Transportation Consortium of South-Central States

Tran-SET

Solving Emerging Transportation Resiliency, Sustainability, and Economic Challenges through the Use of Innovative Materials and Construction Methods: From Research to Implementation

Use of Rice Husk Ash (RHA) in Flowable Fill Concrete Mix Material

Project No. 18CASU03

Lead University: Arkansas State University

Final Report
August 2019

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Acknowledgements

The authors would like to acknowledge the financial support from the Transportation Consortium of South-Central States (Tran-SET). The authors are also grateful to NEAR Concrete, and Riceland Foods for providing the test materials for this study. Special thanks to Arkansas Ready Mix Concrete Association (ARMCA) for providing necessary support for arranging the field demonstration and workshop.

TECHNICAL DOCUMENTATION PAGE

1. Project No.	2. Government Accession No.	3. Recipient's Catalog No.
18CASU03		

4. Title and Subtitle	5. Report Date
Use of Rice Husk Ash (RHA) in Flowable Fill Concrete Mix Material	Aug. 2019
	6. Performing Organization Code
7. Author(s)	**8. Performing Organization Report No.**
PI: Zahid Hossain https://orcid.org/0000-0003-3395-564X GRA: Kazi Tamzidul Islam https://orcid.org/0000-0003-1391-9983	
9. Performing Organization Name and Address	**10. Work Unit No. (TRAIS)**
Transportation Consortium of South-Central States (Tran-SET) University Transportation Center for Region 6 3319 Patrick F. Taylor Hall, Louisiana State University, Baton Rouge, LA 70803	**11. Contract or Grant No.** 69A3551747106
12. Sponsoring Agency Name and Address	**13. Type of Report and Period Covered**
United States of America Department of Transportation Research and Innovative Technology Administration	Final Research Report Mar. 2018 – Mar. 2019
	14. Sponsoring Agency Code

15. Supplementary Notes

Report uploaded and accessible at Tran-SET's website (http://transet.lsu.edu/).

16. Abstract

In the way of finding sustainable development, the flowable fill is a relatively new construction technology. Flowable fill is a self-compacting material, which has been developed in recent years. Flowable fill has been used for different applications such as backfilling walls, sewer trenches, bridge abutments, conduit trenches, pile excavations, and retaining walls. This study examines the potential uses of Rice Husk Ash (RHA) as a sustainable cementitious material (SCM) in the preparation of flowable fill concrete. (RHA is an agricultural by-product of the rice milling process. This study has evaluated the usage of RHA in producing low strength and self-consolidating flowable fill concrete (FFC). Two different RHA samples (600 µm and 150 µm) in two different percentages (40%, and 60%, by the weight) of an Ordinary Portland Cement (OPC) have been used to prepare flowable fill mixtures. The evaluation processes of these FFC mixtures include determination of strength, flowability, unit weight, and air content in the laboratory. Test results showed that the FFC mixtures made with coarse RHA particles resulted in lower strength property compared to the regular FFC. On the other hand, the medium fine RHA particle was found to be effective in increasing the strength properties. Furthermore, a field demonstration has been conducted in this study to evaluate the workability, placement, and in-service performance of RHA modified FFC. Findings of this study will help the transportation and construction agencies in using RHA as a cost-effective construction material.

17. Key Words	18. Distribution Statement
RHA, Flowable Fill Concrete, Fly Ash, Backfill	No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	41	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized.**

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ACI	American Concrete Institute
ASCE	American Society of Civil Engineers
ASR	Alkali-Silica Reaction
ASTM	American Society for Testing and Materials
CaO	Calcium Oxide
CFA	Class C Fly Ash
CH	Calcium Hydroxide
CLSM	Controlled Low Strength Material
C-S-H	Calcium Silicate Hydrate
C-A-H	Calcium Aluminate Hydrate
DOT	Department of Transportation
FA	Fine Aggregate
FFC	Flowable Fill Concrete
FHWA	Federal Highway Administration
LS	Limestone powder
OPC	Ordinary Portland cement
QD	Quarry Dust
RHA	Rice Husk Hull/Husk Ash
SEM	Scanning Electron Microscope
TRB	Transportation Research Board
VMA	Viscosity Modifying Admixture
XRD	X-ray Powder Diffraction

EXECUTIVE SUMMARY

Rice husk ash (RHA) is an agricultural by-product in the United States as well as in all over the world. From the chemical perspective, RHA has pozzolanic properties, which make it a potential supplementary cementitious material. In this study, two different types of RHA sample (600-RHA: 600 µm, and 150-RHA: 150 µm) with different particle sizes were utilized to evaluate their application in producing low strength flowable fill concrete (FFC). For comparative analysis, flowable fill concrete produced by using Class C Fly Ash (CFA) was also incorporated in this study. Two different percentages (40% and 60%) of each type of RHA were used as partial replacements of cement for producing modified FFC samples.

The physical and chemical data (e.g., moisture content and loss on ignition) of RHA and CFA particles were collected and analyzed to verify if they meet certain requirements and specifications. Different laboratory tests (e.g., flow, temperature, unit weight, compressive strength, and tensile strength) on fresh and hardened FFC mixtures were performed to evaluate their physical and mechanical properties. To evaluate the reactivity and expansion of the aggregate in the presence of alkaline water, the Alkali-Silica Reaction (ASR) tests were also performed on the modified FFC mortar bars. Considering the outcome of the different physical properties of RHA modified FFC, an optimum dose of RHA has also been determined. Additionally, two field demonstration projects have been completed to verify the field mixing and constructability of RHA-modified FFC.

Fresh FFC tests resulted that different RHA modified FFC required different amounts of water to maintain a desired level of consistency. More water contents were required for RHA modified FFC mixtures compared to the control sample (FFC made with CFA). Almost all types of modified FFC mixtures satisfied the minimum unit weight required for an FFC mix. The hardened FFC tests showed that both amounts of RHA-modified FFC samples made with 600-RHA showed lower compressive strength compared to the control sample. A 40% 150-RHA FFC mixture resulted in a significant increase in compressive strength. Similar results were observed for the tensile strength tests. Cost comparison between conventional FFC mixture and RHA modified mixture revealed that RHA modified FFC mixture would result in 30% lower cost compared to the regular FFC. With the help of Arkansas Ready Mix Concrete Association (ARMCA), the research team has organized a workshop on the application of RHA in flowable fill and laid down RHA-modified FFC mix on a field demonstration site at Razorback plant site in Jonesboro, AR. This workshop and field demonstration helped the research team to engage the professional engineers in open discussion on current research on assessing the feasibility of RHA as a construction material in Arkansas. The second field demonstration site in a parking lot of the Facility Management (FM) department at Arkansas State University was also successful.

1. INTRODUCTION

Controlled low-strength material (CLSM), also commonly known as flowable fill, is one kind of slurry, which can be used to fill different types of cavities without any need of vibration. Flowable fill is a low strength material, which consists of a mixture of sand, Portland cement, fly ash and water. It has self-leveling capabilities with a varying compressive strength from 30 to 1200 psi depending on the field application. According to the application of flowable fill, it may also be known as CLSM, lean mix backfill, controlled density fill, or flowable fill mortar. In the construction site, different kinds of settlements in roadways and trenches, backfills have been a long-standing problem. Moreover, cutting and backfilling trenches beside roadways often disrupts the traffic flow. It has also been seen that the differential settlement is usually caused by the insufficient compaction of trench backfill material. The standard practice for backfilling trenches includes the placement of 6-inches of the soil layer and compacted until a minimum density is achieved. These multiple layers of soil filling and testing for a single backfill area require several days to complete. A search for a rapid solution for the backfilling problem has developed the use of low-strength flowable fill concrete as a backfill material. Different agencies such as ready-mix concrete associations, utility companies, and construction associations in cooperation with the respective department of transportation (DOT) have been continuously trying to develop the standards, specifications, test procedure and research methods of flowable fill concrete.

The material composition of flowable fill provides an opportunity to use waste material in producing flowable fill concrete. A continuous increase in the need for construction material has been depleting the natural resource, which causes an adverse effect on the natural environment. Among all types of construction material, concrete has been the topmost consumed construction material. According to the Statista, in 2016, 94 million metric tons of cement have been produced all over the USA. The annual growth of cement production in 2017 was 2.6% *(1)*, which involved a great amount of natural depreciation. To encounter increasing natural pollution, practitioners have tried to develop and adopt modern technologies incorporating sustainable use of resources and constructions. To this end, rice husk ash (RHA) can be a potential alternative source of cementitious material.

Rice husk (RH) is an agricultural by-product from the rice industry. The main use of RH is as a biofuel in the rice milling company, which ultimately generates a large volume of ashes. Every year the United States produces a large amount of rice. As per the US Department of Agriculture’s national agricultural statistics, about 25.1 million pounds of rice was produced in the United States in 2016, which eventually generated a large quantity of rice husk ash. The pozzolanic properties of RHA define its use in the concrete industry. Through the controlled burning chambers, RHA can be transformed into highly reactive pozzolanic material *(2)*. The hydration process between RHA and cement, a secondary Calcium-Silicate-Hydrate (C-S-H) gel is formed, which determines the pozzolanic activity of the RHA. In addition, the particle size of RHA also greatly influences the hydration process in concrete *(3)*. Moreover, in the field of cementitious products, RHA can be used as a mineral admixture. It has been observed that concrete properties of blended cementitious materials vary with the source of RHA *(4)*.

In this study, RHA has been used as a supplementary cementitious material in producing flowable fill concrete (FFC). Two different percentages of rice husk ash (RHA) by weight (40% and 60%) of total cementitious material have been utilized in the study. For the property evaluation of different RHA particle sizes in concrete, two different RHA sizes (600-RHA: 600 µm, and 150-

RHA: 150 µm) were selected in this study. Moreover, an additional FFC mix containing Class C fly ash and cement had been incorporated in this study to have a comparative analysis. Different laboratory tests, both on fresh modified flowable fill concrete (FFC) and hardened FFC, were performed to evaluate their physical and mechanical properties. To evaluate the reactivity of the aggregate in the presence of alkaline water, Alkali-Silica Reaction (ASR) tests were also performed on the modified FFC mortar bars. Considering the outcome of the different physical properties of RHA modified FFC, an optimum dose of RHA has also been determined.

2. OBJECTIVES

The main objective of this study is to evaluate the usage of RHA in producing low strength and self-consolidating flowable concrete. Specific technical objectives of this study are given as follows:

- Prepare RHA modified FFC and determine their workability and flow behavior;
- Evaluate the effect of curing time and environmental conditions on strength properties (compressive, tensile, elastic modulus, etc.) and durability (Alkali-Silica Reactivity SR) of RHA-modified FFC; and
- Evaluate different dosages of RHA as a pozzolan in preparing FFC.

These objectives have been accomplished by conducting different experiments on RHA modified FFC samples in the laboratory. Also, a field demonstration project on RHA modified FFC has been completed to observe its constructability and field performance to make meaningful conclusions of this project work.

3. LITERATURE REVIEW

The findings of different previous studies in the field of sustainable use of RHA in the construction industry have been overviewed thoroughly. A detailed literature review using relevant research articles has been completed. The literature review primarily focused on the chemical and physical composition of RHA and its effects on the production and durability of concrete. The effect of physical properties such as particle size and specific surface area of RHA on concrete properties have also been examined. In this regard, reputed journals, periodicals and technical reports from government and non-government agencies, conference proceedings were consulted in this study. Specifically, technical articles published in the journals and periodicals of the American Society of Civil Engineers (ASCE), Transportation Research Board (TRB), the Federal Highway Administration (FHWA), and US Departments of Transportation (DOTs), and, the American Society for Testing and Materials (ASTM) test methods and specifications have thoroughly been reviewed.

A number of researchers have studied the material composition of RHA to predict the performance of RHA as pozzolana. The chemical properties of RHA particles reported by different researchers are presented in Table 1. Most researchers stated that RHA particles contain more than 85% of silica, but it varies from source to source.

Table 1. Chemical properties of RHA (wt, %) *(5)*.

Study	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Loss on Ignition
Mehta *(2)*	87.2	0.15	016	0.55	0.35	0.24	1.12	3.68	8.55
Zhang et al. *(6)*	87.3	0.15	0.16	0.55	0.35	0.24	1.12	3.68	8.55
Bui et al. (*7*)	86.98	0.84	0.73	1.4	0.57	0.11	2.46	-	5.14

According to Givi et al. *(5)*, the high percentage of silica content in RHA makes it a potential pozzolanic compound. Thus, for the pozzolanic activity, RHA can be used as a partial replacement of Portland cement while producing concrete. The chemical reactions of the pozzolanic material start when the di-calcium silicate (C_2S) and tri-calcium silicate (C_3S) compounds of cement come into contact with water during the hydration process. Equation 1 describes the chemical reactions of the hydration process which result in calcium silicate hydrate (C-S-H) and calcium hydroxide (Ca $(OH)_2$). Equation 3 shows the reaction between $Ca(OH)_2$, alumina and water which ultimately form calcium aluminate hydrate (C-A-H). Both C-S-H and C-A-H are produced as a cement gel where the presence of excess CH gel is harmful to concrete strength. The presence of pozzolanic material in concrete causes a reaction between silica content and excess Ca $(OH)_2$ that produces additional C-S-H gels (Equation 4). The excess amount of C-S-H gel fills the pores of the concrete and decreases the capillary action, which eventually results in stronger and more durable concrete. Different experiments on RHA modified concrete concluded that the addition of RHA resulted in improved mechanical properties of concrete, according to Givi et al. *(5)*.

$2(3CaO\text{-}SiO_2) + 6H_2O \rightarrow 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2$ [1]

(C3S) (C-S-H) (CH)

$2(2CaO\text{-}SiO_2) + 4H_2O \rightarrow 3CaO.2SiO_2.3H_2O + Ca(OH)_2$ [2]

(C2S) (C-S-H) (CH)

$Ca(OH)_2 + H_2O + Al_2O_3 \rightarrow A1_2O_3.Ca(OH)_2.H2O$ [3]

(CH) (C-A-H)

$SiO_2 + Ca(OH)_2 + H_2O \rightarrow CaO.SiO_2.H_2O$ [4]

Ahsan et al. *(8)* studied the RHA used in the current as an SCM in preparing regular concrete. The researcher stated, RHA has the potential of being an SCM because of its pozzolanic activity. The researcher studied three different graded RHA (600-RHA, 150-RHA, and 44-RHA) in this study. Each type of RHA samples with two different percentages (10% and 20%) of replacement of Type I Ordinary Portland Cement (OPC) were added while making modified concrete samples. It was found that the RHA modified concrete samples (600-RHA and 150-RHA) showed reduced strength properties compared to the regular concrete. However, coarse RHA particles showed the potential use in producing flowable fill concrete. On the contrary, the finer RHA particle showed improved concrete properties. These researchers concluded about the potential use of 44-RHA as SCM in producing regular concrete, and the coarse RHA could be used in backfill and flowable fill as a controlled low strength material.

