Center for By-Products Utilization

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Synopsis: This work was conducted to develop two types of controlled low strength materials (CLSM) or flowable slurry utilizing post-consumer glass (broken glass or glass cullet) aggregate and fly ash. Type A CLSM consisted of glass, fly ash, cement, and water; and Type B CLSM consisted of glass, sand, cement, and water. All mixtures were proportioned to achieve the 28-day compressive strength of 0.7 MPa (100 psi). The Type A CLSM mixtures consisted of a control mixture (100% fly ash without glass) and five other mixtures with glass, as a replacement of fly ash in the range of 20 to 80 percent. The Type B CLSM mixtures were composed of a control mixture (without glass) and two other mixtures at 30 to 75 percent replacement of sand with glass. The flowable slurry developed in this project satisfied the ACI Committee 229 definition of CLSM. Decreasing the amount of fly ash and increasing the glass content led to increased bleeding and segregation at high replacement levels of 60% and 80%. Permeability of Type A CLSM remained essentially unchanged except at high glass contents it was lower. For Type B CLSM, the permeability was about the same.

Keywords: CLSM, glass, fly ash, flowable slurry.

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INTRODUCTION

Wisconsin generates about 155,000 tonnes (170,000 tons) of post-consumer glass by-products each year. Several problems exist in glass recycling due to the breakage of glass leading to co-mingling of colors. Currently, very limited amount of total mixed glass generated is being recycled in Wisconsin and elsewhere in the USA. Additionally, landfilling of mixed glass is prohibited by the Wisconsin Department of Natural Resources. Therefore, there is an urgent need to find alternative uses for post-consumer, mixed color, broken glass. Application of mixed glass in construction materials should provide a large volume use for it. The major objective of this investigation was to determine the technical feasibility of utilizing high volumes of mixed colored, broken glass in Controlled Low Strength Materials (CLSM) meeting ACI 229 requirements.

CLSM flows like a liquid and supports like a solid and placed without compacting. Its consistency resembles that of the batter for pancakes. It can harden within a few hours of placement. CLSM can provide cost-effective alternatives to conventional compacted granular backfill or structural fill materials (soil or other granular materials). This is primarily due to its lower cost of labor and significantly reduced time required for placement. CLSM has been used as a non-structural material for numerous applications including backfills, structural fills, sound insulating and isolation fills, pavement bases, conduit bedding, erosion control, and void filling. For various applications, it can be proportioned to attain strengths up to 8.3 MPa (1200 psi) at the age of 28 days, in accordance with ACI 229. When future excavatibility is desired, CLSM is generally proportioned for compressive strength varying between 0.3 and 0.7 MPa (50 to 100 psi) at the age of 28 days.

RESEARCH SIGNIFICANCE

This investigation was conducted to evaluate the effects of crushed glass on properties of CLSM. The results of this investigation would be useful in establishing mixture proportions for CLSM incorporating large amounts of crushed glass, and low amounts of fly ash, sand, and/or cement for commercial applications. The success of this project will lead to increased utilization of broken glass materials in Wisconsin and elsewhere.

LITERATURE REVIEW

It is well known for several decades that use of glass in concrete will activate Alkali-Silica Reactions (ASR) causing deleterious expansion and cracking [1]. It is also well known for many decades that use of Class F fly ash in concrete will reduce potential of ASR. More recently, Naik and his colleagues [2] have developed high-performance concrete (HPC) mixtures containing Class F fly ash, Class C fly ash, and silica fume to eliminate any potential ASR. HPC is expected to have over 300 percent higher service life than normal strength concrete. Through proper mixture proportioning, glass aggregates have been used in cement-based construction materials [3, 4, 5] in several foreign countries, including Germany and England. They have established that alkali content of cementitious mixtures from all sources in such mixtures should be less than 3 kg/m^3 (5 lb/yd^3) to avoid the occurrence of ASR [6].

More recently, Meyer et al. have re-established that the use of crushed glass in concrete is dependent upon solving the problems associated with the expansion due to ASR between the cement paste and the glass aggregate [7, 8]. Attempts are being made to solve ASR problems in order to use glass as aggregates in concrete. A great deal of research work has been published concerning utilization of conventional coal combustion products in CLSM [9, 10]. However, limited research work has been conducted pertaining to the use of glass material in CLSM [11, 12].

