©2018 Published in 6th International Symposium on Innovative Technologies in Engineering and Science 09-11 November 2018 (ISITES2018 Alanya – Antalya - Turkey)

Properties of Self-Compacting Mortars with Different Contents of Synthetic Macro Fiber

[1]Serkan Etli, [1]Selim Cemalgil and *[1]Onur Onat
[1]Munzur University, Department of Civil Engineering, Tunceli, TURKEY

Abstract

This study is devoted to investigating engineering properties of Self-Compacting Mortar (SCMs) produced with synthetic macro fiber. For this purpose, five different mix designs were prepared with a constant w/c ratio of 0.55 to sustain self-compatibility. Fiber content in these mixtures were changed from 0% to 5%. Engineering properties were investigated in terms of workability, mechanical properties and abrasion resistance. Compressive strength and flexural strength tests were conducted on the specimens exposed to three different water curing age 7 days, 28 days and 56 days respectively. In this study, also optimum synthetic fiber amount was determined to sustain self-compatibility of mortar. It was revealed that 2 and 3 kg/m3 synthetic macro fiber ratio are the key proportions to improve workability and flexural strength properties of hardened mortar. Moreover, adding fiber to mortar decreased abrasion resistance at 28 days age. In reverse, fiber addition increased abrasion resistance at 56 days age.

Key words: Self-compacting mortar, macro fiber, mechanical properties, curing effect, hardened state properties

1. Introduction

Self-compacting mortars (SCMs) are considered as an innovative and advanced solutions product for rehabilitation and repair of reinforced concrete buildings. Self-compacting mortars bring advantages at narrow space application. Properties of mortar were tried to develop by using different ingredients like steel fiber [1], fly ash - metakaolin [2], fly ash - silica fume [3], various type of sand [4], polypropylene fiber [5, 6], plastic waste [7], mineral additives[8], stone dust [9] and recycled aggregate [10]. Contribution of steel fiber is investigated by many researchers in terms of toughness resistance, energy absorption capacity and durability [11,12, 13, 14]. Felekoğlu et al. (2007) studied effect of fibre type and matrix orientation on self-compacting micro-fiber concrete composites called as polypropylene and polyvinyl alcohol. It was emphasized that the best performance was obtained from high strength matrix with a high strength fibre properties [1]. Effects of silica additives on cracking properties were studied with Stynoski et al. (2015) [15] to develop fracture mechanics properties of cementitious composites. It was revealed that silica type ingredients increase fracture properties of mix designed with carbon fibers and carbon nanotubes. Combined effects of nano particles and fly ash on durability performance of self-compacting mortar was studied by Mohseni et al. (2015) [16]. It was reported that average 8% water absorption decrease was obtained from experimental tests. Moreover, it was emphasized that 28 days and 90 days compressive strength test results are nearly the same for different amount of nano particle mix design. Ideal engineering performance was obtained from binary combination at 5% amount. Binary nano particles were used with fly ash to develop durability parameters and mechanical properties of self-compacting mortar [17]. It was reported that nano particle effects engineering

*Corresponding author: Address: Faculty of Engineering, Department of Civil Engineering Munzur University, 62000, Tunceli TURKEY. E-mail address: onuronat@munzur.edu.tr, Phone: +904282131794/2424

