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Research Article

Effect of high temperature on SCC containing fly ash

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ABSTRACT

The effect of high temperature on self-compacting concrete, which contains different amounts of fly ash, has been investigated. By considering the effect of concrete age and increased temperatures, the optimum fly ash-cement ratio for the optimum concrete strength is determined using experimental studies. Self-compacting concrete specimens are produced, with fly ash/cement ratios of 0%, 20% and 40%. Specimens were cured for 28, 56 and 90 days. After curing was completed, the specimens were subjected to temperatures of 20°C, 100°C, 400°C, 700°C and 900°C for three hours. After the cooling process, tests were performed to determine the unit weight, ultrasonic pulse velocity and compressive strength of the specimens. According to the experiment results, an increase in fly ash ratio causes a decrease in the compressive strength of self-compacting concrete. However, it positively contributes to self-compaction and strength loss at high temperatures. The utilization of fly ash in concrete significantly contributes to the environment and the economy. For this reason, the addition of 20% fly ash to concrete is considered to be effective.

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1. Introduction

Reinforced high-performance concrete with chemical admixtures and mineral additives has been employed in modern structures. The behaviour of this concrete at high temperatures should be well understood. Due to the low porosity of concrete, this concrete is a denser structure with a high-temperature performance that is lower than the high-temperature performance of normal strength concrete (Scherefler et al., 2003). In the class of high-performance concrete, self-compacting concrete is another type of concrete. Self-compacting concrete (SCC), which is defined as concrete without the use of internal or external vibration and compacting, is self-placed in a mold (Leemann et al., 2006; Kamal et al., 2017). The two basic features of SCC are the use of large amounts of fine materials and the use of a new-generation superplasticizer, which provide high fluidity and segregation resistance. As a viscosity-enhancing material in SCC, a mineral additive may be employed (Felekoğlu et al., 2007; Apeh, 2019; Agwa and Ibrahim, 2019). One of the most important additives is fly ash (FA). FA decreases bleeding by reducing the rate of hydration. It improves the workability of concrete due to spherical particles and provides a stable structure due to the increased amount of fine material in the concrete. Studies of SCC generally include an investigation of the properties of fresh and hardened SCC. Currently, significant experience and the development of SCC have been achieved. However, some problems remain unsolved, such as the behavior of SCC at high temperatures (Altın, et al., 2006). The effect of high temperature on concrete is dependent on the temperature, test period, structure of the cement paste phase, and aggregate type. These changes cause a significant decrease in the compressive strength of concrete (Akman, 2000). The relationship between the porosity of concrete and the compressive strength of concrete is known. The compressive strength of concrete increases as the porosity of concrete decreases (Vodak et al., 2006). When cement paste and aggregate are exposed to high temperatures, physical and chemical degradation causes changes in the distribution of the total porosity and pore size. Generally, hardened cement paste expands at temperatures from 20-200°C. Due to the effect of different densities, concrete shrinks and an expansion in the aggregates is

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observed at temperatures above 200°C. These changes cause an increase in pore size (Alonzo et al., 2003). Up to 500°C, water from the capillary and the gel water is removed, which causes a significant increase in the total void volume (Haddad and Shannis, 2004). The total pore volume increases to 600°C. This increase is higher than the expected total pore volume, which reveals weight loss similarities in concrete. This finding may be attributed to the increase in voids due to deterioration of the solid phase or formed micro cracks. The micro pore ratio is reduced at high temperatures, which may cause sintering at temperatures above 900°C (Alonzo et al., 2003). Factors such as free water migration and evaporation, the loss of bound and absorbed water at 450°C, calcium hydroxide decomposition, as quartz constitutes the majority of sand at 575°C, the transition of α-quartz to β-quartz occurs, and a deterioration in the structure of calcium silicate hydrate (CSH) at 400-600°C serve an important role in the strength loss of concrete that is exposed at high temperatures (Felicetti and Gambarova, 1998). Three different phases of water are observed in concrete: adsorption water, which connects the solid element of CSH in cement gel paste; the chemically bound water in hydrate; and water that is free in the capillary pores. During the production of concrete, which is dependent on the cement type and water/cement ratio, free water that is available to 4% of the volume of the concrete vaporizes at 100°C and chemically bonded water vaporizes at 300°C. Due to the effect of temperature, shrinkage that occurred after water loss and high vapor pressure caused cracking and spalling of the concrete covering of the reinforcement concrete in this stage. Due to the destruction of the concrete covering, a reinforcement concrete steel bar comes into contact with hot gas at the beginning of the fire (Akman, 2000). During placement, concrete is a wet and porous material. Normal- and high-strength concretes at 70°C retain a maximum of 99% of the initial mass. Between 70-120°C, the free water in the concrete evaporates. At 120°C, normal- and high-strength concrete lose the same amount of water. The loss of mass is approximately 1.4%. The largest amount of weight loss, which is approximately 7%, occurs from 120 to 300°C due to the drying of the bound water in the hardened concrete. The loss of mass between 300 and 600°C is less important due to the small amount of calcium hydroxide in high-strength concrete and the result of pozzolanic effect of the mineral additive (Cülfik, 2001). The length of exposure to temperature, humidity conditions, heating and cooling rates and loading conditions are contributing factors to the compressive strength of the concrete that is exposed to high temperatures (Neville, 2000). In normal-strength concrete, the uniaxial compressive strength at high temperatures in the first stages causes an increase in the compressive strength with an increase in temperature. The strength at temperatures above 200°C begins to decrease. The compressive strength at 700°C decreases by 80% compared with the initial value (Cülfik, 2001). In the first phase, the increase in strength of the concrete produced with siliceous aggregates is significant as the strength of the adherence between the cement and the aggregate is substantial in silica aggregates (Savva et al., 2005). Significant reductions in tensile strength are obtained by the splitting concrete test at temperatures from 100°C, and maximum losses of 70% are attained at 600°C (Guise et al., 1996). With different types and amounts of pozzolan in concrete, a continuous decrease in the modulus of elasticity with temperature has been observed (Savva et al., 2005). The addition of FA and high temperatures caused a significant decrease in the modulus of elasticity was observed (Papayianni and Valliasis, 2005).

