Reviewing Some Properties of Self-Compacting Concrete Containing Recycled Materials

Irmandeep Singh and Sanjay Goel

Abstract The manuscript presents an assessment of the available data on the properties of Self-Compacting Concrete (SCC) containing recycled materials in its fresh and hardened states. A large number of studies has been conducted which showed that SCC is a sensitive product in its fresh state, wherein different recycled products have been used to access its fresh properties like flowability, passing ability and stability. It is assessed that a huge data is available regarding the investigations conducted to study the characteristics of hardened SCC using various recycled materials. The workability and suitability of SCC for various structural applications viz., bridge decks and piers, highway and airfield pavements, offshore structures, rapid mass transport systems, dams, tunnel linings, high-rise structures, precast and prestressed elements has also been accessed. The literature reveals that the use of different recycled materials in SCC would be a sustainable solution for developing a versatile construction material along with the environmental benefits.

Keywords Self-Compacting concrete · Recycled material · Stability · Workability · Environmental suitability

1 Introduction

The rapid growth of high-performance concrete structures resulted in the development of innovative construction materials like Self-Compacting Concrete, which offers the best solutions viz., high workability, passing ability through confined and densely reinforced spaces, economical and noise-free construction for the development of concrete industry and opened up new areas for the use of this product all over the world. Economically and technically, the Self-Compacting Concrete offers very attractive benefits over Normally Vibrated Concrete (NVC),

I. Singh (✉) · S. Goel
DAV IET, Jalandhar, India
e-mail: irmandeep@gmail.com

S. Goel
e-mail: goelsanjay100@yahoo.com

A. K. Agnihotri et al. (eds.), *Recycled Waste Materials*, Lecture Notes in Civil Engineering 32, https://doi.org/10.1007/978-981-13-7017-5_18

which can be further extended when combined with fibres, particularly steel fibres. Today, SCC is widely accepted material for the construction of bridge deck overlays, reinforced concrete bridges, prestressed bridge elements and railroad structures.

2 Self-Compacting Concrete (SCC)

In the past one decade, a significant number of researches related with various aspects of concrete technology and practice have been dedicated specifically to SCC and the available literature on SCC is further growing rapidly. The following section briefly discusses the characteristics of SCC in fresh and hardened state investigated in the recent past.

2.1 Properties of Fresh SCC

The SCC is much more preferred over NVC due to its fresh state properties, i.e. flowing characteristics and it is therefore more important to verify its fresh state properties. Alteration in the water-to-cement ratio and the amount of admixtures is the main properties in obtaining workable and stable SCC mixtures. Feys et al. (2008) and Khayat et al. (2010) studied the effect of water-to-cement ratio, superplasticizer (SP) and viscosity modifying agent (VMA) dosage levels on the workability and rheology of Self-Compacting Concrete. The optimum parameters for self-compatibility were determined through the tests of workability such as L-Box, V-funnel and slump flow. The constant dosage of superplasticizer was more effective in increasing the mix workability when applied at constant at lower water/cement ratios. The decrease in w/c ratio increases the extent of possible workability improvements of SCC. The optimal dosage of superplasticizer depends on the concrete mix proportions, which can be determined through experimental trials only. A range of 0.84–1.07 by volume is the suggested optimum water-to-cement ratio for producing SCC. The blocking may happen if the ratio is above and segregation of the mixture may happen for ratios outside this range. The use and type of VMA have affected the fresh properties of SCC significantly. The addition of VMA resulted in major enhancement in passing ability with the increase in slump flow without any negative impact on surface settlement, rheological properties and mechanical properties (Khayat et al. 2010).

Hwang et al. (2006) investigated about 70 SCC mixtures made with water-to-cementitious material ratios (w/cm) of 0.35 and 0.42 to evaluate the acceptability of various test methods for workability assessment and to propose stipulations for better structural performance of SCC. It was suggested to evaluate workability parameters of SCC to supervise the quality and design for place ability in constrained sections, encountered in various structures, through use of a combination of the slump flow and the L- box, J-Ring or V-funnel tests.