properties of self-compacting mortar in a significant ratio. However, amount of material needs to be optimized by practitioner as reported by Mohseni et al. (2015) [16]. Safi et al. (2015) used seashell in self-compacting mortar to investigate seashells as fine aggregate on mechanical properties of morta. It was underlined that seashells are good adhesion in cementitious composites. However, 100% substitution seashell with fine aggregate results in slight decrease in compressive strength and other hardened state properties [7]. Curing is also other important factor to develop hardened properties of cementitious composites. For this purpose, Chand et al. (2016) studied effect of wet curing, self-curing and without curing conditions on performance of self-compacting mortar. It was concluded that optimum amount of self-curing develops mechanical and durability properties of self-compacting mortar [18]. Curing regime is also investigated by Benli et al. (2017). Their study aimed to investigate effect of curing regime on self-compacting mortar produced with fly ash and silica fume. It was emphasized that the best results were obtained from 10% fly ash as a single additive at 280 days curing age and 10% silica fume and 6% fly ash binary combination at wet sack curing [19]. Karataş et al. (2017) investigated effect of ground pumice powder on durability properties of self-compacting mortar. It was reported that 10% and 25% pumice powder is the optimum amount to obtain better performance than control mortar [20]. Also, Benli et al. (2017) studied effect of MgSO4 and seawater on durability of self-compacting mortar produced with fly ash and silica fume. Property loss was reported due to surface cracks due to softening [21]. On the base listed studies above, the objective of this experimental study is to investigate the effect of curing and macro-fiber amount on the properties of self-compacting mortar. For this purpose, a total of 5 mortar mixtures were designed and these mixtures have a total cement content of 500 kg/m3 and water/cement ratio kept constant at 0.50 level. After mixing, slump flow, V-funnel flow time and viscosity properties were tested as the fresh properties. In addition, flexural tensile strengths, axial compressive strength and splitting tensile strength test of the hardened mortars were tested at 7 days age, 28 days age and 91 days age whilst dry unit weight. 2 kg/m3 fiber contents is the optimum ratio to increase engineering properties of the self-compacting mortars. Moreover, while compared short-term and long-term properties, addition of fiber effected especially long-term engineering properties of fiber.

2. Experimental Campaign

2.1. Materials

In this experimental study, ordinary Portland Cement, type CEM I 42.5, was used in all SCMs composition. Local natural crushed sand was used in mix design as aggregate. Sieve analysis of crushed sand was plotted in Fig. 1 on the base of TS EN 933-1 [22].

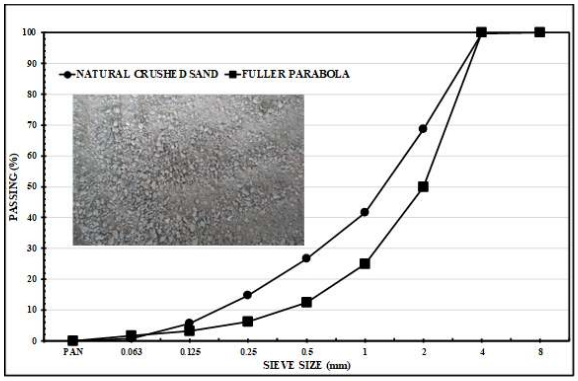

Figure 1. Particle size distribution of crushed natural sand.

High Range Water Reducer (HRWR) additive was used in all mixtures. Specific Gravities of cement, sand and chemical additive were about 3.1, 2.67 and 1.04 g/cm3 respectively. Moisture content and absorption capacity of used sand were 0.38% and 2.42% respectively. Used macro fibers can be seen in Fig. 2.

Figure 2. Macro fiber in mix design.

Raw material of macro fiber was %100 pure copolymer polypropylene. Length of fiber is 54 mm and diameter of fiber is 0.34 mm. Tensile strength of the fiber is between 550-750 MPa. Modulus of elasticity is 5.75 GPa. Density of fiber is 0.91 g/cm3. Melting and burning temperatures are 168^0C and 398^0C respectively.

2.2. Mix proportions

A sum of 5 distinct composition containing 500 kg/m3 cement with a constant 0.55 w/c ratio was used. Mix proportions of mortar was tabulated in Table 1. Fiber content was kept maximum 5 kg/m3. Long form of ID can be presented like this manner; SCM denotes Self Compacting Mortar, 500 denotes cement amount, PPF polypropylene fiber last number presents fiber amount.

Table 1. Amount of constituents of mortars.