Few studies have addressed the effect of high temperatures on SCC (Jin and Yong, 2006; Heiza, 2012; Mathews et al., 2020). When considering the strength performance of SCC, they are located in the class of high-strength concrete (HSC). Thus, the behavior of SCC at high temperatures can be evaluated by the performance of HSC at high temperatures. Compared with normal concrete, HSC at high temperatures is considered to be less durable. The amount of pore reduction in concrete is dependent on the type of aggregate; due to the evaporation of water in cement gel, internal pressure occurs. Concrete expands at high temperatures due to a polymorphic conversion in aggregates and changes in the concrete thermal expansion coefficient. Due to the high moisture content, concrete becomes fractured (Ye et al., 2007). For this reason, HSC that contains fewer pores at high temperatures can incur a greater amount of damage. This situation also applies to SCC. To minimize damage that will occur in HSC and SCC at high temperatures, the use of polypropylene fibers that melt at high temperatures is proposed to form pores in the concrete (ERMCO, 2005). To increase the resistance of HSC to high temperatures, the recommended method is the use the lightweight aggregate. High temperatures are considered to affect the mineralogical structure (Helal and Heiza, 2006). The material properties of HSC with the effect of temperature differ from the material properties of normal-strength concrete; these differences were reported to be more prominent between 25 and 400°C. In this range, high-strength concrete showed a strength loss that was more rapid than the strength loss in normal strength concrete (Phan and Carino, 1998). HSC that contains silica fume was determined to be explosively fragmented (Lawson et al., 2000). The relative residual strength is significant (Poon et al., 2001). The strength of SCC increased at temperatures 150-300°C. The loss of the mechanical properties of SCC increased at temperatures above 300°C due to the formation of permanent strain and micro cracks (Hana et al., 2009). The coefficient of thermal expansion of SCC were determined to be higher than the coefficient of thermal expansion of normal concrete at high temperatures. The use of lightweight aggregate in SCC reduces the coefficient of thermal expansion (Topçu and Uygunoğlu, 2009). Currently, the use of SCC is common. An increasing number of studies are underway to improve the properties of fresh and hardened SCC. This study aimed to improve the properties of fresh SCC by replacing cement with 20-40% FA (Acay, 2010). In addition, the effect of elevated temperatures on the durability properties of SCC, which has been insufficiently explored, was also investigated. Compared to conventional concrete, higher cement and lower water rates are used in SCC production. Therefore, the strength of SCC can be high. High strength concretes can spall under the effect of high temperature due to the water vapor pressure in the internal structure. Here, by using less cement with the use of FA, it is aimed not only to increase the workability, but to reduce the damage under high temperature effect with decreasing rigidity.

2. Experimental Study

2.1. Materials

Cement: Type R CEM I 42.5 cement was employed in the experiment. The chemical properties of this cement are listed in Table 1.

Fly Ash (FA): The entire experimental study was performed using F-type FA from the Tunçbilek Company. The physical and chemical properties of the FA are listed in Table 2.

Superplasticizer: Glenium C303 superplasticizer produced by the YKS Company was employed. The properties of the new-generation superplasticizer are listed in Table 3.

Water: Eskişehir tap water was employed. The chemical analysis of the drinkable water is provided in Table 4.

Aggregate: In this study, crushed sand and crushed stones, which were obtained from Çimsa Ready Mixed Concrete, were employed. The granulometry of the aggregate mixture is presented in Fig. 1, and the properties of the aggregates are listed in Table 5.

Table 1. Properties of the cement.

SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	Na_2O+0.66 K_2O	SO_3	Cl^-
19.4	63.78	5.2	2.38	1.85	0.62	2.84	0.009

Table 2. Properties of the fly ash.

Spec. Gravity	Free CaO	>45μm, %	Reactive CaO	Activite indeks	SO_3	Cl^-	LOI
2.28	0.06	26.2	2.63	82.6	0.41	0.0088	0.56

Table 3. Properties of the superplasticizer.

Cl^-, %	Chemical Structure	Alkali, %	Color	Density, kg/dm^3
0.1	Polycarbocsilic Ester-based liquid	3	Light green	1.02-1.06

Table 4. Chemical analysis of the water (mg/lt).

pH	Na_2O	Ka_2O	Cl^-	SO_4	Zn	Pb	P_2O_3	NO_3	∑alkalinity	Color
7.8	52	11	66	23	10	0.05	1.5	0.1	8	Crystal clear

Table 5. Properties of the aggregate.

Size mm	Fineness modulus	Filler content %	Water absorption %	Saturated density kg/dm^3
0-7	2.46	6	1.59	2.63
7-15	6.01	0.9	0.62	2.67
15-22	6.96	0.4	0.42	2.70

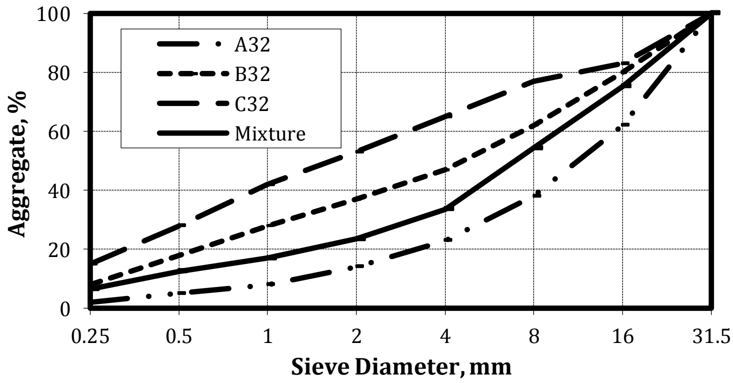

Fig. 1. Granulometry of aggregate mixture.

2.2. Method and tests

In this study, three different series, depending on the rate of FA, were determined at the end of the trial mix designs to fulfil the requirements of SCC. The mixing ratios of these series are shown in Table 6. 15×15×15 cm^3 cubic specimens of each mixture were prepared. In this study, it is aimed to increase the fine material ratio for self-compressibility. Therefore, FA was not added to the mixture instead of cement as in other studies (Mohammed et al., 2014; Topçu and Uygunoğlu, 2009). Slump-flow test to determine the filling ability, L-box test to determine the passing ability and sieve segregation test to determine the segregation resistance of SCC were conducted on fresh SCC. Concrete specimens were cured in standard conditions until 28-day, 56-day and 90-day strengths were attained. The specimens were exposed to temperatures of 20°C, 100°C, 400°C, 600°C, and 900°C for three hours according to TS EN 1363-1. The heating rate was 6°C/min. The specimens were slowly cooled to six hours in ambient air. Unit weight, ultrasonic pulse velocity, and compressive strength tests were performed. The effect of high temperature on the reduction in unit weight, the ultrasonic pulse velocity (UPV), and the compressive strength was investigated.

