Journal of Sustainable Construction Materials and Technologies

Volume 10 | Issue 4 Article 7

2025

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JOURNAL OF SUSTAINABLE CONSTRUCTION MATERIALS AND TECHNOLOGIES 2025;10:552–561

RESEARCH ARTICLE

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ABSTRACT

Alaçatı stone or Alapietra stone is widely used mostly for building cladding. However, its production and use in the construction sites generate high amounts of waste (debris), causing environmental pollution in Çeşme which is a touristic district. This study investigated the reuse of Alaçatı stone as lightweight aggregate (LWA) in both conventional and self-consolidating concrete (SCC) mixtures. The concretes were prepared to have three different water-to-cement ratios (w/c), which were 0.38, 0.42 and 0.48. For each w/c, a conventional concrete mixture and two SCC mixtures with 60 or 70 cm slump flow were produced by varying the superplasticizer SP content. Slump, slump flow, T50, V-funnel, sieve segregation, dry density and compressive strength tests were performed. The results demonstrated that it was possible to use Alaçatı stone aggregate in producing lightweight concretes with good performance in both fresh and hardened states.

Keywords: Alaçatı stone, Lightweight aggregate, Lightweight concrete, Self-consolidating concrete

1. Introduction

Alaçatı is a touristical place located in Çeşme district of Izmir. The unique natural tuffite found in the volcanic rock formations in this region represents an important potential aggregate variety due to its material structure, physical and mechanical properties. It is also considered the most important industrially cultivated material among the other natural porous aggregates in the Izmir region. Alaçatı formations are regionally known as "Alaçatı Stone" or "Alapietra Stone" [1]. Alaçatı stone, of volcanic origin, is white in colour, and has a porous structure containing basalt pebbles. Tuffites, which occasionally exhibit distinct layering, are characteristic of volcano-sedimentary rocks. According to the macroscopic and microscopic examination of the rock samples, the rock material can be named petrographically as "tuffite aggregate with pumice component" or "volcanic tuffite aggregate with pumice component" [2].

Alaçatı stone is widely used today for building cladding (Fig. 1), but its production and integration generate a significant amount of waste (debris). Because the rubble site offered by the local government is far from Alaçatı, the haphazard and illegally dumped debris in Çeşme, a touristic district, causes environmental pollution (Fig. 2).

While Alaçatı stone is widely used as a cladding material in buildings, there are very limited studies on its use as an aggregate. The suitability of Alaçatı stone for dry-mix mortar production for masonry units was studied by Gündüz et al. [2]. The compressive strength of the mixtures ranged from approximately 3 to 10 MPa. The results indicated that Alaçatı stone is suitable for use in dry-mix lightweight mortar combinations as a lightweight construction material. In another study [4], the use of micronized Alaçatı stone in the production of insulating composite filling mortar was investigated. In this study, strengths were lower than 2.5 MPa, and densities were 418 kg/m3. Although there are laboratory studies on the use of Alaçatı stone aggregate in pumice-based blocks [1] and non-autoclaved aerated concrete [5], there is no such industrial application

Received 27 October 2025; revised 15 December 2025; accepted 15 December 2025.
Available online 23 December 2025

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https://doi.org/10.29187/2458-973X.1205

Fig. 1. A building cladding with Alaçatı stone [3].

Fig. 2. Alaçatı stone debris causing environemtal pollution [1].

to date. Unlike the aforementioned studies, this study investigated the use of Alaçatı stone aggregate in conventional concrete and self-compacting concrete (SCC). According to the literature review, no research has been conducted on the use of Alaçatı stone aggregate in SCC.

Self-consolidating concrete (SCC) is a high-performance concrete that can flow under its own weight to completely fill the formwork and self-consolidate without any mechanical vibration. Advances in chemical admixtures and highly effective plasticizers (superplasticizers) played a significant role in the development of SCC [6]. The advantages of SCC over conventional concrete include ensuring void-free placement of concrete in the mold particularly in densely reinforced concrete structures, shortening construction time, reducing labour costs, and its high fluidity [7]. It is stated that these advantages can reduce total construction costs by 5% [8]. Furthermore, the longer-lasting concrete yields savings in the long run. Despite these advantages, SCC is not widely used because its properties vary significantly due to minor variations during production (in other words, its low stability), its production requires qualified technical personnel, the precision required in the use of chemical additives, and the relatively high cost of the concrete itself resulting from relatively higher binder content.

While SCC's most important property is its high fluidity, this poses a threat to concrete's homogeneity. In other words, the more fluid the concrete, the more the homogeneity of its ingredients is compromised. Therefore, SCC design requires special attention. In addition to high fluidity, it must also be resistant to segregation, meaning it must maintain its homogeneity at every stage from mixing to hardening. While lightweight aggregates (e.g., pumice, expanded perlite, etc.) reduce the weight of concrete and provide various advantages (such as thermal insulation, reduced structural weight, reduced earthquake impacts, and reduced cross-sectional area of load-bearing elements), the voids in aggregates can cause them to float to the surface in high-fluidity concretes like SCC, making homogeneity difficult to achieve.