Sonebi et al. (2007) investigated the consequence of the water-to-cement ratio, superplasticizers (HRWRA) and the content of coarse aggregates, on filling ability and passing ability of Self-Compacting Concrete through statistical models. The established models provide a capable method to determine the effect of main variables on fresh characteristics of SCC and the models are applicable for a wide array of mix proportions. Kovler and Roussel (2011) reviewed the data related to workability, i.e. loss of slump, setting time and rheological characteristics of SCC, i.e. thixotropy, bleeding, segregation and problems related to formwork filling and pressure.

A number of investigations have been made to study the impact of different filler material viz., fly ash, limestone powder, metakaolin, chalk powder, etc. on the workability and stability of fresh SCC. The use of some other waste materials like spent foundry sand, ground-granulated blast-furnace slag (GGBFS), crump rubber, were also studied to investigate the SCC in its fresh state. It has been found that different filler materials, as well as waste materials investigated, could be efficiently used to develop SCC mixes with minute modification in dosage of superplasticizer. A summary of the some recent studies conducted in this regard is presented in Table 1.

For the successful placement of SCC, a concrete mixture with tailor-made workability properties was required to ensure a good balance between deformability and stability and ensure a homogeneous distribution of the concrete constituents. To ensure adequate structural performance and durability, such a homogeneous distribution is of utmost importance. There was a huge challenge for researchers and technologists to deal with intricate task of manipulating several variables to enhance concrete performance and at the same time reduce the cost while using SCC. Initially, Okamura and Ozawa (1995) has proposed an effortless mix design method in which the fine and coarse aggregate amount was kept constant and the water/powder ratio and dosage of superplasticizer were adjusted to achieve the self-compactability, which was later on modified by Okamura and Ouchi (1999). Su et al. (2001) used the concept of packing factor (PF) to suggest a new method for proportioning of SCC mixes. The most important deliberation of the proposed method was to fill the voids between the loosely piled aggregates by the paste of binders. The aggregate packing factor (PF) determines the amount of aggregate and affects the strength, flowability and self-compactability and other desired SCC properties. The guidelines for proportioning of SCC mix proposed by EFNARC (2005) and ACI 237R 2007 are presented in Table 2.

Lately, Kheder and Al Jadiri (2010) developed a new method for proportioning SCC mixtures based on specified strength under compression, not just emphasizing on the fulfilment of fresh properties requirements unlike the previous methods of proportioning. It also considers the effect of fineness modulus of fine sand and maximum size of coarse aggregate in proportioning SCC mixtures. This method suggested the design of SCC for compressive strength from 15 to 75 MPa. Silva et al. (2011) also studied the technical practicality of two design methods for proportioning of SCC to obtain required characteristics with minimum number of experiments.

Table 1 Summary of investigations made on properties of fresh SCC

References	Filler material used	Properties investigated	Major conclusions
Ho et al. (2002)	Quarry dust	Plastic viscosity and yield stress	SCC with high dosage of superplasticizer can be obtained
Zhu and Gibbs (2005)	Different limestone and chalk powder	Flowability and passing ability	SCC mix with limestone powder requires less dosage of superplasticizer as compared to chalk powder for the same workability
Gesoglu and Ozbay (2007)	GGBFS, fly ash (FA) and silica fume (SF)	Filling ability, passing ability, viscosity, and setting time	Slump flow time reduced with all admixtures Ternary and quaternary blends yield more satisfactory results for passing and filling ability FA and GGBFS prolonged the setting times
Guneyisi et al. (2009)	Marble powder and slag	Filling ability and viscosity	Use of marble dust increased the flow time and SP dosage, while the addition of slag decreases the flow time as well as superplasticizer demand
Guneyisi (2010)	Crump rubber waste and fly ash	Flowability, viscosity, passing ability, segregation resistance	Use of crump rubber increased the flow time and setting time addition of fly ash to rubberized mix decreases the flow time
Güneyisi et al. (2016)	Fine and coarse recycled concrete aggregates	Rheology, passing and filling ability	The self-compaction of the SCC mixes is outstandingly improved by replacing the coarse RCA and fine RCA at different levels
Singh and Singh (2018)	Recycled concrete aggregates, fly ash and Silica fumes	Shear thickening and thinning	Normal-strength SCRCAs showed shear thickening behaviour, whereas the medium- and the high-strength SCRCAs depicted shear thinning

