High Volume Substandard Fly Ash Roller-Compacted Concrete

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ABSTRACT

High carbon or high loss-on-ignition (LOI) fly ash, referred to as substandard fly ash, is an abundant material in the Southeastern region of the United States. The fly ash is known to contain heavy metals that may leach into ground and surface waters, creating health and environmental concerns. Utilization of this material could provide environmental, as well as economical, benefits.

An investigation was conducted into the performance of a substandard fly ash in a Tennessee Department of Transportation (TDOT) roller-compacted concrete (RCC) mixture composed of more than 50% of the total cementing materials content as substandard fly ash. TDOT Specification SP501RC was selected as the criterion to follow since its compressive strength requirements were among the most demanding, consisting of compressive strengths of 3,000-psi (20.68-MPa) at 7-days and 4,000-psi (27.58-MPa) at 28-days.

Therefore, fifteen verification batches were produced that met the stringent TDOT 7 and 28-day compressive strengths. The specimens yielded average compressive strengths of 3,770-psi (25.99-MPa) and 6,520-psi (44.95-MPa), respectively; the specimens also yielded an average 28-day static modulus of elasticity greater than 4,700-ksi (32.41-GPa).

Additionally, a metal analysis was performed on a high volume substandard fly ash specimen to examine leaching potential from the concrete. Metal concentrations in the specimen were lower than the Environmental Protection Agency (EPA) regulatory limits, resulting in the specimen being not hazardous based on the characteristic toxicity.

INTRODUCTION AND RESEARCH SIGNIFICANCE

The focus of this research was on the use of a substandard fly ash (a fly ash that does not meet ASTM C 618[1] due to a high carbon content or high loss-on-ignition (LOI)) as more than 50% of the total cementing materials content in a roller-compacted concrete (RCC). Substandard fly ash is an abundant material available in Tennessee and the surrounding states as a result of the high volume of coal utilized to generate electricity in the region. Accumulation of the material, unfortunately, has become an issue due to the lack of viable uses and tends to increase power generation costs due to storage or disposal. Therefore, viable uses for the material are desirable.

Interest in the use of substandard fly ash for various applications was motivated by the ash spill at the Tennessee Valley Authority (TVA) Kingston Fossil Plant in late December of 2008. More than 5-million-yd^3 (3.8-million-m^3) of fly ash were released over the surrounding area, covering nearly 300-acres (121-hectares) of land and water.[2,3,4] The recovery process involved shipping the spilled ash to a lined landfill in West Central Alabama; however, this method of disposal requires continuous monitoring of the landfill deposits for leaching of heavy metals into ground and surface waters.[3,4,5] Therefore, other methods of disposal or use are of serious interest. Past experience has shown that substandard fly ashes can present problems in both air-entrained concrete and controlled low strength materials (CLSM)[6], so applications not as affected by sub-quality material appear to be a solution to their utilization.

The Tennessee Department of Transportation (TDOT) has a specification for RCC, TDOT Specification SP501RC[7], that does not require air entrainment, which seems to make RCC a suitable candidate for substandard fly ash use. TDOT Specification SP501RC requires compressive strengths of 3,000-psi (20.68-MPa) at 7-days and 4,000-psi (27.58-MPa) at 28-days. Therefore, the specification was chosen because of its high 7-day compressive strength demand, reasoning that if the TDOT specification requirements could be met with more than 50% replacement of portland cement (PC) with substandard fly ash, other specifications could be met more easily or with even higher replacement percentages.

RESEARCH OBJECTIVES

The primary objective of this research was to determine if a substandard fly ash could be used successfully as more than 50% of the cementing materials content in a TDOT RCC. Testing was performed to determine compressive strength, as well as static modulus of elasticity, and was used as the measure of success in each RCC mixture.

LITERATURE REVIEW

Fly Ash

Fly ash, a byproduct of coal combustion processes in electric power generation, is a common additive used in various engineering applications.[8,9] The two most common fly ashes available are Class C (self-cementing fly ash) and Class F (non-self-cementing fly ash), as specified by ASTM C 618[1]; however, some fly ashes available do not meet this standard specification and are not typically used as a construction material.[8] Fly ash properties vary depending on the type of coal and the combustion process used.[8,10] Young coals will have a lower carbon content and a higher calcium content, while older coals will have a higher carbon content and lower calcium content.[11,12] Additionally, power generation facilities often use activated carbon injections to reduce the amount of nitrous oxide and mercury released to the environment, thus creating an ash with a higher carbon content than usual.[10,13,14]

Fly ash carbon content and fineness are two properties used to determine its quality and are considered when fly ash is to be used in engineering applications.[9,10,15,16,17] Carbon content, which contributes to loss-on-ignition (LOI), has a large influence on the reactivity of the ash; higher LOI fly ashes often have adverse effects on air entrainment, especially in concrete.[9,10,17,18,19] Fineness, related to the gradation of an ash, also influences the reactivity of the ash; larger particle sizes often react at a slower rate, due to a smaller surface area, which can have adverse effects on concrete properties as well.[1,9,10,17,20] Substandard fly ashes typically have a high LOI and a larger particle size.

