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Araştırma Makalesi / Research Article

Fresh and Hardened Behaviour of Self-Compacted Concrete with Different Mineral Additives

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Abstract

Self-compacting concrete (SCC) is developed with the idea of improved flowability of the fresh concrete mixture. The new technology in plasticizing agents and special mix design of concrete has given this opportunity without any segregation and bleeding. In addition to ease of placement, reduction in the construction time, labor costs and construction noise are the other benefits of SCC. The aim of this study is to investigate the fine mineral additive effect on the fresh and hardened properties of the SCC. For this reason, ground granulated blast furnace slag, fly ash, Bilecik marble powder and calcareous aggregate crushing powder is used as fine powder source in SCC mix designs. Fresh properties of the SCC mixtures are evaluated by performing fresh unit weight, slump flow, V-funnel, and L-box tests. The hardened properties of the prepared SCC are evaluated with the unit weight, ultrasound pulse velocity and compressive strength tests on the 150x150x150 mm cubic specimens at the end of the 3, 7 and 28 days of curing periods. The experimental work showed that ground granulated blast furnace slag and fly ash are more effective on the consistency of the fresh SCC properties. Especially the passing ability of the SCC is improved by using fly ash as a powder in the mix design. The compressive strength of the SCC is developed by using ground granulated blast furnace slag in the mixture. The marble dust is also effective and beneficial for the cohesion and cost of the SCC.

Keywords

Self-compacted concrete;
Mineral additive;
Workability;
Mechanical properties

Farklı Mineral Katkılı Kendiliğinden Yerleşen Betonların Taze ve Sertleşmiş Özellikleri

Öz

Kendiliğinden yerleşen beton (KYB), taze beton karışımının akışkanlığının iyileştirilmiş olması fikri ile geliştirilmiştir. Akışkanlaştırıcı katkılardaki yeni teknoloji ve betonun özel karışım tasarımı, ayrışma ve terlemeyi gerektirmeden yapmıştır. Yerleştirme kolaylığına ek olarak, inşaat süresindeki azalma, işçilik maliyetleri ve şantiye gürültüsü KYB'nin diğer yararlarıdır. Bu çalışmanın amacı, KYB'nin taze ve sertleştirilmiş özellikleri üzerindeki ince mineral katkı etkisini araştırmaktır. Bu sebeple öğütülmüş yüksek fırın cürufu, uçucu kül, Bilecik mermer tozu ve kalkerli agrega kırma tozu, KYB karışım tasarımlarında ince toz kaynağı olarak kullanılır. KYB karışımlarının taze özellikleri, taze birim ağırlık, çökme akışı, V-hunisi ve L-kutusu deneyleri yapılarak belirlenmiştir. Hazırlanan KYB numunelerinin sertleştirilmiş özellikleri, 3, 7 ve 28 günlük kür sürelerinin sonunda, 150x150x150 mm küp beton numunelerinde birim ağırlık, ultrases geçiş hızı ve basınç dayanımı deneyleri ile değerlendirilmiştir. Test sonuçları uçucu kül ve öğütülmüş yüksek fırın cürufunun taze KYB özelliklerinin tutarlılığı üzerinde daha etkili olduğunu göstermiştir. Özellikle KYB'nin geçirme kabiliyeti, karışım tasarımında toz olarak uçucu kül kullanılmasıyla iyileştirilmiştir. KYB'nin basınç dayanımı, karışımda öğütülmüş yüksek fırın cürufu kullanılarak geliştirilebilmektedir. Mermer tozu ise KYB'nin uygunluğu ve maliyeti konusunda etkili ve faydalı olmuştur.

Anahtar kelimeler

Kendiliğinden yerleşen beton;
Mineral katkı;
İşlenebilirlik;
Mekanik özellikler

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1. Introduction

Concrete is one of the most widely used construction material depending on the ease of production and cost of the materials used in the

mixture. New technology developments and the trend of designing complex structural members also influence the concrete products with the new achievements in construction. Self-compacting

concrete (SCC) is developed with the idea of improved flowability of the fresh concrete mixture. The new technology in plasticizing agents and special mix design of concrete has given this opportunity without any segregation and bleeding. In addition to ease of placement, reduction in the construction time, labor costs and construction noise are the other benefits of SCC. Also, the mechanical property of the concrete is improved by using higher cement dosage and reduced pore content of the hardened concrete. The utilization of fine materials in the mix design of SCC allows gaining increased cohesion and resistance against segregation during transportation and casting of the fresh concrete. Using SCC allows increasing the on-site job efficiency and raising the quality of concrete and reinforced concrete structures and pre-cast members (Larsen *et al.* 2019). Nevertheless, higher cement dosage and using polymer-based high range water reducing admixture (hyper plasticizer) are the disadvantages of SCC due to the increased cost of the material. However, these negativities can be reduced by using some fine or finely grounded mineral additives in the mix design of SCC. In general, natural and artificial pozzolans are used as powder content in the SCC applications.