MIX ID	w/c	Cement (kg)	Water (kg)	HRWR (kg)	Aggregate (kg)	Fiber (kg)
SCM500PPF0	0.55	500	275	10	1452.7	0
SCM500PPF1	0.55	500	275	10	1452.7	1
SCM500PPF2	0.55	500	275	10	1452.7	2
SCM500PPF3	0.55	500	275	10	1452.7	3
SCM500PPF4	0.55	500	275	10	1452.7	4

It is important to achieve a uniform mix. To satisfy self-compacting standard for all mixtures following mixture sequences were strictly obeyed. First, crushed natural sand and cement was mixed in a dry state for three minutes. Second, the water and high range water reducer additive were mixed in a bottle. Then, this liquid combination was poured into the bowl slowly. Finally, fibers were added and all mortar was mixed along three minutes at low speed rotation. Then, it was conducted slump-flow and V-funnel test as per EFNARC [23].

3. Test Methods

3.1. Fresh State Tests

Mini-slump test apparatus for self-compacting mortar consist of a mould. This mould has the size 60 mm height, 70 mm top diameter and 100 mm bottom diameter. In this part of the experimental study, fresh mortar was poured into the flow table and diameters were measured. To prevent plugging due to settlement of fiber, fiber amount was kept maximum 4 kg/m3 for V-funnel test. Even though this fiber amount extended V-funnel duration, no clumping observed. The V-funnel filled with mortar and then gate was opened suddenly at the same time with stopwatch. V-funnel time was measured for each composition.

3.2. Hardened State Tests

All the specimens were stored in lime saturated curing tank until test day. Flexural strength test was conducted firstly on the 40mmx40mmx160mm dimensions specimens produced with different amount of fiber and at three different curing age 7 days, 28 days and 56 days respectively. Flexural strength tests were performed on the base of ASTM C-349-02 [24]. Flexural strength and compressive strength tests were presented in Fig. 3 and Fig. 4, respectively.

Figure 3. Flexural strength in bending

Figure 4. Compressive strength

Then, one half of the tested specimen was tested under axial compressive strength test as seen in Fig. 4. Abrasion strength test was performed on the cubic specimens with the dimensions 100mmx100mmx100mm. This test was performed on the base of ASTM C 944 [25] standard. Specific gravity test was also performed on the base of ASTM C 128-1 [26].

4. Results

4.1. Fresh State Test Results

The test results related to slump flow and V-funnel were presented in Fig. 4. When fiber amount is increased, slump flow decreased from 26 cm to 8.9 cm. Adding 1 kg/m3 fiber decreased slump flow from 26 cm to 24.9 cm.

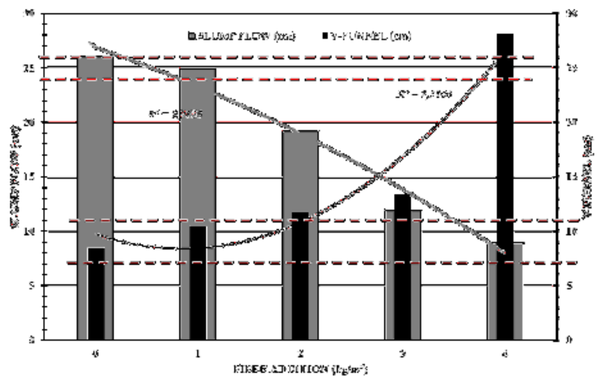

Figure 5. Relation between slump flow – fiber amount and V-funnel time – fiber amount.

After adding 2 kg/m3 fiber, slump flow decreased from 26 cm to 19.2 cm. This is a considerable amount compared to EFNARC [23] acceptance criteria. Moreover, proportionally adding macro fiber to mix composition increased V-funnel time from 8.53 s to 28.07 s. According to Fig. 3, slump-flow diameters of control mortar and modified with 1% fiber are comply with EFNARC [23] while other mixtures cannot fulfill requirements of EFNARC [23].