Fly ash has found utilization in many different areas of engineered construction materials, including concrete, roadway, and geotechnical applications.[10,16,18,21] Its use can provide advantageous results with respect to strength and durability and offers a more sustainable approach to these applications.[10,17,18,22] However, fly ash that does not find utilization in some application is either handled in storage sites at the power generation facility or deposited in landfills.[10,18,22] Moreover, landfilling fly ash can be costly and requires monitoring for various reasons.[18]

Roller Compacted Concrete

RCC is, essentially, a “no-slump” concrete that, when compacted, forms a dense system capable of accommodating large loads.[23,24,25] It is particularly beneficial for areas that endure high point loads from machinery, such as shipping yards and loading docks, since it can withstand the loads that would normally deform an asphalt pavement.[26] This aspect also makes RCC a valid option for some roadway applications due to its resistance to rutting.[24,25] RCC can be placed with the same equipment used to place an asphalt pavement and may be considered an economical choice of concrete, compared to conventional concrete, since it does not require formwork or reinforcing steel, improving construction ease, speed, and cost.[23,24,27]

An RCC mixture typically contains a higher percentage of aggregate than that of conventional concrete, up to 85% compared to 60-75%, consisting of a lower coarse aggregate content and a higher fine aggregate content; this combination allows for better workability and a more compactable mixture.[24,28,29] The cementitious content of RCC is also typically less than that of conventional concrete; enough paste must be present to coat the aggregate to ensure aggregate interlock, but too much paste must be avoided to prevent difficulties with the compaction process.[24,28]

RCC is designed as a dense, durable mixture that results in high compressive strengths to withstand heavy and continual loading, as well as everyday environmental conditions.[24,28] Strength and durability properties of RCC often hinge on the mixture properties and application process.[24,27,28,30] Particularly, higher compaction gives RCC applications the required density needed to produce higher compressive strength values and lower permeability; the use of lower cementing materials contents helps to prevent shrinkage.[24,27]

Environmental Testing

Fly ash is known to contain heavy metals that, in high enough concentrations, can be harmful to humans and other organisms.[31] One of the major concerns with use of fly ash in an application exposed to weather is its potential to leach these heavy metals into ground or surface waters, resulting in water contamination.[32] Regulations have been established by the United States Environmental Protection Agency (USEPA) under the Resource Conservation and Recovery Act (RCRA), with respect to potentially leachable materials, in an effort to control hazardous materials that may be released into the environment.[33,34]

In general, leaching tests involving fly ash are typically performed to determine whether the fly ash, or material containing fly ash, is characteristic hazardous waste based on the characteristic toxicity.[33,34,35] In order to determine if a solid material exhibits the characteristic toxicity under RCRA, a toxicity characteristic leaching procedure (TCLP) is performed.[33,34,35] If a solid material yields TCLP results indicating that any of the constituents included in the “D-list” exceed the regulatory concentration, the material is considered to be a hazardous waste based on the characteristic toxicity.[33,34,35,36]

Several studies have been performed to investigate the potential for the leaching of metals from various fly ash sources. [32,36,37,38,39] These studies indicate that concentrations of heavy metals in the leachate from fly ash are usually less than the RCRA “D-list” limits.[32,36,37,38,39] Based on the studies, barium, as well as arsenic, chromium, and selenium, result in the highest concentrations in fly ash or coal leachate, but were always in concentrations below the RCRA “D-list” limits.[32,36,37,38] Mercury concentrations were typically below detection limits as it is often released during combustion.[36,37,39]

MATERIALS

TDOT RCC Specification SP501RC requires a Type I PC that meets either AASHTO M 85[40] or AASHTO M 240[41] and allows for partial replacement of PC with a Class C or Class F fly ash that meets AASHTO M 295[42]. However, since the objective of this research was to find a beneficial use for substandard fly ash, a fly ash with a high LOI was utilized instead. This ash was reasoned to be underutilized, very economical, and, essentially, a “worst-case scenario” for the project. Therefore, the TVA was contacted and requested to provide the highest LOI fly ash available. As a result, a fly ash from the Colbert Plant in Northwestern Alabama, which is reported to have an LOI that sometimes reaches 12%, was provided. The properties of the Colbert fly ash, as well as ASTM C 618 and AASHTO M 295 requirements, are shown in Table 1.

