engineering proceedings

MDPI

Proceedings Paper

Formulation of Self-Compacting Concrete Mixtures Incorporating Diverse Cement Types †

Khandokar Md Rifat Hossain * and Rupak Mutsuddy

Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka 1213, Bangladesh; mutsuddy@ce.buet.ac.bd
* Correspondence: rifat2976135@gmail.com; Tel.: +880-1821829022

† Presented at the 4th International Electronic Conference on Applied Sciences, 27 October–10 November 2023; Available online: https://asec2023.sciforum.net/.

Abstract: Self-Compacting Concrete (SCC) is a highly flowable, self-leveling and non-segregating type of concrete that requires no form of vibration to maintain its uniformity throughout the mixture as well as performs in an outstanding manner in densely reinforced structures. The main objective of this study is to investigate the primary differences in engineering properties of SCC using CEM-I, CEM-II/A-M and CEM-II/B-M types of cement as primary binding material. The properties of SCC such as cohesiveness, stability, flowability etc. can be modified by selecting definitive amounts of aggregates, cementitious materials and viscosity modifying admixtures. So, it will highlight the effects of mechanical and flow properties of the concrete mix due to the change in cement type with the similar composition and volumetric ratio of other constituent materials. The flow properties are validated using V-funnel test, L-box test, T-500 test and slump flow test. A comparative result highlighting the strength response i.e., compressive, tensile, and flexural strength of the mix designs were recorded at 28 days and correlations among these values were established and analyzed.

Keywords: Self-Compacting Concrete; flow and strength properties; superplasticizers (SP)

Citation: Hossain, K.M.R.; Mutsuddy, R. Formulation of Self-Compacting Concrete Mixtures Incorporating Diverse Cement Types. *Eng. Proc.* **2023**, *52*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s): Name

Published: date

1. Introduction

Self-Compacting Concrete (SCC) is a relatively new phenomena in the field of concrete technology that offers a range of benefits like greater flowability, easy placement in congested reinforcement and complex formwork, improved durability etc. It is mostly recognized due to its self-leveling property while eliminating the possibility of voids in concrete mix [1]. So, it is a better substitute than Normally Vibrated Concrete (NVC) for repair and rehabilitation projects. Also, SCC requires no form of mechanical compaction or vibration that significantly reduces labor cost and time of placement of concrete.

The engineering characteristics of SCC depend on some fundamental properties: reduced volumetric ratio of aggregate to cementitious materials, lower water-powder ratio, smaller elongation index for coarse aggregates, usage of Viscosity Modifying Admixtures (VMA) or superplasticizers to reduce the cohesive action of the cement etc. The properties of SCC can be significantly altered by various factors such as w/c ratio, types of additives i.e., VMA, replacement cementitious materials, fiber reinforcement etc. Reducing the coarse aggregate volume, lowering w/c ratio, increasing the dosage of superplasticizer and incorporating more fines and additional cementitious materials can improve the workability and segregation susceptibility of concrete mix [2]. As higher fluidity and self-leveling property is the key characteristic of SCC, this should result in higher w/c ratio which consequently reduces the binding strength of the cement paste. So, by maintaining an acceptable w/c ratio while enhancing the flowability of the concrete, superplasticizers are used to reduce viscosity and internal friction within the mortar. The amount of replacement cementitious materials like fly ash, metakaolin, limestone also influences the ultimate strength of concrete as well as the shrinkage amount [3]. Amount of replacement cementitious materials (used in CEM-II cements) show inverse relation with compressive strength gain over time [4]. So, the strength values of concrete mix utilizing CEM-I, CEM-II/A-M and CEM-II/B-M vary due to the variations of proportion of clinker, additives, and gypsum content. However, the change in tensile strength demonstrates significantly more pronounced variation in comparison to compressive strength [5]. Flexural Strength development of SCC occurs at much higher pace compared to regular concrete due to the probability of stress induction around coarse aggregates and weakening of bond caused by mechanical vibration [6]. It also affects other fundamental properties like modulus of elasticity, bond to steel, creep, shrinkage, stability, passing ability. The modulus of elasticity can be as much as 20% lower in the case of SCC compared to normally vibrated concrete with same compressive strength value [7].