Rahmat et al. *(9)* studied concrete mixtures with 0-30% RHA and their mechanical properties along with their durability. In this study, the long-term (11 months) durability of the specimens exposed to aggressive environments (5% NaCl with wet-dry cycling) was evaluated. The degree of damage was studied by determining the percentage of reduction of compressive strength and chloride ions penetration as compared to the control specimens that had been cured normally. The experimental results exhibited that the partial replacement of cement by RHA improved the durability and the homogeneity of concrete, but it hindered the early age compressive strength of concrete. In terms of chloride penetration, it was evident that the blending of Portland cement with RHA was beneficial from the standpoint of the prevention of diffusion of Cl ions. The authors stated that the scanning electron microscopy (SEM) of the microstructure of mortar specimens confirmed that RHA filled up the concrete pores, which explained the superior mechanical properties of modified concretes.

Hwang et al. *(10)* used RHA from South Vietnam to investigate its effects on concrete properties. Before the application of RHA in concrete, RHA was grounded for one hour to improve the pozzolanic activity. The non-ground RHA and ground RHA were used to test the strength activity index according to ASTM C311. Test results showed that the non-ground RHA could also be applied as a pozzolanic material, and with the decrease of non-ground RHA's average particle size brought a positive effect on the compressive strength of mortar. The compressive strength of cylindrical concrete specimens was found to be in the range of 47–66 MPa. The authors also stated that 20% of ground RHA could be added to the concrete mix without having any adverse effect on the strength and durability of concrete.

Ahmadi et al. *(11)* studied the development of mechanical properties up to 180 days of self-compacting and ordinary concretes with RHA. Two different replacement percentages of cement by RHA (10%, and 20%) and two different water/cementitious material ratios (0.40 and 0.35), were used for both of self-compacting and normal concrete specimens. It was found that replacement level up to 20% of OPC in concrete would reduce the utilization of cement and expenditures. It was also reported that pozzolanic reactions of RHA in concrete were low in early ages, but by aging the specimens to more than 60 days, a considerable effect on strength properties was observed. With the aging and hardening of concrete mixes, the modulus of elasticity, compressive strength, and flexural strength increased. The unmodified regular concrete mixes showed a higher modulus of elasticity compared to the control sample, and no impact of water-cement ratio was observed in the modulus of elasticity.

Nataraja and Nalanda (*12)* studied three industrial by-products, namely CFA, RHA, and quarry dust (QD) as constituent materials in CLSM. In this study, mixture proportions were developed for the CLSM containing the aforementioned by-products, and different laboratory tests were performed to evaluate various concrete properties such as flowability, unconfined compressive strength (UCS), stress-strain behavior, density, water absorption, and volume changes. From the test results, it was observed that all three by-product materials could be successfully used in CLSM. It was also stated that the engineering properties of CLSM such as flowability, compressive strength, modulus of elasticity, density and volume change could be achieved satisfactorily using a very small amount of cement and a large amount of these industrial wastes. The water-cement ratio varied linearly to maintain a specific consistency in the concrete mixes. The UCS test results showed that the strength of the CLSM mixtures varied over a wide range. The strength mainly depends on the cement and water content, the higher the cement content, the higher the strength and vice versa.

Safiuddin et al. *(13)* studied the hardened properties of self-consolidating high-performance concrete incorporating RHA. In this study, the researcher produced different types of modified self-consolidated concrete depending on different water/binder (W/B) ratios, RHA contents, and air contents. Here, the concrete mixtures were designed based on the W/B ratios of 0.30, 0.35, 0.40, and 0.50, where RHA was substituted with 0% to 30% of cement by weight. The RHA particle used in this study had a median particle size of 6 µm and about 85% of the RHA particles were smaller than 15 µm. For the evaluation of RHA modified self-consolidating concrete, compressive strength, ultrasonic pulse velocity, water absorption, total porosity, and true electrical resistivity tests have been performed. The self-compacting concrete with lower W/B ratio and higher RHA content showed increased compressive strength and electrical resistivity, whereas the water absorption and total porosity decreased. Excellent hardened concrete properties were achieved with a 15% RHA, which was also found to have the required slump flow and air content. In addition, it was also found that the increased air content caused the decrease of compressive strength since the increased void in the concrete decreased the load-carrying capacity of concrete.

Ali et al. *(14)* studied the feasibility of the use of RHA for low-cost self-compacting concrete (SCC) production. It can be noted that deformability and segregation resistance are the two main properties of SCC. Deformability is the ability to flow or deform under its own weight. Segregation resistance is the ability to remain homogenous at the time of construction. High range water reducing admixtures are usually utilized in the construction project to develop sufficient deformability. In addition, chemical viscosity modifying admixture (VMA) is used to ensure segregation resistance. These viscosity modifying admixtures are very expensive and the main cause of the cost increase of SCC. So, in an attempt to produce low-cost SCC, it is very important to find an alternative viscosity modifying agent. Hence, RHA was considered as an alternative modifying agent. From the experimental results, it was found that different SCC mixes had slump value in the range of 595–795 mm, L-box ratio ranged from 0 (stacked) to 1, and flow time ranged from 2.2 to 29.3 s. About four out of nine mixes were found to satisfy the requirements suggested by the European Federation of National Trade Associations. The compressive strength of RHA modified SCC was compared to that of the control sample. A cost analysis showed that the production of certain SCC mix would result in a reduction of 42.47% cost with the incorporation of RHA.

Suaiam and Makul *(15)* used limestone powder (LS) as a modifying agent in self-compacting concrete (SCC) in which a portion of fine aggregate was replaced with RHA. The SCC mixtures were designed to produce a control slump flow. The fine aggregate was replaced up to 100% by RHA and LS by volume. A number of laboratory tests including T50 slump flow, J-ring flow, blocking assessment, V-funnel, air density, and compressive strength of the SCC mixtures were performed. Experimental results showed that the fresh properties of RHA-containing SCC mixtures were improved containing less than 60% RHA by volume. Test results also exhibited that SCCs containing LS exhibited superior hardened properties, and the fresh and hardened properties of SCCs made using RHA were substantially improved when combined with LS. The unit weight of the SCC was found to decrease with the increase of the RHA content and increase with the increase of the LS content. A combination of RHA and LS made lighter SCC mixtures compared to the control mixtures. The compressive strength was found to be decreased at higher water-binder ratios and RHA or LS content. An optimum replacement level of fine aggregate by RHA and LS provided a higher development of compressive strength at the early ages due to the filling effects and pozzolanic reactions. The authors stated that limestone powder contained the potentiality to improve self-compacting concrete mixtures in which the untreated RHA was used as a partial fine aggregate replacement.

Divya et al. *(16)* studied the effect of replacing cement content with RHA as an SCM in SCC and observed the fresh flow (slump flow, V-Funnel, U-box, L-Flow), mechanical strength (compressive and split tensile), and durability properties (porosity and rapid chloride permeability test) at 7, 28 and 56 days. In this study, the authors prepared concrete specimens with 0, 10, 15 and 20% RHA. Experimental results showed that a 20% RHA replacement showed the minimum specified workability and an increase of about 25% strength at 7 days, 33% at 28 days and 36% at 56 days was observed with RHA content of 20% RHA when compared to the control mix. It was also found that maximum split tensile strength was 3.8 N/mm^2 at 28 days and 4.0 N/mm^2 at 56 days for 15% RHA replacement. The authors mentioned that the inclusion of RHA as the partial replacement (up to 20%) to cement improved the strength properties and durability properties . SCC mixes made with RHA reduced the chloride ion penetrability where the increase of replacement of RHA decreased the charge passed. On the other hand, a very low permeability was achieved by the 15% RHA replacement to cement and moderate permeability was recorded for the control mix. Moreover, X-ray powder diffraction (XRD) and scanning electron microscope (SEM) analyses were done to reveal the increased formation of CSH gels for all mixes, which helped to explain the increased compressive strength for 15% RHA concrete. Pores and cracking were at the maximum level for the control mix. The densest structure was observed for 15% replacement with RHA, which resulted in the highest compressive strength for the mix.

4. METHODOLOGY

This study examined the feasibility of the use of RHA in producing low strength FFC. Different laboratory tests were performed to observe the effect of RHA in FFC. The properties of the ingredients of FFC mix such as fine aggregate, RHA, fly ash, and Type I OPC were also determined prior to the start of the laboratory experiments of concrete samples. Concrete cylinders were made from RHA modified FFC mixes. Moreover, fresh FFC mixtures were tested for flow consistency, temperature, unit weight, and air content. The hardened FFC samples were tested for compressive strength, tensile strength, modulus of elasticity, and Poisson's ratio test. The adverse effects of alkaline water on RHA modified FFC were also examined through the ASR test.

4.1. Material Selection and Collection

This section presents information regarding materials that were used in the preparation of making FFC samples. The design mixes prepared in the laboratory were needed to represent the in-situ condition from field application. In order to maintain the relevance to the field condition, the materials used in making the modified FFC samples in the laboratory were also collected from the same ready-mix concrete plant that regularly produces FFC mix for different construction sites. An FFC mix design has also been collected from the respective ready-mix concrete plant. In addition, after the collection of all materials, they were adequately examined in the laboratory to ensure the ASTM standard specifications.

4.1.1. Cement

The cement, which was used in this project work was Type I Portland cement. According to the Arkansas Department of Transportation (ArDOT) standard, any cement used in a construction site needs to be collected from an ArDOT approved manufacturer. Table 2 shows the detail information regarding the cement source.

Table 2. Source information of collected cement.

Supplier	Source	Plant
Holcim (US) Inc. (a Lafarge Holcim Company)	Bloomsdale, MO	Ste. Genevieve Plant.

NEAR Ready Mix, Jonesboro plant has provided the required cement for this study. The main manufacturer of the cement is Holcim (US) Inc., which is an ArDOT approved manufacturer. In addition, the collected cement met all specifications of ASTM C150 *(17).*

4.1.2. Fly Ash

In the concrete industry, fly ash has been used as a pozzolanic material to replace some portion of Portland cement while producing concrete. In the case of FFC, the application of fly ash usually improves the strength of flowable fill. Moreover, it helps to increase the workability, pump ability, cohesiveness, compressive strength, and durability of concrete *(18)*.

In this study, fly ash was collected from the same ready-mix concrete plant as cement. Class C fly ash has been used in this study. The source information of the fly ash is given in Table 3.

Table 3. Source information of collected fly ash.

Supplier	Source
Headwaters Resources	Independence Steam Station - Newark, AR

The collected fly ash source is in the ArDOT approved supplier list. It also met the ASTM C618-19 specifications for its use in preparing concrete. Figure 1 shows the pictorial view of the fly ash used in this project.

Figure 1. Fly ash samples collected from an approved supplier.

4.1.3. Rice Husk Ash

The primary concern material of this study is RHA, which is a by-product in the rice milling industry. Two different types of RHA samples were incorporated into this study. The sources of RHA samples along with their detailed information are shown in Table 4.

Table 4. Source information of RHA samples used in this study.

Material	Description	Source of Material
600-RHA	Coarse RHA with a particle size of 600 µm	Riceland Food, Inc., Stuttgart, AR
150-RHA	Finer RHA with a particle size of 150 µm	Riceland Food, Inc., Stuttgart, AR

Figure 2 shows the pictorial view of RHA samples. It is evident that RHA samples are dark black in color, which indicates the higher percentage of unburnt carbon.

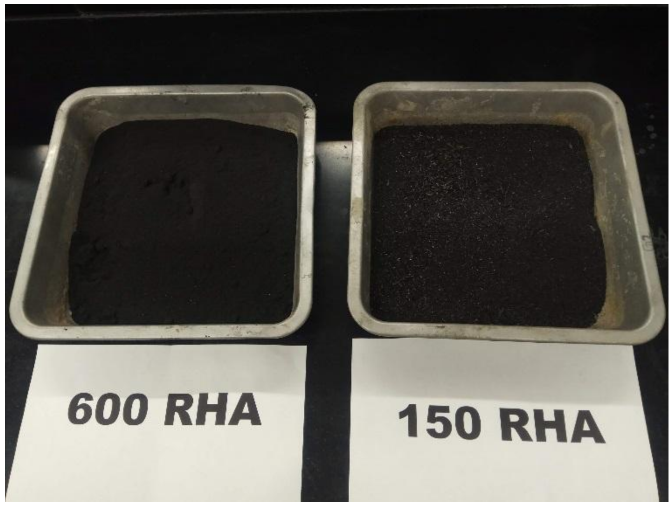

Figure 2. 600-RHA and 150 RHA samples.

Gradation of RHA: The grain size distribution of each type of RHA was determined by using ASTM standard sieves. The gradation curves of 600-RHA and 150-RHA can be found in Appendix A. The gradations of these RHA samples were used to measure their average particle sizes.

4.1.4. Fine Aggregate

The collection of the fine aggregate was done similarly to the other ingredients. Table 5 provides the source information of the fine aggregate. The fine aggregate used in this study was silica sand. Tests on the fine aggregate were performed accordingly ASTM and ArDOT specifications. Screening and gradation were also performed for the fine aggregate.

Table 5. Source information of fine aggregate used in this study.

Supplier	Source
Brenda Kay Sand, LLC	Benton MO

The silica sand used in this study was found to be a light gray to sandy white color. According to Section 501 of the ArDOT specifications, the silica sand needs to be composed of naturally occurring hard, strong, durable, uncoated grains of quartz and graded from coarse to fine.

Gradation of Fine Aggregate: Gradation is one of the most important characteristics of fine aggregate. It influences almost all concrete properties such as relative aggregate ratios, water-cement requirements, workability, economy, porosity, shrinkage, and durability. In the case of flowable fill concrete, the gradation of fine aggregate is one of the primary concerns. Usually, aggregate gradation is the distribution of particle sizes expressed as a percent of the total weight. The standard practice of gradation analysis has been performed for the fine aggregates used in this study. Then the gradation data was compared with the ASTM C33 *(19)* upper and lower limits. Table 6 shows the comparison between ASTM C33 *(19)* upper and lower limits, and gradation for the fine aggregate used in this project.