Demonstrating the usability of Alaçatı stone aggregate in both conventional concrete and SCC is crucial for the recycling of Alaçatı stone rubble, which is often discarded as waste. Furthermore, the usability of Alaçatı stone aggregate in SCC combines the advantages of both lightweight concrete and SCC. In addition to these technical advantages, maintaining the cleanliness of the Çeşme district is important both environmentally and for regional development due to the economic contributions of tourism.

This study investigated the use of Alaçatı stone, a lightweight aggregate, in both conventional and SCC concrete, and the associated challenges such as segregation. Demonstrating its usability in SCC also aimed to combine the advantages of both lightweight aggregate and SCC. Within the scope of the study, concretes with three different water-cement ratios (w/c) and three different consistency levels were produced. The properties of the concretes in their fresh and hardened states were investigated.

2. Experimental program

2.1. Materials

Cement: CEM IV/B (P) 32.5 R cement was used in this project. The chemical properties of this cement were determined using the XRF method and the results are shown in Table 1. The Blaine fineness of the cement used was determined to be 4611 cm2/g and its specific gravity was 3.03.

Alaçatı Aggregate: Alaçatı Aggregate was procured from Sunay Mining, a company operating in Alaçatı.

Table 1. Chemical properties of the cement.

	%, by weight
CaO	54.2
SiO_2	17.7
Al_2O_3	11.6
Fe_2O_3	2.8
SO_3	1.6
MgO	3.1
Na_2O	7.3
K_2O	0.9
Loss on Ignition	5.0
Insoluble Residue	1.2

Aggregates brought to the laboratory were mixed thoroughly on the ground (similar to the quartering method) before performing the tests to ensure uniformity. Then the aggregates were sieved and separated into grain sizes of 0–4, 4–8, and 8–16 mm. Specific gravity, water absorption capacity, and unit weight tests were then conducted for each grain size range. The results of these tests are shown in Tables 2 and 3. Sieve analysis was also performed for each dried aggregate group. The results are shown in Table 3.

Chemical Admixture: A 3rd generation polycarboxylic ether-based superplasticizer (SP) admixture (Glenium SKY 608) was used as the chemical admixture. Its properties, provided by the manufacturer, are presented in Table 4.

It is noted by Kumar et.al. that the specific gravity of several LWA types used in SCC fluctuates between 0.40 and 1.85. For example, the specific gravity of pumice, which is one of the most widely available LWA [9], can range between 0.69 and 1.84. In this study, the specific gravity of Alaçatı stone was between 1.35 and 1.63. Water absorption and compacted unit weight of pumice aggregate were reported to range from 8% to 45%, and from 350 to 1105 kg/m^3, respectively [10]. In this study, water absorption of the Alaçatı stone was determined to vary between 13% and 30%, and its compacted unit weight was between 1001 and 1144 kg/m^3. Expanded perlite, which is also among the most widely used LWA, has water absorption of around 30–40% and a density of about 240 kg/m3 [9]. Much lower densities as 97 kg/m^3 is also available for expanded perlite [10]. Therefore, it can be concluded that the physical properties (specific gravity, water absorption and unit weight) of the Alaçatı stone were comparable with the upper limits given for the pumice aggregate while expanded perlite is much lighter than both of them.

Table 3. Sieve analysis of the aggregates.

Sieve opening (mm)	% passing 0 mm–4 mm	4 mm–8 mm	8 mm–16 mm
16	100.0	100.0	100.0
8	100.0	100.0	0.0
4	100.0	0.0	0.0
2	66.8	0.0	0.0
1	45.7	0.0	0.0
0.5	30.8	0.0	0.0
0.25	19.6	0.0	0.0
0.125	7.1	0.0	0.0

Table 4. Superplasticizer properties.

Type	Modified Polycarboxylic Ether Based
Color	Brown
Density	1.069–1.109 kg/lt
pH	5–7
Cl^- content	$<$ 0.1
Alkali content	$<$ 3.00
Recommended dosage	0.8–1.5 (in 100 kg binder)

2.2. Concrete mixture parameters

The ratio of each aggregate group in concrete was determined according to the Fuller curve drawn by using the equation given below [12].

$$p_i = (d_i/D)\hat{}0.5 \tag{1}$$

where,

p_i: the amount passing through sieve number i,
d_i: sieve number i opening,
D: Maximum aggregate size

Several trials were conducted by mixing three different aggregate sizes at various ratios to ensure that the sieve analysis of the resulting mixture would approximate the Fuller curve. As can be seen in Fig. 3 and Table 5, when 51% 0–4 mm aggregate, 20% 4 mm–8 mm aggregate, and 29% 8 mm–16 mm aggregate were mixed, results close to the Fuller distribution were obtained.

