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

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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 being able to perform in an outstanding manner in densely reinforced structures. The main objective of this study is to investigate the primary differences in the engineering properties of SCC using CEM-I, CEM-II/A-M, and CEM-II/B-M types of cement as the 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. Therefore, it will highlight the effects of the mechanical and flow properties of the concrete mix due to the change in cement type with a similar composition and volumetric ratio to other constituent materials. The flow properties were validated using the V-funnel test, L-box test, T-500 test, and slump flow test. A comparative result highlighting the strength response, i.e., the compressive, tensile, and flexural strength of the mix designs, was recorded at 28 days, and correlations among these values were established and analyzed.

Keywords: self-compacting concrete; flow and strength properties; superplasticizers (SP)

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1. Introduction

Self-compacting concrete (SCC) is a relatively new phenomenon 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 the concrete mix [1]. Therefore, 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 which significantly reduces labor costs and the time required for the placement of concrete.

The engineering characteristics of SCC depend on some fundamental properties: a reduced volumetric ratio of aggregate to cementitious materials, a lower water–powder ratio, a smaller elongation index for coarse aggregates, the usage of viscosity-modifying admixtures (VMAs) or superplasticizers to reduce the cohesive action of the cement, etc. The properties of SCC can be significantly altered by various factors such as the w/c ratio, the types of additives, i.e., VMAs, replacement cementitious materials, fiber reinforcement, etc. Reducing the coarse aggregate volume, lowering the w/c ratio, increasing the dosage of superplasticizers and incorporating more fine and additional cementitious materials can improve the workability and segregation susceptibility of the concrete mix [2]. As higher fluidity and self-leveling properties are the key characteristics of SCC, this should result in a higher w/c ratio, which consequently reduces the binding strength of the cement paste. Therefore, 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, and limestone, also influences the ultimate strength of the concrete as well as the shrinkage amount [3]. The amount of replacement cementitious materials (used in CEM-II cements) shows an inverse relationship with the compressive strength gain over time [4]. Therefore, the strength values of a concrete mix utilizing CEM-I, CEM-II/A-M, and CEM-II/B-M vary due to the variations in the proportion of clinker, additives, and gypsum content. However, the change in tensile strength demonstrates significantly more pronounced variation in comparison to compressive strength [5]. The flexural strength development of SCC occurs at a much higher pace compared to regular concrete due to the probability of stress induction around coarse aggregates and the weakening of bonds caused by mechanical vibration [6]. It also affects other fundamental properties like the modulus of elasticity, bonding to steel, creep, shrinkage, stability, and passing ability. The modulus of elasticity can be as much as 20% lower in the case of SCC compared to normally vibrated concrete with the 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 a higher clay percentage are required, which enhance the resistance to deterioration. Therefore, SCC with diverse properties needs to meet particular conditions. CEM-I cement refers to ordinary Portland cement composed of little to no pozzolanic compounds, whereas PCC, e.g., CEM-II/A-M and CEM-II/B-M, has around 6–20% and 21–35% fly ash, slag, and limestone, along with 0–5% gypsum, while its 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 can also retain workability for longer periods. Moreover, using fly ash in the 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 the binder exhibit a faster hardening process due to its higher content of alumina as well as its greater ultimate strength at 28 days compared to the other two options. It also reveals that increasing pozzolanic contents produce lower strength in the early days of hardening [10]. The split tensile strength is about 5–8 times greater than the compressive strength for each concrete mix. As for flexural strength, concrete beams with CEM-I cement showed 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, and durability are 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). Approximately 0.75 downgrade particles were used by using a sieve to avoid segregation at the opening of the V-funnel and the L-box apparatus. Table 1 outlines the characteristics of coarse aggregates.

Sylhet sand was used as the source of fine aggregates. The non mechanical properties of the fine aggregate (Table 2) were calculated according to ASTM specifications (ASTM C136 for sieve analysis, ASTM C127 for specific gravity, and ASTM C29 for bulk unit weight).

Table 1. Specifications of coarse aggregates.

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

Table 2. Specifications of fine aggregates.

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 polycarboxylic ether (PCE) polymer, was applied as a superplasticizer to reduce the w/c requirement [11]. The amount was established at 1–1.5% volume of total cement weight as per IS 9103 (1999). Primarily, four different sets of mix design were created using CEM-I cement, each with different proportions of coarse and fine aggregates and different w/c ratios that is shown in Table 3.