Table 6. ASTM C33 and derived fine aggregate gradation.

Sieve Specification	% Passing (ASTM C33)	Laboratory Data
9.5 mm (3/8 in)	100	100
4.75 mm(No. 4)	95 to 100	96.28
2.36 mm (No. 8)	80 to 100	88.32
1.18 mm (No. 16)	50 to 85	80.89
0.595 mm (No. 30)	25 to 60	65.96
0.297 mm (No. 50)	5 to 30	21.36
0.149 mm (No.100)	--	1.65
75 µm (No. 200)	0 to 10	--

Figure 3 presents the ASTM C33 upper and lower limits of the fine aggregate and also the gradation of the used fine aggregate. It is seen that the fine aggregate, which was used in this study is nearly between the ASTM C33 upper and lower limits.

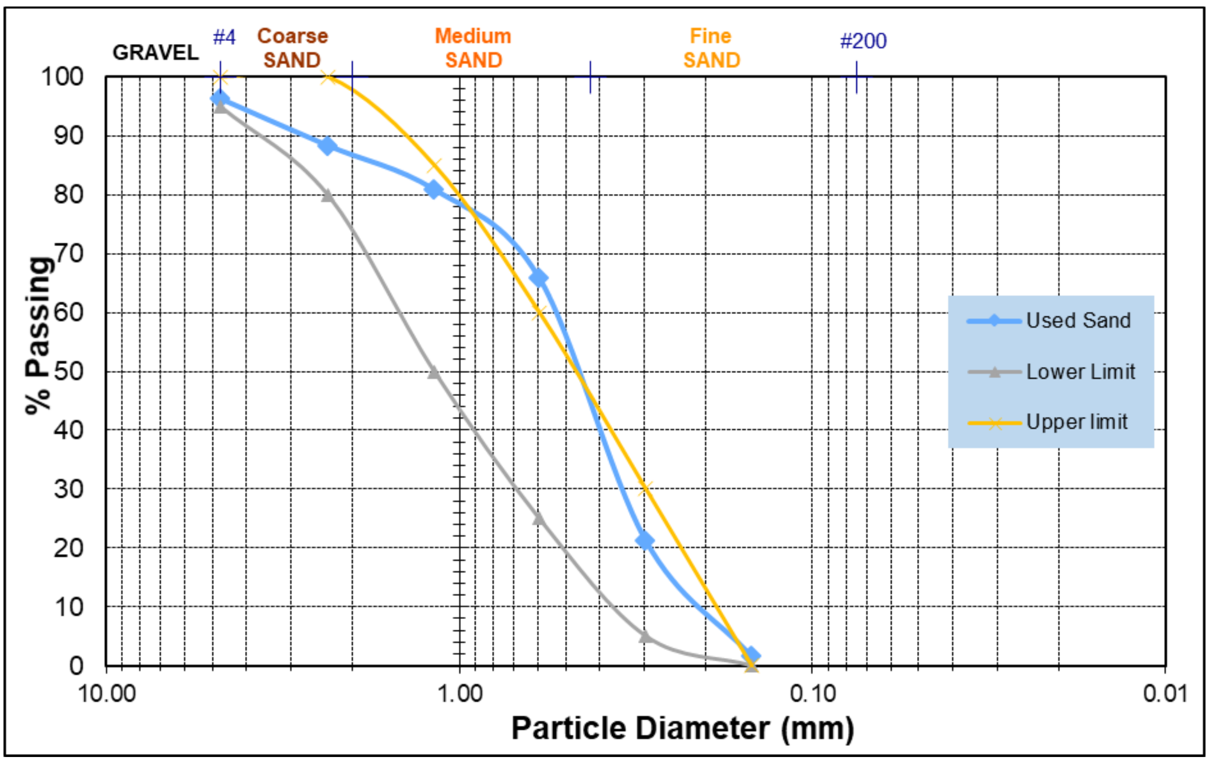

Figure 3. Gradation of Fine Aggregates – ASTM Specification.

Physical Properties of Fine Aggregate: The physical properties of the fine aggregates used in this study were determined as per ASTM standards. Table 7 presents the physical properties of the fine aggregate.

Table 7. Physical properties of fine aggregates (Silica sand).

Physical Properties	Used Fine Aggregate
Fineness Modulus	2.46
Bulk Specific Gravity (SSD)	2.63
Absorption	0.55%
Moisture Content	0.15%

Storage of Fine Aggregate: After the collection of the fine aggregate from a local ready-mix concrete plant, they were stored in the designated place of the laboratory. Figure 4 shows the fine aggregate storage area in the laboratory.

Figure 4. Laboratory storage of fine aggregate.

4.2. Data Collection of RHA and Fly Ash Samples

Physical and chemical data of different RHA samples and fly ash were collected from the respective suppliers. Table 8 shows different physical and chemical data of RHA and fly ash. The properties of RHA and fly ash samples were compared with AASHTO M 321 (Standard Specification for High-Reactivity Pozzolans for Use in Hydraulic-Cement Concrete, Mortar, and Grout) and ASTM C 618 (Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolana for Use in Concrete) specifications.

From Table 8, it is seen that both RHA samples met the AASHTO M 321 specifications for reactive oxides, whereas the fly ash did not meet the AASHTO M 321-04 specification. The fly ash met ASTM C618 specifications for fly ash or natural pozzolan. The AASHTO M 321 specification is given for all high-reactive pozzolans, whereas ASTM C618 is given for only fly ash or natural pozzolan. It is also seen that none of the RHA samples met the specifications for moisture content and loss on ignition. Before the collection of RHA samples, 600-RHA was treated mechanically and heating to obtain 150-RHA. The mechanical and heat treatments were done at the Riceland facility in Stuttgart, AR.

Table 8. Properties of RHA and Class C Fly Ash (CFA).

Chemical Properties	600- RHA	150-RHA	Class C Fly Ash	AASHTO M 321
Reactive oxides (SiO_2+Al_2O_3+ Fe_2O_3)	95.50%	95.50%	60.02%	75% (minimum)
Loss on ignition (LOI)	8.98%	8.98%	0.22%	6% (maximum)
Moisture content	3-5%	3-5%	0.04%	3% (maximum)

4.3. Mix Design

The following section discusses the design processes of FFC mixtures. A control mix design was collected from a ready-mix concrete plant. Compared to that mix design a similar FFC mix was prepared in the laboratory using the same ingredients. Design mixes for different RHA modified flowable fill concrete were determined through a number of trials of FFC mixes. Similar flow consistency was maintained for all modified FFC mixes. Different RHA samples (600 RHA and 150 RHA) have been added to the FFC mixes as partial replacement of cementitious material. Different amount (40% and 60%) of RHAs have been added in the FFC mix. For this study, Type I OPC was considered and it had a specific gravity of 3.15. Using the ACI provided charts and specifications, the amount of fine aggregate, water, and cement were determined for per cubic yard of concrete. Later, a moisture correction factor for the fine aggregate was applied. Different mix proportions for different types of modified FFC mixes are presented in Table 9.

Table 9. Mix proportion for different types of modified FFC mixtures.

Types of FFC Mix	Fly Ash (%Wt)	Cement (%Wt)	600 RHA (%Wt)	150 RHA (%Wt)	W/B	Flow Dia. (in)
Mix-1 (70% Fly Ash)	70	30	0	0	1.7	8
Mix-2 (40% 600 RHA)	0	60	40	0	2.3	8
Mix-3 (60% 600 RHA)	0	40	60	0	2.78	8
Mix-4 (40% 150 RHA)	0	60	0	40	2.3	8
Mix-5 (60% 150 RHA)	0	40	0	60	2.37	8

4.4. Laboratory Tests on RHA-Modified Flowable Fill Concrete

Various ASTM test standards have been performed to ensure the quality of the flowable fill concrete. Different construction agencies and many DOTs such as Arkansas, California, Colorado, Delaware, Florida, Georgia, Illinois, Indiana, Kansas, Kentucky, Maryland, Massachusetts, Michigan, Minnesota, Nebraska, New Hampshire, New Mexico, North Carolina, Ohio, Texas, Washington, West Virginia, Wisconsin etc. have their own specification regarding the application of flowable fill concrete. However, the standards and specifications of flowable fill concrete vary from state to state which also hinders the widespread use of flowable fill concrete. The primary test methods which were followed in this study are summarized below (Table 10).

Table 10. ASTM standards on controlled low strength material (CLSM).

ASTM Specification Number	ASTM Standard Name
ASTM D 4832	Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylinders
ASTM D 6103	Standard Test Method for Flow Consistency of Controlled Low Strength Material
ASTM D 6023	Standard Test Method for Unit Weight, Yield, Cement Content, and Air Content (Gravimetric) of Controlled Low Strength Material (CLSM)
ASTM D 6024	Standard Test Method for Ball Drop on Controlled Low Strength Material (CLSM) to Determine Suitability for Load Application
ASTM D 5971	Standard Practice for Sampling Freshly Mixed Controlled Low Strength Material

It has been observed that high strength of FFC mixes sometimes create difficulty to excavate at the later stages, which eventually increases additional cost and labor. Other technical issues such as workability and compatibility for different types of FFC have also been faced.

It can be noted that some tests pertinent to regular concrete, mentioned in the original proposal, are not applicable for FFC. For instance, the workability (slump test) is an indicator of regular concrete, but the workability of FFC mixes is obtained by flow test. It is obvious that the slump value of FFC mixes is about 12 inches, and it has been the case for the current study. Also, properties of hardened concrete such as elastic modulus and Poisson’s ratio are not important for FFC mixes as they are not used for preparing any horizontal or vertical structures. Rather, compressive strength is the most important strength parameter and it has been investigated thoroughly.

4.4.1. Standard Practice for Sampling Freshly Mixed Controlled Low Strength Material (ASTM D 5971) (20)

According to this test method, representative samples from freshly mixed modified FFC mixtures have been collected. Test samples were large enough to perform different tests to ensure quality. This procedure includes sampling from revolving drum mixers. Figure 5 shows the sampling of FFC mixture.

Figure 5. Sampling of RHA-modified FFC mixtures.

4.4.2. Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylinders (ASTM D 4832) (21)

Cylindrical samples from different types of FFC mixes have been prepared to determine the compressive strength. Plastic molds were used to prepare samples. A compression machine was used to apply load until the specimen failed.

The compressive strength of the specimen is calculated as follows:

$$f'_c = \frac{P}{A} \quad [5]$$

where:
$f'c$ = compressive strength in pounds per square inch (lb/in^2),
P = maximum failure load attained during testing in pounds (lb), and
A = load area of the specimen in square inches (in^2).

Figure 6 shows the pouring and making of the cylindrical samples.

Figure 6. Pouring of concrete in a cylindrical plastic mold.

Figure 7 shows the cylinder samples made from modified FFC mixtures.

Figure 7. Cylindrical samples made from FFC Mixes.

Figure 8. Compressive strength test.

This compressive strength test (Figure 8) helps to maintain the standard quality during the construction phase according to the compliance requirements.

4.4.3. Standard Test Method for Flow Consistency of Controlled Low Strength Material (ASTM D 6103) (22)

This test method determines the fluidity of CLSM mixtures for use as backfill or structural fill. This test method is applicable to the fresh FFC mixtures, which contains only fine aggregates where the maximum particle size is 19.0 mm (3/4 in.) or less, or to the portion of CLSM that passes a 19.0 mm sieve. An open-ended cylinder was placed on a flat, level surface and filled with fresh CLSM. The cylinder was raised quickly so the CLSM will flow into a patty. The average diameter of the patty was determined and compared to established criteria. Figure 9 shows the flow consistency test performed for different types of FFC mixtures.

Figure 9. Flow consistency test.

4.4.4. Standard Test Method for Unit Weight, Yield, Cement Content and Air Content (Gravimetric) of Controlled Low Strength Material (CLSM) (ASTM D 6023) (23)

The density of the flowable fill concrete/CLSM has been determined by filling a measure with CLSM, determining the mass, and calculating the volume of the measure. Density was calculated by dividing mass by volume (Figure 10). The air content of the CLSM was calculated using an air meter (Figure 11).

Figure 10. Measuring the unit weight of CLSM mixtures.

Figure 11. Measuring air content of CLSM mixtures.

4.4.5. Time of Setting of FFC Concrete Mixtures by Penetration Resistance

This test method covers the determination of the time of setting of concrete, with a slump greater than zero, by means of penetration resistance measurements on mortar sieved from the concrete mixture. This test method is suitable for use only when tests of the mortar fraction will provide the information required.

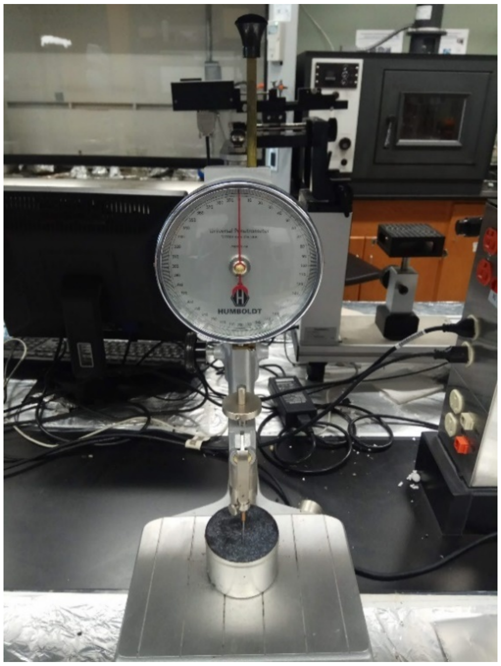

Figure 12. Setting time test using universal penetrometer.

In this experiment the weight of the test plunger itself was 47.5gm and extra 50gm was added before the needle penetration. Figure 12 shows the test set up for the setting time test.

4.4.6. Tensile Strength Test (ASTM C 496) (25)

Splitting tensile strength of cylindrical samples was measured in accordance with the ASTM C 496 method. In this test, 28 days of cured samples, as shown in Figure 13, were used. Like the compressive strength tests, two samples were tested for each test condition and the average value was reported.

Figure 13. Tensile strength test.

