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Full Length Article

Fresh and hardened properties of binary blend high strength self compacting concrete

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ABSTRACT

Self compacting concrete (SCC) made a remarkable impact on the concrete construction industry because of its innovative nature. Assessment of optimal ratio between chemical and mineral admixtures plays a vital role in developing SCC. In the present work three different mineral admixtures were used as partial substitute in different proportions to cement to produce SCC with a characteristic compressive strength of 60 MPa. All the three types of SCC were investigated for its fresh and hardened properties. From the results, 50% GGBFS, 10% SF and 20% MK were found to the optimum values as partial substitute to cement.

1. Introduction

Self compacting concrete (SCC), a flow able concrete and has ability to compact due its own weight. SCC is the most viable option for site conditions with constrained access and locations of congested reinforcements. Some examples are beam-column joint, bridges and foundations. Because of its flowing and passing ability, SCC does not need any external device for compaction and hence minimizes noise pollution at work sites compared with conventionally vibrated concrete (CVC). SCC was originally developed in Japan when they come across labor problems on the construction industry after Kobe earthquake and it was developed in Europe also. Higher flow ability made SCC to fit for uses in repair and retrofitting applications. SCC could be prepared under three distinct forms namely increasing powder content i.e. addition of fines (using mineral admixtures only) as cement and fine aggregate replacement in which water-powder ratio was in the range of 0.8 to1 (as per EFNARC guidelines); using chemical admixtures namely Super Plasticizers (SP) and Viscosity Modifying Agent (VMA) in formulation of SCC mix in which dosages were added in terms of percentage weight of cement (SP < 3% and VMA < 0.3%); incorporating both mineral and chemical admixtures with optimum water-powder ratio between 0.3 to 0.4 in par with optimum chemical dosages. In present study, the combination type SCC was developed for all binary SCC mixes with addition of powder content along with the optimum dosages of super plasticizer (SP) and viscosity modifying agent (VMA).

Cost effective SCC was developed using mineral admixtures such as SF, GGBS and FA as cement replacement (in percentages namely 30%, 40% and 50%) has reduced the dosages of SP necessary to achieve a required fluid property. SCC with less than 30% of FA, GGBS and SF with water powder ratio of 0.35 would be the optimum mix for fresh and mechanical properties was studied [1]. The experimental investigation on SCC using FA (from 25% to 40%) and SF (from 5% to 20%) as cement replacement was found that SF 15% has performed better in terms of mechanical properties and sorptivity tests, was due to quantity of powder addition namely SF in SCC[2]. SCC was exhibited using FA with high and low lime contents to assess the performance of permeation and strength properties of five different combinations and found that SCC with high volume fly ash enhanced both fresh and hardened properties in addition to permeation characteristics [3]. In SCC, the addition of powder content from 10% to 15% as cement replacement improved the early age strength at 28 days respectively [4]. The research was conducted in SCC using high volumes of two SCM's in the form of binary and ternary mixes (with 60% to 90% as cement replacement) inferred that SCC could be prepared with 80% and 90% of SCM's, had higher stiffness and lesser creep strains compared to control mix. However the compressive strength at later ages (56 days) was obtained with 60% and 80% as cement replacement levels in the form of binary & ternary blend respectively [5]. The study on SCC properties using FA, lime stone

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powder, basalt powder, marble powder and ground granulated blast furnace slag as partial substitutes to cement (in different percentages) was inferred that with FA 25% obtained highest compressive strength and slag 45% has performed well against sulphate attack [6]. A novel method was introduced in SCC mix design with material quantities, additives and with lesser cost. It was found that novel method was simpler and easier to adopt when compared to the method developed by Japanese Ready-Mixed Concrete Association (JRMCA) [7]. The fresh and mechanical properties of SCC were studied using high volume FA from 40 to 60% (with two different w/b ratios of 0.35 and 0.45) has obtained the characteristic compressive strength for different mixes from 26 to 48 MPa respectively [8]. New method of mix design using paste and mortar was proposed to fill the gap of non availability of proper mix design and concluded that flow properties of the final product need to be tested to establish its relevance [9]. The binary & ternary form of research conducted in SCC using FA 30%, SF 15% and its combination as FA 10% & SF 10% has obtained highest compressive strength at the age of 28 days [10]. The research on SCC properties was exhibited using GGBS in percentages namely 10%, 15%, 20%, and 25% as cement replacement with two types of super plasticizers namely polycarboxylate based super plasticizer and naphthalene sulphonate. Thus 20% GGBS as cement replacement with optimum 15% SP of Polycarboxylate ether based has obtained improved workability. The Compressive strength decreased with the increase in slag content at early ages as same as conventional concrete, but differences were small at later ages [11]. A research study was conducted using industrial flash- calcined metakaolin (MKF) to produce SCC. It was concluded that substitution of 25% MKF for cement enhanced durability performance of SCC [12]. The mechanical properties of fibre reinforced SCC was studied by replacing cement with FA and GGBS in 30%, 40% and 50% along with addition of polypropylene synthetic fibers of 0.05% and 0.10% with water-powder (w/p) ratio of 0.4. It was reported that 50% mineral admixture and 0.05% fibres gave better fresh properties whereas 30% mineral admixture and 0.1% fibres obtained highest mechanical properties with SP dosage of 2% was added to obtain the required SCC mix [13]. Using industrial by-products like Ground Granulated Blast furnace Slag (GGBS) and Silica fumes (SF) as a replacement to cement SCC was used to study the mechanical properties; using 30% GGBS in SCC has obtained highest strength than 50% SF(less strength) was concluded [14]. The rheology and mechanical properties of SCC using MK as cement replacement obtained increased compressive strength regardless of replacement materials and tensile strength also shown improvement in their trend [15]. A technical study on mix design of high strength SCC using MK was reported that it could be possible to obtain highest compressive strength up to 120 MPa, when MK 22.5% was used [16]. Influence of slag on SCC fresh properties was found to be optimum at 15% with workability retention of about 60 min. and compressive strength decreased with increment of slag content at early ages, but its effect was less prone for later ages namely at 56 and 90 days. To satisfy the workability criteria 20% slag could be used and for compressive strength 15% slag was found to be optimum percentage [17]. Silica fume was a viable secondary mineral material and suggested that no more than 6% silica be replaced by mass [18]. For SCC mix design, test methodology of fresh state properties was determined by the European Federation of specialist construction of chemicals and concrete systems (EFNARC) guidelines [19,20]. Use of GGBS addition in SCC from 20% to 80% could exhibit the compressive strength from 30 to 100 MPa was determined [27].