EXPERIMENTAL PROGRAM

<u>Materials</u>

Materials utilized for this project consisted of one source of fly ash, cement, mixed color broken glass, and concrete sand. Materials were characterized for chemical and physical properties in accordance with appropriate ASTM or other standards.

<u>Sand</u>--One source of concrete sand conforming to ASTM C 33 was utilized in this investigation (Tables 1 and 2).

<u>Cement</u>—A Type I cement was used throughout this investigation. The cement met the ASTM C 150 requriements for Type I cement (Tables 3 and 4).

<u>Fly Ash</u>--Fly ash was tested for physical properties, oxides, basic chemical elements, and mineralogy. The fly ash did not meet the ASTM C 618 requirements for finess and strength activity index (Tables 5 and 6).

<u>Glass</u>--The glass was obtained from a glass recycling company in Wisconsin. The glass was tested for physical properties per ASTM C 33 requirements. The physical properties and gradation of fine aggregate and mixed colored glass are given in Tables 1 and 2, respectively. The grading curves are plotted in Fig. 1, along with the ASTM standard grading requirements for regular sand used for concrete mixtures. These plots exhibit that the glass utilized for this project is coarser than regular concrete sand and is outside the ASTM limits. The grading curves show that the glass contained predominantly coarser particles compared to that for the regular sand. For example, approximately 16 percent of the glass passed through the No. 16 sieve versus 84 percent of the sand passed through the No. 16 sieve.

<u>Mixture Proportions</u>

Two types of CLSM mixtures were proportioned: one with fly ash (Type A) and the other with regular concrete sand (Type B). Such CLSM mixtures are currently used in normal construction work. Six Type A CLSM mixtures based upon typical flowable slurry containing fly ash, cement and water [9] and three Type B CLSM mixtures based upon the components of sand, cement and water [10] were proportioned. One reference mixture was proportioned without glass for each type of CLSM. Five Type A flowable CLSM mixtures were proportioned to have glass content of 20%, 30%, 40%, 60%, and 80% as a replacement of fly ash by mass (Table 7); whereas two Type B CLSM mixtures were proportioned containing glass with sand replacement levels of 30% and 75% by mass (Table 8). To reduce the cost, glass was not processed to conform to the grading requirements of sand replaced in accordance with ASTM C 33. These mixtures were proportioned to maintain a practical value of flow in the range of approximately 350 ± 50 mm (14 ± 2 inches) and a maximum compressive strength of 0.7 MPa (100 psi) at the age of 28 days. The limit on compressive strength was specified to maintain the capability for future excavation.

Manufacturing of Flowable CLSM Mixtures

All CLSM ingredients were weighed and loaded in a concrete mixer. The required amount of the cement together with one-half the specified quantity of fly ash or sand, and glass was loaded into a rotating-drum mixer and mixed for three minutes. Three-quarters of the specified water was then added to the mixer and mixed for an additional three minutes. The remaining fly ash or sand, glass, and water was added to the mixer and mixed for five more minutes. Additional water was added in the mixture as needed for achieving the desired flow. Whenever additional water was added to obtain the desired flow, the concrete mixture was mixed for an additional five minutes. The resulting mixture was then discharged into a pan where the flowable slurry was tested for various properties.

Specimen Preparation and Testing

Fresh CLSM properties such as air content (ASTM D 6023), flow (ASTM D 6103), unit weight (ASTM D 6023), and setting and hardening (ASTM D 6024) were measured. Ambient air CLSM mixture temperature was also measured and recorded. Test specimens were prepared from each mixture for compressive strength (ASTM D 4832), water permeability (ASTM D 5084), and setting and hardening tests. All test specimens were cast in accordance with ASTM D 4832. These specimens were typically cured for one day in their molds in the laboratory at about 21 ± 2°C (70 ± 3°F). These specimens were then demolded and placed in a standard moist-curing room maintained at 100% R.H. and 23°C (73 °F) temperature until the time of test.