Table 2 Proposed limits for constituents for SCC mixes

References	Cementitious material (kg/m^3)	Fine aggregate	Coarse aggregate	Water/cementitious material
EFNARC (2005)	380–600	48–50% of total aggregate by weight	750–1000 kg/m^3	0.85–1.10 by volume
ACI Committee 237R-07 (2007)	386–475	Mortar fraction 68–72% of total mixture by volume	28–32% of total mixture by volume	0.32–0.45 by weight

2.2 Properties of Hardened SCC

Initially, when SCC was adopted by the construction industry, the achievement of fresh properties was the major concern of the research and development work. It is, however, the properties of hardened concrete that are of principal interest to structural engineers and designers and contractors. A significant amount of research data has also been generated relating to properties of hardened SCC and a comprehensive review of the characteristics such as strength under compression and tension, fracture mechanism, modulus of elasticity, creep, shrinkage and other in situ and structural properties are presented in this section.

An investigation to compare the strength, elastic modulus, creep and shrinkage characteristics of SCC with NVC was conducted by Persson (2000). The study included specimens of eight different mix proportions with water-to-binder ratio (w/b) ranging from 0.24 and 0.80. The result shows that modulus of elasticity, creep and shrinkage of Self-Compacting Concrete at constant strength was similar to much extent with the corresponding properties of NVC.

Druta (2003) compared the values of strength under compression splitting tension for SCC and NVC. The coarse aggregate–cement paste bonding was also examined. All SCC mixtures exhibited higher strength compared to NVC under compression as well as split tension. The increase in strength under compression was approximately 60% while the strength under splitting tension of SCC was 30% higher than NVC. The reason for the increase observed in strengths was the enhancement in the bonding between aggregate and cement paste due to the use of mineral and chemical admixtures, which ultimately has increased the strength of concrete. The scanning electron microscope images taken from concrete samples have shown that the greater widths of the aggregate–cement paste interface micro-cracks for NVC than for SCC. Brouwers and Radix (2005) observed a higher splitting tensile strength for SCC compared to NVC of similar strength under compression.

The deformation behaviour of Self-Compacting Concrete under sustained loading was investigated by Wustholz and Reinhardt (2007). The different compressive strength grades of SCC were subject ted to sustained tensile load for up to 2.5 years. It was reported that the long-term tensile strength was found to be 69% of the short-term tensile strength and the stress-induced shrinkage tends to amplify on decreasing the compressive strength.

A widespread assessment of mechanical properties of SCC under hardened state was done by Domone (2007). The data have been analysed from more than 70 investigations and correlated to compare with the properties of NVC with similar strengths. The data so obtained depicted significant scatter, which may be due to a wide variety of materials and mixes used for SCC. It is evident that limestone powder makes a significant increase in strength, which was a common supplementary addition to SCC mixes. SCC showed similar or higher bond strength to reinforcing and prestressing steel as that for NVC. The in situ properties and the performance of the structural elements cast with SCC showed similar behaviour as that with NVC. A significant data has been obtained from this analysis which gives assurance in the general behaviour of Self-Compacting Concrete, and further investigations need to be designed to obtain confirmatory data for particular applications such as earthquake resistant structures and structures subjected to fatigue loads.