After achieving the appropriate gradation specified above, conventional concrete and SCC production

Table 2. Specific gravity and water absorption capacity of the aggregates.

	Dry specific gravity	SSD specific gravity	Water absorption capacity (%)	Loose unit weight (kg/m^3)	Compacted unit weight (kg/m^3)
0 mm–4 mm	1.35	1.77	30.9	1025.0	1143.7
4 mm–8 mm	1.49	1.78	19.4	900.7	1001.5
8 mm–16 mm	1.63	1.85	13.2	966.0	1079.0

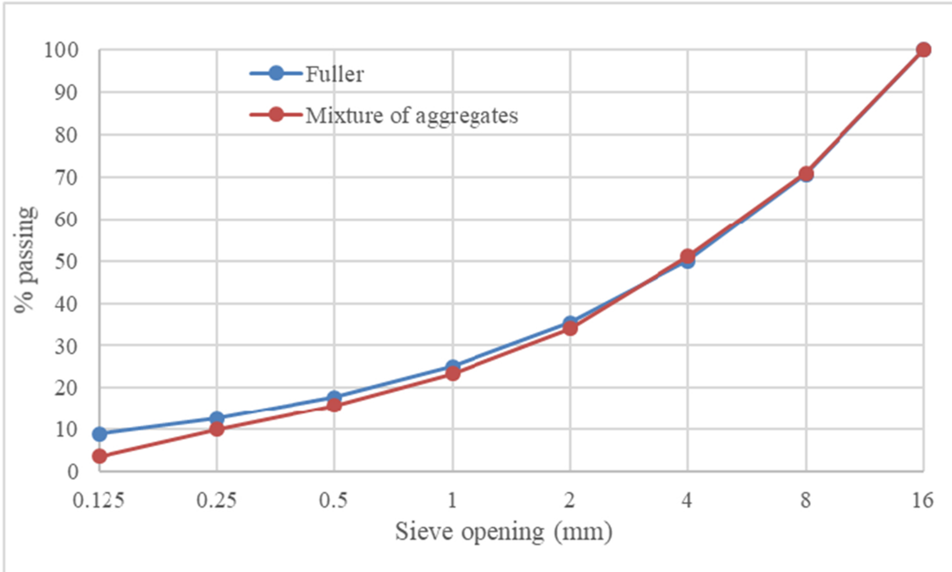

Fig. 3. Fuller curve and grain size distribution of mixed aggregate.

Table 5. Mixed aggregate grain size distribution and Fuller curve.

Sieve opening (mm)	Fuller value (%)	% passing (%)
16	100.0	100.0
8	70.7	71.0
4	50.0	51.0
2	35.4	34.1
1	25.0	23.3
0.5	17.7	15.7
0.25	12.5	10.0
0.125	8.8	3.6

Table 6. Mixture parameters of concrete and SCC prepared using Alaçatı stone aggregate.

w/c	Consistency
0.38	Slump: Not predetermined Slump flow diameter: 60 ± 2 cm Slump flow diameter: 70 ± 2 cm
0.42	Slump: Not predetermined Slump flow diameter: 60 ± 2 cm Slump flow diameter: 70 ± 2 cm
0.48	Slump: Not predetermined Slump flow diameter: 60 ± 2 cm Slump flow diameter: 70 ± 2 cm

was initiated according to the design parameters given in Table 6. The conventional concretes were designed for different water/cement ratios for a constant cement content. No SP was used in such mixtures and the slump value was measured. In other words, the slump of the conventional concretes was not predetermined. On the other hand, for the SCC mixtures both w/c ratio and consistency were varied according to Table 6. The slump flow of the SCC mixtures was adjusted to have 60 or 70 cm spreads solely by varying the SP amount, while the amounts of other ingredients (water, cement, and aggregates) in all concretes for a given w/c were kept constant. (Detailed mixing ratios is going to be provided in the Experimental Results and Discussion section.)

2.3. Tests

All mixtures were prepared in 50-L concrete mixer. The following tests were conducted on nine different mixtures produced according to the parameters in Table 6:

- Slump (for conventional concrete)
- Slump flow (for SCC)
- T50 (for SCC)
- V-funnel (for SCC)
- Sieve segregation (for SCC)
- Density (for hardened SCC and conventional concrete)
- Compressive strength (for SCC and conventional concrete after 7, 28, and 90 days)

Brief information about these test methods is as follows: Slump flow, V-funnel, and T50 tests were conducted according to the EFNARC standard [13]. After completing the fresh concrete tests, three 10-cm cube samples were prepared for each fresh concrete mix for density tests and another nine 10–cm cube samples for compressive strength tests. It is also worthy to state that no limitations or challenges were

Table 7. Concrete mix ratios.