4.2. Hardened State Test Results

4.2.1. Flexural Strength Test Results

Flexural strength test results were located in the range of 4.96 – 6.06 MPa at 7 days age, 5.19 – 6.74 MPa at 28 days age and 4.15 – 6.41 MPa at 56 days age for different fiber amount.

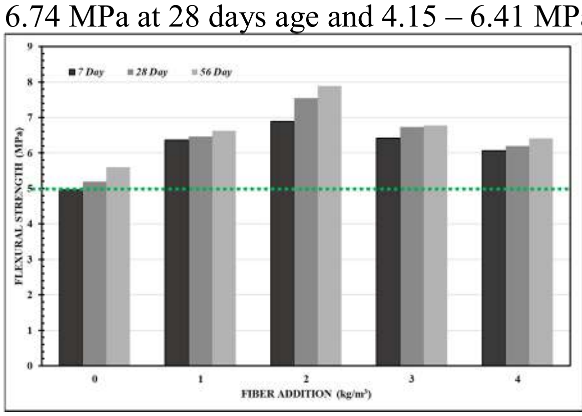

Figure 6. Relation between slump flow – fiber amount and V-funnel time – fiber amount.

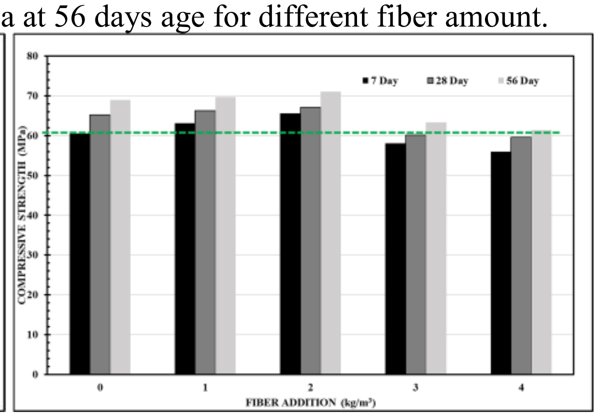

Figure 7. Effect of curing on compressive strength of mortar.

Flexural strength test results showed that control mortar without fiber has the lowest values, maximum flexural strength test results were obtained from 2 and 3 kg/m3 fiber additions especially at 28 days age. 2 kg/m3 fiber content gives the best results for all three ages.

4.2.2. Compressive Strength Test Results

In this research study, fiber addition decreased axial compressive strength of SCMs from 60 MPa to 56 MPa after adding 4 kg/m3. Addition of 1 and 2 kg/m3 has not changed compressive strength considerable amount. However, strength differences are very high at latter ages like 28 days and 56 days. Compressive strength of control mortar at 7 days age is 60.5 MPa, after addition of macro fiber content to mortar, strength values started to decrease until 56 MPa. It was realized that compressive strength decrease values are 2.36%, 7.65%, 11.34% and 12.22% respectively with addition of each 1 kg/m3 fiber. Axial compressive strength of control mortar at 28 days age is 67.9 MPa and then gradually this value decreased to 59.6 MPa. Whereas, compressive strength of 56 days age values of control mortar and compressive strength of modified mortar with 1 kg/m3 macro fiber is the same and equal to 69 MPa. However, addition of 2 kg/m3 and 3 kg/m3 fiber decreased compressive strength to 67.3 MPa and 63.3 MPa respectively. In addition, there is 20.5% strength decrease at 56 days age of mortar produced with 4 kg/m3 macro fibers while compared with control mortar. This paper draws attention to a correlation between dissipated energy and maximum achieved load. For this purpose, this correlation is evaluated and plotted in Figure 8, 9 and 10 respectively for 7 days age, 28 days age and 56 days age. At early age of SCMs, addition of 1 kg/m3 macro-fiber decreased infinitesimal amount of maximum load but increased dissipated energy. 2 kg/m3 and 3 kg/m3 addition of macro fiber decreased maximum achieved load, but increased dissipated energy while compared with control mortar. 28 days results show that maximum measured force is around 160 kN for control mortar, then this value increased to 167 kN with addition of 1 kg/m3 fiber. 2 kg/m3 fiber has not decreased maximum obtained load as is 163 kN.