Hassan et al. (2008) studied the strength under shear and cracking behaviour of large-scale beams made with Self-Compacting Concrete and compared with NVC. The study revealed that ultimate strength under shear for NVC beams was somewhat higher than that of similar beams of SCC and the difference increases with the decrease in main steel reinforcement and increase of depth of beam.

The bond characteristics of Self-Compacting Concrete plays an important role when SCC is specifically to be used in structural elements with dense and congested reinforcement under difficult casting conditions without applying vibration. Esfahani et al. (2012); Desnerck et al. (2010) carried out extensive investigations to determine the bond strength and top-bar effect between deformed steel bars and different SCC mixes. SCC performed better than NVC depicted by less decrease in bond strength of SCC due to more stable and less inhomogeneous mix compared to NVC. The variation in bond strengths at different casting levels was also observed to be lesser in SCC than that of NVC. Due to its more consistent nature and superior filling ability, the Self-Compacting Concrete also showed a lesser top-bar effect compared to NVC. The behaviour of different structural elements of SCC under statically applied loads has been studied by several researchers and the results were compared with that of NVC. Table 3 summarized the results of such tests conducted on various structural elements made with Self-Compacting Concrete and NVC of similar strengths.

The effect of addition of different types of mineral admixtures/filler materials on the characteristics of Self-Compacting Concrete in hardened state viz., compressive strength and tensile strength, fracture processes, rupture modulus, creep and shrinkage, etc. were investigated by a number of researchers under statically applied loads. The impact of specimen size, size and type of aggregate on properties of hardened Self-Compacting Concrete has also been studied by various researchers. Thus, Table 4 presents a brief summary of the investigations carried out to study the afore-mentioned characteristics of SCC in hardened state.

The durability properties of SCC mixes viz., chloride ion penetration, freeze and thaw resistance, alkali-aggregate reaction, carbonation sulphate attack, resistance to fire, etc. have also been a subject of investigation (Persson 2003). It has, in general, been observed that the sorptivity and oxygen permeability of SCC mixes had remarkably reduced than that of NVC of the same strength. Zhu and Bartos (2003) depicted that the type of filler used is one of the main factors affecting the chloride diffusivity of SCC. The Self-Compacting Concrete mixes with no additional cementitious material were found to have significantly better chloride diffusion than the reference mixtures and other Self-Compacting Concretes, in presence of a viscosity modifying agent. Reinhardt and Stegmaier (2006) tested normal and high-performance SCC, respectively, under fire. The study revealed that the risk of spalling was greater in normal SCC as well as high-performance Self-Compacting Concrete in comparison to NVC and high performance NVC. The initial and residual mechanical properties for SCC were similar. The properties viz., internal frost resistance and salt resistance were extensively explored by Persson (2003). The results indicated a significant improve-

Table 3 Summary of tests on structural concrete elements

References	Test details	Type and strength of concrete	Results with respect to NVC
Khayat et al. (1999)	2.35 m columns, axial load	40–50 MPa SCC and NVC	SCC showed 50% higher ultimate strains in columns with comparable stiffness and load response
Sonebi et al. (2003)	4-point bending on 3.8 m span beams	60 MPa NVC and SCC beams	SCC beams showed narrower cracks and 5% greater deflection with similar cracking and ultimate loads
Peter et al. (2004)	3 m beams in 4-point bending: (a) Singly under-reinforced	72 MPa SCC, 69 MPa NVC	SCC beams achieved 12% higher peak loads and 10–15% higher deflection at first cracking
	(b) As (a) with shear stirrups		Similar crack width and spacing with 10% more curvature in Self-Compacting Concrete beams
Das et al. (2005)	4-point bending on 1.2 m span beam	28 days strength of 46 MPa and 59 MPa for SCC and NVC resp.	SCC showed narrower cracks and similar load deflection behaviour, shear strength was 9–12% higher
Naito and Hoover (2005)	10 m pretensioned T-beams	SCC 59 MPa and NVC 51 MPa	SCC showed similar strength and marginal greater deflection in beams
Kumar et al. (2009)	2.5 m T-beams under single point loading	45–55 MPa SCC and NVC	SCC beam was stiffer than NVC beam and depicted similar initiation and propagation of cracks, mode of failure and ultimate strength
Hassan et al. (2010)	Length 1050–4500 mm, depth 150–750 mm, width 400 mm, tested in three point loading	45 MPa SCC, 47 MPa NVC with 1–2% longitudinal steel reinforcement	SCC beams showed similarity in terms of widths, heights, and angles of cracks and overall failure mode