Mixture name	w/c	Water (kg)	Cement (kg)	SP (ml)	0–4 mm (kg)	4–8 mm (kg)	8–16 mm (kg)	Slump (cm)	Slump flow diameter (cm)
NC-0.48	0.48	216	450	–	534.1	209.5	303.7	23	–
SCC-0.48-60	0.48	216	450	2025	534.1	209.5	303.7	–	62
SCC-0.48-70	0.48	216	450	3471	534.1	209.5	303.7	–	69
NC-0.42	0.42	189	450	–	558.6	219.1	317.6	19	–
SCC-0.42-60	0.42	189	450	2314	558.6	219.1	317.6	–	61
SCC-0.42-70	0.42	189	450	4918	558.6	219.1	317.6	–	71
NC-0.38	0.38	171	450	–	574.9	225.5	326.9	17	–
SCC-0.38-60	0.38	171	450	4050	574.9	225.5	326.9	–	62
SCC-0.38-70	0.38	171	450	7811	574.9	225.5	326.9	–	72

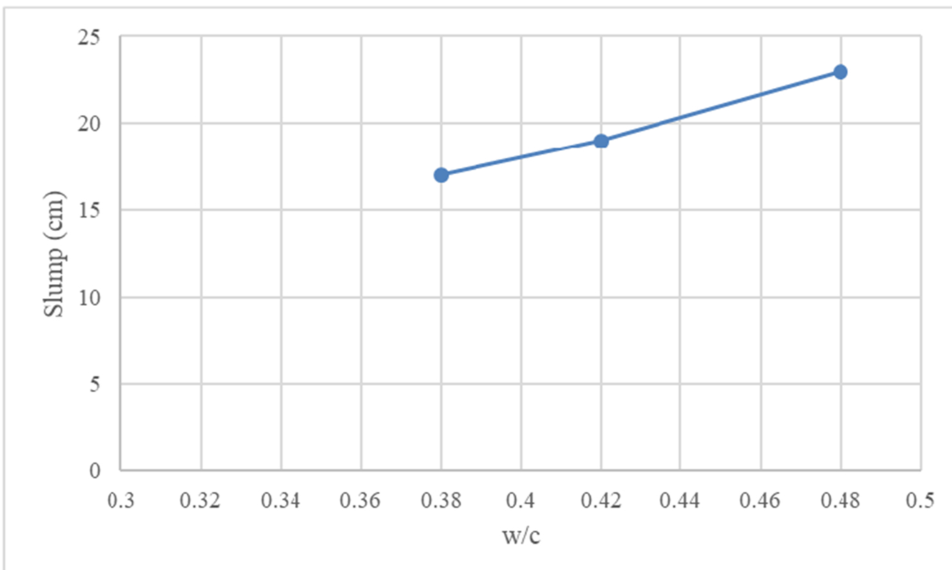

Fig. 4. Slump – w/c relationship in normal concretes.

observed during mixing, casting, or compaction of the mixtures The hardened samples were left in the molds for 24 hours, then removed from their molds and cured in a humid environment at 20 °C in a curing chamber. Density test samples were oven-dried after 7 days, and their dimensions and weight were measured. Density test on hardened concrete was conducted according to TS EN 12390-7 [14]. Compressive strength test samples were tested using a 2000-kN capacity testing machine at the ages of 7, 28, and 90 days. For the compressive strength test, three samples were tested for each concrete type and age, and the average of the three specimens were calculated.

3. Experimental results and discussion

3.1. Mixture proportions and consistency

The amounts of components in 1 m3 of concrete prepared according to the parameters given in Table 6 are shown in Table 7. When naming the concretes, conventional (or normal) concretes were coded NC, while self-compacting concretes were coded SCC. The numbers next to these codes indicate the w/c ratio. The numbers 60 and 70 in the names indicate the class of the slump flow diameter in cm. As can be seen, the cement content in all concretes was kept constant at 450 kg/m3. This amount is the amount commonly used in the literature for SCC mixes.

An interesting finding from Table 7 is that, despite the absence of any SP in the conventional concrete with w/c = 0.48, a high slump value (23 cm) were achieved. Even for the w/c = 0.38 mixture, the slump was 17 cm, which is fairly good for most site applications, although there was no SP. Fig. 4 shows the variation in the slump value in standard concretes depending on the w/c ratio. As expected, slump increased as the w/c ratio increased. This is because, for a constant cement content, the w/c ratio increases with increasing water content. Concrete with a higher water content exhibited greater slump.

Table 8. Test results for concretes.

