A Study on Mechanical Properties of M 25 Grade Concrete Made With Glass Powder As A Partial Replacement of Fine Aggregate

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Abstract- *Glass Powder (GP) used in concrete making leads to greener environment. In shops, damaged glass sheets & sheet glass cuttings are go to waste, which are not recycled at present and usually delivered to landfills for disposal. Using GP in concrete is an interesting possibility for economy on waste disposal sites and conservation of environment.*

This project examines the possibility of using GP as fine aggregate replacement in concrete. Natural sand was partially replaced (0% - 30%) with GP in concrete. Compressive strength, Tensile strength, Modulus of Elasticity and Flexural strength were compared with those of concrete made with natural fine aggregates at different curing periods.

Keywords- Glass Powder, Compressive strength, Tensile strength, Modulus of Elasticity and Flexural strength

I. INTRODUCTION

1.1 GLASS POWDER

Glass is produced in many forms, including packaging or container glass, flat glass, bulb glass, and cathode ray tube glass. All of each type of glass have a limited life in the form in which they are produced and need to be reused in order to avoid environmental problems. The plain glass dust waste can be recycled, but it is costly to remove the colour of coloured glasses and recycle again. The glass waste was collected from shops with type bottles. Cathode ray tube glass (TV screens, monitors, etc.) was not used in this study due to concern about hazardous metals content. Glass containers compositions from abundant raw materials are sand, soda ash, limestone and cullet. The proportion of raw materials is based on availability, chemical and physical consistency, sizing, purity and cost. The goal is to use the most economical and high quality raw materials available. Glass containers are commonly made with a combination of various oxides or oxygen based compounds and are commonly referred to as “Soda-Lime” glass. The combining of raw materials creates glass containers that are durable, strong, impermeable, easily shaped, and inexpensive. Some oxides will form glass without adding any other elements and are known as network formers. The most common of these is silica (SiO_2). The land filling of waste glasses is undesirable because they are not biodegradable, which makes them environmentally less friendly. There is huge potential for using waste glass in the concrete construction sector. When waste glasses are reused in making concrete products, the production cost of concrete will go down. Glass concrete products can be categorized as commodity products and value-added products. For simple commodity products, the primary objective is to utilize as much waste glass as possible. This research has been conducted to identify the suitable composition of glass dust waste as fine aggregate replacement material in concrete and also to study the compressive strength of concrete

It's easy not to think about garbage. You throw away your empty cartons, bags, and cups, and once a week the trash collector comes and takes it all away. Out of sight, out of mind… except that it's not really gone.Most US garbage is simply relocated from your garbage can to a landfill or incinerator, both of which are fraught with problems:

- **Incinerators:** Emit toxic dioxins, mercury, cadmium, and other particulate matter into the air, and convert waste into toxic ash (which is sometimes used to cover landfills).
- **Landfills:** There are more than 3,000 active landfills, and 10,000-old landfills, in the US. While the number of landfills in the US has been decreasing in recent decades, they have, individually, been increasing in size.

Along with being a major source of methane emissions, landfills produce "leachate," a toxic fluid composed of pollutants like benzene, pesticides, heavy metals, endocrine-disrupting chemicals, and more, which come from the compressed trash.

Although landfills are technically supposed to keep garbage dry and are lined to prevent leachate from contaminating nearby soil and groundwater, the landfill liners are virtually guaranteed to degrade, tear, or crack eventually, allowing the toxins to escape directly into the environment.

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Glass is made up of sand, soda ash and limestone substances. It is a hard material that is normally breakable and transparent. These substances are heated altogether and the molecules bond that is formed is a substance that we call glass. Glass has been used for many functions and usually a popular tool for storage purposes

II. LITERATURE REVIEW

Glass cullet is recycled container glass (previously used for bottles, jars and other similar glass vessels) prior to processing. The material is typically collected via bottle banks, curbside collection schemes and from premises handling large quantities of containers. The primary aim for cullet collecting is processing it for returning to the glassmaking process to manufacture new glass products. The term ―Cullet‖ also refers to waste glass produced as a result of breakage and rejection on quality control grounds during manufacturing process. Crushed, graded glass cullet has been extensively investigated and tried in a number of construction and non-construction related applications (Meyer, 2001).