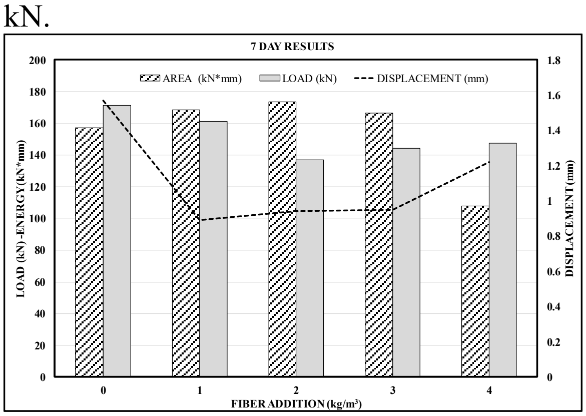

Figure 8. Load, dissipated energy and displacement diagram for 7 days age SCMs.

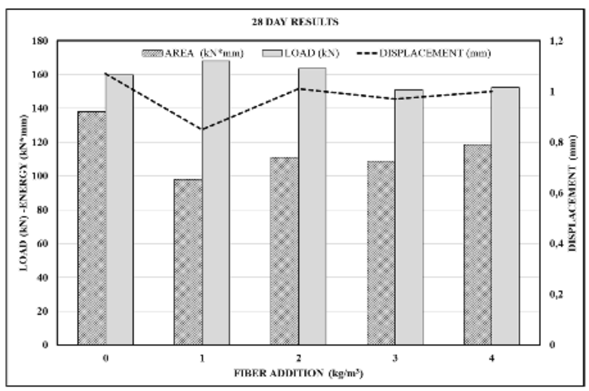

Figure 9. Load, dissipated energy and displacement diagram for 28 days age SCMs.

Addition of 3 kg/m3 and 4 kg/m3 fiber decreased maximum loads to 151 kN and 153 kN compressive strength values respectively as seen in Figure 8. However, it is obvious that maximum dissipated energy obtained from control mortar. Modified mortar types dissipated less energy that control mortar. 56 days age test results present that maximum axial compressive strength is achieved with control mortar around 180 kN. Moreover, 2 kg/m3 fiber addition revealed closest maximum load to control mortar. The modified SCMs produced with rest of the fiber content give lower compressive strength test result than SCM500PPF2 type mortar as seen in Fig. 10.

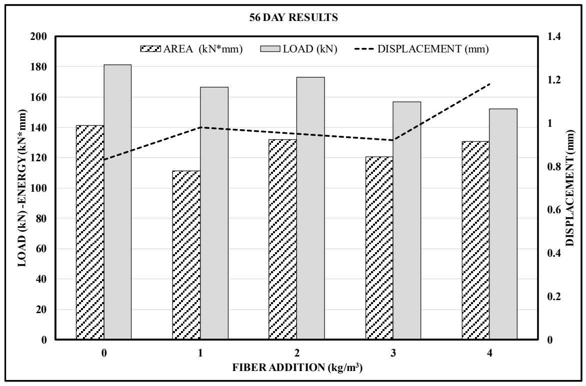

Figure 10. Load, dissipated energy and displacement diagram for 56 days age SCMs.

4.2.3. Diagonal Tensile Strength Test Results

Diagonal tensile strength test called as also split tension strength of diagonal cubes is used to estimate fracture of concrete. However, assessment of fracture parameters of mortar is indispensable due to increasing lateral tensile stress under diagonal vertical loading condition [27]. For this purpose, diagonal tensile strength test was performed on the mortar specimen to measure tensile strength resistivity. This test was performed on the mortar specimen produced with different macro fiber contents at two different age of mortar. Results of diagonal tensile strength test can be seen in Fig. 11.