TDOT RCC aggregate can be produced by blending ASTM C 33[43] “scalped” No. 57 limestone, ASTM C 33 No. 8 limestone, and manufactured limestone sand. The “scalped” designation refers to the fact that the No. 57 limestone was sieved over a ¾-in (19-mm) sieve to comply with laboratory compaction requirements for TDOT RCC; however, less than 10% of the original aggregate weight was lost during “scalping” and the “scalped” limestone still met the ASTM C 33 No. 57 gradation requirements. The component and blend gradations, as well as TDOT RCC grading requirements, are shown in Table 2.

Two chemical admixtures were used in the RCC mixtures: a mid-range water-reducing admixture and an accelerating admixture; both admixtures met ASTM C 494[44] specifications. Finally, local tap water was used for all mixtures.

Table 1: Fly Ash Properties and Requirements

Property	Colbert Ash	ASTM C618-08a	AASHTO M295-07
Silicon Dioxide (%)	47.8	—*	—
Aluminum Oxide (%)	21.5	—	—
Iron Oxide (%)	8.7	—	—
$SiO_2 + Al_2O_3 + Fe_2O_3$ (%)	78	70 min.	70 min.
Calcium Oxide (%)	7.9	—	—
Magnesium Oxide (%)	1.7	—	—
Sulfur Trioxide (%)	0	5 max.	5 max.
Loss on Ignition (%)	8	6 max.	5 max.
Moisture Content (%)	25	3 max.	3 max.
Alkalies as Na_2O (%)	1.1	—	1.5 max.

** data not applicable*

Table 2: Aggregate Gradations and Requirements

Sieve Size	Sieve Size, (mm)	Scalped No. 57 Limestone, % Finer by Mass	No. 8, % Finer by Mass	Limestone Manufactured Sand, % Finer by Mass	RCC Blend, % Finer by Mass	TDOT RCC Aggregate Specification, % Finer by Mass
1.5-in	37.5	100	100	100	100	—*
1-in	25	100	100	100	100	100
¾-in	19	100	100	100	100	90 - 100
½-in	12.5	33	100	100	80	70 - 90
3/8-in	9.5	16	100	100	75	60 - 85
No. 4	4.75	2	27	100	46	40 - 60
No. 8	2.36	1	8	94	37	—
No. 16	1.18	1	5	61	24	20 - 40
No. 30	0.6	1	1	34	13	—
No. 50	0.3	1	1	17	7	—
No. 100	0.15	1	1	9	4	—
No. 200	0.075	1	1	6	2.8	—

** data not applicable*

PROCEDURE

Optimum Moisture Content Determination

TDOT Specification SP501RC requires that mixtures be designed in a method similar to that of determining the optimum moisture content (OMC) and maximum dry unit weight of soil mixtures and be prepared at a minimum of three different total cementing materials contents. The OMC for each mixture was determined according to ASTM D 1557 Method C[45]. Five samples were initially designed for each cementing materials content at nominal moisture contents ranging from 3 to 9%. Additional samples were required to better define the moisture-density curves for total cementing materials contents of 500-lb/CY (297-kg/m^3) and 550-lbs/CY (326-kg/m^3). The results of tests, as well as the OMC, are shown in Figure 1 and are identified by the total cementing materials content of the mixture.