Table 6. Mixing ratio, kg/m^3.

	FA-0	FA-20	FA-40
Cement	450	450	450
Fly Ash	0	90	180
Water	175	175	175
Fine Aggregate (0-7)	992	931	870
Coarse Aggregate (7-15)	430	404	377
Coarse Aggregate (15-22)	313	294	275
Admixture	4	4	4

3. Discussion

3.1. Properties of fresh SCC

The flow diameter and the average time to attain T50 cm of the SCC series by adding different amounts of FA are shown in Fig. 2. The ratio of FA was observed to increase with an increase in diameter of the flow. The increase in the flow diameter can enhance the workability of the SCC by FA. The time to attain T50 cm of SCC flow decreased with an increase in the ratio of FA. FA causes a lubrication effect in SCC due to its round-grained shape and increases the rate of flow of SCC. If a slump-flow test, which is a common method for determining the filling ability of SCC, is considered, the flow diameter of SCC should fall within 650 to 800 mm for acceptable filling ability. According to the Europe Ready Mixed Concrete Association's (ERMCO) flow diameter classification, all mixtures are in the SF2 group. For the time to attain T50, all mixtures are in the VS2 group because all T50 values exceed 2 seconds. The increase in the amount of fine material and the round shape of FA positively affected the filling ability of SCC.

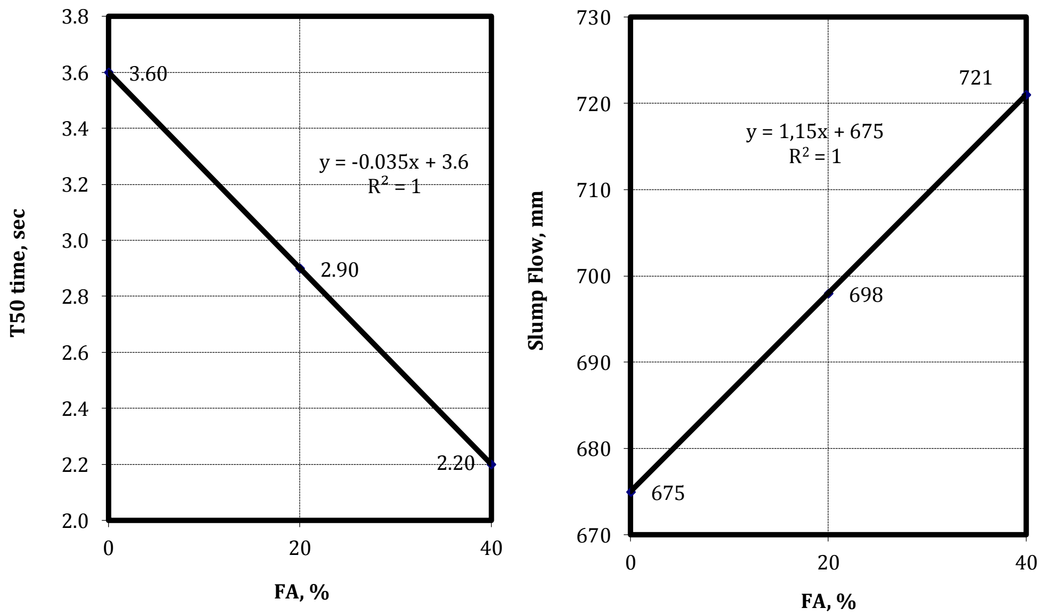

Fig. 2. Slump-flow test results of SCC.

To measure the passing ability of SCC, the most common test is the L box test; the results are provided in Fig. 3. The ratio of FA, which is measured by SCC's ability to pass between reinforcement bars, increased. Due to the lubrication effect of FA, a reduction in the wall effect is considered. As shown in Fig. 4, the proportion with regards to height level increases the proportion of FA and an increase in the passing rate to 0.91. This increase can be explained by an increase in the amount of fine particles in the mixture. According to the classification of the ERMCO passing rate, all types of mixtures are in the PA2 group as all values exceed 0.8. With the increase in FA amount, the decrease of coarse grains in the mixture and the round shape of FA positively affected the passing ability of SCC.

Sieve segregation test results of SCC are shown in Fig. 4. Segregation decreased with the use of FA in the SCC mixtures. The reason for this decrease can be attributed to the increase in the amount of binding. It can be used in inert mineral additives in SCC, but in this case the segregation resistance may decrease. However, since FA is a pozzolanic material, the segregation resistance of SCC is positively affected by the increase in cohesion in the internal structure.

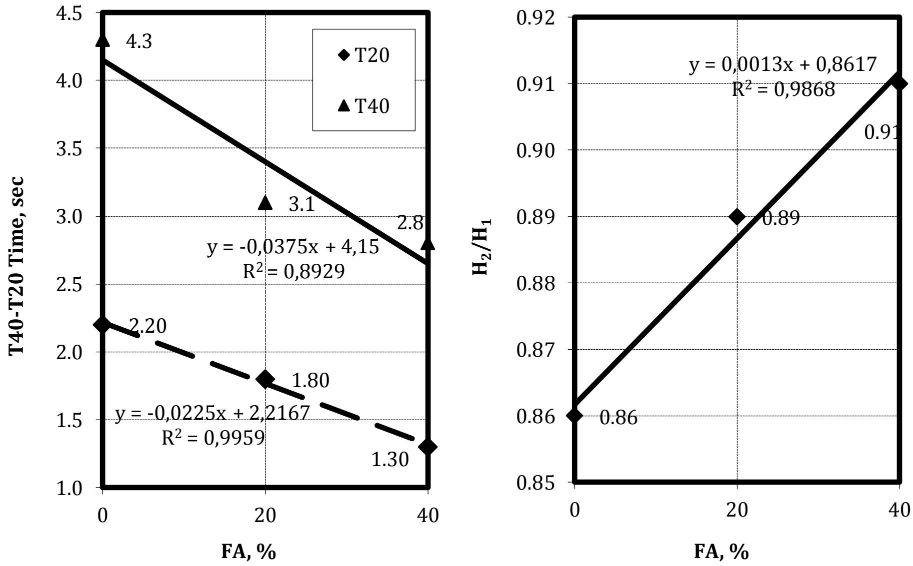

Fig. 3. L box test results of SCC.