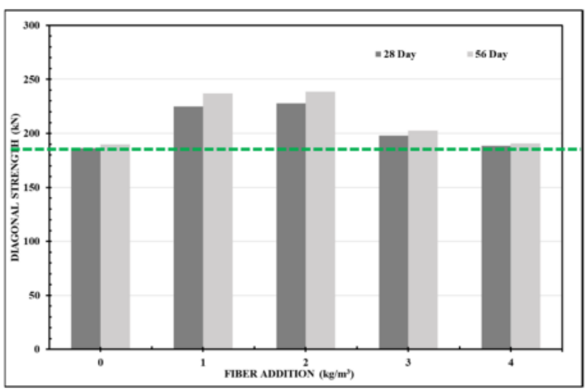

Figure 11. Diagonal Tensile Strength Test Results of SCMs.

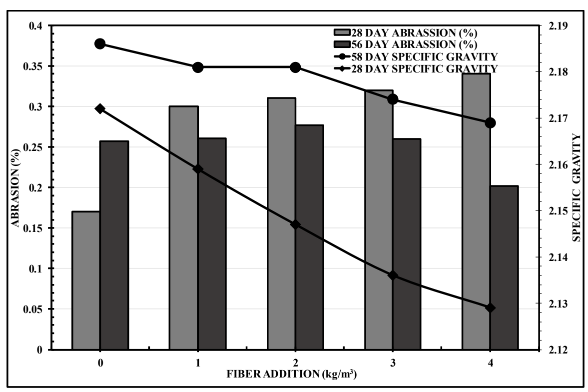

Figure 13. Abrasion resistance and specific gravity of SCMs.

On the base of plotted results in Fig. 11, diagonal tensile strength test results show that the best results were obtained 233 kN from control mortar at 28 days age. Then, gradually these results were decreased with addition of each 1 kg/m3 macro fiber from 225 kN to 157 kN. Whereas, addition of macro fiber has a reverse effect on modified mortar. While diagonal tensile strength test results of control mortar 168 kN, 1 kg/m3 macro fiber addition increased tensile strength resistance of mortar to 237 kN at 56 days age.

4.2.4. Abrasion Resistance Test Results

Abrasion resistance tests were performed on 100mmx100mmx100mm cubic samples on the base of ASTM C 944 [25]. This standard clearly presents how to perform abrasion resistance of concrete and mortar by using rotating-cutter. Each surface of the specimens exposed to abrasion test along

2 minutes at 200 rev/min. Vertical force on each specimen kept constant at 197 kN. Abrasion resistance test results and specific gravity results were plotted on Fig. 12.
Abrasion resistance experiments were conducted on the mortar specimens along 2 minutes at each 2-minute interval duration. Plotted values in Figure 13 are the average values that measured end of the two minutes time interval for three specimens. After conducting test on the specimen along 2-minutes, weight loss of specimen was measured and calculated in percent. It was measured that average weight loss of the control mortar 0.17%, addition of each 1 kg/m3 fiber increased average weight loss of the specimens 0.3%, 0.31%, 0.32% and 0.34% respectively at 28 days age. In reverse, average weight loss of the control specimen increased 0.26% at 56 days age while compared with 28 days age weight loss. Moreover, addition 1 kg/m3 macro fiber increased weigh loss of the SCMs 0.26%, addition 2 kg/m3 macro fiber increased weigh loss of the SCMs 0.28%. However, weight loss of the modified mortar with 3 kg/m3 macro fibers is 0.26%. This loss amount is equal to control and modified mortar with 1 kg/m3 macro fiber. Average weight loss of last set of SCMs is 0.2%. Addition of macro fiber to mortar more than 3 kg/m3 has positive effect on specimen while decreasing weight loss due to abrasion. Decreasing weight loss amount with increasing fiber content proves that macro fibers contribute durability and resistance to mortar at 56 days age. As for specific gravity, calculated specific gravity of control mortar is 2.172 g/cm3. Then this amount started to decrease until 2.129 g/cm3 gradually.

