which is close to the controlled specimen. The fact that the amount of pozzolan existing in the combination is greater than the volume needed to be added with liberated lime during hydration, results in leaking out of excess silica. Although it does not give strength, it replaces cementitious material, and, as a result, it reduces its strength (38). Also, the defects produced when nanoparticles disperse could be the cause.

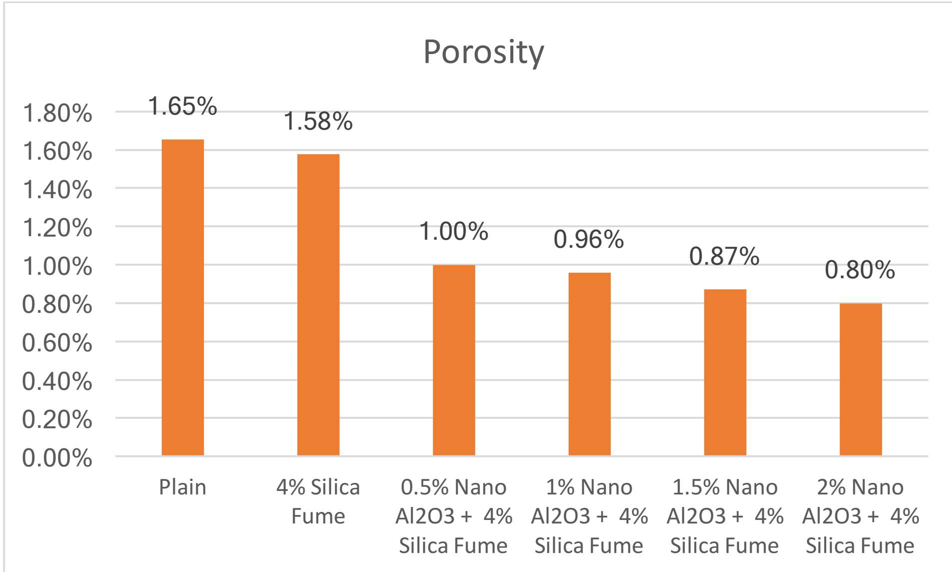
3.2 Porosity Test

In the porosity test, 18 cylinders were tested. Moreover, a constant amount of SF (4%) and varied amounts of nano aluminum oxide (0.5%, 1%, 1.5%, 2%) were used. Also by using the following equation, the results are as indicated in Graph 3.3:

$$P = \left(1 - \frac{W_d - W_s}{\rho_w}\right) * \frac{1}{V_t} * 100 - 100$$

Table 3. 2: Porosity

#	Plain	4% SF	4% SF + 0.5% NA	4% SF + 1% NA	4% SF + 1.5% NA	4% SF + 2% NA
height (in)	8	8	8	8	8	8
Radius (in)	2	2	2	2	2	2
Volume (in^3)	100.53	100.53	100.53	100.53	100.53	100.53
Average Dry Weight (lb)	8.4604	8.3677	8.3867	8.4599	8.435	8.4631
Average Submerged Weight (lb)	8.5204	8.4251	8.423	8.4947	8.4666	8.4921
Water Density (lb/in^3)	0.036	0.036	0.036	0.036	0.036	0.036
Porosity	1.65	1.58	1.00	0.96	0.87	0.80



Graph 3. 2: Porosity Test

By observing results in Graph 3.2, the following analysis could be determined:

A) The continuous increase of nano Al_2O_3 reduces the porosity of concrete. The more the content of silica fumes in the mixture, the higher the capillary-pore development. A 2% nano Al_2O_3 gives a 0.80% porosity, whereas a 4% silica fume creates more space between the particles. Also, plain content gives a porosity of 1.65%, thus it affects the compressive strength of the cement.