4.4.7. Alkali-Silica Reaction (ASR) Test

The alkali-silica reaction (ASR) test was conducted to predict the expansion of the flowable fill concrete in the presence of alkaline water and reactive aggregate. To conduct the test, 285-mm by 25-mm by 25-mm mortar bars were prepared (Figure 14) from different FFC mixtures. FFC mixture mortar bars were molded within 2 minutes and 15 seconds. Molds were filled in two equal layers and each layer was compacted with a tamper until obtaining a homogenous mix. Two samples for each test condition were prepared and kept in the air for 48 hours.

Afterward, mortar bars were demolded and placed in air curing for another 24 hours. Then the initial reading was taken. The mortar bars were then placed in 1N NaOH solution for the next 14 days (Figure 15) and intermediate readings (expansion) were taken at 4, 8, 12, and 14 days, respectively. A linear variable differential transducer (LVDT) was used to take the readings with the help of a data storage unit (Figure 16).

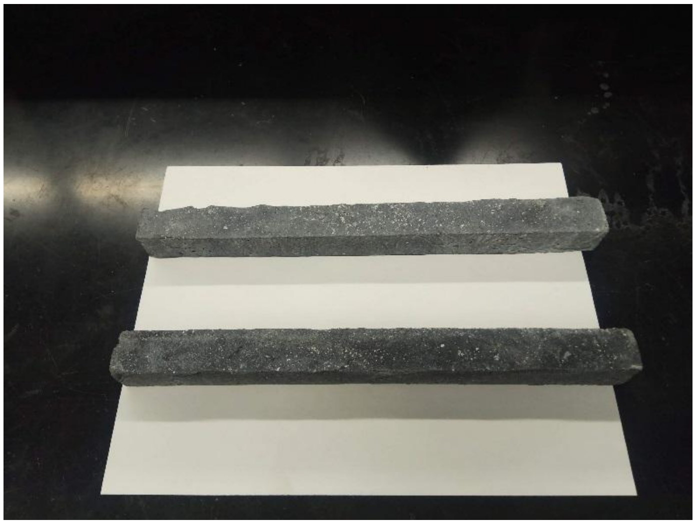

Figure 14. Mortar bar samples.

Figure 15. Curing under 1N NaOH solution for the next 14 days.

Figure 16. Set up of a linear variable differential transducer (LVDT).

5. ANALYSIS AND FINDINGS

In this section, the laboratory test results for five different flowable fill mixtures, and cost analysis on RHA modified FFC mixture were discussed. Several laboratory tests were conducted to evaluate the workability and performance properties of RHA modified flowable fill concrete mixtures. Properties of fresh FFC mixtures (flow consistency, temperature, unit weight, and air content) and mechanical properties (compressive and tensile strength) of hardened FFC samples have also been evaluated in this section.

5.1. Flow Consistency

Flowability is the most important characteristics of flowable fill concrete. Flowability/consistency allows any material to be placed without compaction, regardless of location. Flowable fill concrete flows around and under the utility pipes and trenches, and forms homogeneous structure, which cannot be obtained through soil compaction. Moreover, good consistency of an FFC mixture helps to reach into some inaccessible places such as underground storage tank, under the sewerage system, etc. Therefore, before any kind of field application, it is important to ensure the proper flowability of FFC mixtures.

Though the flow consistency test in the laboratory does not completely represent the field condition, the engineers involved in the application of flowable fill concrete have performed this test. This test involves the use of a 3 in. x 6in. open-ended cylinder where it was placed on a smooth level surface and filled with freshly mixed flowable fill concrete. Then, the cylinder was quickly lifted and the average diameter of the flowable fill spread was taken. A spread diameter of 8 to 12 in is considered workable according to ASTM and ArDOT standards. In this study, five different types of FFC mixtures have been prepared using fly ash and RHA samples. The flow behavior for each type of FFC mixtures has been examined through a number of trial mixes.

5.1.1. Mixture-1 (70% Fly Ash and 30% Cement)

The addition of fly ash to the flowable fill facilitate the consistency of the FFC mixture. The sand particles cannot flow alone because of the frictional resistance at particle-to-particle contact, which also hinders the flowability of any mixture. Moreover, the sand particles segregate with the presence of water. In that case, the presence of fly ash retains water, which ultimately helps to flow the FFC mixture.

In this study, an FFC mix design containing fly ash has been collected from a ready-mix concrete plant. Later, in the laboratory flow experiments were performed to simulate the flow mixture. In this FFC mix, 70% (by wt.) of total cementitious material was fly ash and 30 % (by wt.) was OPC. Figure 17 shows the three trail flow tests with different w/c ratios.

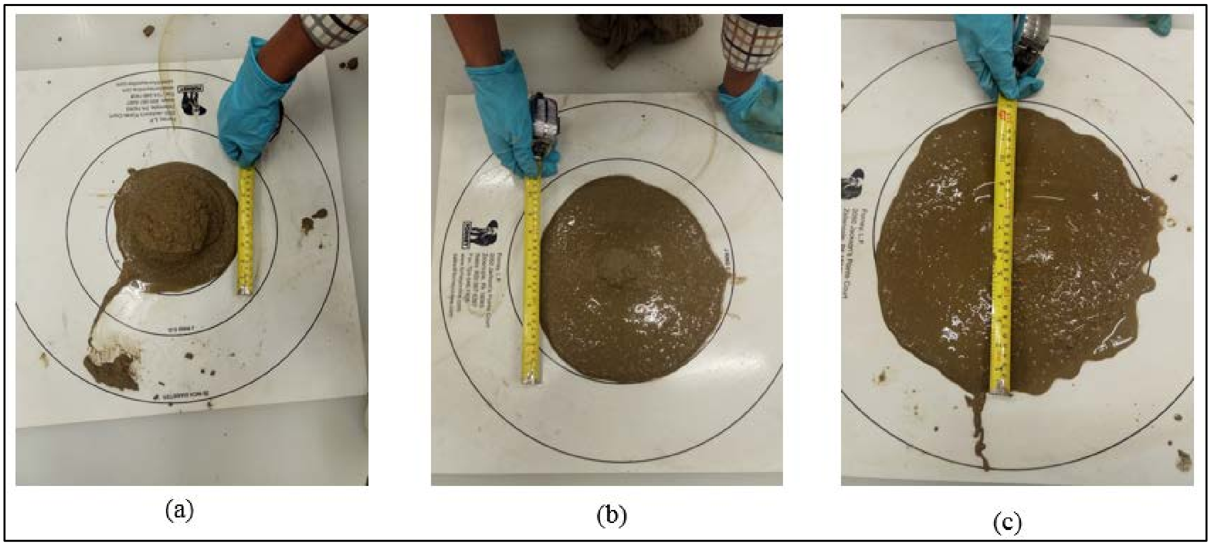

Figure 17. Mixture-1 flow diameter with (a) w/c-1.7, (b) w/c-1.75, and (c) w/c-1.80.

Figure 18 shows a graphical representation between w/c Vs flow diameter. It was evident that for an 8-in of flow diameter, the w/c needs to be 1.7.

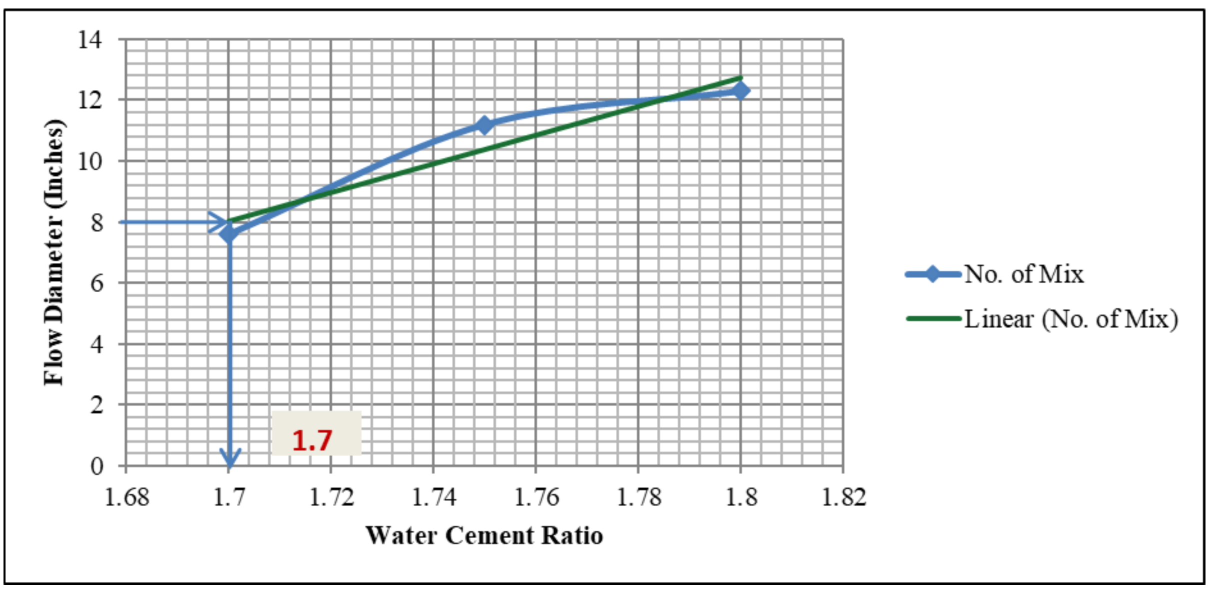

Figure 18**. Flow consistency diagram for Mixture-1.**

5.1.2. Mixture-2 (40% 600-RHA and 60% Cement)

In mixture-2, 40% (by wt.) of the total cementitious material was 600-RHA and 60 % (by wt.) was OPC. Three-flow tests have been conducted with different w/c ratios. Figure 19 shows flow diameters from three flow tests.

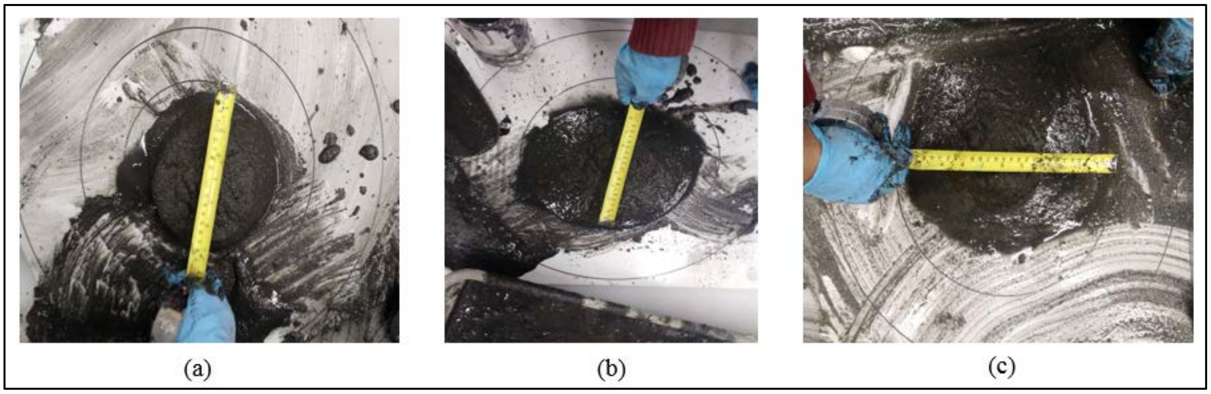

Figure 19. Mixture-2 flow diameter with (a) w/c-2.2, (b) w/c-2.3, and (c) w/c-2.5.

From Figure 20, it is seen that a 2.3 w/c ratio is needed to have a flow consistency of 8 in, which seemed to be larger than mixture-1. It was because the larger RHA particles have more surface area and pore size compared to the fly ash. Therefore, more water was needed to perform minimum flowability.

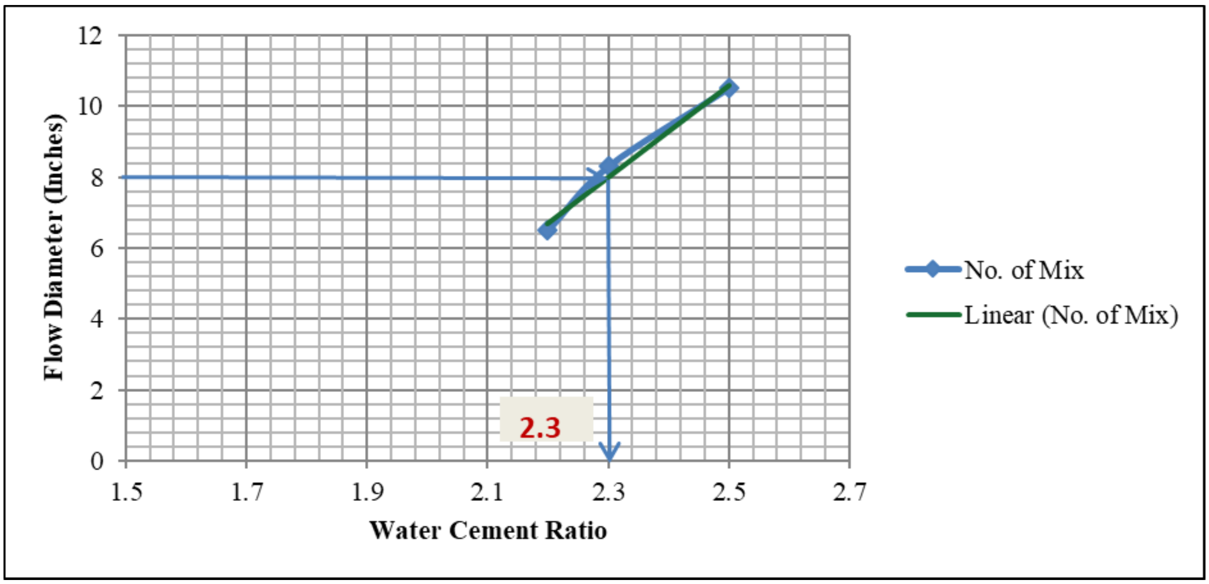

Figure 20. Flow consistency diagram for Mixture-2 (40% 600-RHA and 60% Cement).

5.1.3. Mixture-3 (60% 600-RHA and 40% Cement)

In mixture-3, 60% (by wt.) of the total cementitious material was 600-RHA and 40 % (by wt.) was OPC. The flow test with this mix proportion showed that a large quantity of water was needed to maintain the minimum consistency. The larger amount of RHA particle in the mix required more water compared to Mixture-2.