For different purposes, different properties of cement are prioritized. For example, for high early strength or rapid hardening properties, cements with higher alumina content are preferred; for chemical attack prevention or hydraulic structures, different pozzolanic compounds and higher clay percentage is required which enhance the resistance to deterioration. So, SCC with diverse properties is to meet particular conditions. CEM-I cement refers to Ordinary Portland Cement composed with little no pozzolanic compound whereas the PCC e.g., CEM-II/A-M and CEM-II/B-M has around 6–20% and 21–35% of fly ash, slag, and limestone respectively along with 0–5% gypsum while their ultimate strength capacity differs [8]. Fly ash, granulated blast furnace slag and silica fume can serve as filler materials that can be beneficial since SCC requires a higher amount of fine particles [9]. These powder contents also improve workability, enhance durability for appropriate proportions and also can retain workability for longer period. Moreover, using fly ash in concrete mix is also a sustainable solution as it is a byproduct of coal combustion.

This study shows the change in strength and flow properties due to the addition of replacement cementing materials which was achieved by using CEM-I and two types of PCC cement for similar mix proportions of constituent materials. The result indicates that concrete blocks with OPC as binder exhibit faster hardening process for its higher content of alumina as well as greater ultimate strength at 28 days than the other two options. It also reveals that increasing pozzolanic contents produce lower strength at the early days of hardening [10]. The split tensile strength is about 5–8 times greater than compressive strength for each concrete mix. As for flexural strength, concrete beams with CEM-I cement have shown higher flexural capacity while the other two have somewhat similar deflection values for specific loads.

2. Materials and Methods

The SCC mix design procedure is greatly influenced by the intended functions or properties to be achieved depending on different situations. Flowability, strength, durability is some of the major parameters of the desired mix. While the Particle Packing Method stands as the most advanced and scientific approach for SCC design, this study utilizes the Empirical Method due to the wider range of variability. To achieve a uniform coarse grain size distribution, crushed stone was utilized in mixed concrete that was sieved through standard sieves as specified in Bangladesh Standard (BS 2011). 0.75 in downgrade particles were used using sieve to avoid segregation at the opening of V-funnel and L-box apparatus.

Table 1. Specifications of coarse aggregate.

Properties	Value
Apparent Specific Gravity, Sa	2.91
Bulk Specific Gravity (O-D basis), Sd	2.77
Bulk Specific Gravity (SSD Basis), Ss	2.82

Absorption Capacity, D	1.7%
Unit Weight (lb./ft^3)	99.31
Gradation	Open Graded

Sylhet Sand was used as the source of fine aggregate. The non mechanical properties of the sand were calculated according to ASTM specifications. (ASTM C136 for sieve analysis, ASTM C127 for Specific Gravity, ASTM C29 for Bulk Unit Weight).

Table 2. Specifications of fine aggregate.

Properties	Value
Finesse Modulus, FM	2.71
Bulk Specific Gravity (O-D basis), Sd	2.6
Bulk Specific Gravity (SSD Basis), Ss	2.63
Apparent Specific Gravity	2.68
Absorption Capacity, D	1.21%
Bulk Unit Weight (lb./ft^3)	94.21

Auramix 300, a high-performance retarding agent formulated from a Poly carboxylic ether (PCE) polymer, was applied as a superplasticizer to reduce w/c requirement [11]. The amount was established at 1–1.5% volume of total cement weight as per IS 9103 (1999). Primarily, 4 different sets of mix design were created using CEM-I cement: each with different proportion of coarse and fine aggregates and w/c ratio.

Table 3. Volumetric mix design using CEM-I cement.

Mix	Cement (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	Water (mL)	SP (mL)	w/c Ratio
M1	624	1053	792	330	226	0.53
M2	675	1053	1065	252	150	0.37
M3	500	867	878	209	138	0.42
M4	402	879	770	187	103	0.46

After formulating the initial trial mixes, flow properties of the mix designs were calculated to identify the most suitable one for further experimentation with CEM-II cements. The flow tests are the initial parameters for testing out SCC mix design and make necessary changes in the ratios of constituent materials to adjust the properties accordingly. V-Funnel test, L Box test and Slump test (T500 test and slump flow test) were carried out consecutively to determine the flow properties. The typical duration for conducting these tests on a single mix design was approximately 35 to 40 min. Cylinder specimens and prismatic beams were made according to mix designs to evaluate compressive and flexural strength respectively. Following a curing period of 28 days, the samples were surface dried and subjected to testing.