Mixture name	w/c	T50 (s)	V-funnel (s)	Sieve segregation (%)	Dry density (kg/m3)	Compressive strength, 7-d (MPa) (COV, %)	Compressive strength, 28-d (MPa) (COV)	Compressive strength, 90-d (MPa) (COV)
NC-0.48	0.48	–	–	–	1773.8	6.5 (4.2%)	10.2 (3.6%)	14.3 (3.4%)
SCC-0.48-60	0.48	1.3	1.5	3.4	1754.2	7.3 (4.5%)	11.7 (4.5%)	18.0 (4.2%)
SCC-0.48-70	0.48	1.0	1.2	4.8	1744.4	8.3 (4.8%)	14.9 (4.1%)	20.6 (4.4%)
NC-0.42	0.42	–	–	–	1803.2	12.7 (4.0%)	20.1 (3.7%)	25.8 (3.8%)
SCC-0.42-60	0.42	1.5	1.6	4.5	1783.6	13.0 (4.8%)	18.8 (5.3%)	23.4 (4.6%)
SCC-0.42-70	0.42	0.8	1.0	5.1	1744.4	13.2 (4.3%)	20.4 (3.8%)	24.4 (4.9%)
NC-0.38	0.38	–	–	–	1793.4	13.3 (3.4%)	20.4 (3.6%)	28.1 (3.8%)
SCC-0.38-60	0.38	1.4	1.6	5.4	1783.6	13.2 (3.2%)	23.2 (3.5%)	28.9 (4.5%)
SCC-0.38-70	0.38	1.1	1.3	6.0	1773.8	15.3 (5.2%)	23.6 (4.2%)	33.3 (4.8%)

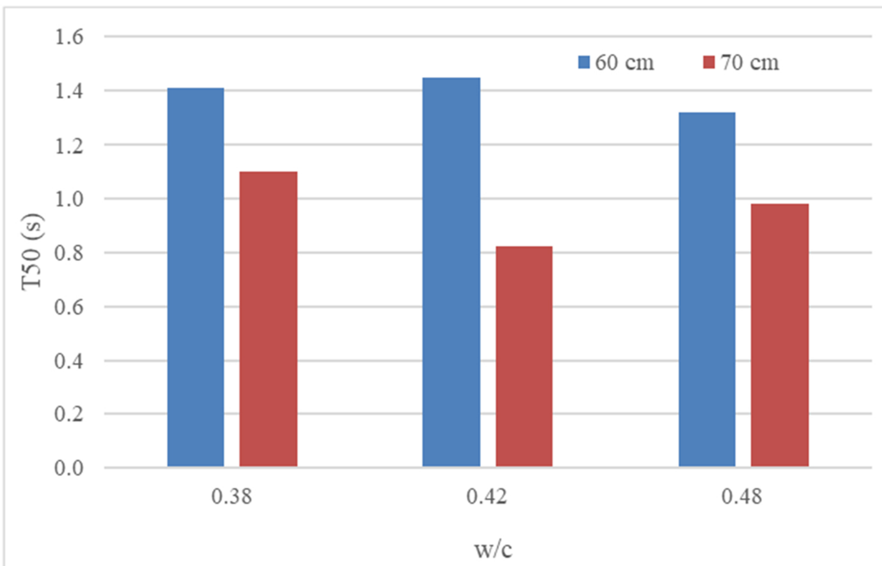

Fig. 5. Change of T50 values with w/c and slump flow diameter.

3.2. T50 test results

The T50 test results for the SCC mixtures are given in Table 8. As can be seen, since the T50 time for all SCC mixtures was less than 2 s, all SCCs conform to the VS1 class according to the EFNARC viscosity classification [13].

The changes in T50 times with the flow diameter and w/c ratio are shown in Fig. 5. As seen, T50 times shortened as spreading increased. Because the SP content increased to increase the spreading diameter, the mixtures became more fluid. Therefore, the flow accelerated and the T50 times decreased.

In concretes with similar flow diameters, changing the w/c did not affect the T50 times as much as changing the SP content. This is because, when the w/c ratio changes, the SP dosage also changes to achieve the same slump flow diameter. For example, when the w/c ratio is high, the T50 time might be expected to be short; but on the other hand, the T50 time did not change significantly due to the low SP content.

3.3. V-funnel test results

The V-funnel test results for SCC mixtures are presented in Table 8. These results are also shown in Fig. 6. Because the V-funnel test was conducted solely on SCC, only these concretes were evaluated. As can be seen in Table 8, the V-funnel values for all SCC mixtures were below 2 sec. Therefore, according to EFNARC viscosity classification, all SCCs comply with class VF1 [13].