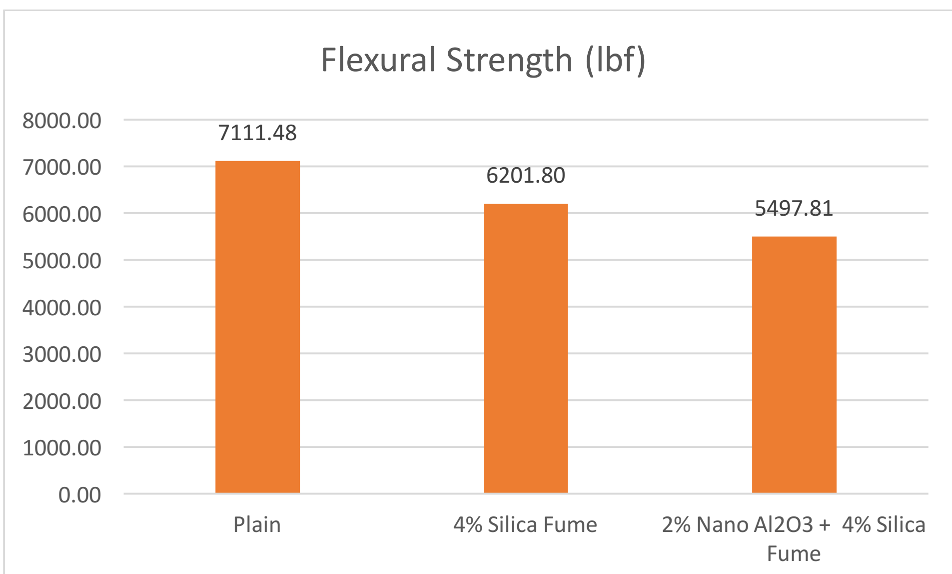
B) Basing on the graph above, the addition of nano tends to refill the open spaces found in cement paste and aggregates. Thus, the quality of the movement zone improves. The addition of nano AL_2O_3, improves the surface hardness and abrasion resistance. Thus, 2% is the best ratio that can be used. Also, it is important to note that in the cement the optimum ratio of nano AL_2O_3 should be 2%.

3.3 Flexural Strength

In the flexural strength test, six beams were tested. Moreover, a constant amount of SF (4%) and 2% of NA were used to investigate their effect in flexural strength.

Table 3.3: Flexural Strength

#	Plain (lbf)	4% Silica Fume (lbf)	2% Nano Al2O3 + 4% Silica Fume (lbf)
1	6191.29	6620.36	5266.92
2	8031.66	5783.232	5728.7
AVG	7111.48	6201.80	5497.81



Graph 3.3: Flexural Strength

According to Table 3.3 and Graph 3.3:

A) The optimum results of the porosity test were using 4% silica fume and 2% nano AL2O3; any additional percentage of AL2O3 weakens its flexural strength. Therefore, only 2% of Nano AL2O3 should be used.

B) When silica and nano aluminum oxide are added to a specimen, the flexural strength decreases in about 22.6% of the plain concrete and 11.3% after only fixing the amount of silica fume to 4%. However, when the volume of nanoparticles increases, the time decreases, which indicates that nano AL2O3 hydrates faster as compared to plain cement because of its greater surface energy. Besides, its surface energy is high and its particles are smaller in size. The latter characteristics make the number of surface particles rise faster. The surface molecules are highly unstable and active, which increases the reaction speed. Thus, when using nano AL2O3, a careful tactic should be considered (39).

Figure 3.1: NA 2% samples before starting the test

3.4 Cost

Table 3. 4: Cost of Using Nano Aluminum Oxide

<table>
<tr><th>#</th><th>Cement
%</th><th>Nano Al2O3
%</th><th>Cement
(lb/ft^3)</th><th>Nano Al2O3
(lb/ft^3)</th><th>Cost
(25$*142lb/ft^3)</th></tr>
<tr><td>1</td><td rowspan="4">25.07</td><td>0.50%</td><td rowspan="4">35.6</td><td>0.18</td><td>22.25</td></tr>
<tr><td>2</td><td>1%</td><td>0.36</td><td>44.49</td></tr>
<tr><td>3</td><td>1.50%</td><td>0.53</td><td>66.74</td></tr>
<tr><td>4</td><td>2%</td><td>0.71</td><td>88.98</td></tr>
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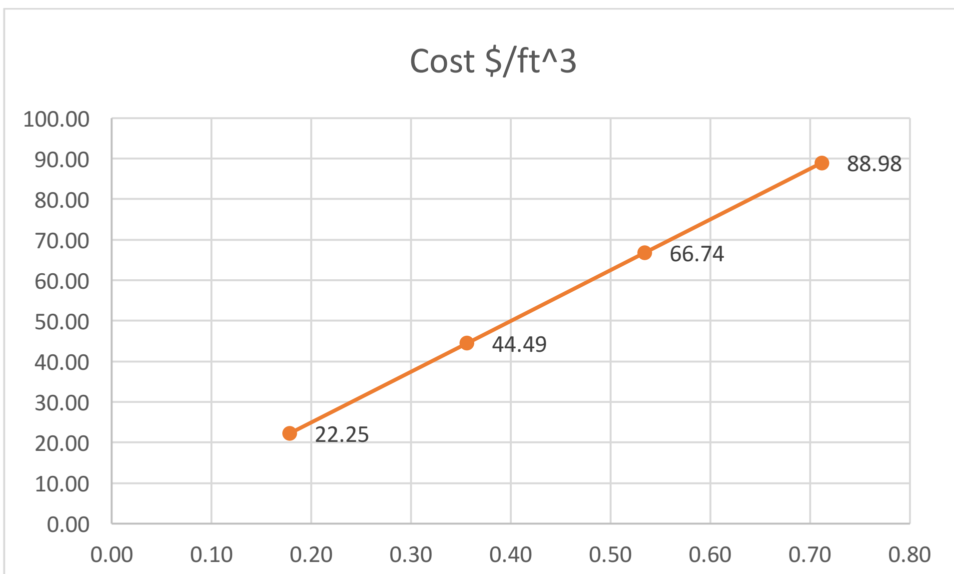
3.5



