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Research paper

Effect of Coarse Aggregate Size on Shear Behavior of Self-Compacting Concrete and Conventional Concrete Beams

Murtada A. Ismael [1]*, Haitham J. Abd [2], Adham A. Hameed [1]

[1] *University of Diyala, College of Engineering, Department of Civil Engineering, Iraq*
[2] *University of Baghdad, Department of Reconstruction and Projects, Iraq*
**Corresponding author E-mail: murtadaameer13@yahoo.com*

Abstract

This research presents an experimental study to investigate the effect of coarse aggregate maximum size on the shear behavior of self-compacting concrete (SCC) and conventional concrete (CC) slender beams having the same compressive strength and make a comparison between the shear behavior of concrete beams. The experimental program included casting and testing eight beams with a constant size of 150mm height ×125mm width×1000mm length. Two coarse aggregate maximum sizes were used (10mm and 20mm) with SCC and CC in normal and high strength concrete. The results showed that increasing the coarse aggregate maximum size from 10mm to 20mm results in a slight increase in the diagonal cracking load and ultimate shear strength of SCC beams, while for CC beams the result was more significant. Also, it was found that the effect of increasing the coarse aggregate maximum size was more significant for normal strength as compared with high strength beams for both concrete types. Furthermore, the comparison between the shear behavior of SCC and CC beams having the same compressive strength and a concrete with the same coarse aggregate maximum size revealed that the SCC exhibited less diagonal cracking load and less ultimate strength compared with CC.

Keywords: *Beam, Coarse aggregate, Conventional concrete, Self-compacting concrete, Shear behavior.*

1. Introduction

Shear quality of solid shafts is a standout amongst the most critical attributes, because of the shear disappointment innate of solid pillars which will in general be sudden and without giving timely guidance. Accordingly, there is a need to assess legitimately the shear quality of solid pillars with the end goal to give the required shear support which keeps the sudden crumple. Shear move in solid pillars which speaks to an essential factor of the aggregate shear quality for these individuals, depends mostly on the interlock of coarse total; in this way the size and substance of coarse total is viewed as an imperative parameter in the shear quality of solid bars [1].

Then again, in the course of recent decades, self-compacting concrete (SCC) has been developed as elite cement and turned into a superb option in contrast to customary cement in numerous fields because of its extraordinary properties, for example, its capacity to stream and fill the formwork under its very own weight without the need to utilize outer vibrators, simple position of cement in confined segments and blocked support territories without isolation, decrease in site labor and quicker development [2]. In the meantime, As contrasted and regular solid (CC), SCC comprises of lesser sum and littler greatest size of coarse total, in this way, it is normal that the shear quality of bars made with SCC is lesser than that completed by CC, where the interlock component of coarse total is weaker.

Numerous exploratory works have been done on the impact of coarse total size on the properties of SCC in its new and solidifying states, for example, Rao et al [3], Khaleel et al [4], Oladele et al [5] and Vishnukanth [6]. Likewise, an examination between the impact of coarse total on mechanical properties of SCC and CC was made by Krishna et al [7], and Kumar [8]. While, Kozul, and Darwin [9] examined the impacts of total sort, size, and substance on CC quality and crack vitality and Abdullahi [10], Vilane and Sabelo [11] contemplated the impact of total size and type on compressive quality of ordinary cement. Hassan et al [12] examined the impact of various coarse-to-fine total proportions and coarse total sorts on the shear conduct of high quality and light weight SCC pillars, and Aly et al [13] explored the impact of reused coarse total on shear conduct of strengthened solid shafts.

All the displayed works in this field didn't explore the impact of coarse total size on the shear quality of SCC bars and CC, along these lines this exploration means to research that, likewise making a correlation between the shear conduct of SCC pillars and CC shafts having the equivalent compressive quality and the equivalent coarse total most extreme.

2. Experimental Program

The experimental program includes casting and testing eight simply supported concrete beams. The tested beams are divided into two main groups as listed in Table (1); the first group includes four beams were made of SCC and the second group involves four beams were made of CC. In each group two beams were casted with normal strength concrete (one beam with concrete of 10mm coarse aggregate maximum size and the other beam with concrete of 20mm coarse aggregate maximum size) and the two others beams of each group were casted with high strength concrete (also one beam with concrete of 10mm coarse aggregate maximum size and the other beam with concrete of 20mm coarse aggregate maximum size). All the tested beams have the same dimensions of 1000 mm length, 125 mm width and 150mm height, and have the same longitudinal reinforcement of percentage 2.749% without shear reinforcement. Figure (1) shows the layout and cross sections of these beams.