ment in the freeze and thaw resistance of SCC as compared to NVC whereas, frost scaling due to salt and internal fundamental frequency were more or less similar in SCC and in NVC.

Dinakar et al. (2008) studied the effect of adding high volume fly ash on the durability of Self-Compacting Concrete. The results indicated that the high volume fly ash SCCs depicted higher water absorption and permeable voids in comparison to normal NVCs of the similar strength under compression. The high-volume fly ash SCCs has shown a significant reduction in loss of weight and diffusion of chloride ion.

Table 4 Summary of investigations on properties of hardened SCC

References	Filler/recycled material	Property investigated	Major conclusions
Kim et al. (1998)	Class F fly ash content and aggregate-concrete ratio	Compressive and split tensile strength, elastic modulus, creep and shrinkage	Gain in compressive strength is slower As compared to NVC Splitting tensile strength is similar to NVC Creep rate is higher for SCC in early ages
Bouzoubaa and Lachemi (2001)	Class F fly ash	Compressive strength and drying shrinkage	No significant difference in compressive strength and drying shrinkage of SCC and control NVC was observed SCC can replace NVC of similar strength at the same cost
Bosiljkov (2003)	Limestone powder	Compressive strength	Better compressive strength than NVC due to improved fine particle packing of limestone filler
Bignozzi and Sandrolini (2006)	Tyre rubber waste	Compressive strength and stiffness	Compressive strength and stiffness of SCC decreases on the addition of tyre waste but the values better than the NVC with rubber tyre waste
Roziere et al. (2007)	Limestone fillers and paste volume	Fracture properties shrinkage and cracking	Increasing paste volume causes decrease in strength, elastic modulus, fracture resistance and increase in shrinkage and cracking. SCC becomes more brittle
Esping (2008)	Limestone fillers with different surface areas	Compressive strength	Compressive strength increased for mixes with limestone fillers with larger surface area because of denser packing
Gowda et al. (2009)	Quarry dust	Compressive strength and splitting tensile strength	Hardened properties remained unchanged for both SCC without and with quarry dust up to 70% replacement level
Karjinni et al. (2009)	Fly ash, metakaolin and silica fume	Compressive strength, flexural strength, tensile strength, Young's modulus, Poisson's ratio and density	Mechanical properties were better with silica fume than with fly ash and metakaolin Young's modulus increased with increase in strength Poisson's ratio was identical for all mixes

(continued)

Table 4 (continued)