In order to increase the durability of the structural concrete, the SCC was first developed in 1988 (Okamura and Ouchi 2003). SCC reduces the construction time with the ease of placement in the molds around narrow reinforcement bars. SCC increases the durability of concrete by means of proper fluidity without any segregation and bleeding, high-performance in homogeneity and reduced porosity. Another benefit of SCC is the lowered water-cement ratio by using high-performance superplasticizer which allows producing high early strength concrete with earlier de-molding and faster use of structural members (EFNARC 2005). Nowadays, the usage of SCC has been spread, for instance in the precast applications and concrete wall structures. In these types of structures, high initial strength is very important, so it is a solution to use higher C_3S content cement in the concrete mixtures. Various researchers were studied with high volume mineral additives in SCC

mixtures due to the benefits of these additives on the durability and cohesion of the concrete (Anjos *et al.* 2020). For this purpose, ground granulated blast furnace slag (GGBFS), fly ash (FA), and lime-stone filler can be evaluated as powder material source in the SCC mixtures (Karakurt *et al.* 2018). On the other hand, the usage of mineral admixture in SCC cause an increase in workability without any cost increase of the SCC mixture by reducing the plasticizing agent amount in the fresh mixture (Siddique 2011). According to some studies, higher amount of fly ash ($\geq 30\%$) remarkably affects the properties of the SCC (Singh *et al.* 2019). At the same time, the spherical shape of the FA particles leads to a further reduction in the water requirement with the increased workability of the fresh concrete. When compared with GBFS, the FA-blended SCC showed better slump flow, slump flow stability, drying shrinkage resistance and longer setting times (Zhao *et al.* 2016).

The aim of this study is to determine the effect of different mineral additives on the fresh and hardened properties of the SCC. For this purpose GBFS, FA, marble dust, and stone dust was evaluated as mineral powder additive for SCC mixtures at constant mix values. Thus the effect of these widely used additives has been evaluated in the light of the test results.

2. Material and Method

The fine material content of the SCC mixtures is very significant for the viscosity and the resistance against the segregation of aggregates. In addition, the production cost of the SCC can be reduced by using these mineral additives. Therefore, four different types of powder materials are used in the SCC mixtures. The fresh and hardened concrete properties are determined as defined below.

2.1 Material

The powder amount of the SCC mixtures is performed with fly ash (FA), ground granulated blast furnace slag (GBFS), marble dust (MD), and calcareous stone dust (SD). The FA is supplied from Seyitömer Power Plant, GBFS was obtained from Bolu Cement Factory, MD and SD were also supplied

from the marble plants in Bilecik and Dağ-İş Mining respectively. The main oxide composition of the powder materials is presented in Table 1.

Table 1. Chemical properties of the powder materials

Oxide	Fly Ash (%)	GBFS (%)	Marble Dust (%)	Stone Dust (%)
SiO ₂	54.49	34.76	0.63	0.15
Al ₂ O ₃	20.92	14.26	0.20	0.23
Fe ₂ O ₃	9.27	0.84	0.13	0.32
CaO	4.26	35.56	53.66	55.35
MgO	4.48	5.50	0.79	0.25

Limestone aggregate is used in two different sizes as 0-4 mm and 4-12 mm for the SCC production. Consistency of the fresh SCC is obtained with a polymer-based superplasticizer named as BASF Glenium RMC 303. The CEM I 42.5 R type Portland cement used in the experimental studies is obtained from the SANCIM Cement factory. The properties of the cement are presented in Table 2.

Table 2. General properties of CEM I 42.5 R cement.

Chemical Property		Physical and Mechanical	
SiO ₂	10,1	Fineness	7,15
Al ₂ O ₃	4,48	(above 45 μm sieve %)	
Fe ₂ O ₃	3,09	Density (g/cm ³)	3,12
CaO	63,6	Fineness (cm ² /g)	3690
MgO	2,50	Initial setting (min.)	150
SO ₃	2,84	Final setting (min.)	190
Loss on ignition	3,90	Soundness (mm)	1
Na ₂ O	0,21	Comp. Strength (MPa)	
Equivalent alkali %	0,62	2 days	27,9
Cl	0,01	28 days	58,0
Free CaO, %	0,44		
Insoluble residue %	0,55	Water requirement, %	29,5

2.2 Method

The mixing procedure of the SCC was carried out as prescribed in EFNARC document. The powder content of the mixtures is constant as 500 kg/m³ with a w/c ratio of 0.4. The fresh mixture design of the SCC specimens is presented in Table 3.