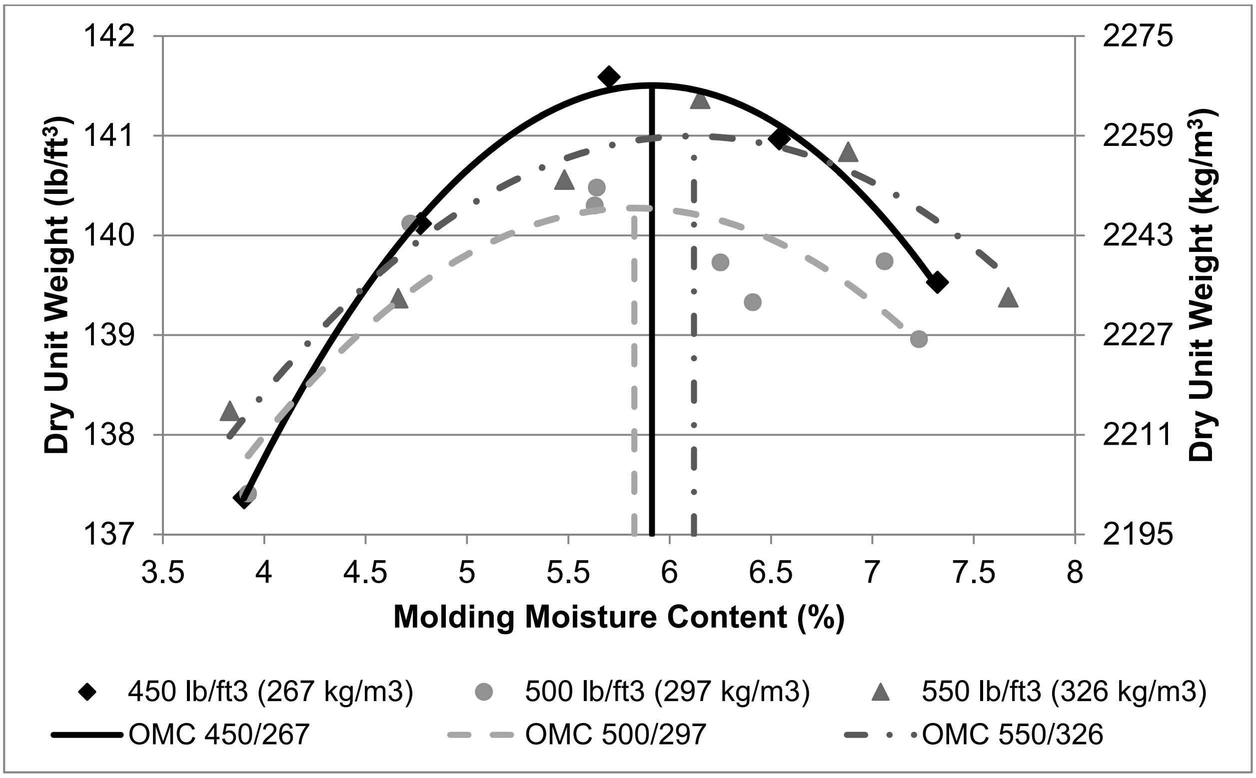

Figure 1: Modified Proctor Results for Three Different Cementing Materials Contents

Selection of Final Cementing Materials Content

TDOT SP501RC requires that compressive strength specimens be cast at the OMC for each of the three total cementing materials contents. Prior experience and literature[46] have indicated that high fly ash replacement rates can reduce early compressive strengths. Therefore, since the specification allows for chemical admixtures, an ASTM C 492 water-reducing accelerator and mid-range water reducer were added to each mixture for compressive strength determination. The mixture designs that produced the OMC for each cementing materials contents are shown in Table 3.

Four 6 by 12-in (150 by 300-mm) specimens were cast for each cementing materials content, two for each test age, according to ASTM C 1435[47]. The specimens were then tested according to ASTM C 39[48] for two specimens at 7-days and two-specimens at 28-days for each cementing materials content. The curves showing compressive strength versus the total cementing materials content are shown in Figure 2. From this data, the 500-lb/CY (297-kg/m3) mixture was selected as the final cementing materials content since it had the lowest total cementing materials content that met both the TDOT Specification 7 and 28-day compressive strength requirements.

Table 3: RCC Candidate Mixtures that Produced OMC

Component	450-lbs/CY (267-kg/m^3) Total Cementing Materials	500-lbs/CY (297-kg/m^3) Total Cementing Materials	550-lbs/CY (326-kg/m^3) Total Cementing Materials
Type I PC, lb/CY (kg/m^3)	224 (133)	249 (148)	274 (163)
Colbert Fly Ash, lb/CY (kg/m^3)	226 (134)	251 (149)	276 (164)
Scalped No. 57 Limestone (SSD), lb/CY (kg/m^3)	1082 (642)	1073 (637)	1035 (614)
No. 8 Limestone (SSD), lb/CY (kg/m^3)	1208 (717)	1196 (710)	1154 (685)
Manufactured Limestone Sand (SSD), lb/CY (kg/m^3)	1307 (775)	1295 (768)	1249 (741)
Water, lb/CY (kg/m^3)	200 (119)	201 (119)	237 (141)