Table 1: The parameters and beams properties

Group No.	Details of group	Beam code	Strength of concrete	Coarse Aggregate Maximum size	Concrete Mix
1	Beams With Self Compacting Concrete (SCC)	B1	Normal	10	SCCN10
		B2		20	SCCN20
		B3	High	10	SCCH10
		B4		20	SCCH20
2	Beams with Conventional Concrete (CC)	B5	Normal	10	CCN10
		B6		20	CCN20
		B7	High	10	CCH10
		B8		20	CCH20

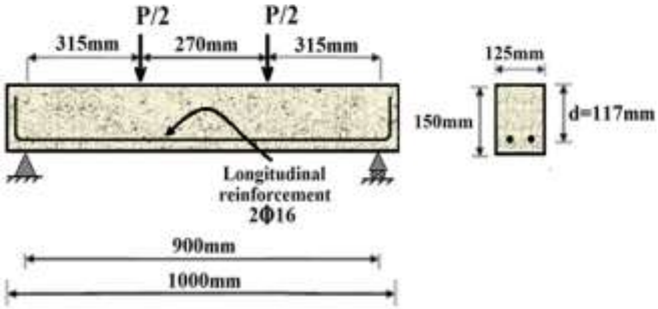

Fig. 1: Details of the beams used in this study

3. Constituent materials

3.1. SCC and CC ingredients

Many mix proportions were tried to get the target strengths of SCC and CC. From each type of concrete, four mixes were considered to get the concrete of normal compressive strength at 28 days of about 28MPa and high compressive strength at 28 days of about 52 MPa. SCC mixes were designed according to the European Guidelines for Self-Compacting Concrete (EFNARC) [2], while CC mixes were designed according to ACI committee 211 [14]). The ingredients and their quantities per cubic meter for each mix of SCC and are listed in Table (2) and of CC are listed in Table (3).

The cement used in this study is Ordinary Portland cement Type I conform to the requirements of the Iraqi specification No.5/1984 [15], crushed gravel obtained from Al-Sudoor region was used as coarse aggregate with maximum size of 10 mm and 20mm conform to the requirements of the Iraqi specification No.45/1984 [16], natural sand obtained from Al-Sudoor region was used as fine aggregate conform to the requirements of the Iraqi specification No.45/1984 [16], the limestone powder was used of particle size less than 0.125 mm (Sieve No.200) satisfies EFNARC [2], Glenium 51 was used as high range water reducers (Superplasticizer) complies with ASTM C494 type A and Fb[17], and tap water was used for concrete mixing and curing.

Table 2: Quantities of SCC ingredients per cubic meter for each mix

Mix Name	Cement (kg)	Limestone powder (kg)	Water (liter)	Sand (kg)	Gravel (kg)	Super - plasticizer (liter)
SCCN10	400	134	192	821	767	2.2
SCCN20	400	187	172	821	767	2.6
SCCH10	550	46	176	821	767	3.5
SCCH20	550	74	165	821	767	4.1

Table 3: Quantities of CC ingredients per cubic meter for each mix

Mix Name	cement (kg)	water (liter)	sand (kg)	gravel (kg)	super plasticizer (liter)
CCN10	400	176	735	1109	_
CCN20	400	168	722	1083	3.26
CCH10	500	155	739	1109	_
CCH20	500	140	722	1083	4.35

3.2. Steel reinforcement

All the beams are longitudinally reinforced by two bars of 16 mm diameter of 492 MPa yield stress as flexural reinforcement without shear reinforcement so that failure would occur by diagonal tension to evaluate the shear strength of concrete of these beams. The test results of the bars (ϕ16mm) satisfy ASTM A615 requirements [18]

3.3. Compressive strength of hardened SCC and CC

For each batch of SCC and CC, cylinders of 100×200mm were casted with the beams to determine the compressive strength of concrete at 28days. The compressive strength test was carried out in accordance with ASTM-C39 [19]. The results of this test are listed in Table (4).

