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Research Article

Investigation of Engineering Properties of Lightweight Concrete Made With the Addition of Sodium Salt Based Powder Additive

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ABSTRACT

In the construction sector, which is needed for the rapidly increasing world population, the production of strong and safe buildings is given importance. This is achieved as a result of the functionality, durability and economical material production in construction materials. In order to reduce the dead load in buildings, the use of elements made of lightweight concrete is the most appropriate and alternative method. In the current study, lightweight concrete with 4 different mixtures was produced by using 0%, 0.5%, 1.5% and 2.5% powdered sodium salt-based styrene butadiene polymer admixtures (SBPA). The workability effect of the additive on the fresh mixtures was investigated by the flow table test. The 7 and 28 day compressive and flexural strengths of the obtained samples were tested. Density and porosity ratios of the samples were calculated before the 28-day compressive strength test. According to the results, it was observed that the additive material caused a slight decrease in workability. In addition, decreases were observed in mechanical strengths, but when compared with the literature, considering the decrease in density, it was understood that it is in the class of lightweight concretes with suitable strength.

Keywords: *lightweight concrete, density, porosity, mechanical properties, powder additive*

ÖZET

Sodyum tuzu esaslı toz katkı ilavesi ile üretilen hafif betonların mühendislik özelliklerinin araştırılması

Hızla artan dünya nüfusu için ihtiyaç duyulan inşaat sektöründe, güçlü ve güvenli binaların üretimine önem verilmektedir. Bu, yapı malzemelerinde işlevsellik, dayanıklılık ve ekonomik malzeme üretimi sonucunda elde edilmektedir. Binalarda ölü yükü azaltmak için hafif betondan yapılmış elemanların kullanılması en uygun ve alternatif yöntemdir. Bu çalışmada %0, %0,5, %1,5 ve %2,5 sodyum tuzu bazlı stiren bütadien polimer katkıları (SBPA) kullanılarak 4 farklı karışımla hafif beton üretilmiştir. Katkı maddesinin taze karışımlar üzerindeki işlenebilirlik etkisi yayılma tablosu testi ile araştırılmıştır. Elde edilen numunelerin 7 ve 28 günlük basınç ve eğilme dayanımları test edilmiştir. 28 günlük basınç dayanımı testinden önce numunelerin yoğunluk ve gözeneklilik oranları hesaplanmıştır. Elde edilen sonuçlara göre katkı maddesinin işlenebilirlikte bir miktar azalmaya neden olduğu gözlemlenmiştir. Ayrıca mekanik dayanımlarda azalmalar gözlenmiş ancak literatürle karşılaştırıldığında yoğunluktaki azalma dikkate alındığında uygun dayanımlara sahip hafif betonlar sınıfında olduğu anlaşılmıştır.

Anahtar kelimeler: *hafif beton, yoğunluk, gözeneklilik, mekanik özellikler, toz katkı*

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I. INTRODUCTION

Concrete, whose application area has become very widespread since its invention, is used especially in load-bearing structural elements where high strength is required [1], [2]. The high unit weight of conventional concrete used in traditional reinforced concrete constructions is often a disadvantageous feature of this material [3]. Since the unit volume weights of the building elements are high, it creates significant problems in high-rise buildings. Even if there are larger openings than normal, the unit weight reaches very large dimensions, which increases the dead loads in the structures. It is a known fact that these structures are also adversely affected by earthquakes due to their excess weight [4].

Today, the importance of earthquake phenomenon is increasing day by day, the production of light building materials is gaining importance. Instead of traditional materials in building materials, the production of products with relatively lighter materials comes to the fore [5]. Significant reductions in the weight of structures manufactured with lightweight concrete are achieved [6]. This situation is effective in reducing the cross-sectional dimensions of the building elements and thus in making the building costs more economical. However, the fact that the compressive strength of lightweight concrete is lower than that of normal concrete is one of the disadvantages of lightweight concrete [7]. Nowadays, the production of lightweight concrete is carried out with various materials and construction methods. Special additives are used for this purpose [8], [9].