RESULTS AND DISCUSSION

Properties of Fresh CLSM

The fresh properties for the ash/glass Type A CLSM mixtures are given in Table 7. The results indicated that as the quantity of glass was increased in these mixtures, less water was required to maintain the flow. This is due to the larger particle size and higher density of glass compared with that of fly ash. The unit weight of the CLSM mixtures increased with increased amount of glass. Decreasing the amount of fly ash and increasing glass lead to increased bleeding and segregation of the mixtures shortly after casting the CLSM test specimens, especially at the higher replacement levels of 60 and 80 percent. This was attributed to the decreased amount of the cohesive material, fly ash, and increased amount of denser and larger size glass particles compared to fly ash particles. The properties for sand/glass Type B CLSM (Table 8) were similar to that of Type A CLSM. However, unit weight of Type B mixtures remained essentially unchanged because the sand and glass had similar values of specific gravity.

Setting and hardening characteristics of the flowable mixtures are shown in Figs. 2 and 3. The slurry was cast directly into a mold and left uncovered for the entire setting and hardening measurement period. Measurements were taken in accordance with ASTM D 6024. ASTM D 6024 specifies the suitability of slurry to support load as a maximum diameter of impression of 76 mm (3 inches). This value was considered to be too high for the cylinders to be safely demolded without damaging the test specimens. Based upon comparing the hardness/firmness of Type A CLSM, as cast in the cylinder molds, a more reasonable value was considered to be approximately 50 mm (two inches).

The setting times for Type A CLSM mixtures were delayed considerably by the addition of the glass compared with the control mixture at high glass content levels. The setting of mixtures containing the largest percentage of glass (80%) was delayed more than other mixtures. This occurred probably due to the decrease in the cementitious materials content of the mixture. The setting and hardening characteristics of Type B (Sand/Glass) mixtures (Fig. 3) also exhibited a similar general delay in setting at high glass content levels as Type A mixtures.

Compressive Strength of CLSM

The compressive strength of Type A CLSM mixtures increased with age (Fig. 4). The rate of increase in compressive strength was the highest for the mixtures containing 60 and 80% glass (Mixtures A-5 and A-6). This was probably due to the fact that at lower glass contents, the CLSM mixtures behave like pastes versus at high glass contents they behave like concrete with small aggregates due to the coarse glass. The compressive strength values of the Type A mixtures with and without glass ranged from 0.4 to 0.6 MPa (60 to 90 psi) at the age of 28 days. The compressive strength values of the Type B CLSM mixtures with and without glass were similar, about 0.6 ± 0.15 MPa (85 ± 20 psi) at the 28-day age. The compressive strength values of all the CLSM mixtures were considered acceptable for future excavatability.

Permeability of Flowable Concrete

The permeability of the Type A slurry mixtures varied from 2.2×10^{-6} cm/s to 35.9×10^{-6} cm/s at the age of 73 days (Table 9), and for Type B slurry mixtures it varied from 5.4×10^{-6} cm/s to 7.6×10^{-6} cm/s at the age of 91 days (Table 10). Permeability of the CLSM was very low, approximately 10 to 100 times lower than that of compacted sand. The results exhibited by both types of CLSM mixtures at the 73-day age indicates that mixtures containing glass had permeability approximately equivalent to or slightly lower than the control mixture without glass. Decreased permeability with increased age was noted, Tables 9 and 10. This is a positive benefit by decreasing the potential future leaching.

CONCLUSIONS

Based on data collected in this investigation, the following general conclusions can be drawn.

- The water demand for the CLSM mixtures decreased with increasing glass content. This was attributed to decreased surface area of glass particles compared to either fly ash or sand.
- The setting time was delayed due to inclusion of crushed glass in the CLSM mixtures at high glass content levels. This is believed to be the dilution effect resulting from decreased amount of cementitious materials used at the high glass content levels.

- Both types of CLSM mixtures with and without glass attained the specified strength of about 0.7 MPa (100 psi) or less at the age of 28 days.
- The permeability of both CLSM mixtures varied between 2.2 x 10^{-6} cm/s to 35.9x10^{-6} cm/s at the later age which is approximately 10 to 100 times lower than that for compacted sand.
- Based on the results obtained, excavatable CLSM mixtures with glass content up to 80% as replacement of fly ash (Type A flowable slurry) or up to 70% as a replacement of regular concrete sand (Type B CLSM mixtures) can be manufactured for construction applications.