The findings of V-funnel results are similar to those of the T50 results (Fig. 5). Namely, V-funnel times decreased with increasing slump flow diameters. For concretes with the same slump flow diameter, changing the w/c ratio had less impact on V-funnel values compared to the effect of slump flow. The close relationship between the T50 and V-funnel results is due to the fact that both tests are related to concrete viscosity. The high correlation between these two test results is evident in Fig. 7.

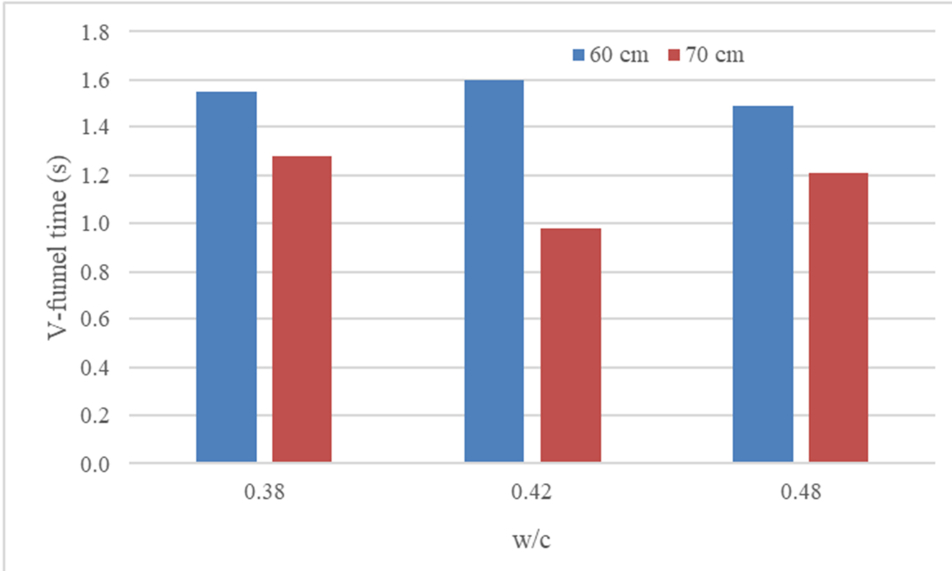

Fig. 6. Change of V-funnel values with w/c and slump flow diameter.

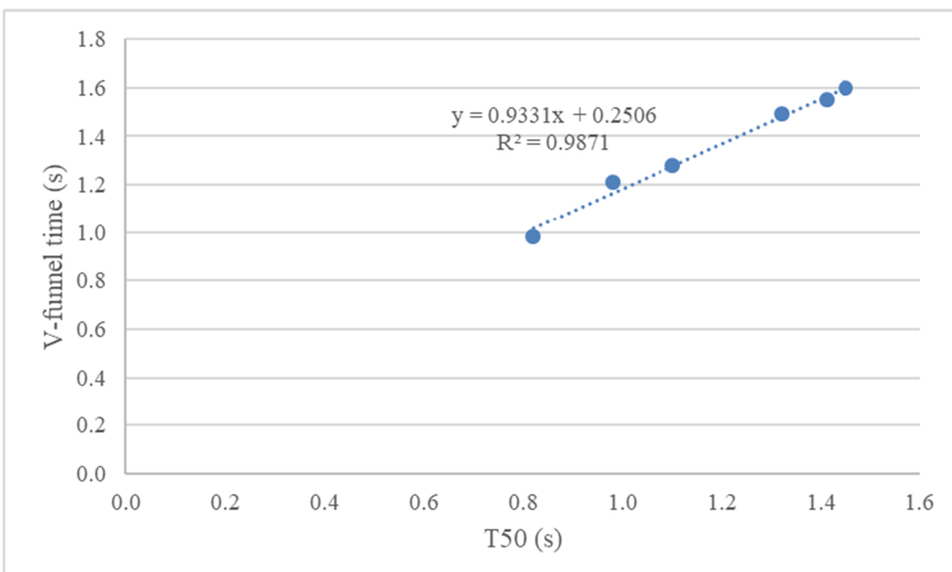

Fig. 7. Relationship between T50 and V-funnel test results.

3.4. Sieve segregation test results

A concrete with a high slump flow diameter and low T50 and V-funnel values are not sufficient to qualify it as SCC. A proper SCC mixture must have high fluidity and resistance to segregation simultaneously. Therefore, in this study, in addition to the slump flow, T50 and V-funnel tests, a sieve segregation test was also conducted to evaluate resistance to segregation. Segregation testing is even more important in case of lightweight concretes because the density differences in concretes using lightweight aggregates can result in segregation. The sieve segregation values of the SCC mixtures produced in this study are given in Table 8. As seen, the sieve segregation values were less than 15% in all SCC mixtures, therefore all SCCs meet the SR2 classification according to the EFNARC classification [13].