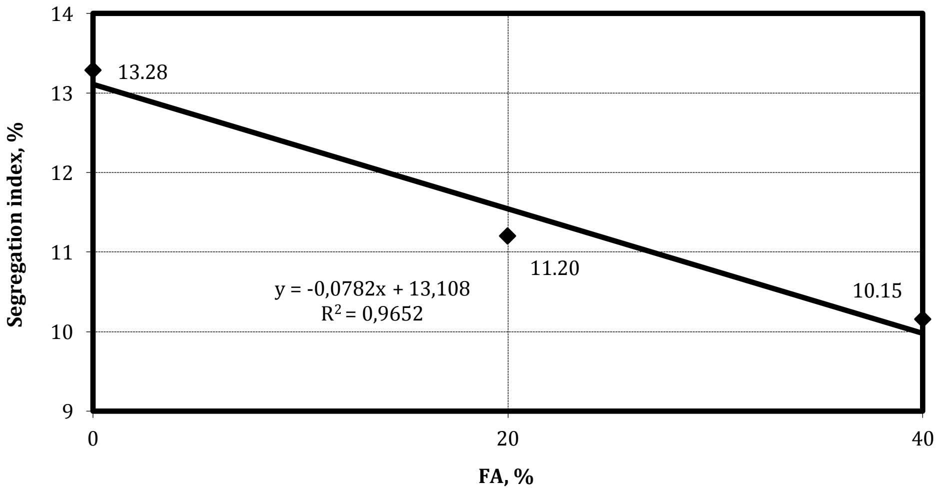

Fig. 4. Sieve segregation test results of SCC.

The lubrication effect of FA is significant in terms of workability. Grains in the form of small spheres, as shown in Fig. 5, simplify self-placing and compaction. Calcium silicate hydrates the structures that formed by reaction of FA with calcium hydroxide at the end of the cement hydration reactions, improves strength and increases compactness. Thus, the increase in compactness decreases segregation.

3.2. Properties of hardened SCC

The unit weight of SCC specimens at different ages are provided in Fig. 6. The unit weight of the specimens with 40% FA at 28 days decreased by 1.8%. The unit weight of the control specimens at 56 days was 2.4 kg/dm³. With the addition of 20% FA, the unit weight of the mixture decreased by 0.7%; with 40% FA, the unit weight decreased by 1.4%. The unit weight of the 90-day control specimens was 2.42 kg/dm³. With 20% FA, the unit weight decreased by 1.3%; with 40% FA, the unit weight decreased by 2.6%. The largest reduction in the 90-day specimens that contain 40% FA was observed. As the specific gravity of FA is less than the specific gravity of the aggregate weight, a decrease in the unit weight was observed. Ninety days of FA reaction produces a low specific weight; as a result, the decreasing rate of the unit weight increases.

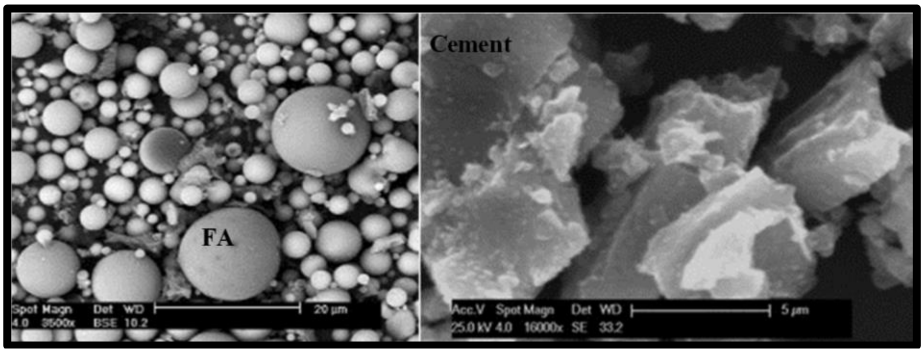

Fig. 5. Shape effect of cement and FA particles (Mohammed et al., 2014; Patrick et al., 2011).

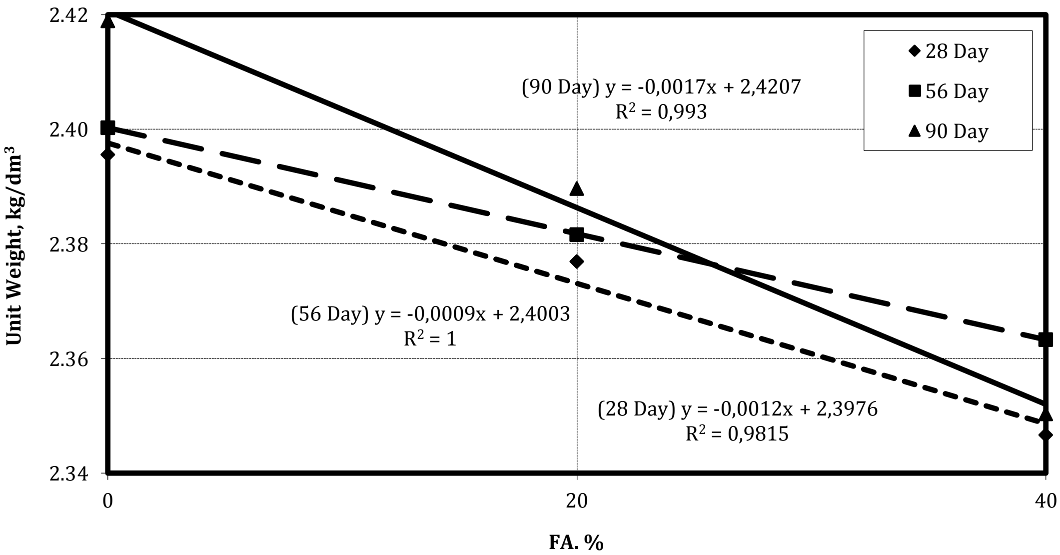

Fig. 6. Unit weight of SCC.

The results for UPV are shown in Fig. 7. In the experiments, the pulse velocity of the 28-day and 56-day control mixtures were determined. An increase of 20% FA produced an increase in velocity; 40% FA caused a decrease in velocity. These results indicate that the use of 20% FA to reduce the pores within the hardened concrete, causes an increase in the UPV. In the case of a higher rate of usage of FA, a reduction in the amount of coarse aggregate produced a decrease in the UPV. FA caused a reduction in coarse aggregate and the UPV, which is more apparent after 90 days. The pulse velocity of the concrete increases with an increase in age and the highest velocity rate values were determined on day 90.