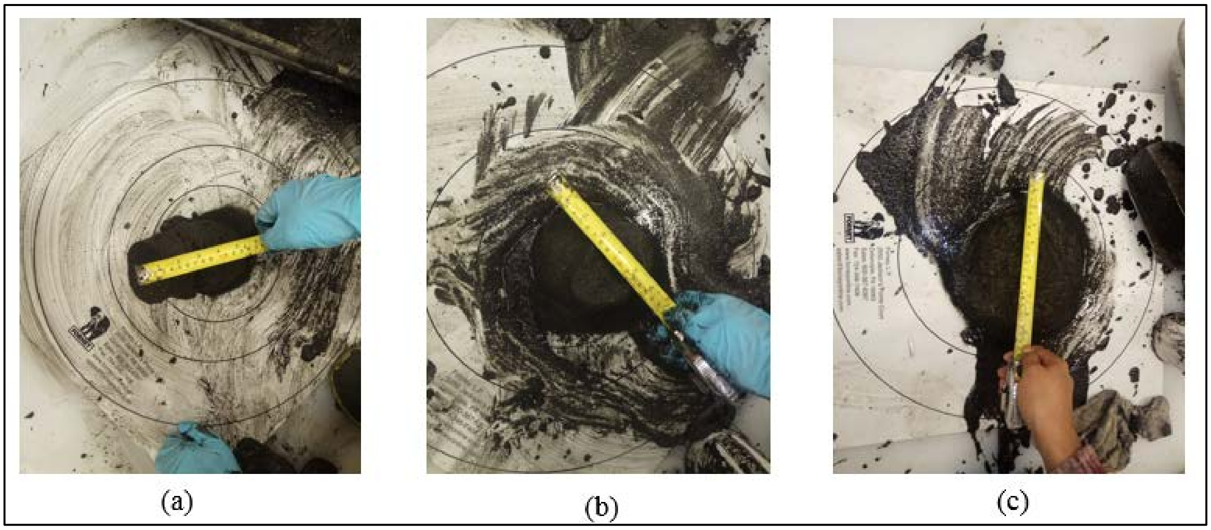

Figure 21. Mixture-3 flow diameter with (a) w/c-2.5, (b) w/c-2.7, and (c) w/c-3.0.

From Figure 21, it is seen that with a w/c ratio of 2.5, the FFC mixture did not flow where w/c ratio of 3.0 shows a flow diameter of 9.5 in.

Figure 22 shows a graphical representation between w/c vs flow diameter of Mixture-3. It was found a w/c ratio of 2.78 was needed to have the minimum flow diameter (8 in).

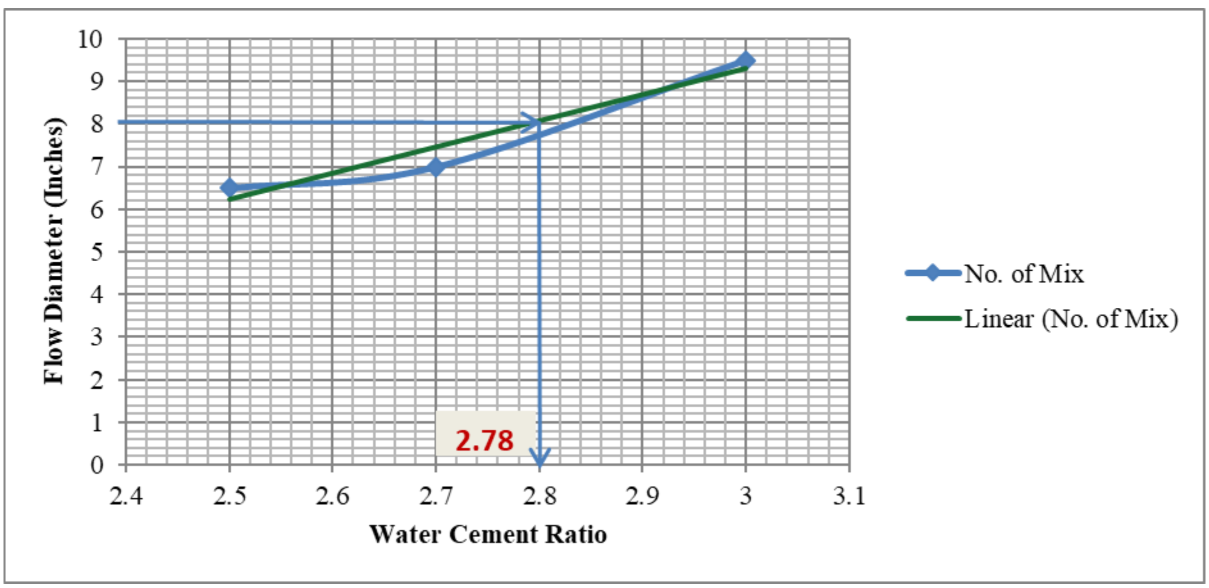

Figure 22. Flow consistency diagram for Mixture-3 (60% 600-RHA and 40% Cement).

5.1.4. Mixture-4 (40% 150-RHA and 60% Cement)

In mixture-4, 40% (by wt.) of the total cementitious material was 150-RHA and 60 % (by wt.) was OPC. From Figure 23, it is seen that with a 2.0 w/c ratio, the FFC mixture did not flow at all. With the increase of w/c content flow diameters were increased.

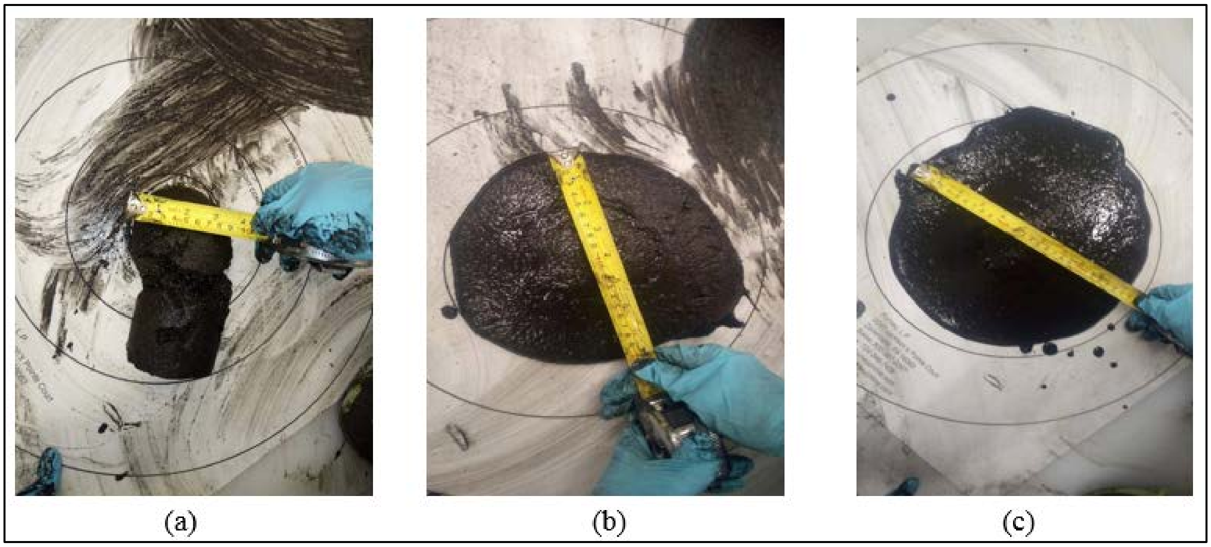

Figure 23. Mixture-4 flow diameter with (a) w/c-2.0, (b) w/c-2.3, and (c) w/c-2.5.

Figure 24 shows that a w/c ratio of 2.3 is needed to perform a flow consistency of 8 in.

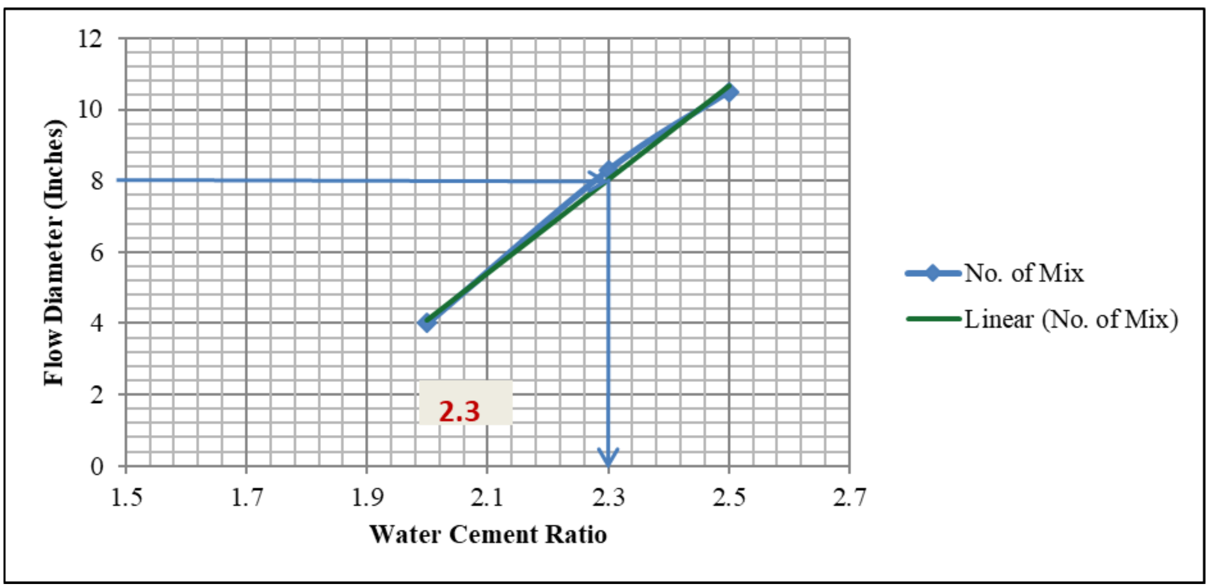

Figure 24. Flow consistency diagram for Mixture-4 (40% 150-RHA and 60% Cement).

5.1.5. Mixture-5 (60% 150-RHA and 40% Cement)

In mixture 5, 60% (by wt.) of the total cementitious material was 150-RHA and 40 % (by wt.) was OPC. With the w/c ratio of 2.3, mixture-5 showed a flow diameter of 7 in. and with the increase of w/c, the flow diameter increased. A flow diameter of 13.25 in. was obtained using a w/c of 2.7 (Figure 25).

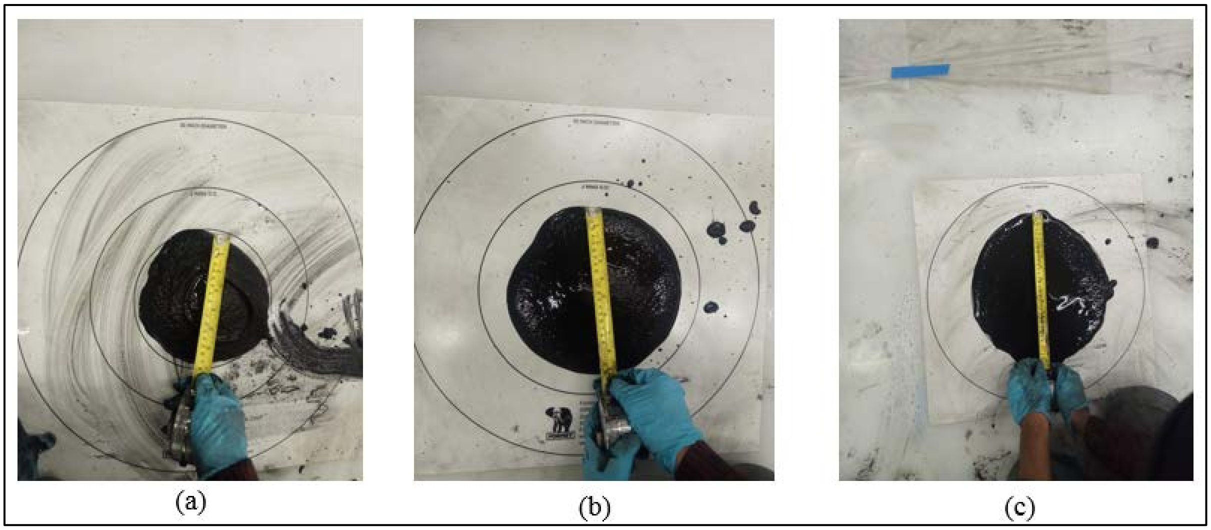

Figure 25. Mixture-5 flow diameter with (a) w/c-2.3, (b) w/c-2.5, and (c) w/c-2.7.

From Figure 26 it is seen that FFC mix with an 8-in of flow diameter needed w/c ratio of 2.37.

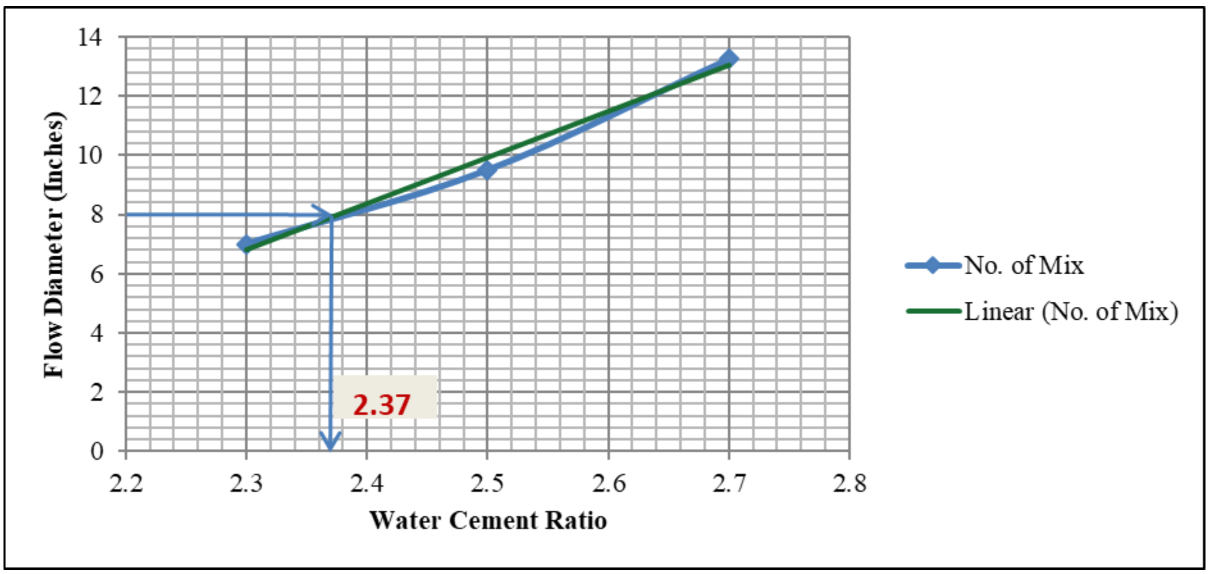

Figure 26. Flow consistency diagram for Mixture-5 (60% 150-RHA and 40% Cement).