3. Results and Discussions

Primary selection of SCC mix design depends on the flow properties. From Table 4, the analysis demonstrates that with increasing w/c ratio and higher fine aggregate percentage, the flowability increases. Higher values from these tests indicate higher fluidic properties [12]. The conventional approach is not followed to determine the slump value of SCC. The diameter of the concrete flowing out of the slump cone is measured by taking the average of two perpendicular diameter lengths and the T500 test is the amount of time of viscous flow of SCC to spread to reach a diameter of about 500 mm. Each of these tests has a specific range of acceptable values. The acceptable time limit for V-Funnel test is 8–12 s approximately while for T500 test, it must be less than 7 s [13]. In the case of the L-

Box test, the acceptable Passing Ability value ranges from 0.8–0.92 and the standard limit for slump flow diameter is 650–800 mm.

Table 4. Flow properties of SCC mix for CEM-I cement.

Mix	V-Funnel (s)	L-Box	Slump (mm)	T500 (s)
M1	3.84	0.98	983	1.11
M2	22.13	0.67	546	7.31
M3	14.09	0.81	645	6.01
M4	12.01	0.83	662	5.69

After assessing the flow properties, it was concluded that the most appropriate choice is mix design 4 (M4). It shows that mixture with higher w/c ratio and lower coarse aggregate content spreads faster and wider. Coarse aggregates tend to remain at the center and water seeps out outwards if the water content is high (M1) with significantly low spread time for T500 and slump test. Here, the PCE superplasticizer was used to enhance stability and achieve high deformability. This admixture was selected for its long workability retention property as well as easy availability.

At the second phase, two types of PCC were used instead of CEM-I to observe the strength and flow properties with similar composition. PCC samples showed higher fluidic property with CEM-II/B-M cement having higher flow values in all aspects.

From Table 5, it is evident that mix design with CEM-II/A-M cement showed lower V-Funnel, L-Box and T50 values followed by CEM-II/B-M. A shorter duration indicates less adhesive force between the binder and inert materials. Although lower fluidity sometimes results in segregation at the opening of V-funnel and in between the metal bars at L-Box apparatus due to excess amount of viscosity. But in this case, such a phenomenon did not occur. This also results in greater slump diameter for T500 test indicating higher spread of the concrete mix over base plate. So, it can be concluded that with the increasing percentage of replacement cementitious components, the viscosity of the concrete reduces and shows higher workability and weaker bond between the particles. Though in many cases it is preferred because OPC cement has a higher rate of hydration which sometimes is not desirable for uniform distribution of concrete and self-leveling in broad formworks.

Table 5. Flow properties of mix design 4 for CEM-I, CEM-II/A-M and CEM-II/B-M cement.

Mix	V-Funnel (s)	L-Box	Slump (mm)	T500 (s)
M4	12.01	0.83	662	5.69
M4AM	10.47	0.86	671	5.29
M4BM	7.67	0.9	790	4.8

The data presented in Table 6 provides clear evidence of a gradual change in strength response. Only mix 3 and 4 shows acceptable results. General construction woks require a compressive strength between 2000–4000 psi. For CEM-I and CEM-II/AM cement, the concrete mix shows acceptable strength capacity; but should not be used as high strength concrete (which may require as much as 6000 psi). The ultimate strength for CEM-II/B-M cement resides at the lower end of the acceptable range. Although the ultimate strength capacity can be approximately 1.25 times higher than the values at 28 days. Concrete does not possess a notable level of tensile strength in comparison to compressive strength; still higher tensile strength results in fewer reinforcement bars in design which is more economical. A gradual change in tensile strength can be observed for the mix designs. In this study, flexural Capacity was determined using the two-point loading test.

Table 6. Strength Response of SCC Mix at 28 days.