Contrary to popular belief, the history of chemical additives is not so new. The first chemical additive used in history is a calcium chloride-based set accelerator, and it is known that the first use dates back to 1873 and the first patent was obtained in 1885 [10]. While the rate of use of chemical additives in the ready mixed concrete sector at the beginning of the 90s did not reach 20% [11], today the use of additives in ready-mixed concrete is considered an indispensable element. Chemical additives can interact with the cement physically, electrically or physicochemically and change the hydration rate and rate of the cement. However, the main effect of chemical additives is physical. Chemical additives do not enter into a chemical reaction with the cement paste, but have an accelerating or slowing effect on the hydration of the cement paste indirectly [12].

Lightweight aggregate concrete was first used for floors in buildings. The use of lightweight concrete dates back to 3000 BC. Lightweight concrete was used in the construction of Babul Palaces in Iraq in the 3rd century, and the current Ayasofya Mosque, which was built by the Sumerians in the 4th century. They are lightweight aggregate concretes produced by using natural and artificial lightweight aggregates with voids instead of normal aggregates, and very light and multi-void aggregates such as pumice stone, expanded perlite, expanded clay, plastic foam or wood shavings are used as lightweight aggregates [13].
Due to the low modulus of elasticity of lightweight concretes, the creep is high [14]. Excessive use of cement and less rigidity of the aggregate also increase the shrinkage [15]. We can reduce the water-cement ratio to prevent shrinkage. The shrinkage of lightweight concrete is 20% higher than that of normal concrete. The higher the stiffness of the aggregate, the lower the shrinkage. Water absorption amount of lightweight concrete is 12-22% higher than normal concrete. Lightweight concretes are weaker against freeze-thaw effects compared to normal concrete, due to the porous structure of lightweight aggregates [16], [17]. It has this feature in air-entraining lightweight concretes and aerated concretes [18]. Reducing the water-cement ratio of concrete can increase the frost resistance of concrete [19].

Lightweight concretes have a unit weight of 300–1850 kg/m^3, and their compressive strength is in the range of 0.3–90 MPa. Generally, lightweight concretes with a unit weight of 1850 kg/m^3 and a compressive strength of more than 17 MPa are called load-bearing lightweight concrete. Lightweight concretes with a unit weight of 1400-1600 kg/ m^3 and a compressive strength of 10-15 MPa are in the medium strength concrete class. Insulation lightweight concretes are non-structural, have a density of 700–1400 kg/m^3 and a compressive strength of around 10 MPa [20].

In general, it is aimed to change and improve some concrete properties and to give new properties to concrete by changing the portland cement matrix phase and aggregate phase in some way. Although these special types of concrete have been used in the construction industry for a long time, some of them are brought to the concrete industry with new studies. In this study, it was aimed to investigate some mechanical and physical properties of lightweight concretes produced with a sodium salt-based chemical additive in powder form.

II. MATERIALS AND METHOD

A. USED MATERIALS

CEM-1 42.5 R type cement produced by Nuh Çimento Sanayi A.Ş. was used in the experiments. The physical and chemical properties of this cement are given in the Table 1. Standard sand in accordance with TS EN 196-1 [21] was used as filling material in the mixtures. In the experiments carried out in the laboratory, the university's tap water with a pH of 7.05 was used as the mixing water. For the production of lightweight concrete, sodium salt-based styrene butadiene polymer admixtures (SBPA) obtained from Aerodurit Company and trade name Konzentrat 2000 were used. Some physical and chemical properties of the chemical additive are given in Table 2. Mixture details of mortars containing additives in different ratios are given in the Table 3.