5.2. Fresh Flowable Fill Concrete Properties

The density or unit weight of flowable fill mixtures depends primarily on the unit weight of the filler or fine aggregate. According to the ASTM C138 method, unit weights of all modified flowable fill concrete mixes along with the control mix were measured. From Table 11, it is seen that the unit weights of the FFC mixtures made from 40% and 60% 600-RHA particles were found to be 114 lb/ft$_3$ and 109 lb/ft^3, respectively. The control FFC mix exhibited a unit weight of 134 lb/ft^3. The unit weights of the 40% 150-RHA and 60% 150-RHA modified FFC mixtures were determined as 117 lb/ft^3 and 114 lb/ft^3, respectively. Incorporation of RHA in flowable fill concrete reduced the unit weight of the FFC mix since RHA is lighter than cement and fly ash. According to section 206 ArDOT specification minimum unit weight of flowable fill concrete needs to be

110 lb/ft^3. Therefore, it is evident that almost all FFC samples resulted in higher unit weight compared to the standard minimum. Temperatures of fresh FFC mixes were around 60^{o}F.

Table 11. Properties of fresh FFC mixtures.

Types of FFC Mix	Unit Weight (lb/ft^3)	Air Content (%)	Temperature (^{o}F)
Mixture-1 (70% Fly Ash)	134	1.1	63
Mixture-2 (40% 600 RHA)	114	2.5	65
Mixture-3 (60% 600 RHA)	109	2.4	60
Mixture-4 (40% 150 RHA)	117	0.7	60
Mixture-5 (60% 150 RHA)	114	0.5	58

Another important property of the fresh concrete mix is air content. From Table 11, it is seen that FFC mixtures made from 600-RHA showed higher air content. Air content of 2.5% and 2.4% were measured for 40% 600-RHA and 60% 600-RHA modified FFC mixtures, respectively. The FFC mix containing fly ash resulted in air content of 1.1%. Similarly, 0.7% and 5% air contents were measured for 40% 150 RHA and 60% 150 RHA modified FFC samples, respectively.

5.3. Setting Time Test

Figure 27, shows the preparation and placement of different types of FFC mixtures.

Figure 27. Placement of different types of modified FFC mixtures.

Figure 28 shows the penetration values of different types of FFC mixtures at Day-1, Day-2, and Day-3 where high penetration indicates less stability and less penetration defines higher stability of FFC mixtures. It was observed that penetration resistance from Day-1 to Day-3 was found to be increased for all types of FFC mixtures. Among all types of FFC mixtures, the Control sample (CFA modified FFC) showed less penetration, which defines the higher FFC mixture stability. The

600-RHA (40%) modified FFC mixture showed less penetration compared to the other RHA modified FFC mixtures. Thus, the set times for RHA-modified FFC mixtures found to be higher than the Control FFC mix. After 48 hours, the penetration value of any of the FFC mixes does not reduce significantly. Considering the outcomes of this experiment, a set of two days is reasonable for the Control FFC mixture, whereas a set time of three days is observed for RHA-modified FFC mixtures.

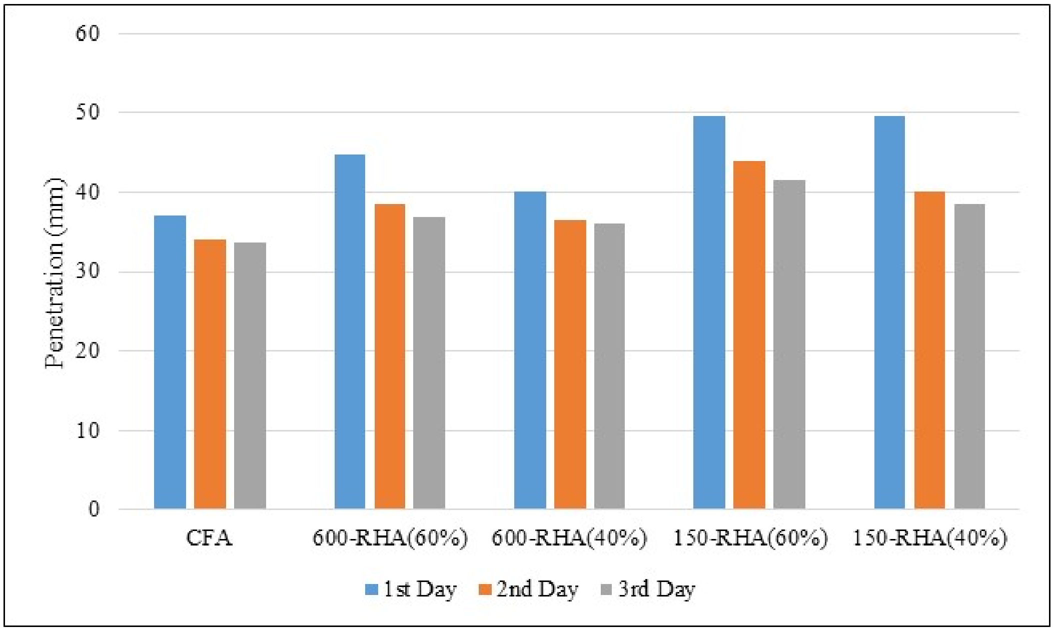

Figure 28. Penetration of different types of FFC mixtures.

5.4. Compressive Strength

Compressive strength is considered one of the most important properties when considering any types of flowable fill concrete. Compressive strength values are required as an indicator for performance and long-term excavatability of the FFC mix. Minimum strength requirements are necessary for performance criteria, and maximum strength requirements are necessary for long-term excavation.

In this study, five different types of FFC mixture were produced to investigate the application of RHA in producing FFC mixtures. Cylindrical samples from each type of FFC mixtures were tested for 7, 14, 21, and 28 days curing period. Figure 28 presents the effects of curing on the development of compressive strength of different types of flowable fill concretes. Detailed results of the compressive strength tests of all FFC mixture samples are provided in Appendix B. It was also observed that all samples from RHA modified FFC along with the control mix (fly ash mixture) showed a similar trend in the development of strength over the 28-day curing period.

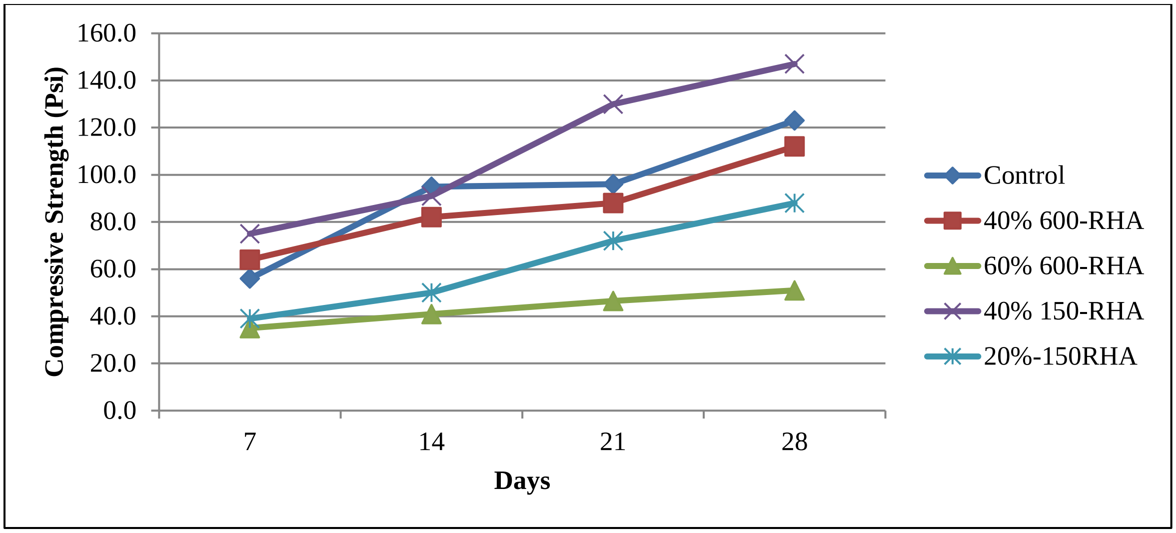

Figure 29. Compressive strength of different types flowable fill concrete.

Mixture-1 developed a compressive strength of 56 psi at 7 days, whereas 95 psi, 96 psi, and 123 psi were found at 14, 21, and 28 days, respectively. In the case of 600 RHA modified FFC (Mixture-2), compressive strength of 64 psi was found at 7 days, whereas it showed a compressive strength of 112 psi at 28 days. Mixture-2 showed a 9% decrease of compressive strength compared to Mixture-1 at 28 days of curing period. The incorporation of coarse RHA in concrete might not generate enough cement gel to develop strength compared to the control sample. Figure 29 shows the compressive strengths of all modified flowable fill concrete samples at 28 days.

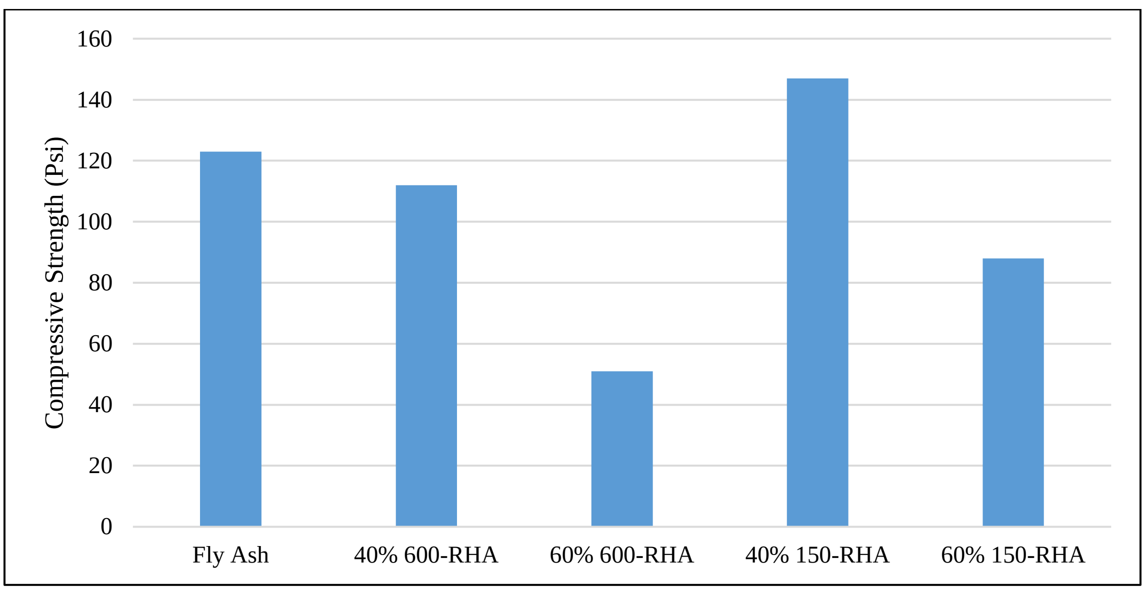

Figure 30. Comparison of compressive strengths of modified flowable fill concrete at 28 days.

From Figure 30, it is observed that both samples made from 600 RHA showed less compressive strength compared to the FFC mixture made from fly ash. On the other hand, FFC mixture made with 40% 150 RHA and 60% cement showed a 19% increase in compressive strength, but the addition of 60% 150 RHA resulted in lower compressive strength. In the microscopic point of view, both the degree of hydration and the porosity of RHA particles play important roles in gaining strength. The greater the volume of the pores, the lower the strength of the concrete would be. In addition, with the decreasing binder/space ratio (defined as the ratio of the content of C–S-H gel to the original volume of space), the strength would become greater *(10).*

5.5. Tensile Strength Test

Like the compressive strength, a similar trend of strength gain was observed in the split tensile strength test results. Figure 31 presents the tensile strengths of modified flowable fill concretes. Raw data of tensile strength tests can be found in Appendix C.

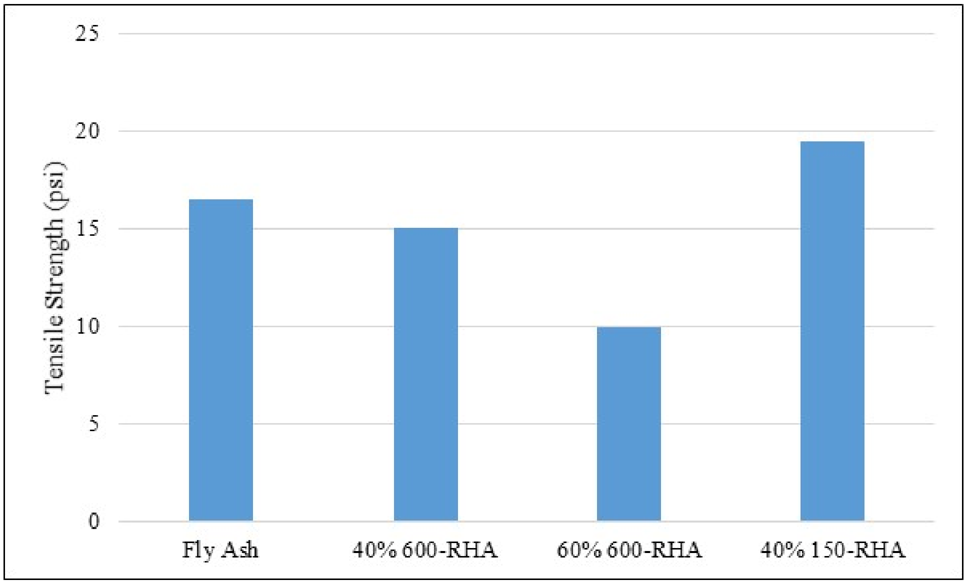

Figure 31. Comparison of tensile strengths of modified concrete.