Table 4: Mechanical properties of SCC and CC mixes

Concrete type	Mix name	fc' (MPa)
Self-compacting concrete	SCCN10	28.2
	SCCN20	28.4
	SCCH10	52.1
	SCCH20	52.7
Conventional concrete	CCN10	28.6
	CCN20	28.2
	CCH10	52.3
	CCH20	52.8

According to ACI 363R-92 [20], the high strength concrete is the concrete which has a compressive strength greater than 41MPa, therefore, the concrete of mixtures SCCH10, SCCH20, CCH10, and CCH20 is considered high strength concrete.

4. Testing procedure of the beams

The beams were lifted from the curing water tank at the age of 28 days after casting, left to dry, and then painted with white color so that cracks can be easily detected. The beams were tested under four-point loading using a universal hydraulic machine of 2000kN capacity available in the Structural Engineering Laboratory, College of Engineering, Diyala University as shown in Figure (2). The beam specimens were tested as simply supported using rigid supports with 900mm clear span and loading distance of 315mm from the support, in order to provide a shear span to effective depth ratio (a/d) equal to 2.5. The loads were applied in successive increments up to failure. A dial gauge of 0.001 mm accuracy was attached firmly at the center of the bottom face of the beam to record midspan deflection. The load that produced the diagonal crack and the ultimate shear strength were recorded. Crack patterns were marked on the beams.

Fig. 2: Beam testing setup

5. Results and discussion

5.1 Failure modes and crack patterns

Figures (3) and (4) show the crack patterns of the tested beams after the failure, the tested beams exhibited similar behavior, it can be explained as follows, at low load levels; fine flexural cracks appeared in the midspan region between the two concentrated loads.

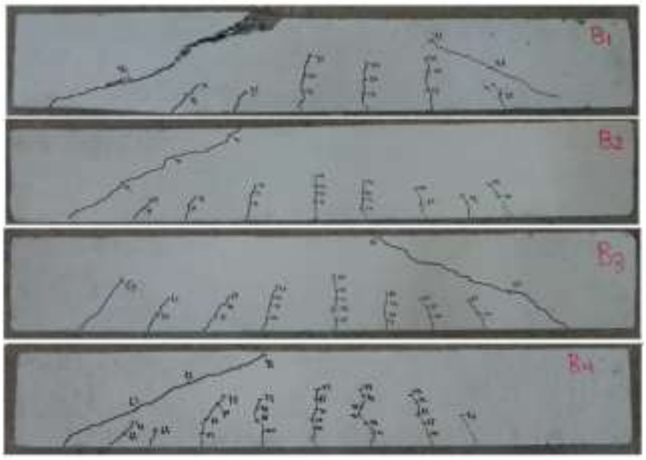

Fig. 3: Crack pattern at failure of SCC beams

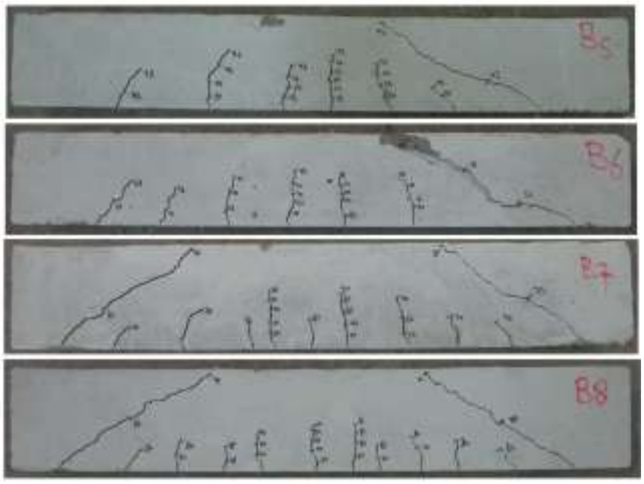

Fig. 4: Crack pattern at failure of CC beams

With increasing the applied load the initiated flexural cracks slightly extended vertically, and new flexural cracks were initiated in the same region and additional cracks were formed in the shear spans between the load positions and the supports. With further increase in load, diagonal inclined cracks were formed suddenly in the shear span between the point loads and support on one side or on the two sides of the beams at the same time or in successive. Finally, failure occurred as the diagonal crack expanded and extended deeply into the compressive zone towards the point load. Thus, all the tested beams in this study failed in diagonal tension mode as planned.