Table 1. *Chemical components of cement used.*

Components	**Ratio** *(%)*
SiO_2	20.4
Al_2O_3	5.61
Fe_2O_3	3.27
CaO	63.01
MgO	2.49
SO_3	2.26
Cl	0.006
L.O.I.	1.64
Undetectable	1.68

Table 2. *Physical and chemical properties of the chemical additive.*

Form	powder
Colour	Light Yellow, Light brown
Smeel	Mild Fragrance
PH value	6.9-9.7
Flash point	>89°C
Bulk Density	380 kg/m^3

Table 3. *Mixture details.*

Sample code	**Sand** *(g)*	**Cement** *(g)*	**Water** *(g)*	**SBPA** *(%)*
Ref	1350	450	189	0
LWC1	1343	448	189	0.5
LWC2	1357	443	189	1.5
LWC3	1361	439	189	2.5

B. TEST METHODS

In this study, in order to obtain lightweight concrete and investigate its engineering properties, 3 different lightweight concrete mixtures were obtained by using chemical additives in different ratios (0.5 wt%, 1.5 wt% and 2.5 wt%). The samples were cast in two different forms as 50 x 50 x 50 mm cube and 40 x 40 x 160 mm prismatic. Water curing process was applied for 7 and 28 days. After curing, the samples were subjected to compressive and flexural strength tests according to the related standards. In addition, the slump and density values of the samples were determined.

After the mixtures were prepared, flow table test has been performed according to TS EN 1015-3 standard [22] to control their workability. Flexural and compressive strength tests were carried out in accordance with the TS EN 196-1 standard [21]. In addition, densities were calculated by measuring the dry weight and dimensions of all 7 and 28-day samples. Fig. 1 shows images from the test flow.

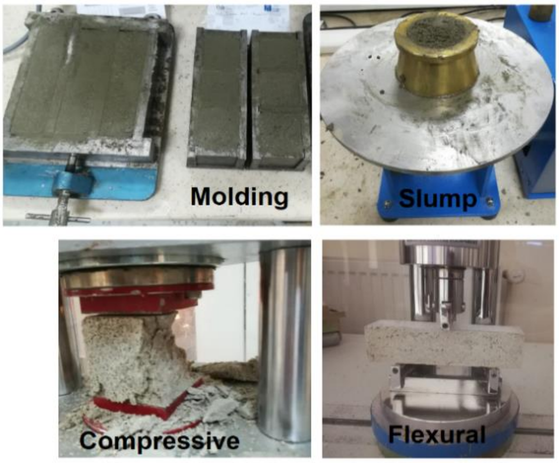

Figure 1. *Images from the experiment flow.*

III. RESULTS

The mechanical and density properties of light mortars produced using sodium salt-based additives were investigated and presented in detail in this section. When the Slump flow (Fig. 2) test results of the fresh mortars were examined, a slight reduction effect of the additive on the consistency was observed. The flow diameter of the LWC1 mixture containing 0.5 wt% SBPA was 2.78% lower than Ref. Also, flow diameters of LWC2 and LWC3 mixtures were 4.17% and 7.87% less, respectively, compared to Ref. When Comparing only between mixtures containing SBPA, it was observed that the flow diameters of LWC2 and LWC3 were 1.43% and 3.86% lower, respectively, compared to LWC1. This shows that a further increase in the additive ratio leads to more decrease in workability.

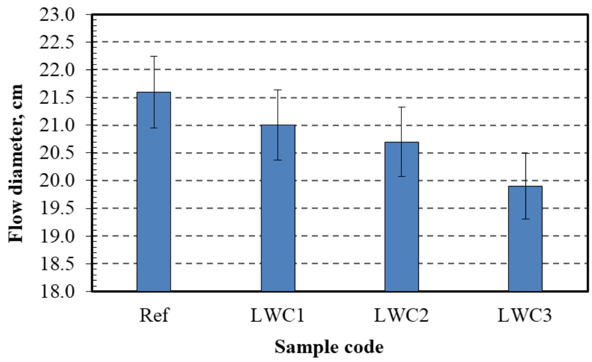

Figure 2. *Slump flow diameter values.*

The 7 and 28-day compressive strength results of the mortar samples obtained from four different mixtures, including Ref, are shown in Fig. 3 comparatively. It was observed that the maximum 28-day compressive strength belonged to Ref as 48.13 MPa and the minimum 28-day compressive strength to the LWC3 mixture as 15.35 MPa. The 28-day compressive strengths of all samples increased at similar rates compared to the 7-days. For example, the strength of Ref and LWC1 improved by 12.98% and 13.03%, respectively. When the compressive strength results are correlated with the additive ratio, the strength of the mixture with low additives decreased more significantly than the mixture with high ratio additives. The 28-day compressive strength of LWC1, LWC2 and LWC3 decreased by 48.10%, 58.30% and 68.11%, respectively, compared to Ref. When the compressive strength results were compared with the flow diameter values, it was observed that there was a clear parallel relationship between them.