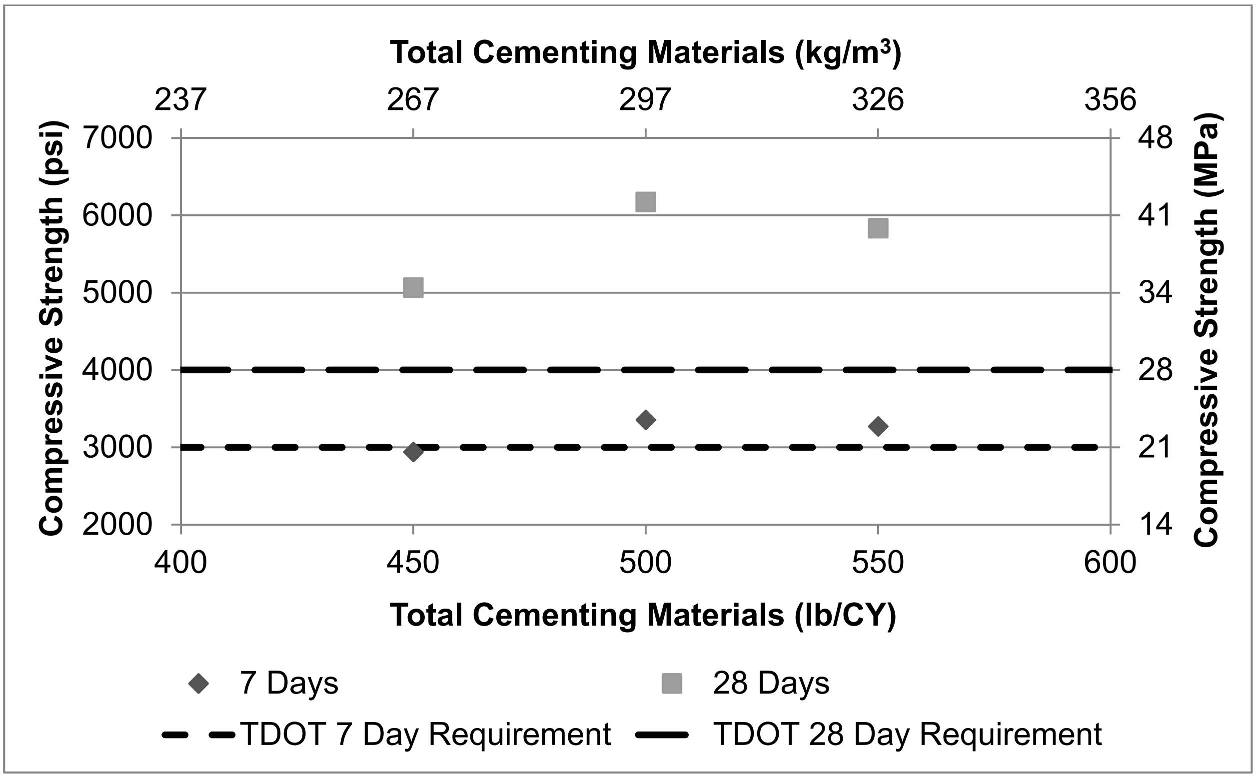

Figure 2: Compressive Strength for Three Cementing Materials Contents

Verification Specimens

Fifteen two-cylinder sets of 7-day specimens and 15 two-cylinder sets of 28-day specimens were cast to determine TDOT Specification SP501RC compressive strength compliance for the selected mixture according to ASTM C 1435. The specimens were de-molded the day after casting and cured using lime-water immersion according to ASTM C 192[49]. At the conclusion of the respective curing period, each specimen was tested according to ASTM C 39 using a 400-kip (1.48-MN) electric compression frame. The 28-day specimens were also tested for static modulus of elasticity according to ASTM C 469[50].

Hazardous Waste Evaluation

A variation of the TCLP[51], sometimes referred to as the “20 Percent Rule”, may be used on specimens having a 100% solids concentration; this method was used to make a hazardous waste determination on an RCC specimen with regard to toxicity.

RESULTS AND ANALYSIS

The compressive strength results for each15 two-cylinder set of compliance specimens for 7 and 28-day testing are shown in Tables 4 and 5, respectively. The modulus of elasticity for the 15 two-cylinder sets of compliance specimens for 28-day testing are shown in Table 6. The results of the hazardous waste evaluation for the RCC specimen can be seen in Tables 7.