5.2 Effect of coarse aggregate maximum size on the diagonal cracking load and ultimate shear strength

Table (5) lists the results of the tested beams. Generally, it can be observed from this Table that increasing the coarse aggregate maximum size from 10mm to 20mm leads to an increase in the diagonal cracking load and the ultimate shear strength of the normal strength SCC beam by about 8% and 12% respectively and for high strength SCC beam by about 5% and 9% respectively. While the increases in the diagonal cracking load and ultimate shear strength of normal strength CC beam by about 21% and 23% respectively and for high strength CC beam by about 9% and 14% respectively. The increases in diagonal cracking load and ultimate shear strength can be attributed to that increasing coarse aggregate maximum size leads to increase the aggregate interlock surface along the crack which is the crucial parameter in the shear transfer between the two faces of crack in concrete beams, resulting in an increase the shear strength.

Table 5: The results of the tested beams

Beam	Concrete mix	Diagonal cracking load (kN)	Increasing percentage (%)	Ultimate shear load (kN)	Increasing percentage (%)
B1	SCCN10	36	-	41	-
B2	SCCN20	39	8	46	12
B3	SCCH10	60	-	67	-
B4	SCCH20	63	5	73	9
B5	CCN10	43	-	47	-
B6	CCN20	52	21	58	23
B7	CCH10	75	-	80	-
B8	CCH20	82	9	91	14

Also, it can be noted from these results that the enhancement in the diagonal cracking load and ultimate shear strength for CC beams is more significant than that of SCC beams, this difference can be attributed to the larger content of coarse aggregate in CC as compared to SCC, thus the aggregate interlock surface in CC is larger than that of SCC. Furthermore, it can be observed that the enhancement of normal strength beams is more significant than that of high strength for the both kinds of concrete (SCC and CC). This behavior can be attributed to that the cracks in the high strength concrete, has the ability to penetrate the aggregates due to the high stresses resulting in concrete as a result of the high loads and also due to the high strength of paste matrix which resists these stresses, thus the aggregate interlock becomes weaker, while in normal strength beams, the aggregate is stronger than the paste matrix which suffers from early cracks as compared with the aggregate, thus, the aggregate retains a large interlock surface comparing with that of high strength concrete beams.

Table (6) shows a comparison between shear performance of SCC and CC beams having the same compressive in terms of diagonal cracking load and ultimate shear strength. It can be observed generally that the diagonal cracking load and ultimate shear strength of SCC beams is lower than that of CC. However, the beams of normal strength concrete (compressive strength of about 28MPa) and coarse aggregate maximum size of 10mm, the diagonal cracking load and ultimate shear strength of CC beam is higher than that of SCC beams by 19% and 15% respectively, while the CC beams of normal strength concrete with coarse aggregate maximum size 20mm have diagonal cracking load and ultimate shear strength higher than that SCC beams by 33% and 26% respectively. On the other hand, for the beams of high strength concrete (compressive strength of about 52MPa) and coarse aggregate maximum size of 10mm the experimental results reveals that the diagonal cracking load and ultimate shear strength of CC beam is higher than that of SCC beams by 25% and 19% respectively, while for beams of coarse aggregate maximum size of 20mm the CC beams have diagonal cracking load and ultimate shear strength higher that SCC beams by 30% and 25% respectively. The reduction in the shear strength of the SCC beams can be attributed to the lower content of the coarse aggregate, subsequently reducing the aggregate interlock leading to lower shear strength.

Table 6: Comparison between the shear strength of SCC and CC beams

Beam	Concrete mix	Diagonal cracking load (kN)	Increasing percentage (%)	Ultimate shear strength (kN)	Increasing percentage (%)
B1	SCCN10	36	-	41	-

B5	CCN10	43	19	47	15
B2	SCCN20	39	-	46	-
B6	CCN20	52	33	58	26
B3	SCCH10	60	-	67	-
B7	CCH10	75	25	80	19
B4	SCCH20	63	-	73	-
B8	CCH20	82	30	91	25

5.3. Load deflection curves and ultimate deflection

Figures (5) and (6) reveal that all the beams have load-deflection curves consists of three parts; the first part is linear with constant slope until formation the first flexural cracks in the tension zone, the second began after the first crack with a slope less steep than that of the first part due to increase and enlargement the flexural cracks and formation shear cracks, the third part began as the crack of diagonal tension in the shear zone become large and the deflection increase until the failure occurs.