Sasikumar &Tamilvanam[1] performed an experiment investigation on properties of glass powder as a partial replacement of cement. Main parameter investigated in this study is M30 grade concrete with partial replacement of cement by glass powder 0%, 5%, 10%, 20%, 25%.the optimum 7 and 28 days compressive strength has been obtained in the 25% glass powder replacement level.

Alok [2] write a research paper on partial replacement of cement in M30 concrete from glass powder were 0%, 2.5% and 7% water cement ratio was kept 0.43 in all the cases 43.1 N/mm^{2}was the maximum compressive strength.

Kumar & Dhaka [3] write a review paper on partial replacement of cement with glass powder and its effect on concrete properties the main parameter investigated in this study M35 concrete with partial replacement of glass powder with varying 0,5,10,15,20,25% by weight of cement. The paper presents a detailed study on compressive strength, flexural strength and split tensile strength for 7 days and 28 days respectively.

Sharma & Seema [5] examined the effect of partial replacement of cement with glass powder on compressive strength of concrete with w/c ratio as 0.5 and percentage replacement was 0%,10%,15%,20%,25%.The optimum compressive strength is obtained at 20% cement replacement by a glass powder at all levels.

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Weitz (2005) reported that the American Association of State Highway and Transportation Officials (AASHTO) had recognized the use of recycled materials in pavement and created a new specification titled ―Glass Cullet Use for Soil Aggregate Base Course. The specification illustrates that when properly processed, glass cullet can be expected to provide adequate stability and load support for use as road or highway bases. Crushed glass cullet that has been used as aggregate in road construction or bituminous concrete pavements is popularly known as ―glassphalt. A number of field trials of glassphalt pavements have been carried out since 1971. It was observed that holds heat longer than conventional asphalt. This may be advantageous when road works are carried out in cold weather or when long transport distances are required. Furthermore, the glass particles will increase the reflectivity of the road surface, therefore, improve the night-time road visibility.

Pattengil had apparently also found similar effects. The experimental work of Phillips and Cahn [31] has been taken to shown that up to 35% glass cullet could be used in concrete in combination with low alkali cement, without detrimental effects.

III. EXPERIMENTAL PROGRAMME

3.1 Materials

Constituent materials used to make concrete can have a significant influence on the properties of the concrete. The following sections discuss constituent materials used for manufacturing of both conventional concrete (CC) and Fly Ash based Fiber Reinforced Concrete (FFRC). Chemical and physical properties of the constituent materials are presented in this section.

3.1.1 Cement

Ordinary Portland Cement 53 grade was used corresponding to IS 12269 (1987). The physical properties of the cement as obtained by the manufacturer are presented in the Table 3.1.

Table 3.1 Physical Properties of Cement

Physical properties	Test result
Specific gravity	3.15
Fineness (m^2/Kg)	311.5
Normal consistency	30%
Initial setting time (min)	90
Final setting time (min)	220
Soundness Lechatelier Expansion (mm) Autoclave Expansion (%)	 0.8 0.01
Compressive strength (MPa) 3 days 7 days 28 days	 25 39 57

3.1.2 Glass Powder

The physical properties of the Glass Powder as obtained by the manufacturer are presented in the Table 3.2.

Table 3.2 Physical properties of Glass Powder

Material	Specific gravity	Fineness (m^2/kg)	Water absorption (%)
Fly Ash	2.6	336	40-60

3.1.3 Coarse aggregate

Crushed granite stones of size 20 mm used as coarse aggregate. The bulk specific gravity in oven dry condition and water absorption of the coarse aggregate 20 mm per IS 2386 (Part III, 1963) are 2.6 and 0.3% respectively. The bulk density, impact strength and crushing strength values of 20 mm aggregate are 1580 kg/m3, 17.9% and 22.8% respectively.

3.1.4 Fine aggregate

Natural river sand is used as fine aggregate. The bulk specific gravity in oven dry condition and water absorption of the sand as per IS 2386 (Part III, 1963) are 2.6 and 1% respectively. Fineness modulus of sand is 2.26.