Mix	Compressive Strength (psi)	Tensile Strength (psi)	Flexural Capacity (kN)
M3	4640	850	14.3
M4	3930	820	10.9
M4AM	3350	720	7.8
M4BM	2050	470	5.4

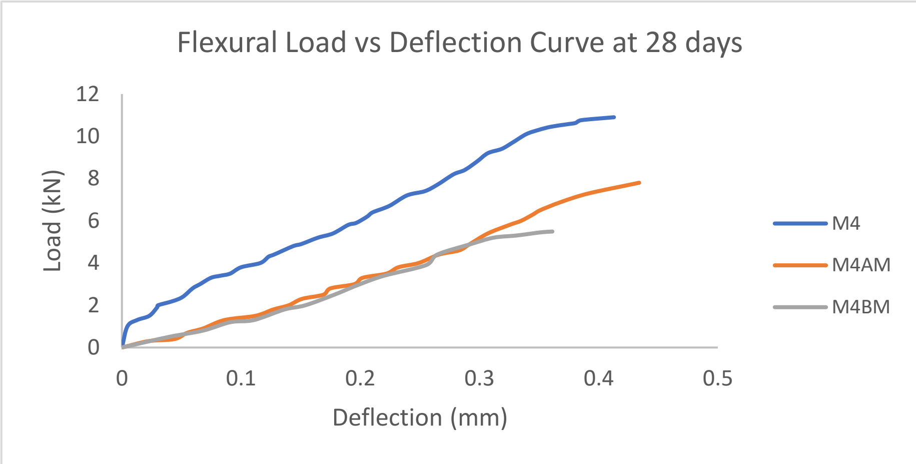

Figure 1. Load vs. Deflection curve for Flexural Strength.

Regarding CEM-II mix compositions, the 28-day flexural strength differs notably from that of CEM-I. They show lower value in comparison to the latter, particularly due to the increase in admixture content. These values are determined at 28 days. But the ultimate capacity of CEM-II cements after reaching its maximum potential can be similar and even greater than that of CEM-I cement for the same amount of deflection.

SCC has an enormous diversity of compositions and there is no unique composition for a given application [14]. It requires a much higher percentage of fine particles than normal concrete. Also, to increase the fluidity and stability of the concrete mix, a viscosity modifying admixture or superplasticizer is required. The desired properties can be obtained by adjusting the proportion of the composition materials. The experimental results show that M3 occupying higher coarse aggregate content results in greater strength capacity than M4 while the amount of fine aggregate is almost similar. The volumetric proportion of cement is another parameter to be considered. A higher proportion of these contents can increase the strength capacity. However, it also reduces the flowability of concrete, although it can be adjusted by increasing the superplasticizer dosage within permissible limit. As per the experimental results, it can also be deduced that early-age strength reduces with increase in supplementary cementitious materials. CEM-II/B-M occupies 20–35% less clinker compared to CEM-I which is the primary binding material of cement and shows about 48% less compressive strength capacity at 28 days for similar composition of materials. The similar can be said about flexural capacity too. CEM-II/A-M samples also showed reduced strength values than OPC in addition to higher flow properties. So, the initial strength gain can be increased by altering the proportion of coarse and fine aggregates, lowering water-powder ratio, or reducing the amount of replacement cementitious materials. It is best suited to use CEM-I cement where early strength is required. Although, in structural applications where high early strength is not crucial, using PCC may be a better option as they can be cost effective and also the presence of fly ash or slag may provide long term durability by reducing permeability and improving resistance to chemical attacks.

4. Conclusions

From this study, it is evident that passing ability, time requirement for V-Funnel, L-Box and slump test are related to w/c ratio and volumetric ratio of coarse and fine aggregates. Lower w/c ratio results in lower fluidity that can create segregation and blockage at opening of the apparatuses. However, this issue can be mitigated by using higher dosage of superplasticizers. The strength response from the result can be represented as CEM-I > CEM-II/A-M > CEM-II/B-M. The compressive strength of CEM-I cement exceeds that of CEM-II/A-M and CEM-II/B-M by approximately 15% and 48% respectively. This variation in early-age strength may occur due to the presence of supplementary cementitious materials in CEM-II cements, although they can enhance durability and long-term strength. It largely depends on the proportion of aggregates and binder material along with the types of additives. So, the strength properties can be controlled up to a certain extent by changing the material proportions or adding the amount of supplementary cementitious materials.