It was seen that both 40% 600-RHA and 60% 600-RHA modified flowable fill concrete samples showed a reduction of tensile strength compared to the control sample (FFC mixture with fly ash). The 40% dosage level of 600-RHA and 60%-RHA modified FFC samples yielded tensile strengths of 15 psi and 10 psi, respectively, whereas the control had a tensile strength of 16.5 psi. Thus, 40% 600-RHA and 60% 600-RHA samples yielded about 91% and 61% of the tensile strength of the control sample, respectively. Similar results were reported by Rahman et al. *(9)* who found that split tensile strength decreased with increases in the percentage of coarse RHA.

On the contrary, the 40% 150-RHA modified FFC showed more tensile strength values compared to the control sample. The 40% 150-RHA modified FFC sample yielded a tensile strength of 19.5 psi, which is 18% higher, compared to the control sample. The optimum results have been found for the 40% replacement with 150-RHA.

5.6. Alkali-Silica Reaction (ASR) Tests

Concrete resistance to adverse weather, such as in the presence of alkaline water, can be measured by performing ASR tests. The ASR data for modified flowable fill concrete are presented in Figure 32.

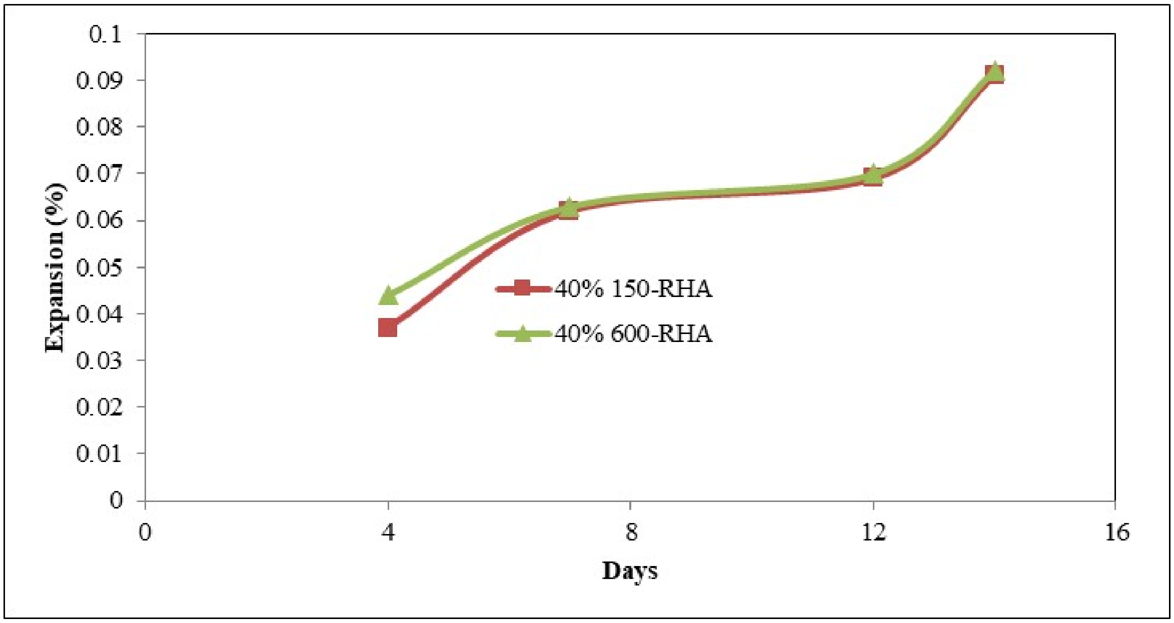

Figure 32. ASR effect on RHA modified FFC samples.

Figure 32 represents the ASR data for 40% 600-RHA, and 40% 150-RHA, respectively. From Figure 32, it is also observed that both samples exhibited expansion lower than the ASTM C1567 recommended limit of 0.10%. This phenomenon could be explained by the particle size and amount of the RHA in FFC mix. The incorporation of the large amount of RHA into FFC mix was found to be effective in producing a sufficient homogeneous mix and ASR gel to mitigate the ASR problem. The SEM imaging along with the EDX analysis could be incorporated in the future to explain the ASR gel production phenomena inside the mortar bars.

5.7. Field Demonstration

Based on the findings of the current project work, the research team organized a workshop and completed two field demonstrator projects in Jonesboro, Arkansas. The first demonstration project included a workshop on the application of RHA in flowable fill on November 27, 2018. The Arkansas Ready Mix Concrete Association (ARMCA) has arranged all necessary supports to make the workshop successful. The team delivered an oral presentation based on the laboratory test results of RHA-modified regular concrete and FFC mixtures. Several ArDOT and City Engineers, local ready-mix concrete company engineers, and plant operators from northeast Arkansas were present during the presentation (Figure 33).

Figure 33. Presentation session in front of professional personnel.

After the oral presentation session, a field mixing and placement operation of an FFC mix was performed. An FFC mix with 40% 600-RHA and 60% cement was prepared and placed in a small trench (48-inch x 9-inch x 8-inch) containing a 2 in. diameter hollow pipe. Figure 34 shows the preparation of the FFC mixture.

Figure 34. Preparation of an FFC mixture containing 40% 600-RHA and 60% cement.

Figure 35 shows the top and sectional view of the trench. It is seen that the trench has 48 in. length, 9 in. width, and 8 in. depth. The hollow pipe was placed 1 in. from the bottom of the trench.

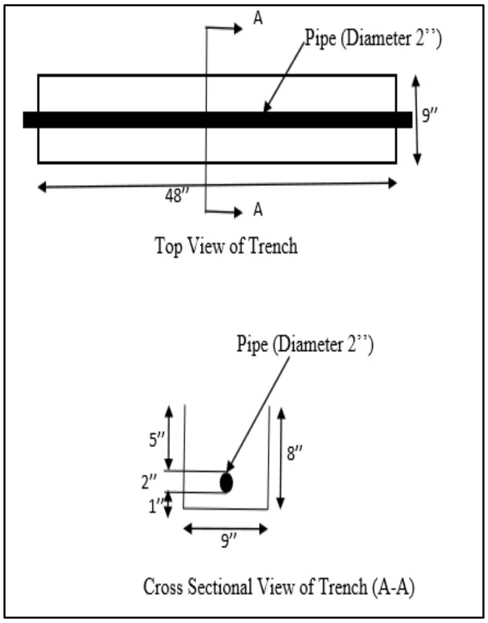

Figure 35**. Plan and cross-sectional view of the trench.**

Figure 36 shows the FFC mixture placement pit with a hollow pipe.

Figure 36. FFC placement pit site.

After the mixing preparation, FFC mixture was placed on the pit site (Figure 37).

Figure 37**. FFC mixture placing.**

The research team monitored the placement site for a certain time. It was seen that after 3 days, the FFC mixture was strong enough to stand on. Besides the technology transfer of gained knowledge, this session also helped the research team to engage the audience in open discussion on current research on assessing the feasibility of RHA as a construction material in Arkansas. The second field demonstration project (a trench similar to the first demonstration site) was conducted at a parking lot of A-State's Facility Management on July 24th, 2019. In this project, 40% 150-RHA and 60% cement, and appropriate amounts of sand and water, as per the mix design sheet, were used. After successful mixing and placement of the FFC mixture, the research team monitored its performance, which was found to be satisfactory. The research team will continue to monitor these sites and record any issues that may arise in the future.

5.8. Cost Analysis

The cost comparison between the conventional CLSM and RHA modified FFC was performed on a cross-drain trench site. The dimensions of the trench were 100-foot length, six-foot height, and an average of six-foot width. In the cost analysis procedure, only the cost of cementitious material in the FFC mixture was considered. Other factors such as labor (including fringe benefits), equipment (including fuel, lubricants, filters), construction liability, remedial work, productivity, inspection, and testing were being considered uninfluential in a cost comparison of FFC mixtures.

According to ArDOT specification, the conventional flowable fill material was considered to be produced using fly ash and cement. The cost data of conventional flowable fill material was collected from ArDOT material pricing data. The cost for per cubic yard of FFC material was considered as $196.04 as per ArDOT price data. A 60% 600-RHA flowable fill mixture cost was analyzed and the unit price was found to be the $136.04/cubic yard. Table 12 shows the total cost comparison between the conventional FFC mixture and RHA modified FFC mixture.

Table 12. Cost comparison between conventional FFC mix and RHA modified FFC mix.

Types of FFC Mix	Total Required FFC (Cubic Yard)	Unit Price ($/ Per Cu. yard)	Total Cost ($)
Conventional FFC mix	133.33	196.04	26,138
60% 600 RHA FFC mix	133.33	136.04	18,138

This cost comparison was generated using identical volumes flowable fill materials. Table 12 shows that the total cost of conventional flowable fill is significantly larger than the RHA modified FFC mix. RHA modified FFC mixture resulted in 30% less of total cost compared to the conventional FFC mixture. Therefore, it can be concluded that RHA modified CLSM/ flowable fill material is more economically beneficial compared to other FFC mixture.

5.9. Life-Cycle Cost Analysis

The overall long-term economic efficiency between RHA modified flowable fill concrete and regular flowable fill concrete have been compared through a life-cycle cost analysis (LCCA). Usually, in LCCA, a net present worth (NPW) represents all activity costs considering a discount rate over time. In this study, “LCCA Express” software was used to represent the LCCA analysis. The following two example scenarios have considered for LCCA in this study:

1. Using conventional FFC in the subgrade of asphalt pavement construction; and
2. Using RHA modified FFC in the subgrade of asphalt pavement construction.

In the process of comparing different types of FFC, LCCA Express does not directly quantify the longevity of the FFC. To evaluate the expected improvement of the pavement, a mechanistic-empirical prediction model was used for expected service life. For the construction of asphalt pavement, assumptions were made based on previous research. Figures 38 and 39 show the pavement design conditions and other traffic properties, which were considered for performing life cycle analysis.

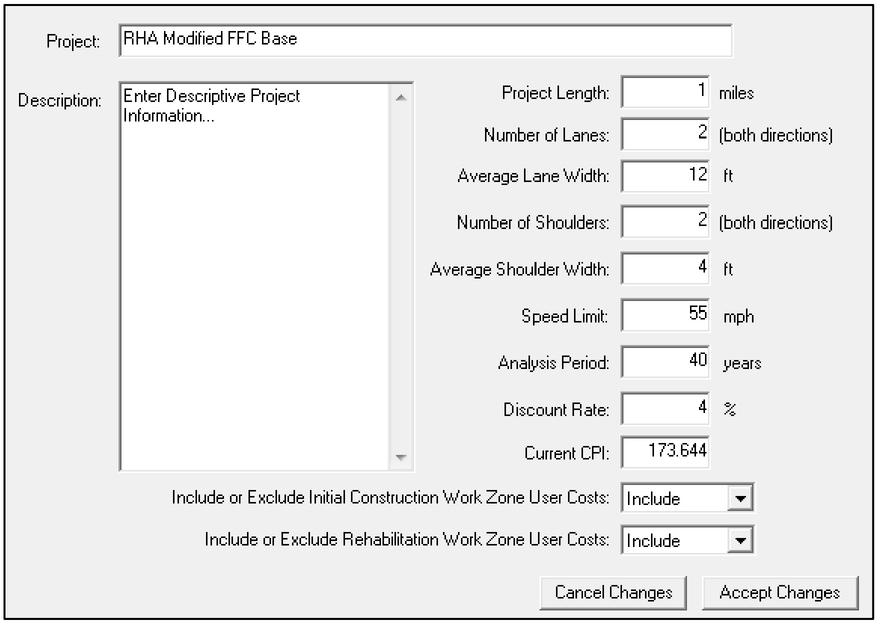

Figure 38. Assumed pavement criteria for performing LCCA.

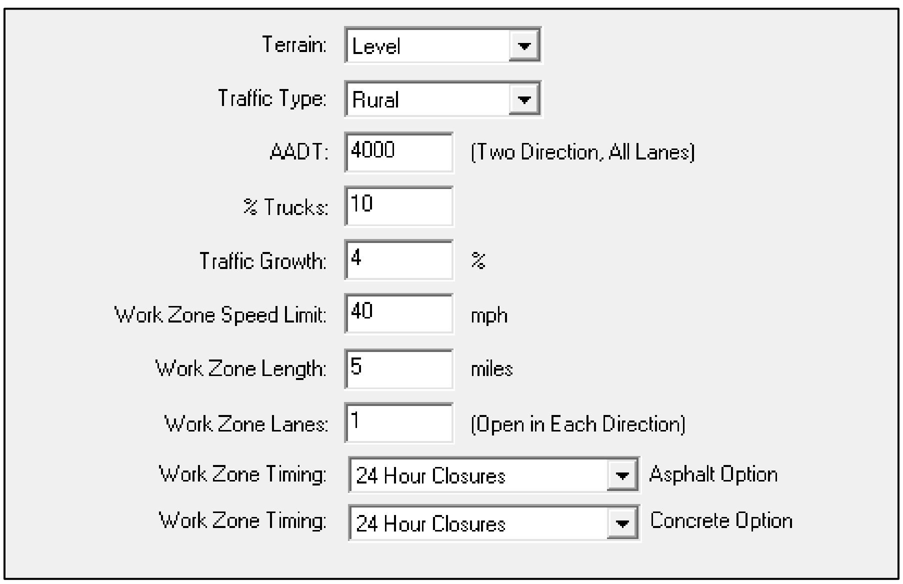

Figure 39. Assumed work zone data for performing LCCA.

Figure 38 shows that a 1-mile road of 24-foot width was considered in this study. An analysis period of 40 years with a discount rate of 4% was also considered. Figure 39 shows that a 4% traffic growth 4000 AADT was assumed for the work zone data. The pavement dimensions and traffic criteria remained the same for two LCCA analyses. A traffic type of “Rural” was considered because RHA-modified FFC is expected to be placed in the subgrade of rural roadways (e.g., County Roads) before approved on urban roads or interstate systems.