Table 4: RCC 7-Day Compressive Strength Results

Set	Cylinder 1, psi (MPa)	Cylinder 2, psi (MPa)	Range, psi (MPa)	Mean, psi (MPa)
1	3519 (24.26)	3548 (24.46)	29 (0.20)	3530 (24.4)
2	3522 (24.28)	3606 (24.86)	84 (0.58)	3560 (24.6)
3	3809 (26.26)	3922 (27.04)	113 (0.78)	3870 (26.7)
4	3819 (26.33)	3826 (26.38)	7 (0.05)	3820 (26.4)
5	3656 (25.21)	3687 (25.42)	31 (0.21)	3670 (25.3)
6	3573 (24.63)	3764 (25.95)	191 (1.32)	3670 (25.3)
7	3850 (26.54	4120 (28.41)	270 (1.86)	3990 (27.5)
8	3685 (25.41)	3663 (25.26)	22 (0.15)	3670 (25.3)
9	3970 (27.37)	3863 (26.63)	107 (0.74)	3920 (27.0)
10	3888 (26.81)	3589 (24.75)	299 (2.06)	3740 (25.8)
11	3970 (27.37)	4050 (27.92)	80 (0.55)	4010 (27.6)
12	3878 (26.74)	3932 (27.11)	54 (0.37)	3910 (26.9)
13	3699 (25.50)	3766 (25.97)	67 (0.46)	3730 (25.7)
14	3831 (26.41)	3707 (25.56)	124 (0.85)	3770 (26.0)
15	3587 (24.73)	3907 (26.94)	320 (2.21)	3750 (25.8)

Table 5: RCC 28-Day Compressive Strength Results

Set	Cylinder 1, psi (MPa)	Cylinder 2, psi (MPa)	Range, psi (MPa)	Mean, psi (MPa)
1	6594 (45.46)	6664 (45.46)	70 (0.48)	6630 (45.7)
2	6539 (43.84)	5959 (41.09)	400 (2.76)	6160 (42.5)
3	6609 (45.57)	6289 (43.36)	320 (2.21)	6450 (44.5)
4	6861 (47.30)	6508 (44.87)	353 (2.43)	6690 (46.1)
5	6422 (44.28)	6870 (47.37)	448 (3.09)	6650 (45.8)
6	6623 (45.66)	6429 (44.33)	194 (1.34)	6530 (45.0)
7	6577 (45.35)	6591 (45.44)	14 (0.10)	6580 (45.4)
8	6343 (43.73)	6540 (45.09)	197 (1.36)	6440 (44.4)
9	6104 (42.09)	6454 (44.50)	350 (2.41)	6280 (43.3)
10	6886 (47.48)	6123 (42.22)	763 (5.26)	6510 (44.8)
11	6872 (47.38)	6455 (44.51)	417 (2.88)	6660 (45.9)
12	6525 (44.99)	6319 (43.57)	206 (1.42)	6420 (44.3)
13	6389 (44.05)	6583 (45.39)	194 (1.34)	6490 (44.7)
14	6495 (44.78)	6703 (46.22)	208 (1.43)	6600 (45.5)
15	6749 (46.53)	6561 (45.24)	188 (1.30)	6660 (45.9)

Table 6: RCC 28-Day Static Modulus of Elasticity Results

Set	Result 1, ksi (GPa)	Result 2, ksi (GPa)	Range, ksi (GPa)	Static Modulus of Elasticity, psi (GPa)
1	4600 (31.7)	4660 (32.1)	60 (0.4)	4650 (32)
2	4730 (32.6)	4740 (32.7)	10 (0.1)	4750 (33)
3	5050 (34.8)	5100 (35.2)	50 (0.3)	5100 (35)
4	4720 (32.5)	4700 (32.4)	20 (0.1)	4700 (33)
5	4810 (33.2)	4800 (33.1)	10 (0.1)	4800 (33)
6	4860 (33.5)	4860 (33.5)	0 (0.0)	4850 (34)
7	4690 (32.3)	4680 (32.3)	10 (0.1)	4700 (32)
8	4820 (33.2)	4790 (33.0)	30 (0.2)	4800 (33)
9	4690 (32.3)	4700 (32.4)	10 (0.1)	4700 (32)
10	4780 (33.0)	4820 (33.2)	40 (0.3)	4800 (33)
11	4690 (32.3)	4730 (32.6)	40 (0.3)	4700 (33)
12	4650 (32.1)	4630 (31.9)	20 (0.1)	4650 (32)
13	4660 (32.1)	4710 (32.5)	50 (0.3)	4700 (32)
14	4700 (32.4)	4680 (32.3)	20 (0.1)	4700 (32)
15	4630 (31.9)	4610 (31.8)	20 (0.1)	4600 (32)

Table 7: RCC Metal Concentrations Results

Metal	Solid Basis Metal Concentration in Sample, mg/kg	Equivalent Maximum Metal Concentration in TCLP Extraction Fluid, mg/L	Maximum Allowable Metal Concentration in the Extraction Fluid[52], mg/L
Arsenic	3.681	0.184	5.0
Barium	127.341	6.367	100.0
Cadmium	0.455	0.023	1.0
Chromium	13.255	0.663	5.0
Lead	< 2.399	< 0.120	5.0
Selenium	< 5.997	< 0.300	1.0
Silver	< 0.24	< 0.12	5.0

Variability of Results

The average results and parameters pertaining to the variability of results for compressive strength are shown in Table 8. No guidance was found on acceptable variability for RCC laboratory specimen compressive strengths; therefore, the results were compared with variability standards from ASTM C 39, ASTM C 192, and ACI 214R[53] for normal concrete. The overall variation and within-test variation of the RCC specimens indicated “excellent” and “good” characterizations, respectively, according to ACI. Additionally, the majority of the specimen pairs met ASTM C 39 and ASTM C 192 precision requirements. Therefore, the compressive strength results were determined to be adequate to characterize material behavior.