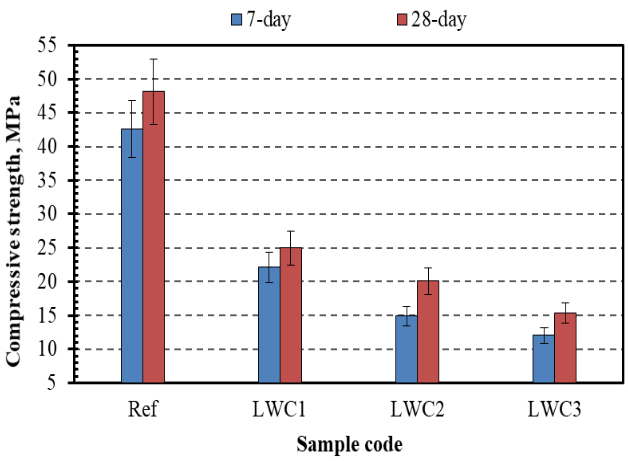

Figure 3. *Compressive strength results.*

The 7 and 28-day flexural strength results of the mortar samples obtained from four different mixtures, including Ref, are shown in Fig. 4. When the flexural strength results were examined, in contrast to the compressive strength results, 0.5% SBPA content did not affect the flexural strength. The most effective additive ratio on compressive strength was 0.5%, and the ratios of 1.5% and 2.5% were slightly affected. However, the 0.5% additive ratio was completely ineffective in the flexural strength results, and the strength was adversely affected when the additive ratios were 1.5% and 2.5%. The 28-day flexural strengths of all samples increased at similar rates compared to the 7-days. For example, the strength of Ref and LWC1 improved by 37.14% and 34.66%, respectively. The 28-day flexural strength of LWC1, LWC2 and LWC3 decreased by 4.36%, 25.76% and 55.11%, respectively, compared to Ref. It was observed that the maximum 28-day flexural strength belonged to Ref as 5.28 MPa and the minimum 28-day flexural strength to the LWC3 mixture as 2.37 MPa.

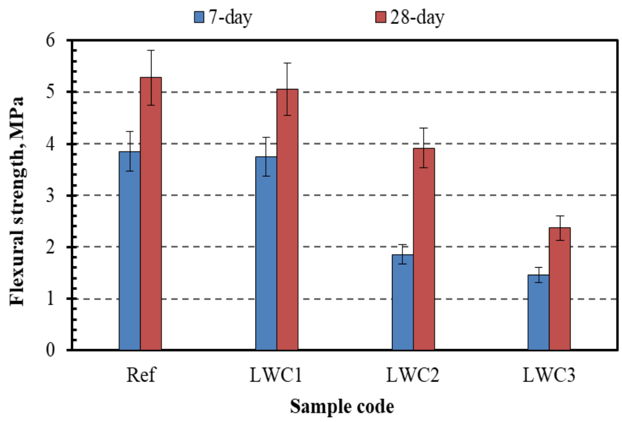

Figure 4. *Flexural strength results.*

Density and porosity properties of the produced 28-day mortar samples were examined and compared in Fig 5. Density values were between 1.73-2.13 g/cm3 and porosity ratios were between 10.93% and 21.80%. Considering the density and porosity results, it is seen that there is a strong inverse relationship between them. Depending on the increase in the SBPA ratio, the density values decreased while the porosity ratio increased. The exponential equations produced in this context were obtained according to the 0%-2.5% dosage used and can be referenced in other studies according to their high correlation coefficients. However, these equations are valid for 0.5-2.5% SBPA, different relationships can be observed at different dosage ranges. Density values of LWC1, LWC2 and LWC3 decreased by 8.92%, 14.08% and 18.78%, respectively, compared to Ref. Also porosity ratios of same samples increased by 15.65%, 55.35% and 99.45%, respectively, compared to Ref. It shows that the porosity ratio is more affected than the density, and the non-void filled regions of the sample have a more dense and rigid structure.