Fig. 8 shows that for the same w/c ratio there was a slight increase in segregation values as the slump flow diameter increased. Increasing the amount of SP to increase the slump flow diameter made the mixtures less stable. On the other hand, in concretes with similar slump flow diameters, less segregation was observed in case of higher w/c ratios. Increasing the amount of water in a concrete might be expected

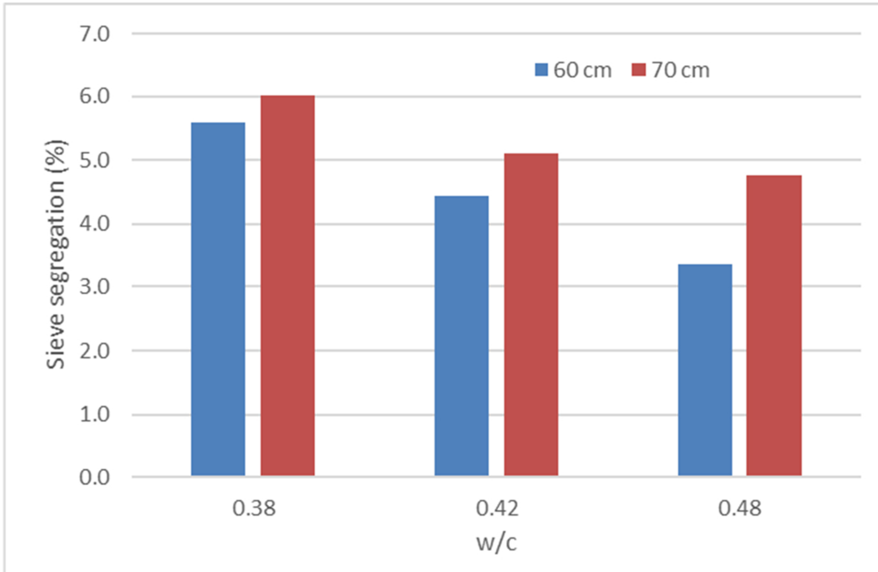

Fig. 8. Change of sieve segregation values with w/c and slump flow diameter.

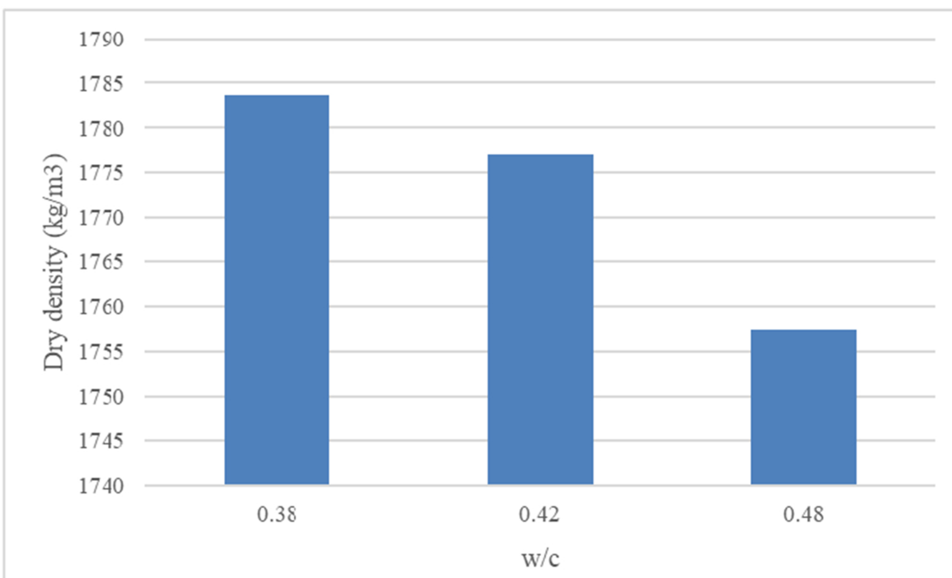

Fig. 9. Change of dry density with w/c.

to increase segregation, but in this study, more SP was used in mixtures with lower w/c ratios to obtain the same spread. Higher SP amounts, however, relatively increased the segregation even when the w/c ratio was low.

3.5. Dry density

The dry density results of the hardened concretes are shown in Table 8. According to the TS EN 206-1 standard [15], concretes with a dry density of less than 2000 kg/m3 are considered lightweight concretes. As seen, all concretes can be considered lightweight concretes.

For a given w/c ratio, the density values were very close to each other since the mix ratios remain the same except SP the contents. When the w/c ratio changes, the densities also change because the amounts of the components in the concrete change. Fig. 9 shows a graph averaging the densities of concretes with the same w/c ratio. This figure shows that as the w/c ratio increases, the density decreases. Concretes with higher w/c ratios have higher water content and lower aggregate content, resulting in lower density.