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Table 1 - Physical Properties of Fine Aggregate and Glass (ASTM C 33)

	Unit Weight kg/m^3 (lb/ft^3)	Bulk Specific Gravity	SSD Bulk Specific Gravity	Apparent Specific Gravity	SSD Absorption Percent	Percent Void	Fineness Modulus	Material Finer Than 75 µm (#200 Sieve) Percent	Clay Lumps and Friable Particles Percent
ASTM Test Designation	C 29	C 127/C 128				C 29	C 136	C 117	C 142
Sand (Fine Aggregate)	1666	2.67	2.70	2.73	0.9	38.0	2.3	0.6	0.0
Glass	1338	2.46	2.48	2.50	0.6	42.1	4.6	1.2	0.0

	(%)	SS Passing, (%)		(%)	Passing for Sand (%)
9.5-mm (3/8")	100.0	100	9.5-mm (3/8")	90.0	100
4.75-mm(#4)	100.0	95 to 100	4.75-mm(#4)	75.7	95 to 100
2.36 mm (#8)	93.0	80 to 100	2.36 mm (#8)	39.5	80 to 100
1.18 mm (#16)	83.6	50 to 85	1.18 mm (#16)	16.4	50 to 85
600 µm (#30)	65.8	25 to 60	600 µm (#30)	6.7	25 to 60
300 µm (#50)	24.8	10 to 30	300 µm (#50)	3.3	10 to 30
150 µm (#100)	2.8	2 to 10	150 µm (#100)	1.7	2 to 10

* Values reported for % passing are the average of three tests. As received glass was initially sieved over 12.7 mm (½in.) sieve.

Table 3 - Physical Properties of Cement

ASTM TEST DESIGNATION	TEST PARAMETER	RESULT	ASTM C 150	
C 109	Compressive Strength, MPa 3-day 7-day 28-day	 23.1 MPa 27.9 MPa 39.5 MPa	 12.4 MPa 19.3 MPa 27.6 MPa	-- --
C 151	Autoclave Expansion, %	-0.02	--	0.8
C 430	Fineness (% Retained on No. 325 Sieve)	7.8	--	--
C 204	Fineness (Air Permeability, Specific Surface, m^2/kg)	340	280	--
C 191	Vicat Time of Initial Setting (min)	275 Initial 365 Final	45	375
C 185	Air Content of Mortar, %	11.0	--	12.0
C 188	Specific Gravity	3.17	--	--

Table 4 - Analysis for Oxides, SO_3, and Loss on Ignition for Cement

OXIDES, SO_3, AND LOSS ON IGNITION ANALYSIS, (%)		
Analysis Parameter	Cement	ASTM C 150 Requirements (Maximum)
Silicon Dioxide, SiO_2	21.9	--
Aluminum Oxide, Al_2O_3	4.9	--
Iron Oxide, Fe_2O_3	3.0	--
Calcium Oxide, CaO	64.1	-
Magnesium Oxide, MgO	2.4	6.0
Titanium Oxide, TiO_2	0	--
Potassium Oxide, K_2O	0.5	--
Sodium Oxide, Na_2O	0.1	--
Tricalcium Aluminate, C_3A (as calculated from oxides)	7.9	--
Sulfite, SO_3	1.4	3.5
Loss on Ignition, LOI	1.7	3.0
Moisture	0.9	--
Available Alkali, Na_2O, (ASTM C-311)	0.88	0.60*

* Required only where potentially reactive aggregates are utilized.