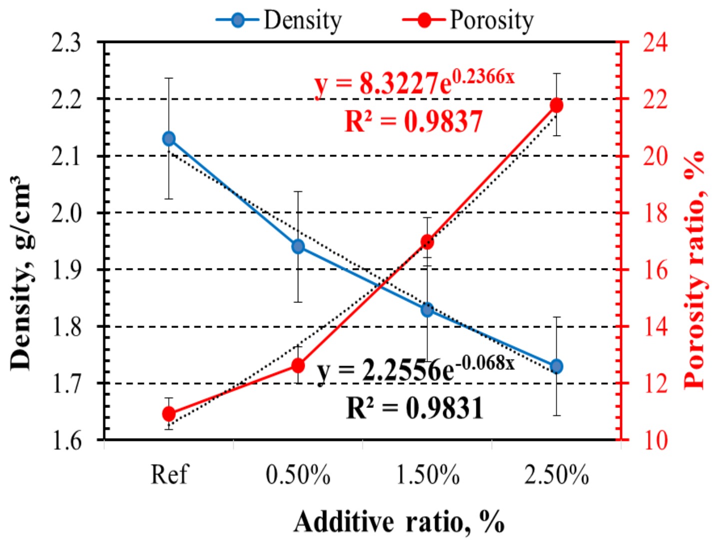

Figure 5. *Density and porosity values of 28-day mortars.*

A consistent linear relationship was observed between all data in this study. For example, the relationships between density-compressive and density-flexural results are explored in Fig. 6. According to Fig. 6, correlation slope between flexural-density was more severe than the correlation slope between compressive-density. The observed parallel relationship between compressive strength and flexural strength was also observed among the workability (flow diameter) results. However, looking at the intensity of decrease in values, the decrease slope of the results obtained for the flow values was more similar to the decrease slope of the values obtained for the flexural strength. In other words, the additive ratio had a sudden effect on the compressive strength at the first rate (%0.5), whereas the bending results began to be affected more at 1.5%.