References	Filler/recycled material	Property investigated	Major conclusions
Hossain and Lachemi (2010)	Volcanic ash	Compressive strength	SCC mixes for structural applications can be developed with compressive strength more than 15 MPa by replacing up to 50% of cement with volcanic ash but the compressive strength reduces drastically after 40% of replacement
Uysal and Yilmaz (2011)	Limestone, basalt and marble powder	Compressive strength, static and dynamic eastic moduli	Mixes with marble powder were having maximum compressive strengths and dynamic and static modulus of elasticity. A reduced dynamic and static elastic modulus was observed on addition of mineral admixtures
Siddique et al. (2012)	Coal fly ash and bottom ash, water-cementitious material ratio	Compressive strength	Indicated similar behaviour of strength increase on decrease of water-cementitious ratio. Recommends an optimum quantity of 25–35% and up to 20% for fly ash and bottom ash, respectively
Dehwah (2012)	Quarry dust powder (QDP), Fly ash (FA) and silica fume (SF)	Compressive strength, split tensile strength, flexural strength, UPV	The mechanical properties of SCC incorporating QDP (8–10%) shown improvement over the SCC prepared with SF plus QDP or FA alone and resulted in significant cost saving
Pereira-de-Oliveira et al. (2014)	Recycled concrete aggregates	Permeability	The water permeability was not significantly affected by recycled coarse aggregate incorporation. On increasing the percentage of recycled aggregates, the water penetration depth is reduced in SCC
Corinaldesi and Moriconi (2015)	Expanded clay aggregates, synthetic fibres	Tensile and flexural strength, post-cracking behaviour	Use of synthetic macro-fibres has improved the post-cracking behaviour and other mechanical and functional properties
Omrane et al. (2017)	Fine and coarse recycled concrete aggregates	Compressive strength, chloride ion penetration, sulphuric acid attack	The results indicate that using 50% recycled coarse and fine aggregates produced comparable compressive strength. It resulted in reduction in the chloride ions penetration depth to 50% and also showed a better resistance for sulphuric acid attack

Boel et al. (2008) concluded in a study that the gas permeability of SCC is almost five times less than the gas permeability of similar NVC.

Hwang and Khayat (2009) suggested that regardless of the water/cementitious material (w/cm) ratio, binder type or admixture combination, properly designed SCC can develop high resistance to freezing and thawing with frost durability factor greater than 80%. Guneyisi et al. (2011) have studied the permeability properties of SCCs made with different blends of Portland cement, fly ash, metakaolin and GGBFS. The type and amount of the cementitious material used significantly effects the permeability properties of SCCs. The metakaolin has been found to be the most efficient in reducing the permeability properties of Self-Compacting Concrete mixes.

The results derived from different investigations showed an overall improvement in the properties of SCC in hardened state over the NVC of similar grades. The improved homogeneity and density of concrete coming from vibration free production and better interface bond between aggregates and paste has contributed to the better performance of SCC over NVC.

3 Concluding Remarks

The review of the literature in the preceding sections presented in brief the characteristics of Self-Compacting Concrete made using recycled materials. It can be seen that numerous investigations have been carried out to assess the properties of fresh SCC as well as the properties of hardened SCC under static conditions of loading. Different types of cementitious materials have been incorporated in concrete to enhance the properties of SCC. The aim has been to review the workability and suitability of SCC concrete for use in different structures viz., in bridge decks and piers, highway and airfield pavements, offshore structures, rapid mass transport systems, dams, tunnel linings, high-rise structures, precast and prestressed elements.

References

ACI Committee-237 (2007) Self consolidating concrete. ACI Emerging Technology Series, ACI 237R-07, 1–30

Bignozzi MC, Sandrolini F (2006) Tyre rubber based recycling self compacting concrete. Cem Concr Res 36:735–739

Boel V, Audenaert K, De Schutter G (2008) Gas permeability and capillary porosity of self-compacting concrete. Mater Struct RILEM 41:1283–1290

Bosiljkov VB (2003) SCC mixes with poorly graded aggregate and high volume of limestone filler. Cem Concr Res 33:1279–1286

Bouzoubaa N, Lachemi M (2001) Self compacting concrete incorporating high volume of class F fly ash preliminary results. Cem Concr Res 31:413–420

Brouwers HJH, Radix HJ (2005) Self compacting concrete: theoretical and experimental study. Cem Concr Res 35:2116–2136