3.1.5 Water

Generally, water that is suitable for drinking is satisfactory for use in concrete. When it is suspected that water may contain sewage, mine water, or wastes from industrial plants or canneries, it should not be used in concrete unless tests indicate that it is satisfactory. Water from such sources should be avoided.

3.2 Test Methods

This section describes the test methods that are used for testing the hardened properties of concrete.

3.2.1 Compressive strength test

Compressive strength test was conducted on the cubical specimens for all the mixes at different curing periods as per IS 516 (1991) shown in fig 3.1. Three cubical specimens of size 150 mm x 150 mm were cast and tested for each age and each mix. The compressive strength (f'c) of the specimen was calculated by dividing the maximum load applied to the specimen by the cross-sectional area of the specimen.

Fig.3.1 compressive strength of cubes

3.2.2 Split Tensile Strength

Splitting tensile strength (STS) test was conducted on the specimens for all the mixes at different curing periods as per IS 5816 (1999). Three cylindrical specimens of size 150 mm x 300 mm were cast and tested for each age and each mix. The load was applied gradually till the failure of the specimen occurs. The maximum load applied was then noted. Length and cross-section of the specimen was measured. The splitting tensile strength (f_{ct}) was calculated as follows:

$$f_{ct} = 2P / (\Pi\, l\, d)$$

Where, f_{ct} = Splitting tensile strength of concrete (N/mm^2)
P = Maximum load applied to the specimen (in Newton)
l = Length of the specimen (in mm)
d = cross-sectional diameter of the specimen (in mm)

Fig.3.2Split Tensile Strength of Cubes

3.2.3 Flexural Strength

Flexural strength test was conducted on the specimens for all the mixes at different curing periods as per IS 516 (1991). Three concrete beam specimens of size 100 mm x 100 mm x 500 mm were cast and tested for each age and each mix. The load was applied gradually till the failure of the specimen occurs. The maximum load applied was then noted. The distance between the line of fracture and the near support '*a*' was measured. The flexural strength (f_{cr}) was calculated as follows:

When '*a*' is greater than 13.3 cm for 10 cm specimen, f_{cr} is

$$f_{cr} = (P \times l) / (b \times d^2)$$

When '*a*' is less than 13.3 cm but greater than 11.0 cm for 10 cm specimen, f_{cr} is

$$f_{cr} = (3 \times P \times a) / (b \times d^2)$$

Where, f_{cr} = Flexural strength of concrete (N/mm^2)

P = Maximum load applied to the specimen (in Newton)
b = measured width of the specimen (in mm)
d = measured depth of the specimen at the point of failure (in mm)
l = Length of the specimen on which the specimen was supported (in mm)

Fig.3.3 Flexural Strength of Cubes

3.3 Mix Design

Table 3.3Mix Proportions of CC & GPC

Mix	Cement kg/m^3	Water lt/m^3	Fine Aggregate kg/m^3	Glass Powder kg/m^3	Coarse Aggregate (20 mm) kg/m^3
CC	384	202	636	0	1139
GPC_10	384	202	572.4	63.6	1139
GPC_20	384	202	508.8	127.2	1139
GPC_30	384	202	445.2	190.8	1139

This section describes the proportions of M 25 grade conventional concrete mix proportions as per IS 10262 (2009) and IS 456 (2000) shown in Table 3.3.

IV. RESULTS AND DISCUSSIONS

4.1 Introduction

In this Chapter, the test results are presented and discussed. The test results cover the performance of Conventional Concrete (CC) and Glass Powder blended Concrete (GPC) at different replacement levels of glass powder (10%, 20% and 30%). The hardened properties of CC and GPC viz. compressive strength, split tensile strength and flexural strength were determined at different curing periods (7, 28 and 56 days).

4.2 Variations in Compressive Strength

The variations in compressive strength values of CC and GPC at different curing periods are shown in Table 4.1.

The variations in compressive strength values after curing are represented in fig 4.1.

The average value recorded from compressive strength tests carried out on specimens cured for 7 days can be seen below in Figure 4.1. An increasing trend can be witnessed along with the addition of glass aggregate, until the maximum compressive strength (13.24 MPa) was developed at a replacement level of 20%. All mixture proportions containing waste glass to this point exceeded the strength developed by the control, with the 20% glass mix recording a compressive strength 20% higher. These findings support earlier research conducted by Tuncan et al. (2001), where the compressive strength of concrete after 7 days of curing was found to increase with the addition of glass, albeit at lower levels of replacement.