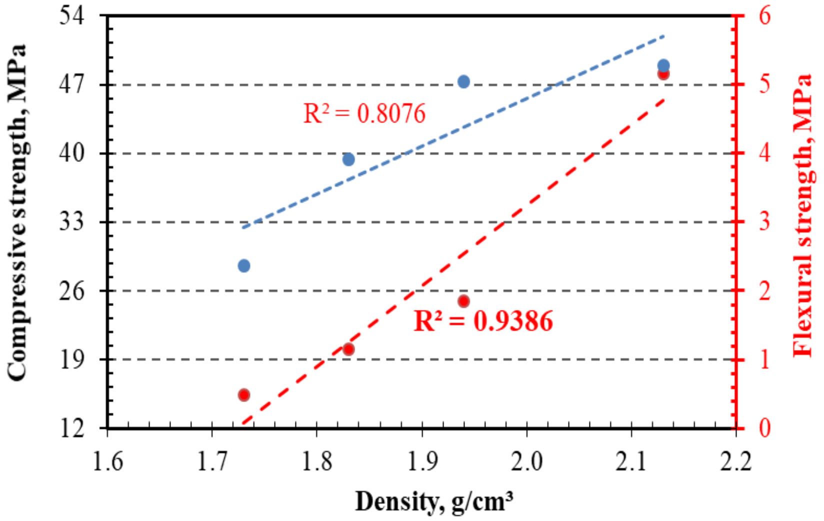

Figure 6. *Relationship between 28-day compressive and flexural strength.*

IV. DISCUSSION

In the literature, the effects of sodium salt-based admixtures on lightweight concrete have been investigated for different purposes. Wei et al. [23] used various sodium salts in a fly ash/coal mixture to investigate the effect of sodium salt types on the formation mechanism of lightweight aggregates. Microanalysis results showed that despite the great similarity in melting point of salt additives, the change of additive from one sodium salt to another leads to significantly different light aggregate formation mechanism and thus affects aggregate properties. All sodium salts can indirectly form sodium silicate with SiO_2 in the volatile charcoal/glass mixture following two-step sequential reactions. Sodium silicates are recommended as the main components of the viscous layer during sintering; they can envelop bloated gases to expand the size of lightweight aggregates. The solubility of the coal fly ash/glass mixture in molten NaCl during sintering is not as great as in molten Na_2O and Na_2SO_4, thus requiring a higher sintering temperature to prepare lightweight aggregates. In the literature [24], there are also studies on the production of aggregates with higher porosity using sodium salt-based additives.

Since the additive used is in powder form, it absorbed the water in the mixture and adversely affected the workability of the fresh mortar. Similarly, negative effects of different powder additives on workability have been confirmed in the literature. Zaleska et al. [25] investigated the effects of crushed polypropylene random copolymer, regranulated polypropylene random copolymer, and crushed glass fiber reinforced polypropylene powders on lightweight concrete. Flow table results showed that workability was significantly reduced. However, little positive effect of SBPA on machinability has also been reported in the literature [26], [27]. Also the workability of fresh mixtures was found closely related to the shape of particles; the particles with sharp edges (crushed plastic aggregates CPPR and CPPGF) worsened the workability more than particles with round shapes (regranulated plastic aggregates RPPR). The difference between this study and the present study is that in this study, the authors used the powders mentioned as substitutes instead of aggregates. Whereas, in the present study, the powder used was used as an additive material at low rates.

When the obtained porosity and density values are compared with their mechanical properties, it is understood that the produced concrete is among the lightweight concretes with suitable strength. Bogas et al. [28] produced lightweight concretes with sufficient stability and self-compactability for compressive strengths between 37.4 and 60.8 MPa, density classes 1.8–2.0 g/cm^3, and fine grain content of 490–599 kg/m^3 containing 33% by weight fly ash. Zaleska et al., using different types of waste powders, produced lightweight concretes with a bulk density of 1.20-1.85 and a compressive strength of 3.6-50.2 MPa. Tassew and Lubell [29] produced lightweight concretes with a density of about 1.60-1.85 and a compressive strength of 15-40 MPa. In the present study, the density values were between 1.73-2.13 g/cm^3, the porosity ratios were between 10.93-21.8% and the compressive strength was 15.35-48.13 MPa.

V. CONCLUSION

For the production of lightweight concrete, 4 different cementitious mixtures were obtained by using sodium salt-based powder additives at different rates. Flow table test was performed to investigate the workability of the mixtures. 4 x 4 x 16 cm prismatic samples were produced to determine the flexural strength and 5 x 5 cm cube samples were produced to determine the compressive strength from all mixtures. In addition, 28-day cube samples were used to determine the density and porosity ratio. The results obtained were as follows.

According to the flow table test results, it was observed that the diameter of the flow linearly decreased up to 7.87% with the increase of the additive ratio from 0% to 2.5%. With the addition of the additive material, the compressive strength and flexural strength decreased, but the 0.5% additive rate strongly affected the compressive strength while this ratio had insignificant effect on the flexural strength. The lowest compressive and flexural strength values were observed for the mixture containing 2.5% additive with 55.11% and 68.11% reductions, respectively. With the addition of additives, significant decreases were observed in the density values, which confirmed its suitability for lightweight concretes class when compared with the literature. The relationship between density and compressive and flexural strength results was investigated and a linear relationship between them was confirmed. As a result, it has been confirmed by the results of this study that the SBPA admixture used in this study is a suitable additive material for the production of lightweight concrete. For future studies, it is recommended to examine this material in wider ranges and to conduct tests such as durability.

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