Table 5 - Physical Properties of Fly Ash

TEST PARAMETER	FLY ASH	ASTM C 618 REQUIREMENTS	
		CLASS C	CLASS F
Retained on No.325 sieve, (%)	43.9	34 max	34 max
Strength Activity Index with Cement (% of Control)			
3-day	85.3		
7-day	69.6	75 min	75 min
28-day	83.0	75 min	75 min
Water Requirement (% of Control)	101	105 max	105 max
Autoclave Expansion, (%)	0.04	0.08	0.08
Unit Weight (lb/ft^3)	61.1		
Specific Gravity	2.41		
Variation from Mean, (%) Fineness	1.5	5 max	5 max
Specific Gravity	0.4	5 max	5 max

Table 6 - Analysis for Oxides, SO_3, and Loss on Ignition for Fly Ash

OXIDES, SO_3, AND LOSS ON IGNITION ANALYSIS, (%)			
Analysis Parameter	Ash	ASTM C 618 Requirements	
		Class C	Class F
Silicon Dioxide, SiO_2	45.7	--	--
Aluminum Oxide, Al_2O_3	22.2	--	--
Iron Oxide, Fe_2O_3	9.6	--	--
SiO_2 + Al_2O_3 + Fe_2O_3	77.4	50.0 Min	70 Min
Calcium Oxide, CaO	10.3	--	-
Magnesium Oxide, MgO	2.5	--	--
Titanium Oxide, TiO_2	1.1	--	--
Potassium Oxide, K_2O	1.2	--	--
Sodium Oxide, Na_2O	1.5	--	--
Sulfite, SO_3	0.8	5.0 Max	5.0 Max
Loss on Ignition, LOI	5.0	6.0 Max	6.0 Max
Moisture	0.2	3.0 Max	3.0 Max

Table 7 - Type A, Ash/Glass, CLSM Mixtures

Mixture Number	A-1	A-2	A-3	A-4	A-5	A-6
Glass (%)	0	20	30	40	60	80
Fly Ash, (%)	100	80	70	60	40	20
Cement, kg/m^3 ($lb/yd.^3$)	45 (76)	40 (67)	40 (67)	40 (67)	40 (67)	40 (67)
SSD Glass, kg/m^3 ($lb/yd.^3$)	0 (0)	245 (413)	400 (674)	540 (910)	900 (1517)	1310 (2208)
Fly Ash, kg/m^3 ($lb/yd.^3$)	1100 (1854)	975 (1643)	930 (1568)	825 (1391)	595 (1003)	330 (556)
Water, kg/m^3 ($lb/yd.^3$)	520 (876)	450 (758)	430 (725)	430 (725)	345 (581)	335 (565)
Air Temperature, ºC (ºF)	25 (77)	21 (70)	25 (77)	21 (70)	25 (77)	21 (70)
Fresh Slurry Temperature, ºC (ºF)	23 (73)	25 (77)	23 (73)	26 (79)	23 (73)	24 (75)
Flow, mm (in.)	337 (13-1/3)	343 (13-1/2)	313 (12-1/2)	359 (13-1/8)	389 (15-1/3)	330 (13)
Air Content (%)	0.8	0.9	0.7	1.3	0.6	2.1
Unit Weight, kg/m^3 (lb/ft^3)	1660 (104)	1725 (108)	1800 (112)	1840 (115)	1880 (117)	2020 (126)
Hardened Slurry Density, kg/m^3 (lb/ft^3)	1640 (102)	1640 (102)	1685 (105)	1710 (107)	1840 (115)	1990 (124)

Table 8 - Type B, Sand/Glass, CLSM Mixtures

Mixture Number	S-1	S-2	S-3
Glass (%)	0	30	75
Fine Aggregate (%)	100	70	25
Cement, kg/m^3 ($lb/yd.^3$)	40 (67)	25 (42)	30 (51)
SSD Glass, kg/m^3 ($lb/yd.^3$)	0 (0)	340 (573)	940 (1584)
SSD Fine Aggregate, kg/m^3 ($lb/yd.^3$)	1280 (2157)	800 (1348)	320 (539)
Water, kg/m^3 ($lb/yd.^3$)	330 (556)	275 (464)	305 (514)
Air Temperature, ºC (ºF)	26 (79)	28 (82)	26 (79)
Fresh Slurry Temperature, ºC (ºF)	24 (75)	27 (81)	27 (81)
Flow, mm (in.)	330 (13)	343 (13-1/2)	311 (12-1/4)
Air Content (%)	0.7	1.2	1.9
Unit Weight, kg/m^3 (lb/ft^3)	2085 (130)	2050 (128)	2030 (127)