Addition of waste glass beyond the optimum level resulted in a significant reduction to the level of compressive strength developed. At a glass replacement level of 30%, the compressive strength achieved (10.21 MPa) was 8% below the control and 23% below the maximum recorded value.

The average value recorded from compressive strength tests carried out on specimens cured for 28 days can be seen below in Figure 4.1. An increasing trend can be witnessed along with the addition of glass aggregate, until the maximum compressive strength (35.29 MPa) was developed at a replacement level of 20%. All mixture proportions containing waste glass to this point exceeded the strength developed by the control, with the 20% glass mix recording a compressive strength 6% higher. These findings support earlier research conducted by Tuncan et al. (2001), where the compressive strength of concrete after 28 days of curing was found to increase with the addition of glass, albeit at lower levels of replacement.

Addition of waste glass beyond the optimum level resulted in a significant reduction to the level of compressive strength developed. At a glass replacement level of 30%, the compressive strength achieved (29.58 MPa) was 11% below the control and 16% below the maximum recorded value.

The average value recorded from compressive strength tests carried out on specimens cured for 56 days can be seen below in Figure 4.1. An increasing trend can be witnessed along with the addition of glass aggregate, until the maximum compressive strength (36.58 MPa) was developed at a replacement level of 20%. All mixture proportions containing waste glass to this point exceeded the strength developed by the control, with the 20% glass mix recording a compressive strength 6% higher. These findings support earlier research conducted by Tuncan et al. (2001), where the compressive strength of concrete after 56 days of curing was found to increase with the addition of glass, albeit at lower levels of replacement.

Addition of waste glass beyond the optimum level resulted in a significant reduction to the level of compressive strength developed. At a glass replacement level of 30%, the compressive strength achieved (30.65 MPa) was 12% below the control and 17% below the maximum recorded value.

Table 4.1 compressive strength of concrete mixes

Mix Type	Compressive Strength (MPa)		
	14 days	28 days	56 days
CC	11.05	33.25	34.75
GPC_10	12.56	34.52	35.19
GPC_20	13.24	35.29	36.58
GPC_30	10.21	29.58	30.65

4.2 Variations in Split Tensile Strength

The variations in split tensile strength values of CC and GPC at different curing periods are shown in Table 4.2.

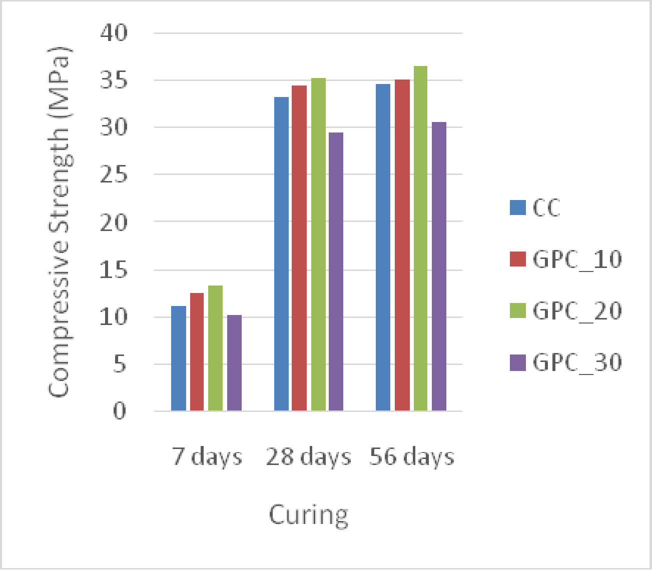

Fig 4.1 compressive strength of concrete mixes

The average value recorded from split tensile strength carried out on specimens cured for 7 days can be seen below in Figure 4.2. An increasing trend can be witnessed along with the addition of glass aggregate, until the maximum split tensile strength (8.36 MPa) was developed at a replacement level of 20%. All mixture proportions containing waste glass to this point exceeded the strength developed by the control, with the 20% glass mix recording a split tensile strength 8.36% higher. These findings support earlier research conducted by Tuncan et al. (2001), where the split tensile strength of concrete after 7 days of curing was found to increase with the addition of glass, albeit at lower levels of replacement.