Depending on the unit weight and the UPV test results, the dynamic elasticity modulus values were calculated, as shown in Fig. 8. The dynamic modulus of elasticity after 28 and 56 days using a 20% increase in FA produced an increase, whereas a mixture of 40% FA produced a decrease. For 90 day specimens, the modulus of elasticity linearly decreased with the use of FA. The decrease in UPV with the increase of FA on the 90th day can be explained as the less volume coating of the products that occur with the increase of pozzolanic reactions and the decrease of coarse aggregate.

The compressive strength test results at different ages are shown in Fig. 9. In the experiments conducted after 28 days and 90 days, the compressive strength decreased with the addition of FA. The 56-day compressive strength increased with 20% FA but decreased with 40% FA. The compressive strength of concrete increases with age, and the highest values were measured in the experiments that were conducted after 90 days. Studies have shown that the effect of ash on concrete compressive strength occurs after 56 days (Güçlüer, and Ünal, 2010). In this study, it was seen that the strength of the control concrete could not be obtained up to 90 days. Water and plasticizer remained the same despite the addition of ash. In this case, the necessary environment for the reaction of the ash with cement hydration products was not sufficiently formed. Therefore, the expected strength increase did not occur.

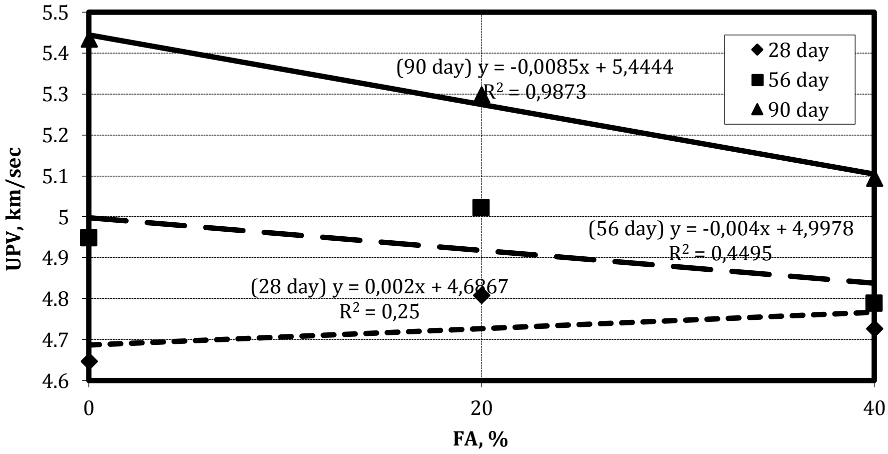

Fig. 7. UPV of SCC.

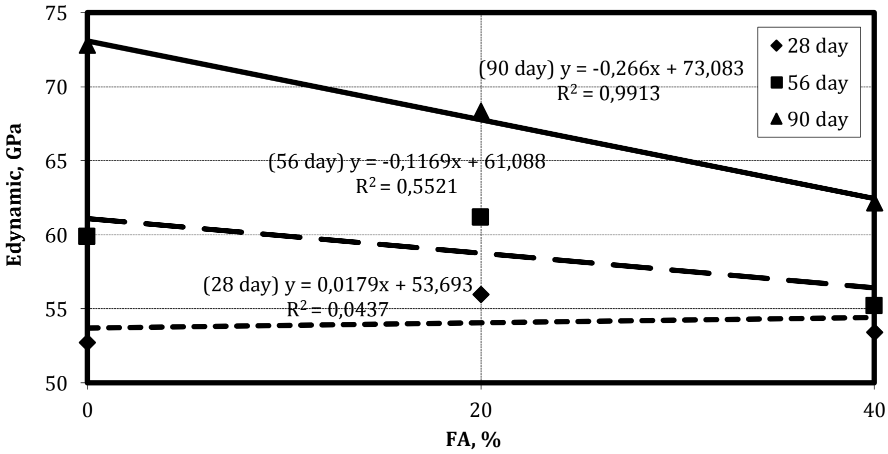

Fig. 8. Dynamic modulus of elasticity of SCC.

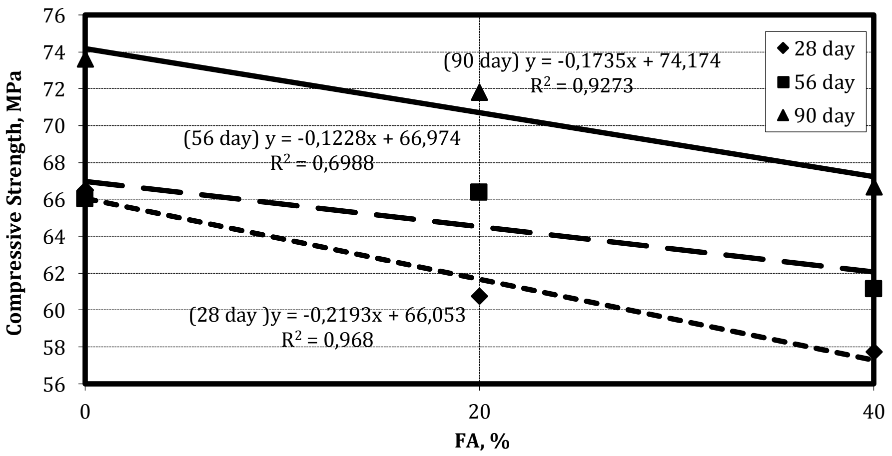

Fig. 9. Strength of SCC.