Table 9 - Permeability of Type A, Ash/Glass, CLSM Mixtures

Mixture Number	Glass (%)	Fly Ash (%)	Permeability (cm/sec)*	
			38-day	73-day
A-1	0	100	19.3×10^{-6}	12.4×10^{-6}
A-2	20	80	79.4×10^{-6}	24.6×10^{-6}
A-3	30	70	418.7×10^{-6}	26.4×10^{-6}
A-4	40	60	167.4×10^{-6}	35.9×10^{-6}
A-5	60	40	8.3×10^{-6}	2.9×10^{-6}
A-6	80	20	7.2×10^{-6}	2.2×10^{-6}

* Average of three readings

Table 10 - Permeability of Type B, Sand/Glass, CLSM Mixtures

Mixture Number	Glass (%)	Sand (%)	Permeability (cm/sec) *	
			28-day	91-day
S-1	0	100	39.1 x 10^{-6}	7.6 x 10^{-6}
S-2	30	70	7.1 x 10^{-6}	6.6 x 10^{-6}
S-3	75	25	10.6 x 10^{-6}	5.4 x 10^{-6}

*Average of three readings

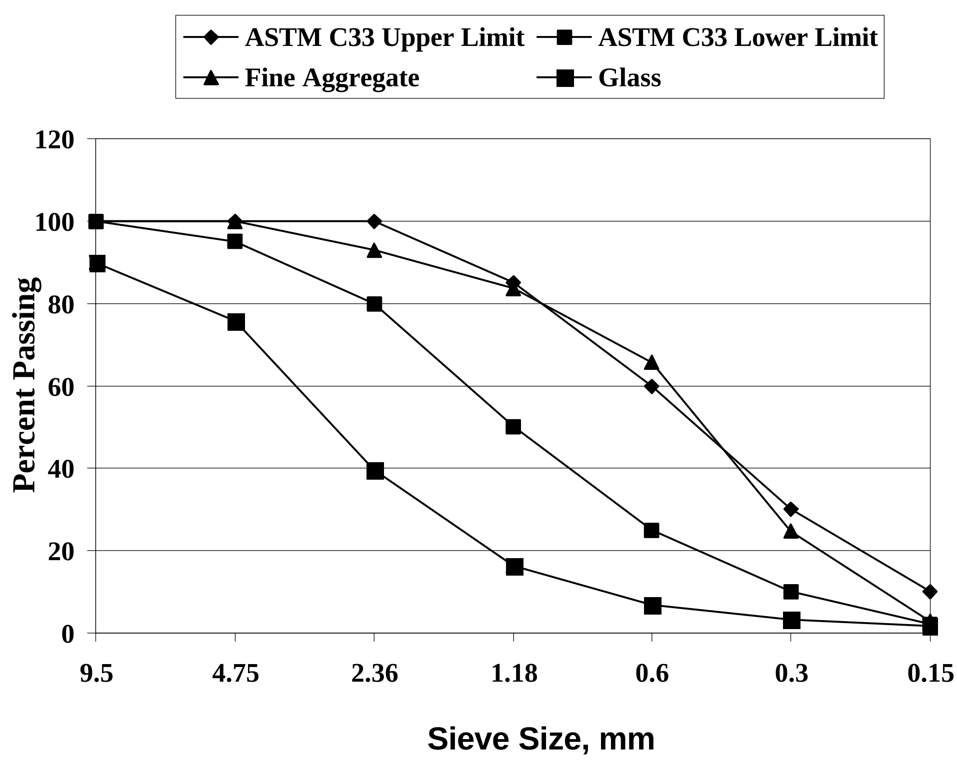

Fig. 1 – Sieve Analysis of Fine Aggregate and Glass

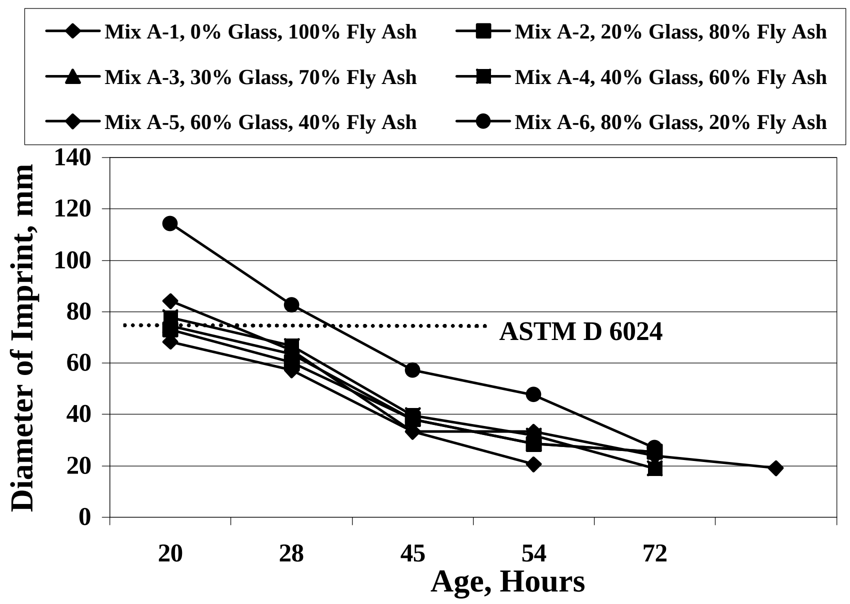

Fig. 2 – Setting and Hardening Characteristics of Type A (Ash/Glass) CLSM Mixtures

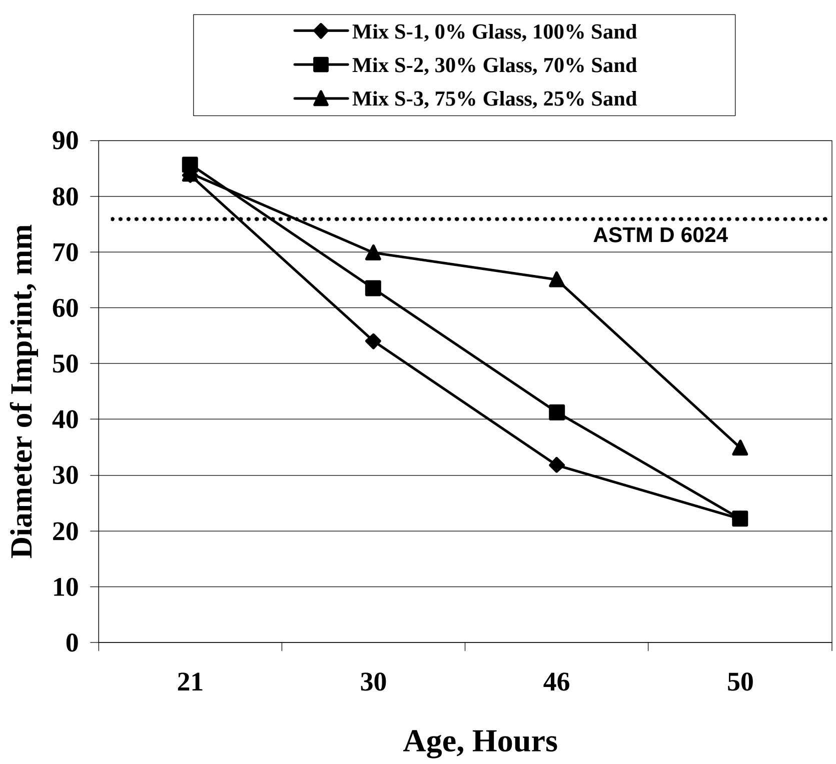

Fig. 3 – Setting and Hardening Characteristics of Type B (Sand/Glass) CLSM Mixtures