Corinaldesi V, Moriconi G (2015) Use of synthetic fibers in self-compacting lightweight aggregate concretes. J Build Eng 4:247–254
Das D, Kaushik SK, Gupta VK (2005) Shear resistance of self compacting concrete. In: Proceedings of SCC 2005 conference, centre for advanced cement based materials, USA, Northwestern University, pp 453–461
Dehwah HAF (2012) Mechanical properties of self compacting concrete incorporating quarry dust powder, silica fume or fly ash. Constr Build Mater 26:547–551
Desnerck P, De Schutter G, Taerwe L (2010) Bond behaviour of reinforcing bars in self compacting concrete: experimental determination by using beam tests. Mater Struct RILEM 43:53–62
Dinakar P, Babu KG, Santhanam M (2008) Durability properties of high volume fly-ash self compacting concrete. Cem Concr Res 30:880–885
Domone PL (2007) A review of the hardened mechanical properties of self compacting concrete. Cem Concr Compos 29:1–12
Druta C (2003) Tensile strength and bonding characteristics of self compacting concrete. Thesis, Department of Engineering Science, Agricultural and Mechanical College, Louisiana State University, Louisiana, USA
EFNARC (2005) The European guidelines for self compacting concrete-specification, production and use. BIBM, CEMBUREAU, ERMCO, EFCA, EFNARC, 68 pp
Esfahani MR, Lachemi M, Kianoush MR (2012) Top-bar effect of steel bars in self consolidating concrete. Cem Concr Compos 30:52–60
Esping O (2008) Effect of limestone filler BET(H_2O) area on the fresh and harden properties of self compacting concrete. Cem Concr Res 38:938–944
Feys D, Verhoeven R, De Schutter G (2008) Fresh self compacting concrete, a shear thickening material. Cem Concr Res 38:920–929
Gesoglu M, Ozbay E (2007) Effects of mineral admixtures on fresh and hardened properties of self compacting concretes: binary, ternary and quaternary systems. Mater Struct RILEM 40:923–937
Gowda MR, Narasimhan MC, Karisddappa, Rajeeva SV (2009) Study of the properties of SCC with quarry dust. Indian Concr J 83:54–60
Guneyisi E (2010) Fresh properties of self compacting rubberized concrete incorporated with fly ash. Mater Struct 43:1037–1048
Guneyisi E, Gesoglu M, Ozbay E (2009) Effects of marble powder and slag on the properties of self compacting mortars. Mater Struct RILEM 42:813–826
Guneyisi E, Gesoglu M, Ozbay E (2011) Permeation properties of self consolidating concretes with mineral admixtures. ACI Mater J 108:150–158
Güneyisi E, Gesoglu M, Algın Z, Yazıcı H (2016) Rheological and fresh properties of self-compacting concretes containing coarse and fine recycled concrete aggregates. Constr Build Mater 113:622–630
Hassan AAA, Hossain KMA, Lachemi M (2008) Behavior of full scale self consolidating concrete beams in shear. Cement Concr Compos 30:588–596
Hassan AAA, Hossain KMA, Lachemi M (2010) Strength, cracking and deflection performance of large scale self consolidating concrete beams subjected to shear failure. Eng Struct 32:1262–1271
Ho DWS, Sheinn AMM, Ng CC, Tam CT (2002) The use of quarry dust for SCC applications. Cem Concr Res 32:505–511
Hossain KMA, Lachemi M (2010) Fresh, mechanical, and durability characteristics of self-consolidating concrete incorporating volcanic ash. J Mater Civ Eng ASCE 22:651–657
Hwang SD, Khayat KH (2009) Durability characteristics of self consolidating concrete designated for repair applications. Mater Struct RILEM 42:1–14
Hwang SD, Khayat KH, Bonneau O (2006) Performance-based specifications of self-consolidating concrete used in structural applications. ACI Mater J 103:121–129
Karjinni VV, Anadinni SB, Patil DS (2009) An investigation on the characteristic properties of high performance SCC with mineral admixture. Indian Concr J 83:15–19

Khayat KH, Trembley S, Paultre P (1999) Structural response of self consolidating concrete columns. In: Skarendahl A, Petersson O (eds) First international RILEM symposium on self compacting concrete, Sweden, Stockholm, pp 291–305

Khayat KH, Hwang SD, Belaid K (2010) Performance of cast-in-place self-consolidating concrete made with various types of viscosity-enhancing admixtures. ACI Mater J 107:403–412