3.3. Properties of SCC subjected to high temperatures

The SCC specimens that were subjected to standard curing conditions for 28 days were exposed to temperatures of 100, 400, 700 and 900°C for three hours. The unit weight loss caused by the high temperature effect were calculated, as shown in Fig. 10. The effect of high temperatures to 700°C on the unit weight loss is approximately 5%, whereas the unit weight loss at 900°C increased above 10%. When the temperature increased above 100°C, the free water in the apparent pores evaporates, which causes the unit weight to suddenly decrease. The water in the remaining pores in the concrete evaporate at a slower rate, which causes unit weight reduction at a slower rate to 700°C. At temperatures above 700°C the unit weight rapidly declines with the restructure of CSH and limestone aggregates, which turn into lime. With the addition of FA and an increase in temperature, the unit weight loss increased. A maximum unit weight loss of 14% was attained at 900°C as a high proportion of FA is employed. As a result, a reduction in the aggregates is observed due to the expansion effect of high temperatures on the chemical structure binding phase, which facilitates the deterioration of the unit weight. The unit weight loss for the 56-day SCC control specimens increased above 15% when exposed to a maximum temperature of 900°C. The unit weight loss of the 56-day specimens suddenly increased with an increase in temperature to 200°C and above 700°C. No significant change in unit weight wffas observed between 200-700°C. A reduction in unit weight loss occurred with the addition of a higher amount of FA in SCC at high temperatures. The unit weight loss decreased as a result of filling pores and became a stronger structure with products due to the reaction between FA and calcium hydroxide after 56-days. As the temperature increases, the sudden unit weight losses for 90-day specimens decreased and a more linear reduction is observed. An increase in temperature and the addition of FA generates a unit weight loss behaviour that is similar to the control specimens. After 90 days, the reaction of the FA and cement hydration products are predominantly complete; as a result, the variation in unit weight loss is reduced. As shown in Fig. 10, when we examine the increased percentage of FA with high temperature, an increase in the unit weight loss and concrete age is observed. The unit weight losses with 0%, 20% and 40% FA added to the specimens at high temperatures are similar.

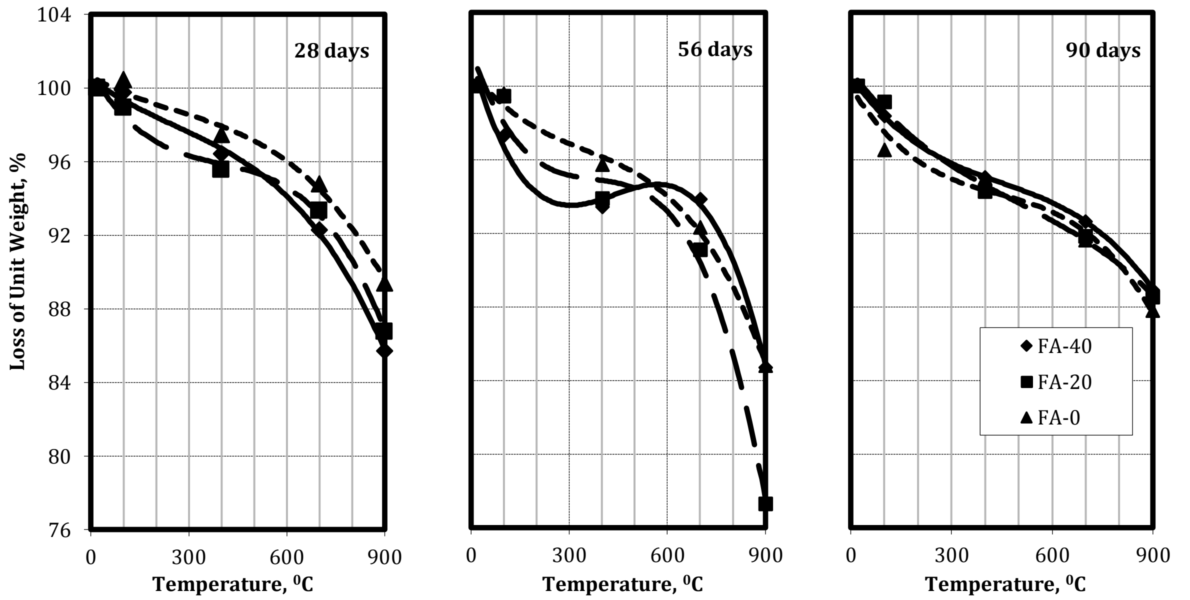

Fig. 10. Relative unit weight according to the temperature of SCC.

UPV loss for SCC specimens that were exposed to high temperature are shown in Fig. 11. The UPV loss of the control specimens for a maximum temperature of 900°C is less than 50%. With increasing temperature, the UPV decreased, whereas this reduction showed variable behaviour after the addition of FA to SCC above 700°C. The UPV losses decrease in the control concrete as the temperature increases. If high proportions of FA are added, the UPV decreases to 80%. At 28 days, the levels of reaction between FA and the products of hydration of cement are considered to be lower. When cured for 56 days and subjected to high temperatures during the UPV experiments, the specimens with FA showed the best results at temperatures between 400°C and 700°C. At 56 days, the reaction between FA and cement hydration products accelerates and reduce the pores, which reduce UPV losses. The restructure of the resulting products at high temperatures is considered to cause an increase in losses in UPV. At a curing time of 90 days, UPV losses are reduced by an average of 60% at 900°C. The UPV of 90 day specimens with a temperature increase reveals a linear increase in losses. By FA addition, the variation in losses are reduced at high temperatures. The addition of FA to 90 day specimens had a positive effect on UPV loss. FA reaction products increase the compaction of concrete; its effect on the pulse velocity loss rate is considered to be positive.

A loss of dynamic modulus of elasticity for the specimens that were exposed to different temperatures are shown in Fig. 12. The control specimens that were exposed to temperature increases to 900°C experience an accelerated loss of dynamic modulus of elasticity, which exceeded 72%. A dynamic modulus of elasticity loss for 28-day specimens showed a linear increase with an increase in temperature with the addition of FA. FA is considered not to completely react at an early age, which increases the loss of the dynamic elasticity modulus. At the curing time of 56 days, the loss of dynamic modulus of elasticity showed variable behaviour with the addition of FA in SCC. The dynamic modulus of elasticity of the control specimens decreased to 700°C. Considering the dynamic modulus of elasticity, a significant decrease was observed. At a maximum temperature of 700°C, a slower loss in the dynamic modulus of elasticity occurs for specimens with the addition of 40% FA compared with the addition of 20% FA as the hydration of cement continued in concrete and its products react to the high ratio of FA. The dynamic modulus of elasticity loss of 90-day specimens with FA positively affected compared with the control specimen with temperature increases. Losses in the dynamic modulus of elasticity obtained more positive results due to FA increases compactness of binding paste and strengthening of the structure by the reaction products.