Conclusions

An experimental study was conducted to investigate workability, engineering properties and abrasion resistance of self-compacting mortar with synthetic fiber at different curing age. Following conclusions can be listed below based on the obtained test results:1) Control mortar and modified mortar with 1 kg/m3 synthetic fiber provided satisfactorily self-compacting properties at fresh state. 2)Rest of the composition has not been fulfilled the self-compacting requirements of EFNARC (2002). 3)Addition of 1 and 2 kg/m3 fiber to mortar increased flexural strength of hardened mortars at all test age. However, addition of 3 and 4 kg/m3 fiber decreased flexural strength test results while compared to test results of modified mortar with 1 and 2 kg/m3 fiber added mortar. 4) 1 and 2 kg/m3 fiber additions have not changed compressive strength test results while compared to control mortar without fiber. However, addition of 3 and 4 kg/m3 fiber resulted a considerable decrease in compressive strength while compared to control mortar. 5)Diagonal tensile strength test results showed that 1 and 2 kg/m3 fiber addition provided strength to modified mortar specimens compared to control specimens. Whereas, addition of 3 and 4 kg/m3 fiber has not any effect on diagonal tensile strength test. 6) Addition of fiber increased abrasion resistance of the hardened specimens at 28 days age. However, increasing fiber amount except 4 kg/m3 fiber amount gave nearly the same weight loss. 4 kg/m3 fiber addition resulted considerable amount of weight loss while compared other sets at 56 days age. 7)Optimum fiber content was determined as 1 kg/m3 for self-compacting mortar with this study. Fiber content limit ratio can be determined between 1 kg/m3 and 2 kg/m3 fiber amounts with a sensitive experimental study as a future indication.

References

1. Felekoğlu, B., Türkel, S., and Altuntaş, Y. " Effects of steel fiber reinforcement on surface wear resistance of self-compacting repair mortars ", Cement and Concrete Composites, 29(5), 391-396., 2007.