Author Contributions: Conceptualization, K.M.R.H. and R.M.; methodology, K.M.R.H.; software, K.M.R.H.; validation, R.M.; formal analysis, K.M.R.H.; investigation, K.M.R.H.; resources, K.M.R.H. and R.M.; data curation, K.M.R.H.; writing—original draft preparation, K.M.R.H.; writing—review and editing, K.M.R.H.; visualization, K.M.R.H.; supervision, R.M.; project administration, K.M.R.H. and R.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not Applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Okamura, H.; Ouchi, M. Self-Compacting Concrete. Development, Present Use and Future. In Proceedings of the First International RILEM Symposium on Self-compacting Concrete, Stockholm, Sweden, 13–15 September 1999.
2. Sahraoui, M.; Bouziani, T. Effects of Fine Aggregates Types and Contents on Rheological and Fresh Properties of SCC. *J. Build. Eng.* **2019**, *26*, 100890. https://doi.org/10.1016/j.jobe.2019.100890.
3. Suksawang, N.; Nassif, H.; Najm, H. Evaluation of Mechanical Properties for Self-Consolidating, Normal, and High-Performance Concrete. *Transp. Res. Rec. J. Transp. Res. Board* **2006**, *1979*, 36–45. https://doi.org/10.1177/0361198106197900106.
4. Lachemi, M.; Hossain, K.M.A.; Lambros, V.; Bouzoubaa, N. Development of Cost-Effective Self-Consolidating Concrete Incorporating Fly Ash, Slag Cement, or Viscosity-Modifying Admixtures. *Mater. J.* **2003**, *100*, 419–425. https://doi.org/10.14359/12818.
5. Amhudo, R.; Tavio, T.; Raka, I.G.P. Comparison of Compressive and Tensile Strengths of Dry-Cast Concrete with Ordinary Portland and Portland Pozzolana Cements. *Civ. Eng. J.* **2018**, *4*, 1760. https://doi.org/10.28991/cej-03091111.
6. Khudhair, J.; Chkheiwer, A. Mechanical Properties of Self Compacting Concrete Made with Local Materials. *Thi Qar Univ. J. Eng. Sci.* **2016**, *7*, 1–14.
7. Holschemacher, K.; Klug, Y. A Database for the Evaluation of Hardened Properties of SCC. *Leipz. Annu. Civ. Eng. Rep. (LACER)* **2002**, *7*, 123–134.
8. Temiz, H.; Köse, M.; Koksal, S. Effects of Portland Composite and Composite Cements on Durability of Mortar and Permeability of Concrete. *Constr. Build. Mater.-Constr Build Mater* **2007**, *21*, 1170–1176. https://doi.org/10.1016/j.conbuildmat.2006.06.011.
9. Khurana, R.; Saccone, R. Fly Ash in Self-Compacting Concrete. *Spec. Publ.* **2001**, *199*, 259–274.
10. Ali, M. The Effect of Various Percentages of Fly Ash on the Fresh and Hardened Properties of Self Compacting Concrete. **2014**, *3*, 7–14.
11. Lachemi, M.; Hossain, K.M.A.; Lambros, V.; Nkinamubanzi, P.-C.; Bouzoubaâ, N. Self-Consolidating Concrete Incorporating New Viscosity Modifying Admixtures. *Cem. Concr. Res.* **2004**, *34*, 917–926. https://doi.org/10.1016/j.cemconres.2003.10.024.
12. Mohammed, M. Stress-Strain Behavior of Normal and High Strength Self-Compacting Concrete. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *737*, 012003. https://doi.org/10.1088/1757-899X/737/1/012003.
13. Anand, R.M.; Jayaram, P.; Shanthi, R.; Aishwaryalakshmi, V. Flexural Behaviour of Self Compacting Concrete Beams. *Int. J. Civ. Eng. Technol.* **2017**, *8*, 305–318.

14. Neto, E. Self-Compacting Concrete: Composition Methodology. In Proceedings of the Design, Production and Placement of Self-Consolidating Concrete 6th International RILEM Symposium on Self-Compacting Concrete, Montreal, QC, Canada, 26–29 September 2010.