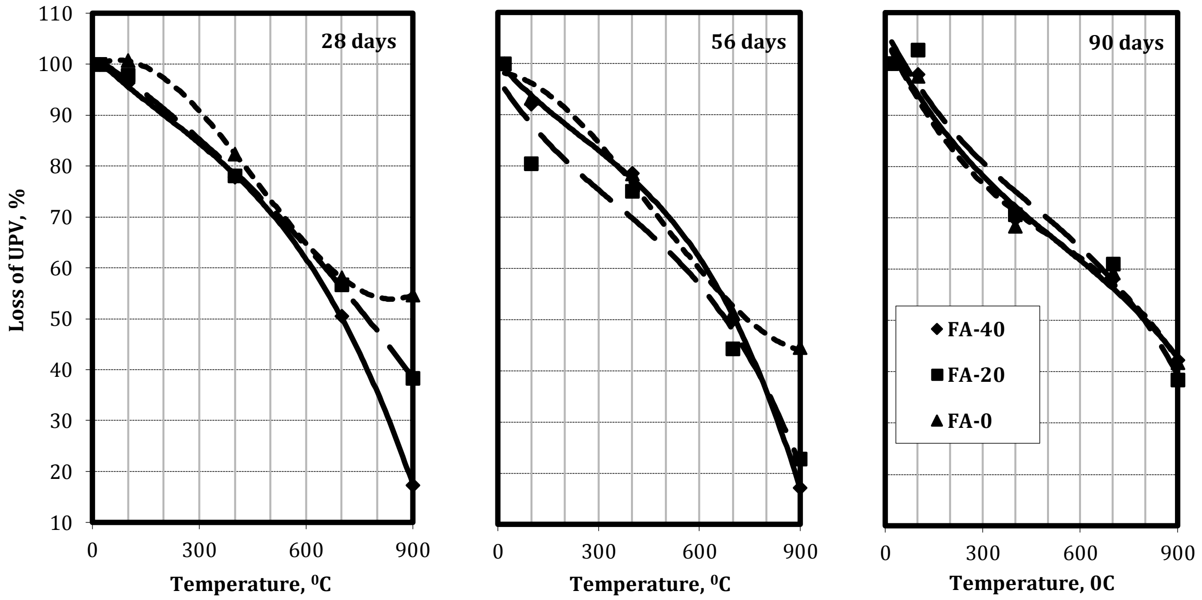

Fig. 11. Relative UPV values of SCC according to the temperature.

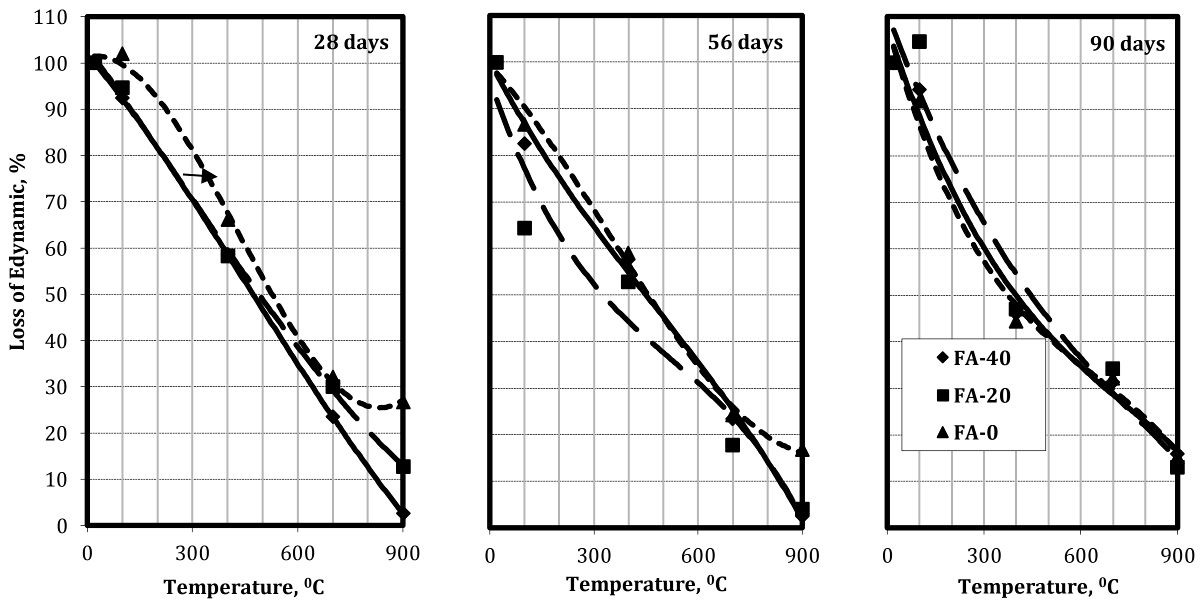

Fig. 12. Relative dynamic modulus of elasticity of SCC at high temperatures.

The strength losses of SCC exposed to high temperatures is shown in Fig. 13. The control specimens that were exposed to 100°C strength decrease by approximately 4%; at 700°C, the loss in the compressive strength increased to 20%. While the temperature increased to 900°C, the loss in strength increased above 60%. At 900°C, the loss of strength for specimens with 20% FA was 45%, whereas the loss of strength for specimens with 40% FA was 65%. With an increase in temperature to 400°C, no significant change was observed in the 28-day compressive strength of specimens. The compressive strength rapidly decreased after 400°C. As the FA did not completely react at an early age and due to the reduction in the coarse aggregate ratio, a significant loss of compressive strength occurred. These losses do not fall below 30%, which provides a significant advantage in terms of the bearing capacity of a structure. The 56-day strength of SCC specimens that were exposed to 400°C increased by 5% when a temperature of 900°C was attained. The loss of strength accelerated to losses over 65%. The loss in strength of specimens, including FA, reached 70% at 900°C. The compressive strength of 56-days specimens decreased at temperatures above 400°C. This reduction, which was similar for the 28-day specimen, showed similar behaviour by adding FA. A disadvantage of coarse aggregate, which is the decline caused by the acceleration of FA reactions, is eliminated. The compressive strength of 90-day specimens with a maximum temperature of 400°C did not show any change similar to the 28- and 56-days specimens; however, the strength rapidly decreased above 400°C and the strength did not reduce below 45%. The compressive strength positively affected the pozzolanic reaction of FA at high temperatures and even increased at temperatures to 400°C. A minor reduction in the loss of compressive strength at high temperatures was reflected by an increase in the age of concrete.