2. Güneyisi, E., and Gesoğlu, M. "Properties of self-compacting mortars with binary and ternary cementitious blends of fly ash and metakaolin." Materials and Structures, 41(9), 1519-1531, 2008.
3. Turk, K.. "Viscosity and hardened properties of self-compacting mortars with binary and ternary cementitious blends of fly ash and silica fume." Construction and Building Materials, 37, 326-334, 2012.
4. Benabed, B., Kadri, E. H., Azzouz, L., and Kenai, S. "Properties of self-compacting mortar made with various types of sand." Cement and Concrete Composites, 34(10), 1167-1173, 2012.
5. Liu, X., Ye, G., De Schutter, G., Yuan, Y., and Taerwe, L. "On the mechanism of polypropylene fibres in preventing fire spalling in self-compacting and high-performance cement paste." Cement and Concrete Research, 38(4), 487-499, 2008.
6. Gencel, O., Ozel, C., Brostow, W., and Martinez-Barrera, G. "Mechanical properties of self-compacting concrete reinforced with polypropylene fibres." Materials Research Innovations, 15(3), 216-225, 2011.
7. Safi, B., Saidi, M., Daoui, A., Bellal, A., Mechekak, A., and Toumi, K. "The use of seashells as a fine aggregate (by sand substitution) in self-compacting mortar (SCM)." Construction and Building Materials, 78, 430-438, 2015.
8. Şahmaran, M., Christianto, H. A., and Yaman, İ. Ö. "The effect of chemical admixtures and mineral additives on the properties of self-compacting mortars." Cement and concrete composites, 28(5), 432-440, 2006
9. Muhit, I. B., Raihan, M. T., and Nuruzzaman, M. "Determination of mortar strength using stone dust as a partially replaced material for cement and sand." Advances in concrete construction, 2(4), 249-259, 2014.
10. Yaragal, S. C., and Roshan, M. A. "Usage potential of recycled aggregates in mortar and concrete." Advances in Concrete Construction, 5(3), 201-219, 2017.
11. Altun, F., Haktanir, T., and Ari, K. "Effects of steel fiber addition on mechanical properties of concrete and RC beams." Construction and Building Materials, 21(3), 654-661, 2007.
12. Song, P. S., Wu, J. C., Hwang, S., and Sheu, B. C. "Assessment of statistical variations in impact resistance of high-strength concrete and high-strength steel fiber-reinforced concrete." Cement and Concrete Research, 35(2), 393-399, 2005.
13. Taylor, M., Lydon, F. D., and Barr, B. I. G. "Toughness measurements on steel fibre-reinforced high strength concrete." Cement and Concrete Composites, 19(4), 329-340, 1997.
14. Corinaldesi, V., & Moriconi, G. "Durable fiber reinforced self-compacting concrete." Cement and concrete research, 34(2), 249-254, 2004.
15. Stynoski, P., Mondal, P., and Marsh, C. "Effects of silica additives on fracture properties of carbon nanotube and carbon fiber reinforced Portland cement mortar." Cement and Concrete Composites, 55, 232-240, 2015.
16. Mohseni, E., Miyandehi, B. M., Yang, J., and Yazdi, M. A. "Single and combined effects of nano-SiO2, nano-Al2O3 and nano-TiO2 on the mechanical, rheological and durability properties of self-compacting mortar containing fly ash." Construction and Building Materials, 84, 331-340, 2015.
17. Rao, S., Silva, P., and De Brito, J. "Experimental study of the mechanical properties and durability of self-compacting mortars with nano materials (SiO2 and TiO2). Construction

and Building Materials, 96, 508-517, 2015.
18. Chand, M. S. R., Giri, P. S. N. R., Kumar, P. R., Kumar, G. R., and Raveena, C. "Effect of self curing chemicals in self compacting mortars." Construction and Building Materials, 107, 356-364, 2016.
19. Benli, A., Karataş, M., and Bakir, Y. "An experimental study of different curing regimes on the mechanical properties and sorptivity of self-compacting mortars with fly ash and silica fume." Construction and Building Materials, 144, 552-562, 2017.
20. Karataş, M., Benli, A., and Ergin, A. "Influence of ground pumice powder on the mechanical properties and durability of self-compacting mortars." Construction and Building Materials, 150, 467-479, 2017.
21. Benli, A., Karataş, M., and Gurses, E. "Effect of sea water and MgSO 4 solution on the mechanical properties and durability of self-compacting mortars with fly ash/silica fume." Construction and Building Materials, 146, 464-474, 2017.
22. TS EN 933-1, "Tests for geometrical properties of aggregates - Part 1: Determination of particle size distribution - Sieving method", TSE Institution, Ankara, TURKEY, 2015
23. EFNARC, The European guidelines for self-compacting concrete specification, production and use. The European Federation of specialist construction chemicals and concrete systems. May, 2002
24. ASTM C349-02, "Standard Test Method for Compressive Strength of Hydraulic-Cement Mortars (Using Portions of Prisms Broken in Flexure)", ASTM International, West Conshohocken, LA, 2002.
25. ASTM C 944, "Standard test method for abrasion resistance of concrete or mortar surfaces by the rotating-cutter method", ASTM International, West Conshohocken, LA, 2012.
26. ASTM C 128-1, "Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate", ASTM International, West Conshohocken, LA, 2003.
27. Ince, R., Gör, M., Eren, M. E., & Alyamaç, K. E. "The effect of size on the splitting strength of cubic concrete members." Strain, 51(2), 135-146, 2015.