The average results and parameters pertaining to the variability of results for static modulus of elasticity are shown in Table 9. No guidance was found on acceptable variability for RCC laboratory specimen static modulus of elasticity; therefore, the results were compared with variability standards from ASTM C 469 for normal concrete. Though required for normal concrete with a lower modulus range, ASTM C 469 states that results of duplicate cylinders from different batches should not differ by more than 5% of their average; over 85% of the RCC laboratory data met this requirement. Therefore, the static modulus of elasticity results were determined to be adequate to characterize material behavior.

Table 8: Statistical Parameter of the Compressive Strength Specimens

Parameter	7-Day	28-Day
Mean Strength, psi (MPa)	3774 (26.02)	6515 (44.92)
Standard Deviation, psi (MPa)	143 (0.99)	150 (1.03)
Coefficient of Variation (COV), %	3.8	2.3
Mean Range of Specimens within a Test, psi (MPa)	120 (0.83)	288 (1.99)
Within-Test COV from ACI 214 (%)	2.8	3.9
Overall Variation Category from ACI 214	Excellent	Excellent
Within-Test Variation Category from ACI 214	Very Good	Good
Meets ASTM C 39 COV Requirement of 2.4%	No	Yes
Meets ASTM C 39 Within-Test Range of 6.6%	12 of 15 (80%)	13 of 15 (86%)
Meets ASTM C 192 7-Day Within-Test Range of 574-psi (3.96-MPa)	15 of 15 (100%)	—*

** data not applicable*

Table 9: Statistical Parameters of the Modulus Specimens

Parameter	28-Day Modulus
Mean Static Modulus of Elasticity, ksi (GPa)	4742 (32.7)
Standard Deviation, ksi (GPa)	116 (0.80)
COV (%)	2.4
Mean Range of Specimens Within a Test, ksi (GPa)	26 (0.18)
Meets ASTM C 469 Requirement of 5%	90 of 105 (86%)

TDOT SP501RC Specification Compliance

TDOT Specification SP501RC requires minimum compressive strengths of 3,000-psi (20.68-MPa) at 7-days and 4,000-psi (27.58-MPa) at 28-days. Despite using more than 50% replacement of PC with substandard fly ash, the compressive strengths of the verification specimens met both 7 and 28-day requirements.

Modulus Correlations

A comparison was made between the measured values of 28-day static modulus of elasticity and the predicted values of static modulus of elasticity calculated by the ACI 318[54] equation using unit weight and 28-day compressive strength. The ACI 318 equation predicted the measured values of static modulus of elasticity extremely well. The absolute values of the maximum percent difference and the average percent difference between the measured and predicted static modulus of elasticity were 5.5 and 2.3%, respectively. This prediction was usually not conservative, that is, in 13 of the 15 cases (86.7%), the prediction was greater than the measured static modulus of elasticity.

Hazardous Waste Evaluation Specimen Analysis

The hazardous waste evaluation demonstrated that the RCC specimen was not hazardous waste based on the characteristic toxicity.[55] The results show that barium does yield a higher concentration as literature suggests, but is still below the regulatory limit.

Cost

Both economical and environmental benefits were sought by using substandard fly ash in RCC. A fly ash that meets ASTM C 618 was estimated to cost approximately $50/ton delivered to a ready mix producer in middle Tennessee. Substandard ash was assumed to have a negligible cost, other than transportation, since it has no known beneficial uses. Since past experience with high volume fly ash mixtures indicated that early compressive strength development could be a problem, an ASTM C 494 water-reducing accelerator was used in the mixtures; however, the use of a chemical accelerator would, unfortunately, reduce some of the cost benefits associated with substandard fly ash use. Therefore, a decision was made to use the majority of the remaining materials to determine if the RCC mixture could meet the TDOT Specification SP501RC 7-day compressive strength requirement without a chemical accelerator.