Addition of waste glass beyond the optimum level resulted in a significant reduction to the level of split tensile strength developed. At a glass replacement level of 30%, the split tensile strength achieved (3.56 MPa) was 4% below the control and 11.3% below the maximum recorded value.

The average value recorded from split tensile strength carried out on specimens cured for 28 days can be seen below in Figure 4.2. An increasing trend can be witnessed along with the addition of glass aggregate, until the maximum split tensile strength (3.49 MPa) was developed at a replacement level of 20%. All mixture proportions containing waste glass to this point exceeded the strength developed by the control, with the 20% glass mix recording a split tensile strength 8% higher. These findings support earlier research conducted by Tuncan et al. (2001), where the split tensile strength of concrete after 28 days of curing was found to increase with the addition of glass, albeit at lower levels of replacement.

Addition of waste glass beyond the optimum level resulted in a significant reduction to the level of split tensile strength developed. At a glass replacement level of 30%, the split tensile strength achieved (3.72 MPa) was 2% below the control and 11% below the maximum recorded value.

The average value recorded from split tensile strength carried out on specimens cured for 56 days can be seen below in Figure 4.2. An increasing trend can be witnessed along with the addition of glass aggregate, until the maximum split tensile strength (3.72 MPa) was developed at a replacement level of 20%. All mixture proportions containing waste glass to this point exceeded the strength developed by the control, with the 20% glass mix recording a split tensile strength 9% higher. These findings support earlier research conducted by Tuncan et al. (2001), where the split tensile strength of concrete after 56 days of curing was found to increase with the addition of glass, albeit at lower levels of replacement.

Addition of waste glass beyond the optimum level resulted in a significant reduction to the level of split tensile strength developed. At a glass replacement level of 30%, the split tensile strength achieved (3.30 MPa) was 4% below the control and 12% below the maximum recorded value.

Table 4.2 split strength of concrete mixes

Mix Type	Split Tensile Strength (MPa)		
	14 days	28 days	56 days
CC	2.19	3.21	3.42
GPC_10	2.28	3.36	3.56
GPC_20	2.39	3.49	3.72
GPC_30	2.12	3.15	3.30

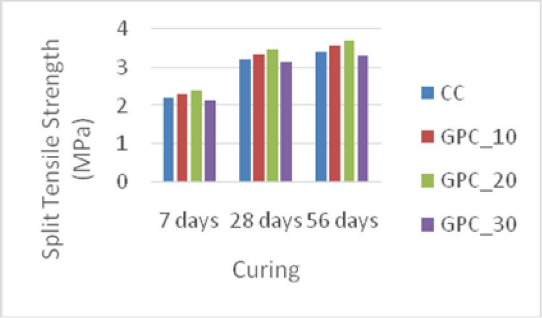

Fig. 4.2variations in split tensile strength of concrete mixes

4.3Variations in Flexural Strength

The variations in flexural strength values of CC and GPC at different curing are shown in Table 4.3.

The average value recorded from flexural strength carried out on specimens cured for 7 days can be seen below in Figure 4.3. An increasing trend can be witnessed along with the addition of glass aggregate, until the maximum flexural strength (4.28 MPa) was developed at a replacement level of 20%.

Table 4.3 flexural strength of concrete mixes

Mix Type	Flexural Strength (MPa)		
	14 days	28 days	56 days
CC	3.23	4.20	4.46
GPC_10	3.28	4.28	4.75
GPC_20	3.35	4.45	4.82
GPC_30	3.15	4.12	4.28

The variations in flexural strength values of CC & GPC after curing are represented in fig 4.3.