Kheder GF, Al Jadiri RS (2010) New method for proportioning self-consolidating concrete based on compressive strength requirements. ACI Mater J 107:490–497

Kim JK, Han SH, Park YD, Noh JH (1998) Materials properties of self flowing concrete. J Mater Civ Eng ASCE 10:244–249

Kovler K, Roussel N (2011) Properties of fresh and hardened concrete review article. Cem Concr Res 41:775–792

Kumar R, Kumar R, Kumar N (2009) In-situ performance of self-compacting concrete in T-beams. J Mater Civ Eng ASCE 21:103–109

Naito C, Hoover M (2005) Applicability of self consolidating concrete for use in precast bridge beam construction. In: Proceedings of SCC 2005 conference, centre for advanced cement based materials, Northwestern University, USA, pp 1037–1044

Okamura H, Ouchi M (1999) Self-compacting concrete-development, present, and future. In: Proceedings of 1st international RILEM symposium on self-compacting concrete, Stockholm, Sweden, pp 3–14

Okamura H, Ozawa K (1995) Mix-design for self-compacting concrete, concrete. Library Jpn Soc Civil Eng 25:107–120

Omrane M, Kenai S, Kadri E-H, Aït-Mokhtar A (2017) Performance and durability of self compacting concrete using recycled concrete aggregates and natural pozzolan. J Clean Prod 165, 415–430

Pereira-de-Oliveira LA, Nepomuceno MCS, Castro-Gomes JP, Vila MFC (2014) Permeability properties of self-compacting concrete with coarse recycled aggregates. Constr Build Mater 51,113–120

Persson B (2000) A comparison between mechanical properties of self compacting concrete and the corresponding properties of normal concrete. Cem Concr Res 31:193–198

Persson B (2003) Internal frost resistance and salt frost scaling of self compacting concrete. Cem Concr Res 33:373–379

Peter JA, Lakshamanan N, Manoharan PD, Rajamane NP, Gopalakrishnan P (2004) Flexural behaviour of RC beam using self compacting concrete. Indian Concr J 78:66–71

Reinhardt HW, Stegmaier M (2006) Self consolidating concrete in fire. ACI Mater J 103:130–135

Roziere E, Granger S, Turery P, Loukili A (2007) Influence of paste volume on shrinkage cracking and fracture properties of self compacting concrete. Cem Concr Compos 29:626–636

Siddique R, Aggarwal P, Aggarwal Y (2012) Influence of water/powder ratio on strength properties of self compacting concrete containing coal fly ash and bottom ash. Constr Build Mater 29:73–81

Silva P, Brito JD, Costa J (2011) Viability of two new mixture design methodologies for self consolidating concrete. ACI Mater J 108:579–588

Singh R, Singh B (2018) Rheological behaviour of different grades of self-compacting concrete containing recycled aggregates. Constr Build Mater 161:354–364

Sonebi M, Tamini AK, Bartos PJM (2003) Performance and cracking behaviour of reinforced beams cast with self consolidating concrete. ACI Mater J 100:492–500

Sonebi M, Grunewald S, Walraven J (2007) Passing-ability and filling-ability of self consolidating concrete. ACI Mater J 104:162–170

Su N, Hsu KC, Chai HW (2001) A simple mix design method for self compacting concrete. Cem Concr Res 31:1799–1807

Uysal M, Yilmaz K (2011) Effect of mineral admixtures on properties of self compacting concrete. Cem Concr Compos 33:771–776

Wustholz T, Reinhardt HW (2007) Deformation behaviour of self-compacting concrete under tensile loading. Mater Struct RILEM 40:965–977

Zhu W, Bartos PJM (2003) Permeation properties of self compacting concrete. Cem Concr Res 33:921–926

Zhu W, Gibbs JC (2005) Use of different limestone and chalk powder in self compacting concrete. Cem Concr Res 35:1457–1462