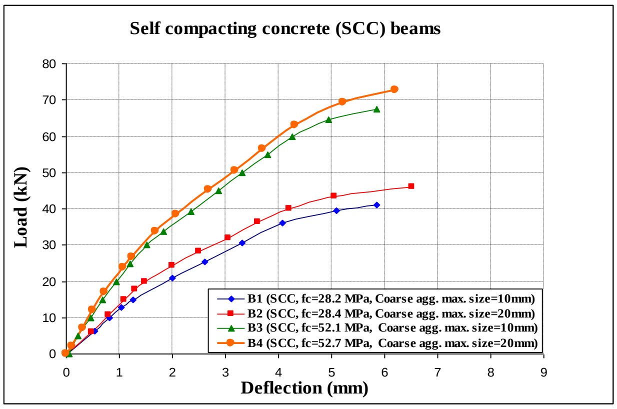

Fig. 5: Effect of maximum size of coarse aggregate on load-midspan deflection of normal strength and high strength SCC beams

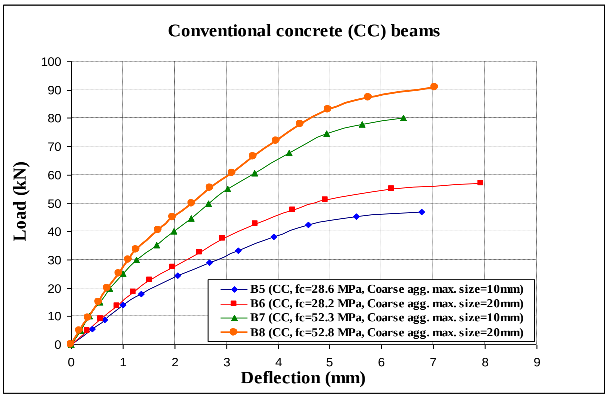

Fig. 6: Effect of maximum size of coarse aggregate on load-midspan deflection of normal strength and high strength CC beams

These figures show that the effect of increasing maximum size of coarse aggregate before first cracks is very little, and after that, the effect becomes larger. Also, it can be seen that this effect is more significant in normal strength than that of high strength and in CC than in SCC due to the same reasons mentioned previously. Furthermore, increasing maximum size of coarse aggregate reduces the deflection in all steps of loading but the ultimate deflection becomes larger, this behavior refers to that the beam becomes stiffer and more ductile.

Figures (7) to (10) show comparison between load-midspan deflection between SSC and CC beams, it can be seen that, although CC beam in normal strength and high strength concrete exhibits more stiffness as compared with the SCC beams in all stages of loading but the ultimate deflection is larger this effect is similar to that of increasing maximum size of coarse aggregate, since both increasing coarse aggregate size and content increase the stiffness and increase the ductility of the beams. The results showed that increasing the maximum size of coarse aggregate from 10mm to 20mm results in slight increasing in the diagonal cracking load and ultimate shear strength of SCC beams, while the effect on CC beams is more significant.

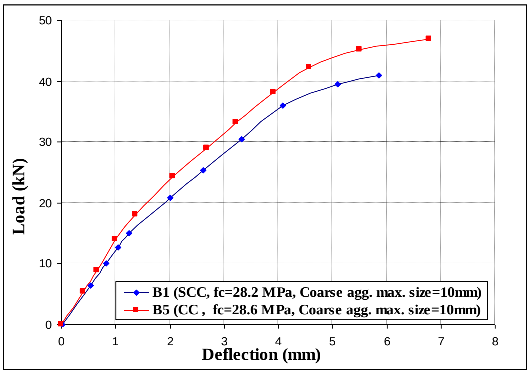

Fig. 7: Comparison between load-deflection behavior of SCC and CC of normal strength and 10mm coarse aggregate maximum size