Table 3. Mix design of the SCC specimens

Specimen Type	Cement (kg)	Water (kg)	0-4 mm (kg)	4-12 mm (kg)	Plasticizer (kg)	GBFS (kg)	FA (kg)	MD (kg)	SD (kg)
GBSC	350	200	650	980	5.5	150	-	-	-
FASC	350	200	650	980	5.5	-	150	-	-
MDSC	350	200	650	980	5.5	-	-	150	-
SDSC	350	200	650	980	5.5	-	-	-	150

The workability of SCC is a very important point for this special type of concrete. In order to determine the flowability, filling ability and viscosity of the SCC mixtures, slump flow TS EN 12350-8 (2011) and V-funnel tests TS EN 12350-9 (2011) are performed on the produced fresh SCC specimens. These tests are carried out in Bilecik Seyh Edebalı University Materials of Construction Laboratory and presented in Figure 1.

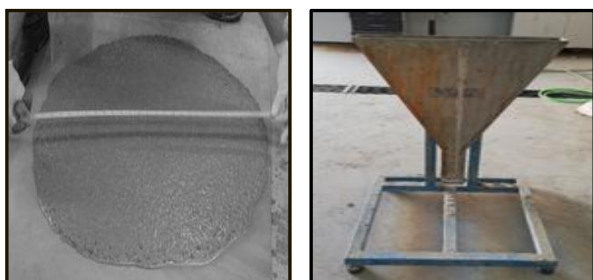


Figure 1. Slump flow and V-funnel tests

The hardened properties of the SCC specimens are determined on the 150x150x150 mm cubic specimens which were cured at lime saturated water at 20±1 °C for 3, 7 and 28 days cured specimens. The unit weight, ultrasound pulse velocity (UPV) and compressive strength tests TS EN 12390-3 (2003) are performed on these SCC mixtures. The application of hardened concrete tests is presented in Figure 2.



Figure 2. Hardened concrete tests

3. Results

3.1. Fresh concrete properties

The flowability and filling ability of the SCC specimens are determined by slump flow and V-funnel tests respectively. As seen from test results, the effect of mineral powder type affects the workability properties of SCC. The test results are shown in Table 4.

Table 4. Workability test results of the fresh SCC mixtures.

Specimen Type	Slump Flow (mm)	V-Funnel (sec)
GBSC	750	5
FASC	780	4
MDSC	675	11
SDSC	680	11

According to test results, the slump flow values are varied between 675 to 780 mm. The FA and GBFS showed better flow values than the MD and SD used mixtures. FA has spherical particles that allow a reduction in w/c ratios. High volume fly ash usage in concrete will cause an increase in the solid material volume of the paste depending on the k-factor and the lower density of the fly ash (Pade *et al.* 2008). Marble and stone dust showed similar flow and V-funnel results due to the particle size of these waste materials. These mineral additives are a waste of cutting and crushing wastes of industrial processes. The average particle sizes are not finer than the FA and GBFS and this property influenced the workability of the fresh SCC specimens when compared with FA and GBFS used ones. On the other hand, MD and SD used SCC mixtures showed acceptable flow and viscosity behavior in accordance with general SCC expectations in the literature.

3.2. Unit weight

The unit weights of the SCC specimens are determined on 28 days hardened SCC specimens and the test results are presented in Figure 3. As seen from test results, the unit weight values are

varied between 2.31 and 2.34 t/m³. These results showed that these four different types of mineral additives have no significant effect on the hardened unit weight of the SCC specimens in the current mixing ratios.

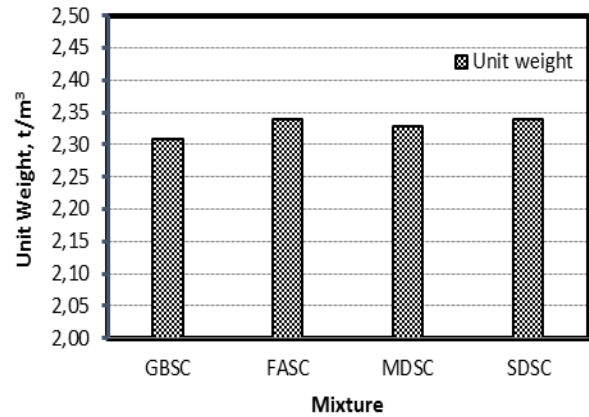


Figure 3. Unit weight of the hardened SCC specimens

3.3. Ultrasound pulse velocity

The UPV test gives a general idea about the internal structure and the compressive strength of the material. This value will increase with the proper stiffness and compaction of the cementitious composites. There is also a good correlation with the compressive strength of the material. The test results of the UPV are given in Figure 4.