Eleven two-cylinder sets were cast with the component materials warmed to various temperatures in order to produce different mixture temperatures, obtained according to ASTM C 1064[56]. The results of the average 7-day compressive strengths compared to the casting temperature are shown in Figure 3. The results show that a minimum casting temperature needed to produce a mixture that met TDOT Specification SP501RC could not be established; however, it was determined that a chemical accelerator was not needed for the mixture at casting temperatures above 74°F (23.3°C).

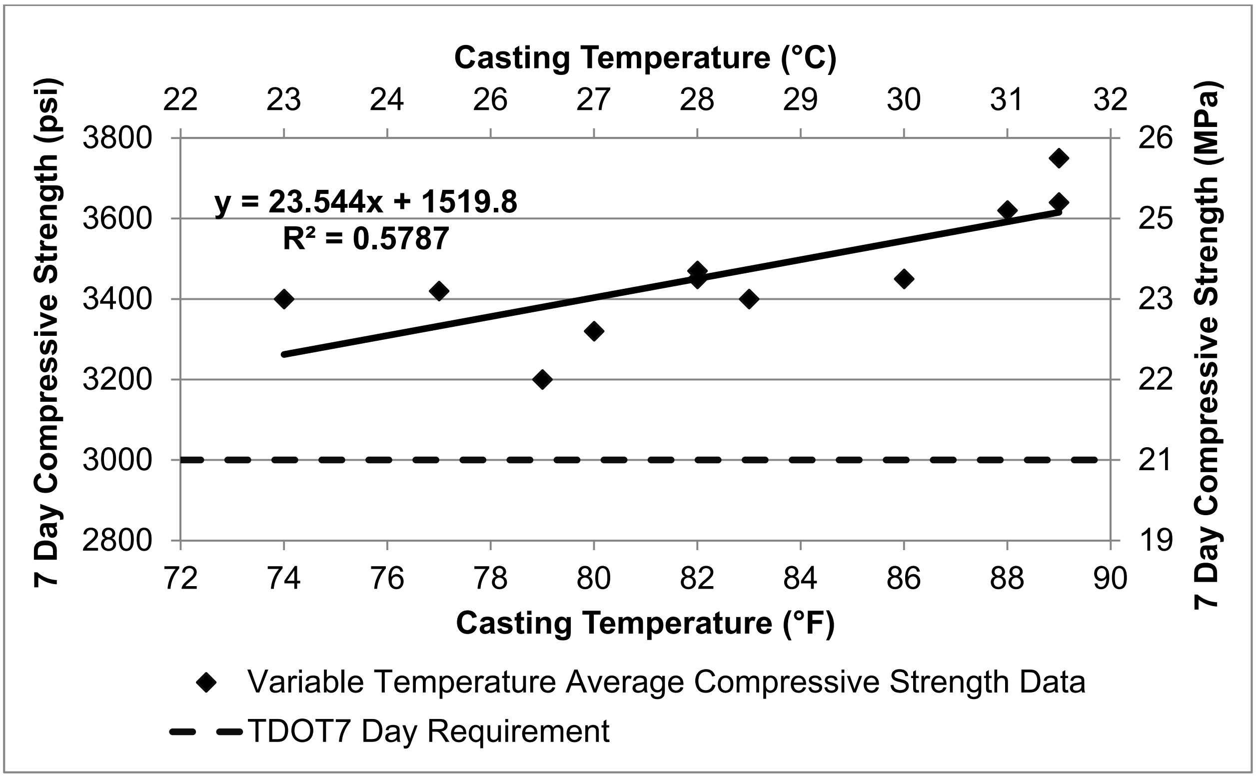

Figure 3: RCC 7 Day Compressive Strength and Casting Temperature Relation

CONCLUSIONS AND SIGNIFICANT OBSERVATIONS

Based on the testing of one substandard fly ash, the following conclusions and significant observations were made:

1. The use of substandard fly ash as more than 50% replacement of the PC in an RCC mixture produced specimens that met the stringent 7 and 28-day compressive strength requirements of 3,000-psi (20.68-MPa) and 4,000-psi (27.58-MPa), respectively, from TDOT Specification SP501RC.
2. The use of substandard fly ash as more than 50% replacement of the PC in an RCC mixture produced specimens with a static modulus of elasticity greater than 4,700-ksi (32.41-GPa).
3. RCC is a viable method to beneficially use substandard fly ash.
4. RCC containing substandard fly ash as a cementing agent will not be a hazardous waste.

FUTURE RESEARCH NEEDS

1. Repeat the research using substandard fly ash from different generating facilities;
2. Perform field testing trials to evaluate the true viability of substandard fly ash use in a TDOT RCC; and
3. Obtain performance, economical, and environmental comparisons with a fly ash meeting ASTM C 618, preferably in a field setting.

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