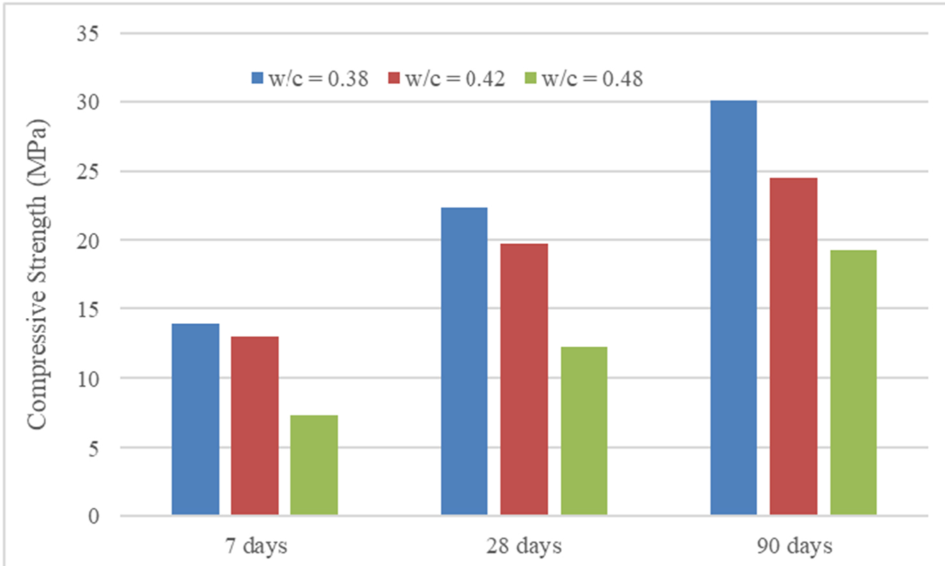

Fig. 10. Compressive strength results.

3.6. Compressive strength test results

Compressive strength tests were performed on 7-, 28-, and 90-day-old samples. Since the content of concretes for a given w/c ratio was the same except for the SP content, the average results and the variance (COV) for these concretes were calculated for each age and are shown in Fig. 10. (While consistency differences are a significant feature when the concrete is fresh, well-placed concretes exhibit almost the same performance after hardening.)

In each of the 7-, 28-, and 90-day results, strength decreased as the w/c ratio increased as expected. Some of the water in the mixtures reacts with the cement, while the remaining water forms capillary voids after the concrete hardens. Therefore, strength decreased in concretes with higher w/c ratios.

28-day strengths are used as a basis for concrete classification. Accordingly, as can be seen in Fig. 10, when the w/c ratio is 0.38, the average strength was found to be above 20 MPa. With a w/c ratio of 0.42, the strength approached 20 MPa. These results indicate that these concretes produced with Alaçatı stone aggregate can be used in many areas of the construction industry. It should also be noted that the concrete strength reached 30 MPa after 90 days.

4. Conclusion

In this study, conventional concretes and SCC mixtures were prepared by using Alaçatı stone aggregate. w/c and consistency of the mixtures were varied. Following conclusions can be drawn from the present study:

1) It was possible to produce sufficient consistency conventional concrete with a w/c ratio of as low as 0.38 and without any SP.
2) Alaçatı stone aggregate was able to produce SCC with low T50 and V-funnel times, in other words, with high-speed flow.
3) The variation in T50 and V-funnel times with the concrete type paralleled each other. Both T50 and V-funnel times decreased as the SP content increased. w/c ratio was considered less important on the T50 and V-funnel times compared to the SP contents.
4) SCC mixtures with low segregation were achieved with Alaçatı stone aggregate. For SCC with the same w/c ratio, SP demand increased as the slump flow diameter increased. On the other hand, for SCC with similar slump flow diameters, the need for SP increased as the w/c ratio decreased. In both cases, higher SP contents resulted in slight increases in segregation.
5) All concretes produced (conventional and SCC) were classified as lightweight concrete. Concretes with higher w/c ratios had relatively lower densities.
6) Lightweight concrete with a 28-day compressive strength exceeding 20 MPa could be produced using Alaçatı stone aggregate. The strength of these concretes reached 30 MPa after 90 days.

Acknowledgements

This study was supported by the Izmir Institute of Technology through the BAP project 2019İYTE234, entitled "Evaluation of the Properties of Self-Compacting Concretes Produced with Alaçatı Stone Aggregate".

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Conflict of interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data availability statement

All graphs and data obtained or generated during the investigation appear in the published article.

Funding

This research was financially supported by Izmir Institute of Technology through the BAP project 2019İYTE234.

Author's contributions

The author was the principle investigator of the project. He performed the tests, analysed the data, wrote and send the paper.

Ethics

There are no ethical issues with the publication of this manuscript.

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