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

Cenk KARAKURT

1 Bilecik Şeyh Edebali Üniversitesi, Mühendislik Fakültesi, İnşaat Mühendisliği Bölümü, Bilecik.

e-posta: cenk.karakurt@bilecik.edu.tr ORCID ID: http://orcid.org/0000-0002-4204-5341

Geliş Tarihi: 02.01.2020 Kabul Tarihi: 29.03.2020

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

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 C₃S 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 (≥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 (GGBFS), 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.

| Oxide     | Fly Ash (%) | GBFS (%) | Marble Dust (%) | Stone Dust (%) |
|-----------|-------------|----------|-----------------|----------------|
| SiO₂      | 54.49       | 34.76    | 0.63            | 0.15           |
| Al₂O₃     | 20.92       | 14.26    | 0.20            | 0.23           |
| Fe₂O₃     | 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 1. Chemical properties of the powder materials

| Oxide     | Fly Ash (%) | GBFS (%) | Marble Dust (%) | Stone Dust (%) |
|-----------|-------------|----------|-----------------|----------------|
| SiO₂      | 54.49       | 34.76    | 0.63            | 0.15           |
| Al₂O₃     | 20.92       | 14.26    | 0.20            | 0.23           |
| Fe₂O₃     | 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           |

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

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 Edebali University Materials of Construction Laboratory and presented in Figure 1.

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.
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 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.

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.

3.3. 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 3. Unit weight of the hardened SCC specimens

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](image)

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](image)

### 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/secs. 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).
5. References

Anjos, M.A.S., Camoes, A., Capos, P., Azevedo, G.A., Ferreira, R.L.S., 2020. Effect of high volume fly ash and metakaolin with and without hydrated lime on the properties of self-compacting concrete. *Journal of Building Engineering*, 27, 100985.

EFNARC guidelines, 2005. The European Guidelines for Self-compacting Concrete; Specification, Production and Use, European Federation of National Associations Representing for Concrete.

Karakurt, C., Çelik, A.O., Yılmazer, C., Kiriççi, V., Özyaşar, E., 2018. CFD simulations of self-compacting concrete with discrete phase modeling. *Construction and Building Materials*, 186, 20–30.

Larsen, O., Naruts, V., Aleksandrova, O., Mendes, B., Self-compacting concrete with recycled aggregates. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2019.07.065.

Okamura, H., Ouchi, M., 2003. Self-compacting concrete. *Journal of Advanced Concrete Technology*, 1, 5–15.

Pade, C., Thrane, L.N., Nielsen, C.V., 2008. Guideliness for mix design of SCC, Danish Technological Institute.

Prošek, Z., Nežerka, V., Hlužek, R., Trejbal, J., Tesárek, P., Karra’a, G., 2019. Role of lime, fly ash, and slag in cement pastes containing recycled concrete fines. *Construction and Building Materials*, 201, 702-714.

Siddique, R., 2011. Properties of self-compacting concrete containing class F fly ash. *Materials and Design*, 32, 1501–1507.

Singh, N., Kumar, P., Goyal, P., 2019. Reviewing the behaviour of high volume fly ash based self compacting concrete. *Journal of Engineering Building*, 26, 100882.

TS EN 12350-8, 2011. Testing fresh concrete: self compacting concrete - slump-flow test, Turkish Standards Institute.

TS EN 12350-9, 2011. Testing fresh concrete: self compacting concrete – v-funnel test, Turkish Standards Institute.

TS EN 12390-3, 2003. Testing hardened concrete: compressive strength of test specimens, Turkish Standards Institute.

Topçu, İ.B., Bilir, T., Uygunoğlu, T., 2009. Effect of waste marble dust content as filler on properties of self-compacting concrete. *Construction and Building Materials*, 23, 1947-1953.

Zhao, H., Sun, W., Wu, X., Gao, B., 2016. The properties of the self-compacting concrete with fly ash and ground granulated blast furnace slag mineral admixtures. *Journal of Cleaner Production*, 95, 66-74.