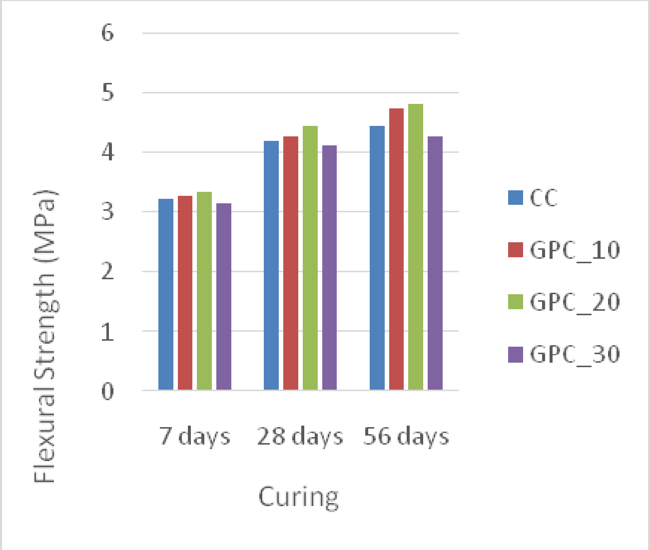

Fig. 4.3variations in flexural strength of concrete mixes

All mixture proportions containing waste glass to this point exceeded the strength developed by the control, with the 20% glass mix recording a flexural strength 4% higher. These findings support earlier research conducted by Tuncan et al. (2001), where the split tensile strength of concrete after 7 days of curing was found to increase with the addition of glass, albeit at lower levels of replacement.

Addition of waste glass beyond the optimum level resulted in a significant reduction to the level of flexural strength developed. At a glass replacement level of 30%, the flexural strength achieved (4.75 MPa) was 2.5% below the control and 6.5% below the maximum recorded value.

The average value recorded from flexural strength carried out on specimens cured for 28 days can be seen below in Figure 4.3. An increasing trend can be witnessed along with the addition of glass aggregate, until the maximum flexural strength (4.45 MPa) was developed at a replacement level of 20%. All mixture proportions containing waste glass to this point exceeded the strength developed by the control, with the 20% glass mix recording a flexural strength 5.6% higher. These findings support earlier research conducted by Tuncan et al. (2001), where the split tensile strength of concrete after 28 days of curing was found to increase with the addition of glass, albeit at lower levels of replacement.

Addition of waste glass beyond the optimum level resulted in a significant reduction to the level of flexural strength developed. At a glass replacement level of 30%, the flexural strength achieved (4.82 MPa) was 2% below the control and 8% below the maximum recorded value.

The average value recorded from flexural strength carried out on specimens cured for 56 days can be seen below in Figure 4.3. An increasing trend can be witnessed along with the addition of glass aggregate, until the maximum flexural strength (4.82 MPa) was developed at a replacement level of 20%. All mixture proportions containing waste glass to this point exceeded the strength developed by the control, with the 20% glass mix recording a flexural strength 9% higher. These findings support earlier research conducted by Tuncan et al. (2001), where the split tensile strength of concrete after 56 days of curing was found to increase with the addition of glass, albeit at lower levels of replacement.

Addition of waste glass beyond the optimum level resulted in a significant reduction to the level of flexural strength developed. At a glass replacement level of 30%, the flexural strength achieved (4.28 MPa) was 4% below the control and 12% below the maximum recorded value.

V. CONCLUSION

This chapter summarizes the overall conclusions drawn from the investigation

of concrete using glass powder (sand replaced glass powder).

1. The optimum percentage replacement of sand with fine glass powder was determined to be 20%.
2. Compressive strength was found to increase with the addition of waste glass to the mix up until the optimum level of replacement. This can be attributed to the angular nature of the glass particles facilitating increased bonding with the cement paste.
3. In proportions exceeding 20%, waste glass was found to negatively impact the development of compressive strength. It is suggested that in larger quantities, the angular nature of the glass aggregate reduces available cement paste and leads to the formation of microscopic voids within the concrete matrix.

REFERENCES

[1] Aarre T, Domone PLJ. 2004. Testing-SCC: Summary report on work package 2: Development of mix designs and material selection.

[2] AASHTO. 2006. Interim bridge design specifications and commentary. American Association of Highway and Transportation Officials (AASHTO LRFD), Washington, D.C.

[3] ACI. 1992. State-of-the-art report on high-strength concrete. ACI 363R, Detroit.

[4] ACI. 1995. Building code requirements for structural concrete. ACI 318-95 and Commentary. ACI 318R-95, Detroit.