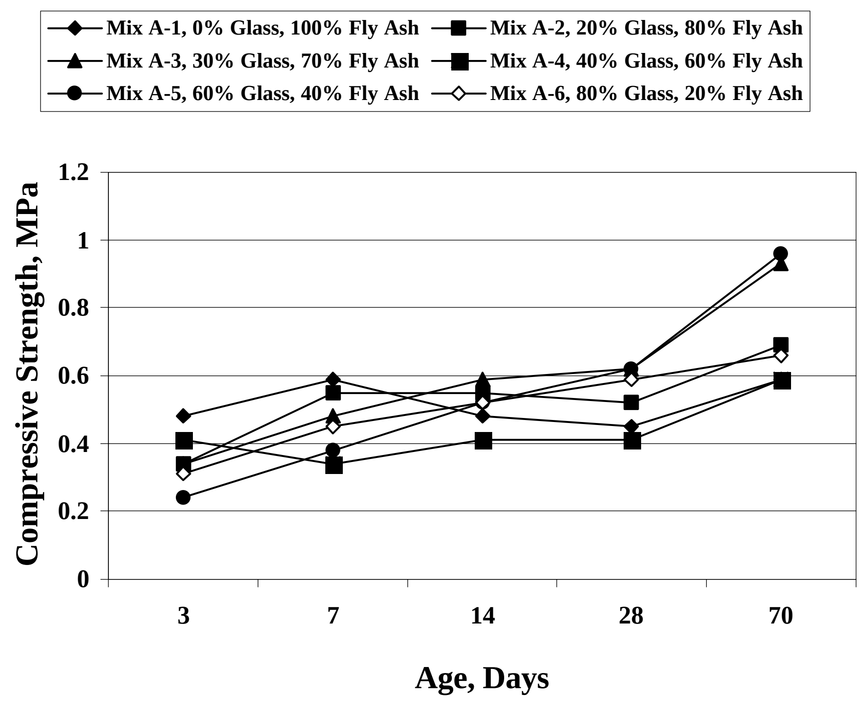

Fig. 4 – Compressive Strength of Type A (Ash/Glass) CLSM Mixtures

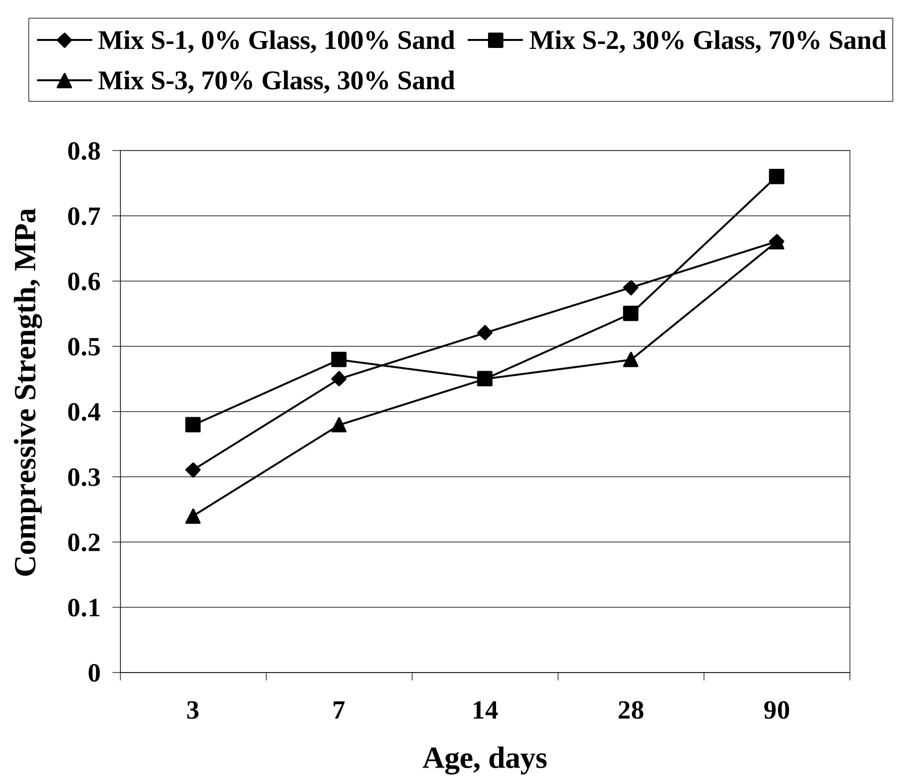

Fig. 5 - Compressive Strength of Type B (Sand/Glass) CLSM Mixtures