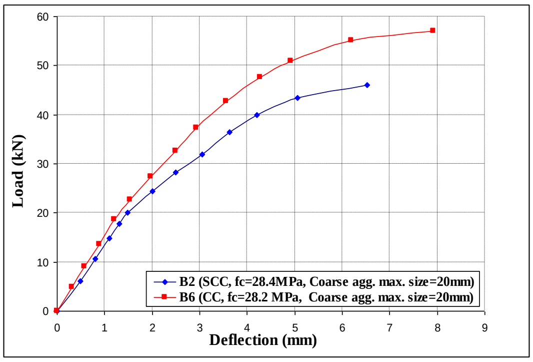

Fig. 8: Comparison between load-deflection behavior of SCC and CC of normal strength and 20mm coarse aggregate maximum size

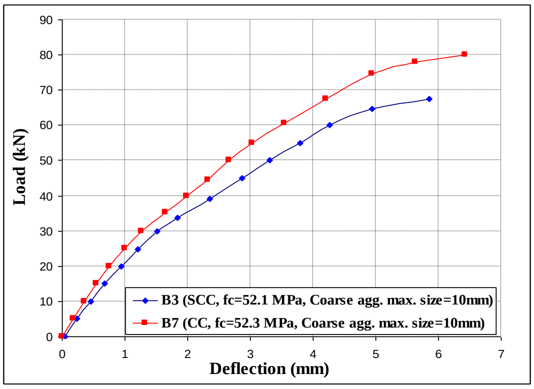

Fig. 9: Comparison between load-deflection behavior of SCC and CC of high strength and 10mm coarse aggregate maximum size

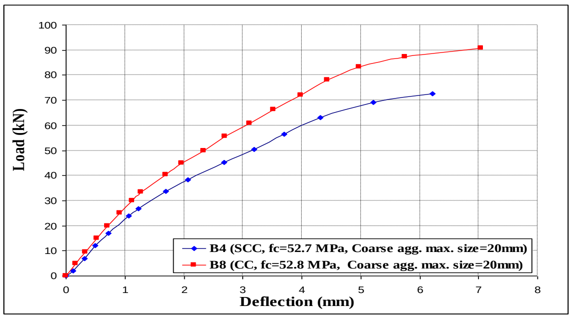

Fig. 10: Comparison between load-deflection behavior of SCC and CC of high strength with 20mm coarse aggregate maximum size

Also, it is found that the effect of increasing the coarse aggregate maximum size is more significant for normal strength beams as compared with high strength beams for the two kinds of concrete. Furthermore, the comparison between the shear behavior of SCC beams and CC beams having the same compressive strength and having a concrete with the same coarse aggregate maximum size revealed that the SCC exhibits less diagonal cracking load and less ultimate strength as compared with CC.

6. Conclusions

1. The effect of increasing coarse aggregate maximum size on diagonal cracking load and ultimate shear strength of conventional concrete beams is more significant than that of self-compacting concrete beams. However, increasing coarse aggregate maximum size from 10mm to 20mm leads to an increase in the diagonal cracking load and ultimate shear strength by about 21% and 23% respectively for normal strength-conventional concrete beams and by about 9% and 14% respectively for high strength-conventional concrete beams.
2. The difference between the effect of increasing coarse aggregate maximum size on self-compacting concrete beams and conventional concrete beams can be attributed to the larger volume of coarse aggregate in conventional concrete comparing with self-compacting concrete, this makes the interlock surface and shear transfer of conventional concrete is larger than that of self-compacting concrete.
3. The enhancement in diagonal cracking load and ultimate shear strength of normal strength-self-compacting concrete beams and conventional concrete beams due to increasing the maximum size of coarse aggregate from 10mm to 20mm is more significant than that of high strength concrete beams for the two types of concrete. This behavior can be attributed to that the cracks in high strength concrete, has the ability to penetrate the coarse aggregates due to high stresses resulting in concrete as a result to high applied loads and also due to the high strength of paste matrix which resists the high stresses, thus the aggregate interlock relatively becomes weaker. While in normal strength beams, the coarse aggregate is stronger than paste matrix which suffers from early cracks as compared with the coarse aggregate, thus, the latter retains a large interlock surface as comparing with that of high strength concrete beams.
4. The diagonal cracking load and ultimate shear strength of self-compacting concrete beam is lower than that of conventional beam, although these beams has the same compressive strength and made of concrete has the same coarse aggregate maximum size.
5. Increasing coarse aggregate maximum size makes the load-deflection curve of the self-compacting concrete beams and conventional concrete beams stiffer and the ultimate deflection higher.
6. The conventional concrete beams are more ductile than self-compacting concrete beams although these beams has the same compressive strength and made of concrete has the same coarse aggregate maximum size.