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, the 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 making necessary changes in the ratios of constituent materials to adjust the properties accordingly. The 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. The cylinder specimens and prismatic beams were made according to the 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

The primary selection of the SCC mix design depends on the flow properties. From Table 4, the analysis demonstrates that with the increasing w/c ratio and higher fine aggregate percentage, the flowability increases. Higher values from these tests indicate better fluidic properties [12]. The conventional approach was 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 measures the amount of time for the viscous flow of the 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 the V-funnel test is approximately 8–12 s, while for the 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 the 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 was mix design 4 (M4). This shows that the mixture with a higher w/c ratio and a 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 a significantly low spread time for T500 and the 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 its 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. The PCC samples showed better fluidic properties, with the CEM-II/B-M cement having higher flow values in all aspects.

From Table 5, it is evident that the 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 the V-funnel and in between the metal bars at the L-box apparatus due to excess amounts of viscosity, in this case, such a phenomenon did not occur. This also results in a greater slump diameter for the T500 test, indicating higher spread of the concrete mix over the base plate. Therefore, it can be concluded that with the increasing percentage of replacement cementitious components, the viscosity of the concrete reduces and shows higher workability and a 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 the 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 provide clear evidence of a gradual change in strength response. Only mixes 3 and 4 show acceptable results. General construction works 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 the 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 the 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 shows that regarding the CEM-II mix compositions, the 28-day flexural strength differs notably from that of CEM-I. They show lower values in comparison to the latter, particularly due to the increase in admixture content. These values were determined at 28 days. But the ultimate capacity of CEM-II cements after reaching its maximum potential can be similar to and even greater than that of CEM-I cement for the same amount of deflection.

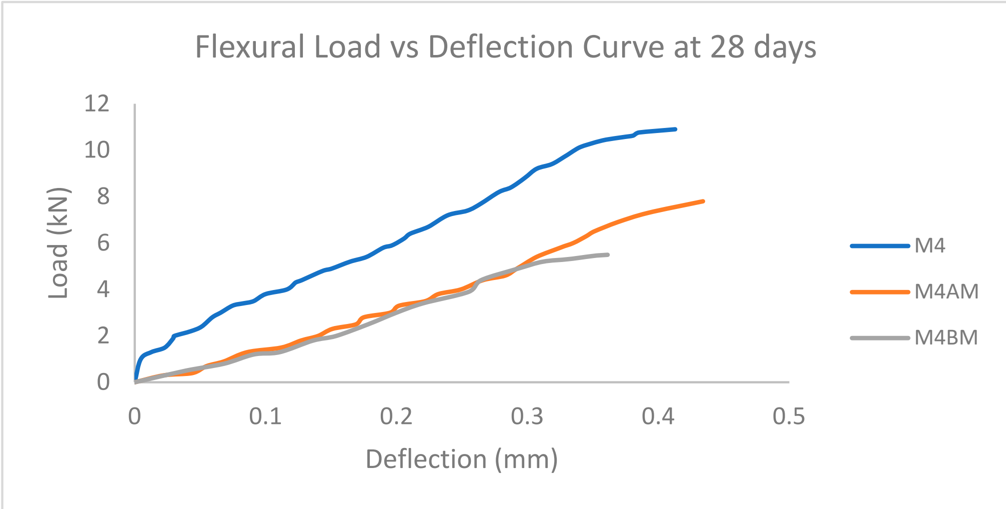

Figure 1. Load vs. deflection curve for flexural strength.

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 having greater coarse aggregate content results in greater strength capacity than M4 while the amount of fine aggregates 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 the permissible limit. As per the experimental results, it can also be deduced that early-age strength reduces with the 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 a similar composition of materials. A similar comment can be made about the flexural capacity too. CEM-II/A-M samples also showed reduced strength values compared OPC in addition to higher flow properties. Therefore, the initial strength gain can be increased by altering the proportion of coarse and fine aggregates, lowering the 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 it 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 and the time requirement for the V-funnel, L-box, and slump tests are related to the w/c ratio and volumetric ratio of coarse and fine aggregates. A lower w/c ratio results in lower fluidity which can create segregation and blockage at the opening of the apparatuses. However, this issue can be mitigated by using a 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. Therefore, the strength properties can be controlled up to a certain extent by changing the material proportions or the amount of supplementary cementitious materials added.

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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. [CrossRef]
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. [CrossRef]
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. [CrossRef]
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. [CrossRef]
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. [CrossRef]
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. *Int. J. Enhanc. Res. Sci. Technol. Eng.* **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. [CrossRef]
12. Mohammed, M. Stress-Strain Behavior of Normal and High Strength Self-Compacting Concrete. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *737*, 012003. [CrossRef]

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.