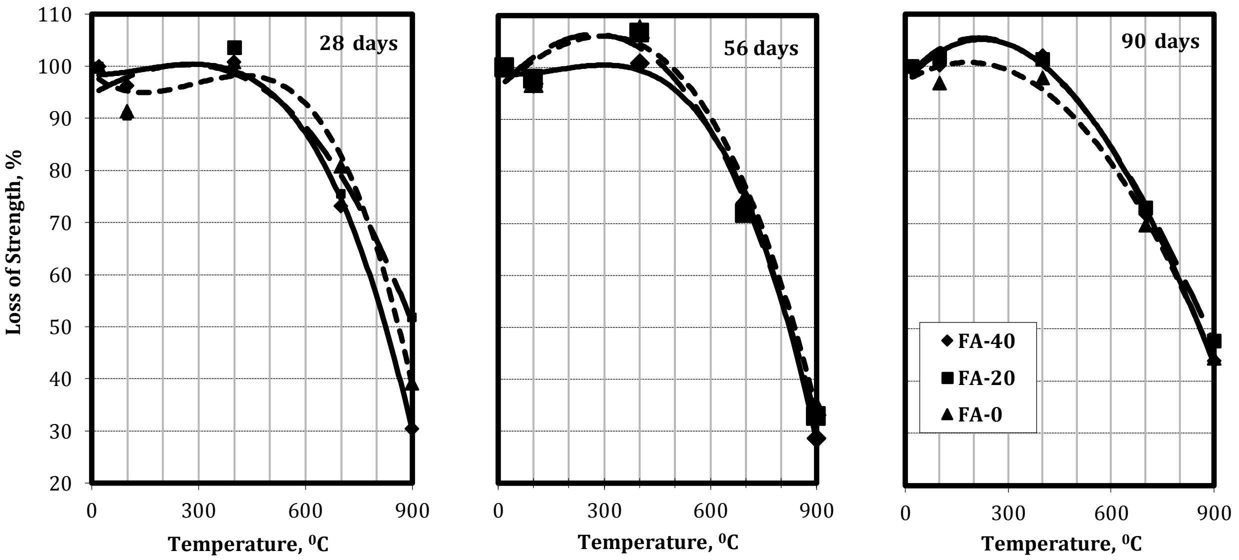

Fig. 13. Relative compressive strength of SCC at high temperatures.

As capillary pores decrease with increasing compactness due to the use of FA, the evaporated water in the microstructure at high temperatures does not easily escape. An increase in internal stress causes micro cracks in concrete, loss of strength and failure. However, compactness decreases the permeability of water and causes less vapor pressure at high temperatures. Growing and branching of these micro cracks were slightly restricted by micro pores, which form with cenosphere FA and plerospher FA, as shown in Fig. 14. It contributes to the elimination of the negative effect of FA on SCC at high temperatures.

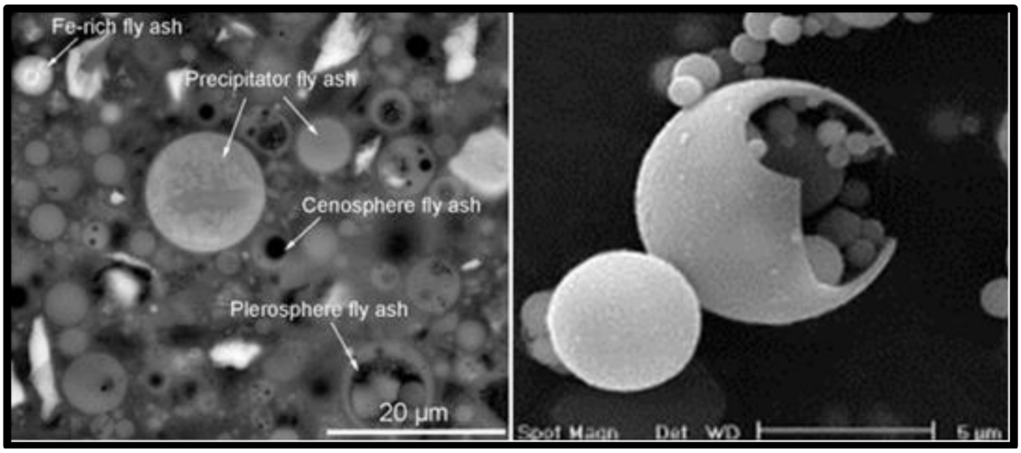

Fig. 14. Microstructure of FA (Patrick et al., 2011; Sujing and Wei, 2014).

4. Conclusions

The conclusions of the study are summarized as follows:

- The decrease in unit weight is dependent on the increase in FA amount in fresh SCC. The filling ability, passing ability, and segregation resistance of SCC are positively affected by increasing the FA amount in fresh SCC.
- An increase in the FA ratio decreases the unit weight of hardened SCC, and unit weight is not affected by concrete age. Although the UPV increases with the age of concrete, the UPV decreases by approximately 6% with the addition of FA in the SCC mixture. The dynamic modulus of elasticity is a similar reaction, such as the UPV, in SCC. The compressive strength of SCC increases with concrete age. An increase in the FA amount in hardened SCC causes a decrease in the

compressive strength. When concrete age is considered, the rate of decrease is approximately 4% of SSC, which includes 20% FA, and approximately 10% of SSC includes 40% FA.

- An increase in temperature in SSC causes a maximum decrease in unit weight of 24%. Due to the effect of high temperature, the difference between the unit weight loss of the control specimens and the unit weight loss of FA mixed specimens is less than 2%.
- As a result of UPV losses, the results conclude that high temperature affects SCC specimens, including FA at early ages. The maximum UPV loss is 60% at 900°C.
- The increase in temperature for SCC linearly decreases in the dynamic elasticity modules. Depending on the increase in concrete age, the differences among the dynamic elasticity modules were not observed between the FA specimens and the control specimens.
- Compressive strength loss is not observed for the SCC at temperatures below 400°C. Specimens older than 90 days are more durable with regard to high-temperature effects and their residual strength approaches the 50% ratio. After 90 days, a positive effect of FA in the SCC that is exposed high temperatures is observed.

According to these results, an increase in the FA amount in SCC decreases the compressive strength and positively affects properties of fresh SCC and the loss of compressive strength at high temperatures. The use of FA in SCC is economical and eco-friendly. The use of 20% FA in SCC decreases the compressive strength by 4%, and the use of 40% of FA in SCC causes a maximum decrease in the compressive strength by 10%. When considering strength, self-compaction, cost and environmental effect, a maximum addition of FA of 20% in SCC mixtures is suggested.

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