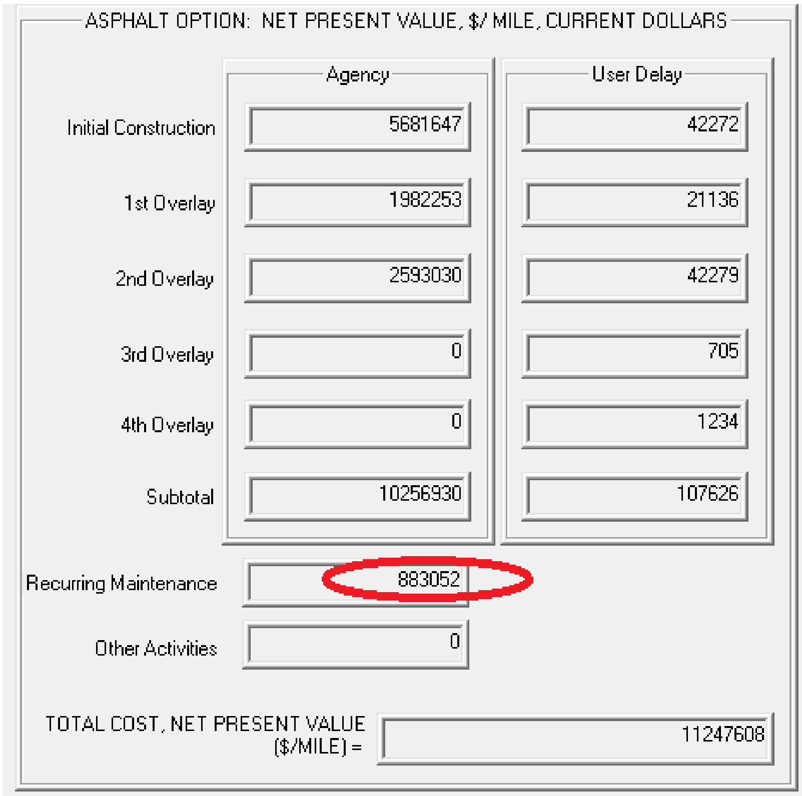

Figure 40. Regular FFC used to construct asphalt pavement.

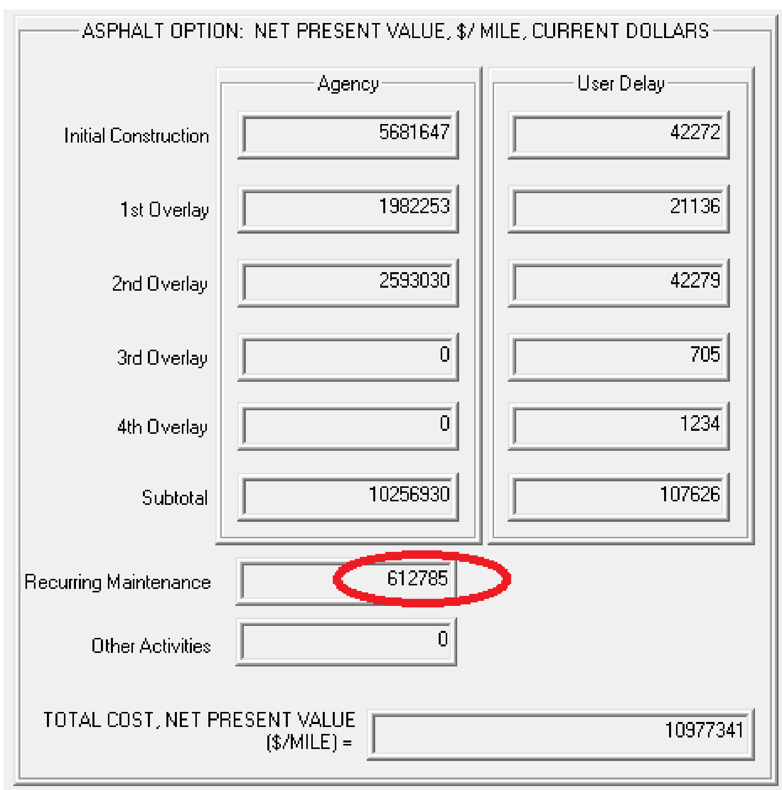

Figure 41. RHA modified FFC used to construct asphalt pavement.

Figure 40 shows the net present worth value of example Scenario 1. For Scenario 1, resurfacing was scheduled for years 20. The unmodified FFC resulted in a net present cost of $883,052/mile. On the other hand, for the RHA-modified FFC (Scenario 2), the net present value was found to be $612,785 (Figure 41), which was about 30% more economical compared to the unmodified FFC.

6. CONCLUSIONS

Rice Husk Ash (RHA) is considered agricultural waste material, but it has the potential to be used as a supplementary cementitious material. This study presents findings from a laboratory experimental plan on RHA-modified flowable fill concrete (FFC) mixtures followed by a field demonstration. The laboratory experimental plan of this study includes physical and chemical properties of raw materials, workability of fresh FFC mixture, and strength properties of hardened FFC samples. The literature review of this study has provided in-depth information on flowable fill technology, type, specifications, mix designs, tests methods, current studies, and different application of FFC. A number of FFC mixtures (trials) were prepared to understand the flow behavior of modified FFC mixtures. It was found that RHA modified FFC mixtures required more water compared to the regular FFC to maintain the same flowability. The RHA-modified FFC mixtures were found to be lighter than the Control (CFA-modified FFC), but they met the ARDOT specified unit weight requirements. The fresh concrete properties of FFC mixtures were also found to be acceptable.

Strength properties (compressive and tensile) indicated that the use of 600-RHA in producing FFC might lower the expected compressive strength of FFC mixtures. On the other hand, 40% addition of 150 RHA particles in producing FFC would increase the strength properties. Two field demonstration sites constructed with RHA-modified FFC appeared to be holding well without any visual cracks and deformities. Moreover, cost analysis between RHA modified FFC and regular FFC suggested that RHA modified FFC would be about 30% more economically friendly. It is recommended to monitor the test sections for long-term durability and performance.

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APPENDIX A: GRAIN SIZE DISTRIBUTION

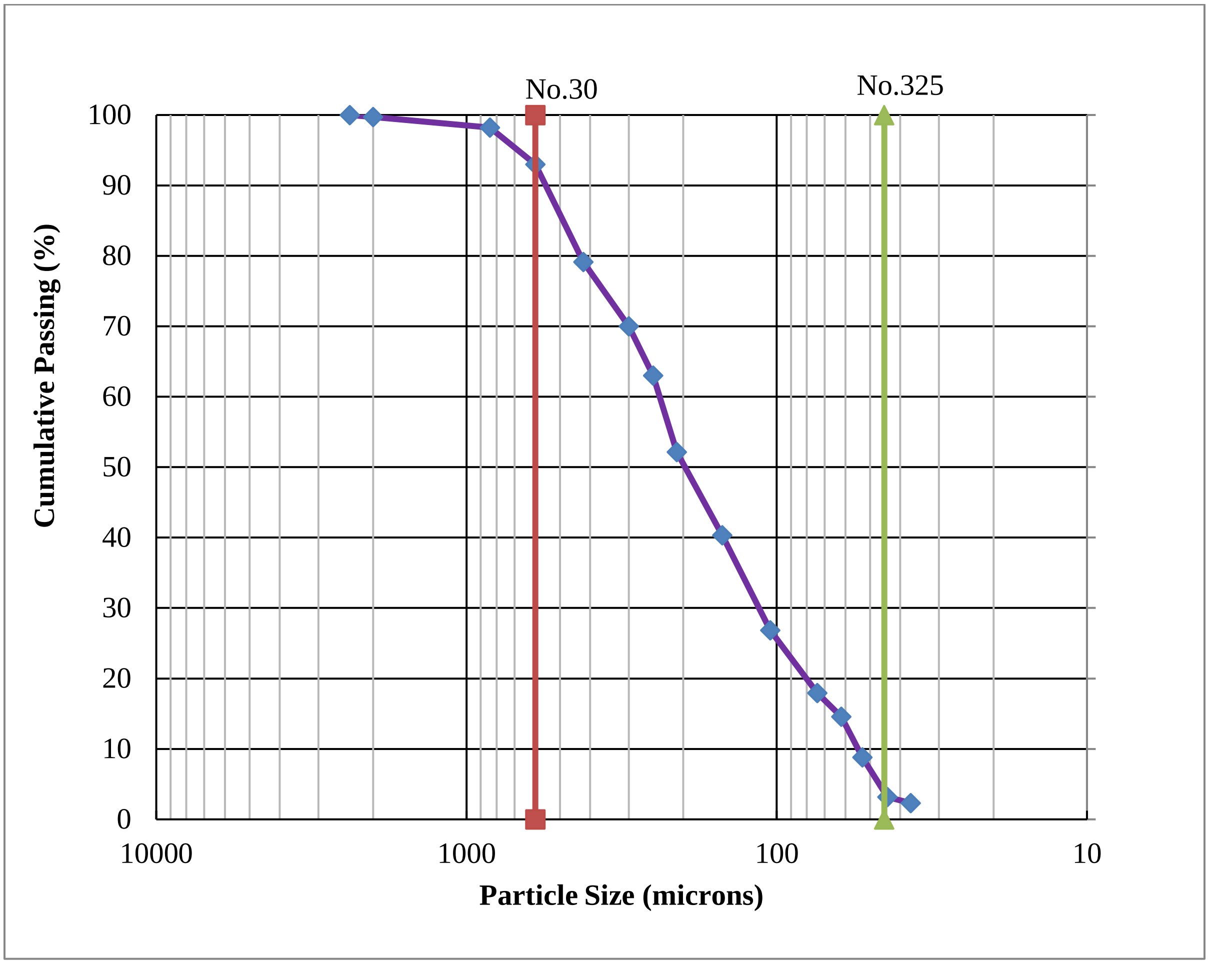

Figure A.1. Grain size distribution of 600-RHA.

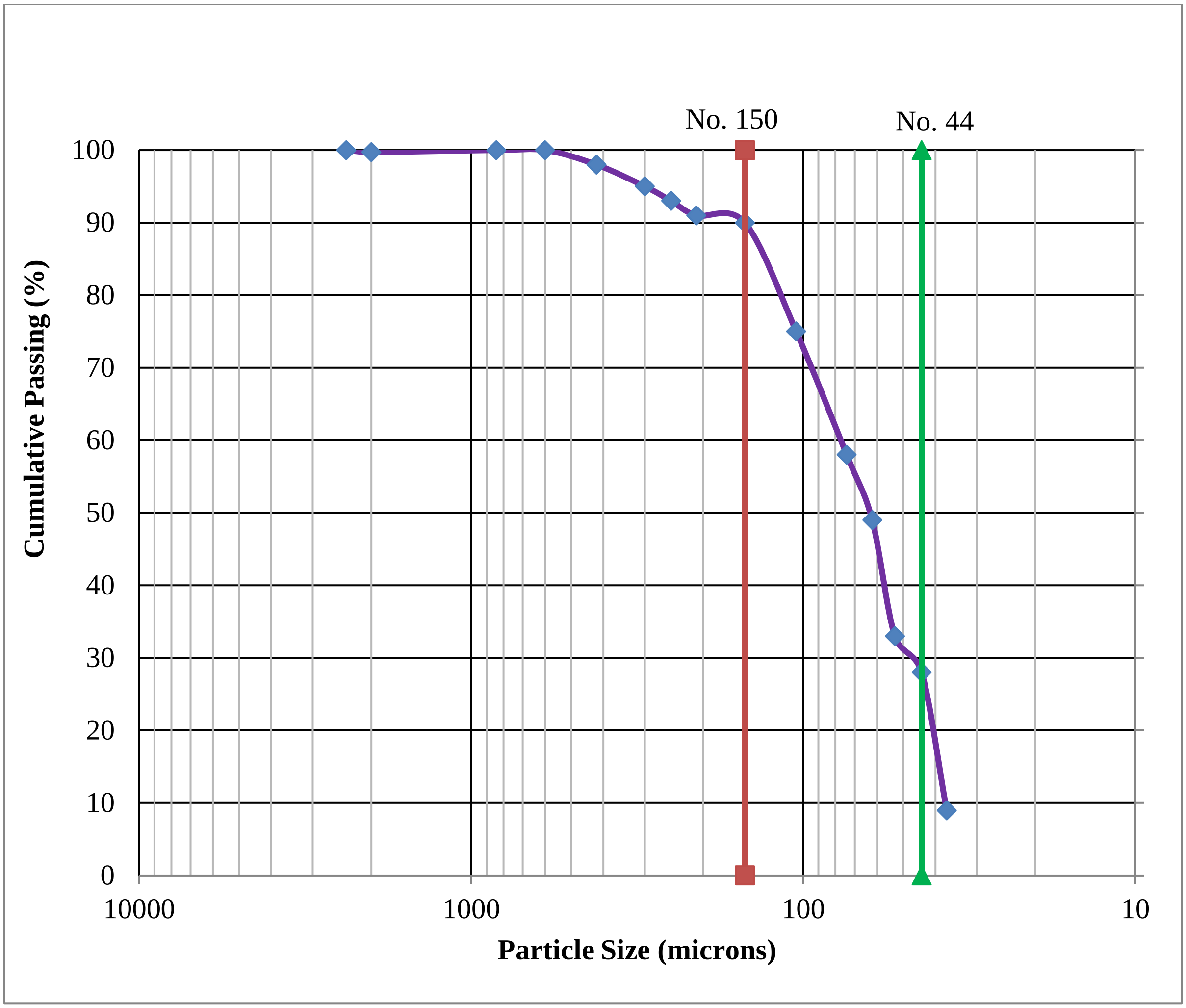

Figure A.2. Grain size distribution of 150-RHA.

APPENDIX B: COMPRESSIVE STRENGTH TEST RESULTS

Table B.1. Compressive strength of 600-RHA modified FFC.

Days	Control	40% 600-RHA (psi)	60% 600-RHA(psi)
7	56	64.0	35.0
14	95	82.0	41.0
21	96	88.0	46.5
28	123	112.0	51.0

Table B.2. Compressive strength of 150-RHA modified FFC.

Days	Control	40% 150-RHA(psi)	60% 150-RHA(psi)
7	56	75.0	39.0
14	95	91.0	50.0
21	96	130.0	72.0
28	123	147.0	88.0

APPENDIX C: TENSILE STRENGTH TEST RESULTS

Table C.1. Tensile strength of modified FFC.

Types of Pozzolan	**Tensile Strength (psi)**
Control	16.5
40% 600-RHA	15
60% 600-RHA	10
40% 150-RHA	19.5