Graph 3.4: Cost of Using Nano Aluminum Oxide

By observing the cost from Table 3.4 and Graph 3.4:

(1) The cost increased by $22.25 per 0.5% of nano aluminum oxide.

(2) Using 0.5% NA will incur a 17.5% increase in compressive strength, so it is not cost effective.

(3) In porosity, using nano aluminum oxide in concrete improves the concrete porosity, so it is not cost effective.

(4) Using 2% NA is cost effective in flexural strength, since it decreased the flexural strength for about 22% of the plain concrete.

CHAPTER IV

CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Nano aluminum oxide is one of the cheapest of the nanomaterials, but it is still an expensive material. It shows very great results in compressive strength and porosity. The study was conducted to investigate the effects of nano aluminum on the compressive strength, porosity, and flexural strength of concrete. Also, the research intended to find out how the combination of the additives silica fume and nano aluminum impacts compressive strength, porosity, and flexural strength. To examine the effects of adding nano aluminum oxide, there was a fixed 4% silica fume added to four percentages of nano aluminum oxide (0.5%, 1%, 1.5%, and 2%). A handheld mixer was used to make a homogeneous mixture between the nano aluminum oxide and the concrete.

From the compressive strength test, the researcher found that the strength when 4% of silica fumes was added was slightly higher, 7518 psi, than that of the plain, 7151 psi. However, the uniformity of the strength of the concrete could not be predicted when various proportions of nano aluminum oxide were added. Further, the findings indicated that the strength of the concrete was optimal at 4% silicate fumes and 0.5% nano aluminum oxide beyond which the strength decreases. Adding nano aluminum oxide to increase the strength of concrete comes with significant impacts. From the experiment, an addition of 0.5% of nano aluminum oxide led to an increase in price by $22.25 on 142lb/ft of concrete.

After performing the porosity test, the results indicated that silica fumes and nano aluminum oxide increase the porosity of the concrete. While a plain content gives a 1.65% porosity, a 2% of nano aluminum oxide leads to 0.80% porosity. Hence, nano aluminum oxide has a positive impact on the strength of the concrete and overall porosity. However, nano aluminum oxide should not exceed 2% as the concrete achieves optimum porosity when it is at 2%. The only drawback of nano aluminum oxide is that it lowers concrete porosity from 37% (0.5% NA) to 50% (2% NA).

Regarding the flexural strength, the findings from the experiment indicated that a combination of silica with nano aluminum particles causes a significant decrease in flexural strength. However, an addition of 2% nano aluminum oxides results in an increased flexural strength. When used at 2%, nano aluminum oxide is cost effective because it has no impact on a concrete deflection. However, when the focus is on the strength and stiffness, then the product becomes less cost-effective.

Overall, when nano Al2O3 particles are blended with concrete, it improves the flexural strength as opposed to using plain concrete. Additionally, it acquires better results in compressive strength and porosity, Nano aluminum oxide works as a bridge between silica fume and cement particles. In compressive strength, it works as a binder, although it decreases the strength when used above the optimum proportion required for the concrete. In porosity, nano aluminum oxide fills out the spaces between all the concrete's particles and reduces its porosity.

4.2 Recommendation

- More investigations are needed to study the effects of varying additives such as silica fume, fly ash, w/c ration, in addition to varying nano aluminum oxide.
- Study the effect by varying nano aluminum oxide as a replacement material instead of additives materials in concrete.
- Study the effect by adding both fly ash and silica fume, in addition to varying nano aluminum oxide.

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