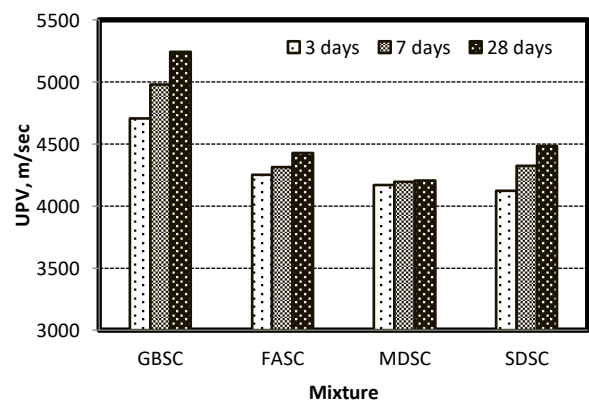


Figure 4. Ultrasound pulse velocity test results of the hardened SCC specimens

According to test results, GBFS used specimens showed the highest UPV values. This means GBSC specimens are stiffer and well placed than the others. The other entire mineral additive used specimens also varied between 4200 to 4490 m/sn

These results are generally higher than the traditional concrete UPV results.

3.4. Compressive strength

The compressive strength of the produced SCC is determined on the 3, 7, and 28 days cured specimens and the results are presented in Figure 5. The results are showed that GBSC used specimen gave the best strength performance than the other mineral additive used mixtures.

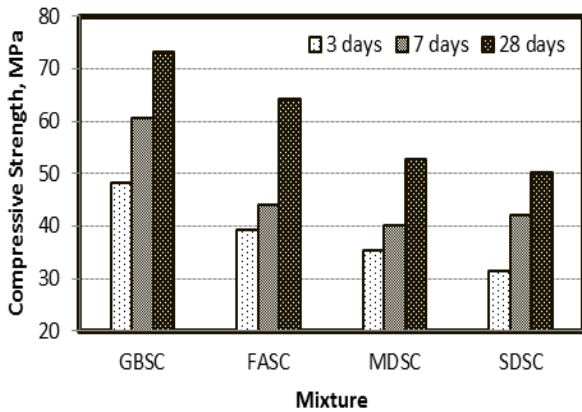


Figure 5. Compressive strength test results of the hardened SCC specimens

The early age strength behavior of GBFS and FA is better than the MD and SD used specimens. At the end of the 28-day curing, the compressive strength of all mixtures is higher than 50 MPa. In light of the test strength, SCC can be produced with MD and SD usage. This will also reduce the production cost of the mixture. Another benefit of this usage is the environmental pollution reduction by using these waste materials in concrete. It can be concluded that the pozzolanic activity of GBFS and FA increased the strength development of the SCC.

The relation between compressive strength and ultrasound pulse velocity is presented in Figure 6. As seen from test results, the correlation between strength and UPV were varied between 0.8433-0.9953. The relation showed better relation for the 3 and 7 days cured specimens. The correlation is reduced for the 28 day cured specimens. This behavior can be attributed to the pozzolanic activity of the GBFS and FA additive for the GBSC and the FASC mixtures.

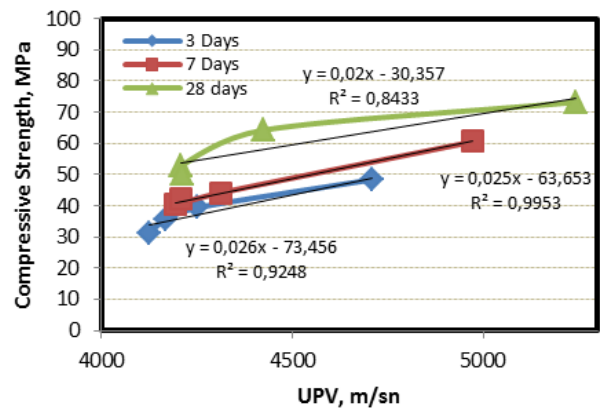


Figure 6. Relationship between compressive strength and UPV

4. Conclusion

The following conclusions can be drawn out from this study.

- Self-compacting concrete is a special type of concrete that allows gaining benefits about the workability, labor and strength behavior of concrete (Prošek *et al.* 2019).
- Fly ash and GBFS is very effective on the slump flow and V-funnel test results. These artificial mineral additives are more effective than the marble dust and stone dust at constant superplasticizer ratios.
- The hardened unit weight of the SCC specimens is similar and varied between 2.31-2.34 t/m³. The UPV results showed that the values are varied between 4125-5241m/sec. These results were indicated that GBFS used SCC mixtures contain lower pore distribution than the other additives.
- According to compressive strength test results, GBFS and FA used specimens gained more strength than the others. This behavior can be related to the fineness and pozzolanic activity of these artificial pozzolans.
- Marble dust and stone dust can also be used as powder material in SCC mix designs. This will also reduce the environmental pollution of these wastes and gain benefits on the production cost of the SCC mixture (Topçu *et al.* 2009).

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