[5] ACI 211.1. Standard Practice for Selecting Proportions for Normal, Heavy weight, and Mass Concrete.

[6] ACI 237R-07. 2007. Self-Consolidating Concrete.

[7] ACI 301. Specifications for Structural Concrete.

[8] Ahmad SH, Shah SP. 1985. Structural properties of high strength concrete and its implications for precast prestressed concrete. PCI J. 30(4–6): pp92–119.

[9] Ahmaruzzaman M. 2010. A review on the utilization of fly ash", Progress in

   a. Energy and Combustion Science J., vol. 36, no. 3, pp. 327–363, Jun.

[10] Aiad I. 2003. Influence of time addition of superplasticizers on the rheological properties of fresh cement pastes. Cement and Concrete Research 33(8):12291234.

[11] ASTM C 618. 2003. Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete.

[12] Atis CD. 2003. High-volume fly ash concrete with high strength and low drying shrinkage. Journal of Materials in Civil Engineering 15(2):153-156.

[13] Billberg P. 1999. Self-compacting concrete for civil engineering structures – the Swedish experience. Swedish Cement and Concrete Research Institute, Stockholm, Sweden.

[14] Billberg P, Petersson O, Westerholm M, Wustholz T, Reinhardt HW. 2004. Summary report on work package 3.2: Test methods for passing ability.

[15] Bonen D, Sarkar SL. 1995. The superplasticizer adsorption capacity of cement pastes, pore solution composition, and parameters affecting flow loss. Cement and Concrete Research 25(7):1423-1434.

[16] Bonen D, Shah S. 2004. The Effects of Formulation on the Properties of SelfConsolidating Concrete. Concrete Science and Engineering: A Tribute to Amon Bentur, Proceedings of the International RILEM Symposium, K. Kovler, J. Marchand, S. Mindress and J. Weiss, eds, RILEM Publications, France. pp43-56.

[17] Khayat KH, Ghezal A, Hadriche MS. 2000. Utility of statistical models in proportioning self-consolidating concrete. Materials and structures 33:338-344.

[18] Khayat KH, Ghezal A. 2003. Effect of viscosity modifying admixture - superplasticizer combination on flow properties of SCC equivalent mortar. In: The 3rd International RILEM Symposium on Self-Compacting Concrete. Wallevik OH, Nielsson I, editors, RILEM Publications S.A.R.L., Bagneux, France. 369-385.

[19] Khayat KH, Guizani Z. 1997. Use of viscosity-modifying admixture to enhance stability of fluid concrete. ACI Materials 94(4):332-341.

[20] Khayat KH, Yahia A. 1997. Effect of welan gum-high-range water reducer combinations on rheology of cement grout. ACI Materials Journal 94(5). Kim BG, Jiang S, Jolicoeur C, Aitcin PC. 2000. The adsorption behavior of PNS superplasticizer and its relation to fluidity of cement paste. Cement and Concrete Research 30(6):887-893.

[21] Kumar V., Mathur M., Sinha S.K., and Dhatrak S. 2005. Fly ash: an environment saviour, in Proc. Fly ash India 2005, New Delhi, pp. I 1.1–1.8.

[22] Kuroda M, Watanabe T, Terashi N. 2000 Feb. Increase of bond strength at interfacial transition zone by the use of fly ash. Cement and Concrete Research 30(2):253-258.

[23] Lachemi M, Hossain KMA, Lambros V, Nkinamubanzi PC, Bouzoubaa N. 2004b. Self-consolidating concrete incorporating new viscosity modifying admixtures. Cement and Concrete Research 34(6):917-926.

[24] Liu M. 2010. Self-compacting concrete with different levels of pulverized fuel ash. Construction and Building Materials. 24: pp1245-1252.

[25] Ma J, and Dietz J. 2002. Ultra high performance self-compacting concrete. University of Leipzig, Germany.

[26] Mahdy M, Speare PRS., Abdel-Reheem AH. 2002. Mechanical Properties of Heavy Weight, High Strength Concrete. 2nd Material Specialty Conference of the Canadian Society for Civil Engineering, Canada. pp1-9.