In present study, SCC was exhibited by replacing cement with three mineral admixtures namely SF (5% to 25%, increment of 5%), MK (5% to 20%, increment of 5%) and GGBFS (25% to 100%, increment of 25%) in different percentages. After conducting fresh properties test on all combinations, the rheology of SCC by the influence of those mineral admixtures was studied. In hardened state, the compressive strength and tensile strength of concrete was compared with control concrete.

The present research focuses more on, what would be the optimum percentages of SF, MK and GGBFS by cement replacement to a maximum extent? In such a way, the fresh properties and hardened state properties test were conducted with different SCC binary blended with mineral and chemical admixed combinations. The control SCC was used as a reference to compare the obtained mechanical properties in hardened state at the age of 7- and 28-days respectively.

2. Materials and methods

2.1. Material properties

Ordinary Portland Cement (OPC) of ASTM Type I [21] was used in this study. The mineral admixture added with cement was ground granulated blast furnace slag, which was obtained from nearby steel industries. The other admixture namely silica fume was supplied by M/s Elkem India PVT Ltd, Navi Mumbai, India. The third admixture Metakaolin was obtained from Chennai. Chemical properties of materials used in the present work are given in Table 1. Chemical properties of silica fume was tested as per as per ASTM C 1240-99 [22]. Locally available river sand with a down size of 4.75 mm conforming to grading Zone III as per ASTM standard [23] was used as fine aggregate (see Fig. 1) and crushed granite stones of 12.5 mm down size (see Fig. 2) were used as coarse aggregates and their particle size distributions confirmed to the requirements of ASTMC33 [24]. The physical properties of fine and coarse aggregates were determined as per ASTM 127 [25] and are listed in Table 2. The study on water absorption was conducted as per ASTMC642-13 [26]. The presence of chemical composition of SF, GGBFS and MK in Table 1 would influence the rheology and mechanical properties of SCC because of their different percentages of addition in each SCC mix. The specific surface area of finer materials used in the study is 1.07, 24.3, 11.5 and 0.45 m^2/g for cement, silica fume, metakaolin and GGBFS respectively.

Super plasticizer was used to obtain sufficient workability for the mixes. The new generation super plasticizer termed Conplast SP 430 was used. The specific gravity was about 1.20. Viscosity modifying agent namely Glenium stream-2 was used as stabilizer to maintain cohesiveness of the mix and to develop resistance against segregation of mix.

Table 1
Chemical properties of materials used.

Formula	Concentration (%)			
	Cement	GGBFS	SF	MK
CaO	66.05	31.25	97.36	0.08
SiO_2	27.11	35.01	0.79	62.58
Al_2O_3	6.45	19.62	0.53	28.73
MgO	0.07	9.11	0.51	0.13
Fe_2O_3	0.12	1.71	0.29	1.10
SO_3	–	0.55	0.15	
TiO_2	–	0.69	0.14	0.55
Na_2O	–	0.48	0.09	1.89
K_2O	–	0.46	0.06	3.94
MnO	–	0.27	0.02	
BaO	–	0.10	0.01	
P_2O_5	–	0.04	0.01	
SrO	–	0.04	0.01	
Cl	–	0.03	100 ppm	
ZrO_2	–	0.03	70 ppm	
As_2O_3	–	37 ppm	51 ppm	