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References

[1] Nilson, A. H. , Darwin, D. and Dolan, C. W. , (2003) , Design of Concrete Structure. McGraw Hill Higher Education; 13Rev Ed edition, 896p.
[2] EFNARC: European Federation Dedicated to Specialist Construction Chemicals and Concrete Systems, (2002), Specifications and Guidelines for Self-Compacting Concrete, Association House, 99 West Street, Farnham, Surrey, U.K, 32p.
[3] Rao, S. V., Rao, M. S., & Kumar, P. R, (2010), Effect of size of aggregate and fines on standard and high strength self-compacting concrete, Journal of Applied Sciences Research, Vol.6, No.5, pp.433-442.
[4] Khaleel, O. R., Al-Mishhadani, S. A., & Abdul Razak, H. (2011), The Effect of Coarse Aggregate on Fresh and Hardened Properties of Self-Compacting Concrete (SCC), Procedia Engineering Procedia Engineering, 14, pp.805-813.
[5] Oladele John, O., Wale, A. O., Olusoji, O. J., & Ihotu, O. D. (2016), Influence of Aggregate Size on Self Compacting Concrete using Nafores 801 Liquid as Plasticizer, IOSR IOSR Journal of Mechanical and Civil Engineering, Vol.13, No.05, pp.125-133.
[6] Vishnukanth, R. T, (2017), Experimental Investigation on Self Compacting Concrete by Introducing Fly Ash with Varied Size of Aggregate, International Research Journal of Engineering and Technology, Vol.4, No.7, pp.2579-2586.
[7] Krishna, A., Rao, B. K., & Rajagopal, A, (2010), Effect of different sizes of coarse aggregate on the properties of NCC and SCC, International Journal of Engineering Science and Technology, Vol.2, No.10, pp.5959-5965.
[8] Kumar, R. D., (2015), Self-Compacted Concrete Mix Design and its Comparison with Conventional Concrete (M-40), Journal of Civil & Environmental Engineering, Vol.5, No.3, 5p.
[9] Kozul, R., & Darwin, D,(1997), Effects of aggregate type, size, and content on concrete strength and fracture energy, University of Kansas Center for Research, Inc.
[10] Abdullahi, M. (2012), Effect of aggregate type on compressive strength of concrete, International Journal of Civil and structural engineering, Vol.2, No.3, pp.791-800.
[11] Vilane, B. R. T., & Sabelo, N. (2016), The Effect of Aggregate Size on the Compressive Strength of Concrete, Journal of Agricultural Science and Engineering, Vol.2, No.6, pp.66-69.
[12] Hassan, A.A.A., Ismail, M. K. and Mayo, J., (2015), Shear Behavior of SCC Beams with Different Coarse-to-Fine Aggregate Ratios and Coarse Aggregate Types, J. Mater. Civ. Eng, Journal of Materials in Civil Engineering, Vol.27, No.11, pp.1-11.
[13] Aly, S. A., Ibrahim, M. A., & Khattab, M. (2015), Shear Behavior of Reinforced Concrete Beams Casted with Recycled Coarse Aggregate, European Journal of Advances in Engineering and Technology, Vol.2, No.9, pp.59-71.
[14] ACI Committee 211.1, (1991), Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete, American Concrete Institute, pp.1-38.
[15] IQS No.5/1984, Portland Cement, Central Agency for Standardization and Quality Control, Planning Council, Baghdad, Iraq.
[16] IQS No.45/1984, Aggregate from Natural Sources for Concrete, Central Agency Standardization and Quality Control, Planning Council, Baghdad, Iraq.
[17] ASTM C494/C494M-1999a, (1999), Standard Specification for Chemical Admixtures for Concrete, ASTM Standard.
[18] ASTM A615/615M-15a, (2015), Standard Specification for Deformed and Plain Carbon Structural Steel Bars for Concrete Reinforcement, ASTM Standards.
[19] ASTM C39/C39M-05, (2005). Standard Test Method for Compressive Strength of Cylindrical Test Specimens. ASTM Standard.
[20] ACI Committee 363, (1992), State-of-the-Art Report on High-Strength Concrete (ACI363R-92), American Concrete Institute, Farmington Hills, Michigan, pp.1-54.