[27] Mata, L. A. 2004. Implementation of Self-Consolidating Concrete (SCC) for Prestressed Concrete Girders, MS Thesis, North Carolina State University, November.

[28] Mehta PK, Monterio PJM. 1993. Concrete: structure, properties and materials, Second edition, Prentice Hall Inc, Englewood Cliffs, New Jersey. pp548.

[29] Mehta PK, Monterio PJM. 2005. Concrete: microstructure, properties, and materials, McGraw-Hill, New York; pp659.

[30] Nagamoto, N., and Ozawa, K. 1997. Mixture proportions of self-compacting high performance concrete, ACI International, SP-172, 623-636.

[31] Nawa T, Izumi T, Edamatsu Y. 1998. State-of-the-art report on materials and design of self-compacting

concrete. In: International Workshop on Self- Compacting Concrete. 160-190.

[32] Nehdi ML, Pardhan M, Koshowski S. 2004. Durability of self-consolidating concrete incorporating high-volume replacement composite cements. Cement and Concrete Research 34(11):2103-2112.

[33] Nepomuceno M, Oliveira L. 2008. Parameters for self-compacting concrete mortar phase. High Concrete Structures and Materials, SP253-21. 323-40.

[34] Neville AM. 1971. Hardened Concrete: Physical and Mechanical Aspects ACI Monograph 6. pp48-53.

[35] Neville AM. 1988. Tecnología del concreto. Tomo I, IMCYC, Editorial Limusa, S.A. DE C.V., Mexico D.F.

[36] Neville AM. 1996. Properties of Concrete (Fourth and Final Edition). John Wiley & Sons, Inc, New York.

[37] Pedersen B, Smelpass S. 2003. The relationship between the rheological properties of SCC and the corresponding matrix phase. Wallevik OH, Nielsson I, editors, RILEM Publications S.A.R.L., Bagneux, France. 106-121.

[38] Pera J, Husson S, Guilhot B. 1999 Apr. Influence of finely ground limestone on cement hydration. Cement and Concrete Composites 21(2):99-105.

[39] Persson B. 2000. Consequence of cement constituents, mix composition and curing conditions for self-desiccation in concrete. Materials and structures 33:352-362.

[40] Peterson O. 1998. Final Report of Task 1: Preliminary Mix Design, SCC. BriteEuram Contract No. BRPR-CT96-0366, February 1998. Available from: www.civeng.ucl.ac.uk/research/concrete/sccBE.asp.

[41] Petersson O, Billberg P, Van BK. 1996. A model for self-compacting concrete. In: The International RILEM Conference on Production Methods and Workability of Concrete. Bartos PJM, Marrs DL, Cleland DJ, editors, E&FN Spon, London, 484-492.

[42] Pineaud A, Cabrillac R., Remond S, Pimienta P, Rivillon P. 2005. Mechanical properties of self-compacting concrete - influence of composition parameters. Proc. of the Second North American Conf. on the Des. and Use of Self Consolidating Concr. and the Fourth Int. RILEM Symp. on Self-Consolidating

[43] Concr., Center for Advanced Cement-Based Materials (ACBM), Chicago; pp863868.

[44] Rashid MA, Mansur MA, ASCE M, Paramasivam P. 2002. Correlations between Mechanical Properties of High-Strength Concrete. Journal of Materials in Civil Engineering. 14(3): pp230-238.

[45] Sonebi M, Bartos PJM. 2002. Filling ability and plastic settlement of self-compactingconcrete. Materials and structures 35:462-469.

[46] Sonebi M, Svermova L, Bartos PJM. 2004. Factorial design of cement slurries containing limestone powder for self-compacting consolidating slurry-infiltrated fiber concrete. ACI Materials Journal:136-145.

[47] Sonebi M, Zhu W, Gibbs JC. 2001. Bond of reinforcement in self-compacting concrete. Concrete 35(7):26-28.

[48] Stock AF, Hannant DJ, Williams RIT. 1979. The effect of aggregate concentration upon the strength and modulus of elasticity of concrete. Mag. Concr. Res. 31(109): pp225-234.

[49] Su N, Hsu KC, Chai HW. 2001. A simple mix design method for self-compacting concrete. Cement and Concrete Research 31(12):1799-1807.